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Early-season Management of Twospotted Spider Mite on Cotton and Impacts of Infestation Timing on Cotton Yield Loss

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EARLY-SEASON MANAGEMENT OF TWOSPOTTED SPIDER MITE ON COTTON AND IMPACTS OF INFESTATION TIMING ON COTTON YIELD LOSS

By

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Historically, most twospotted spider mite, *Tetranychus urticae* Koch, infestations occurred during the late season near maturity, but since 2005, infestations of cotton have become more common throughout the entire season. Several factors may have contributed to the increasing frequency of mites in seedling cotton, one of which is a shift in production practices from furrow applied aldicarb to neonicotinoid seed treatments for thrips control. Another factor that may impact *T. urticae* densities in seedling cotton is a shift from pre-plant tillage to conservation tillage or no-till cropping systems. Although the literature confirms that *T. urticae* can cause extensive cotton yield losses, there is a need to further refine potential late-season yield loss. From 2007 to 2009 a series of experiments were conducted to address these issues.

In a series of 12 field experiments, neonicotinoid seed treatments resulted in twospotted spider mite densities greater than those in the untreated check, aldicarb, and

acephate treatments. Untreated check and aldicarb treatments had the lowest mite densities. Only aldicarb controlled mites compared to the untreated check.

A twospotted spider mite host survey determined that henbit, *Lamium amplexicaule* L., was the most consistent and preferred host. Carolina geranium, *Geranium carolinianum* L., cutleaf geranium, *Geranium dissectum* L., vetch, *Vicia* spp., volunteer soybean, *Glycine max* L., purple deadnettle, *Lamium purpureum* L., and spiny sowthistle, *Sonchus asper* (L.) Hill, were other frequently infested dicotyledonous species.

Herbicide burndown timing in reduced tillage cotton production was not critical, given all weeds were killed before cotton was planted. The herbicide glufosinate was efficacious against *T. urticae*, providing control equal to low- to mid-rates of labeled acaricides. Including glufosinate in a herbicide burndown program was only beneficial for mite control if living weeds were present at planting.

Artificial infestation experiments were adversely affected by unseasonably wet and cool weather. Infestations established at the third true leaf resulted in an average yield loss of 44.7%. It is difficult to make any conclusions about infestations made from first bloom and later because of the difficulty in establishing mite populations later in the season.

DEDICATION

I would like to dedicate this research to my wife, Tara Lynn Smith, and son Wyatt Emory Smith.

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CHAPTER I

LITERATURE REVIEW

Introduction

Traditionally, 400,000- 485,000 ha of cotton *Gossypium hirsutum* L., have been harvested in Mississippi (NASS 2002). However, during 2009 only 119,390 ha of cotton were harvested in Mississippi, representing a 76% decrease since 2006. (NASS 2010).

Twospotted spider mite, *Tetranychus urticae* Koch, is a pest with worldwide distribution. It is a highly polyphagous pest, with numerous cultivated and uncultivated hosts, including cotton. Twospotted spider mites either overwinter in a state of diapause or remain active throughout winter, depending on geographical location and environmental conditions (Brandenburg and Kennedy 1982, Veerman 1985). They become active in the spring and populations increase as temperatures increase and hosts become available. Females lay an average of 97 eggs over a 14 d period (Shih et al. 1976). Twospotted spider mite exhibits arrhenotokous parthenogenesis, whereby unfertilized eggs develop into males and fertilized eggs develop into females (Brandenburg and Kennedy 1987). *Tetranychus urticae* has five life stages, including egg, larva, deutonymph, protonymph, and adult. Larvae are identified by the presence of six legs. Duetonymphs and protonymphs closely resemble adults and are primarily distinguished by differences in size. The complete generation time of *T. urticae* is 7.5

days at temperatures of 27.1° C, but can vary depending on temperature (Shih et al. 1976).

Twospotted spider mite exhibits many characteristics that contribute to its pest status on cotton and other field crops. The short generation time results in numerous overlapping generations that allow the pest to reach damaging densities quickly. Twospotted spider mite has developed resistance to many insecticides/acaricides (Cranham and Helle 1985). Currently, *T. urticae* is resistant to most true insecticides used in cotton (Knowles et al. 1988, Herron et al. 2001), although miticides do effectively control the pest in the southern Unites States (Price et al. 2009, Smith and Catchot 2009). Bifenthrin, a pyrethroid insecticide, is the only insecticide recommended for control of *T. urticae* in Mississippi (Catchot 2010). Resistance to bifenthrin has been confirmed in Australia (Herron et al. 2001). Several insecticides flare *T. urticae* populations by killing beneficial insects and mites; thereby, reducing predation (Davis 1952, Jones 1990, Sclar et al. 1998). Twospotted spider mites also use aerial dispersal, allowing long-range movement (Fleschner et al. 1956, Margolies and Kennedy 1985). Margolies and Kennedy (1985) reported that when corn begins to senesce, mites disperse aerially, causing subsequent infestations in peanut. This behavior likely explains the sudden occurrence of twospotted spider mite on cotton across the Mississippi Delta during late-season.

Diapause and Overwintering of *T. urticae*

Only adult female twospotted spider mites can diapause (Parr and Hussey 1965). Diapause was defined by Beck (1980) as a genetically determined state of suppressed development, which may be controlled by environmental conditions. Unlike quiescence, which is directly triggered by unfavorable conditions and terminated upon the return of favorable conditions, diapause may be initiated before unfavorable conditions arise and extend well past the time when unfavorable conditions end (Beck 1980, Veerman 1985). Veerman (1985) reported that for a large number of tetranychid species, dormant stages have been described and may reasonably be inferred to represent a true diapause state. Although, there is great interspecific variation, twospotted spider mite demonstrates hibernal diapause or more simply, it is dormant during winter months (Cagle 1949, Veerman 1985). Diapause cannot be induced in teneral or adult females unless one or more of the developmental instars are subjected to diapause-inducing conditions (Linke 1953 and Bondarenko 1958, cited from Parr and Hussey 1966). Diapausing females are most readily distinguished by a color change from yellowish-green of the summer form to uniform deep orange-red (Parr and Hussey 1966). During diapause, all *Tetranychus* species exhibit structural changes in the integumentary striae of the dorsal body surface. Prichard and Baker (1952) observed that ridges in the cuticle of summer forms appear broken with semi-circles and triangular patterns. The ridges are smooth in winter forms, most likely to minimize the risk of desiccation during hibernation (Boudreaux 1958). However, Parr and Hussey (1966) observed that intermediate phases of summer and winter forms could be obtained when attempting to induce diapause in immature twospotted spider mite. Brandenburg and Kennedy (1982) observed all life stages of twospotted spider mite active throughout winter months on blackberry, *Rubus* spp.; red clover, *Trifolium pretense* L.; violet, *Viola* spp.; henbit, *Lamium amplexicaule* L.; and senesced switchgrass, *Panicum virigatum* in North Carolina. Both orange and green-colored forms were collected from wild hosts in January, and when placed on bean leaves, 94 and 100% of orange and green-color forms, respectively, laid eggs within 48 hours. Also, 12% of the green-color forms and 52% of the orange-color forms had smooth integumentary striae, contradictory to previous literature. The authors proposed that these mites could represent intermediate forms where diapause was only partially initiated, and that in the presence of moderate temperatures and continual food sources, diapause may be unnecessary in North Carolina and other southern states. Wilson (1995) corroborated those results by reporting that twospotted spider mite remained active on green vegetation throughout winter months in Australia. Average temperature range for the region during July, the coolest month, is 8-16°C (Wikipedia).

Diapause is controlled by three environmental factors: daylength, temperature, and food availability (Parr and Hussey 1966). Of those three factors, daylength has been shown to be the predominant factor governing the process. Veerman (1977), reported a critical daylength of 14 hr for twospotted spider mite, meaning daylengths below the critical value resulted in nearly 100% diapausing females. Diapause was absent in continuous darkness. Experiments conducted in Europe showed twospotted spider mites begin to enter diapause during September. Bondarenko and Khay-yuan (1958, cited in Parr and Hussey 1966) reported that twospotted spider mite in low latitudes respond to shorter critical photoperiods than those in higher latitudes. At 60°N latitude, the critical photoperiod was 17 hr, but at 42°N the critical photoperiod is only 11 hr. Helle (1962) reported that higher temperatures tended to suppress diapause over a range of photoperiods, but low temperatures did not induce diapause when daylengths were > 14 hr. Low temperatures during darkness were more critical to induce diapause than low temperatures during illumination (Veerman 1977). Diapause was only induced in the experiment when nighttime temperatures were low (15°C) or mean temperatures remained at 20°C with a photoperiod of 12:12 LD. High temperatures during illuminated periods had no effect on diapause. In general, low temperatures tend to favor diapause and high temperatures tend to suppress diapause. Food availability has been shown to affect diapause. Older plants or senescent foliage have been reported to cause twospotted spider mite to enter diapause at an earlier date or in higher numbers (Collingwood 1955 and others, cited in Veerman 1985). However, when long daylengths and high temperatures were maintained, Parr and Hussey (1966) observed that twospotted spider mite would not diapause in the absence of nutrition. They concluded that inadequacy of food had a greater impact on twospotted spider mite when photoperiod and temperature were reaching critical points.

Twospotted spider mite is very cold hardy. Bondarenko (1958, cited from Parr and Hussey 1966) observed only 10-15% mortality of natural populations at temperatures of -27°C. Van de Bund and Helle (1960) found complete survival of diapausing mites after five days at -22°C and 35 days at -5°C. Helle (1962) reported that mites could survive eight months at -2°C if protected from desiccation. Parr and Hussey (1966) reported that high relative humidity (RH) (75-90%) is required for long-term survival of diapausing mites; they found that 43% of diapausing mites survived up to eight months when held at 75% RH and 6°C.

Control of Mites with Herbicide Burndown Applications

Ahn et al. (1997, 2001) reported that glufosinate-ammonium caused high mortality of twospotted spider mite nymphs and adults on kidney beans under laboratory conditions. Ahn et al. (1997) also found that the use of glufosinate-ammonium for control of weeds in apple orchards could aid in suppression of twospotted spider mite. In fact, when glufosinate-ammonium was substituted for other herbicides, miticide treatments were reduced from six to one per season (Ahn et al. 1997). Glufosinate-ammonium is a non-selective, postemergence herbicide that controls a broad spectrum of grasses and broadleaf weeds (Sensemen 2007). The development of glyphosate resistant (GR) palmer amaranth, *Amaranthus palmeri* S. Wats, and horseweed, *Conyza canadensis* L., since 2005 in southeastern and mid-south states has led to increased use of glufosinate and glufosinate tolerant crops (Liberty Link®, Bayer CropScience) for weed control. Glufosinate can effectively control both GR horseweed and palmer amaranth (Steckel 2006, Norsworthy et al. 2008, and Culpepper et al. 2009). The release of Liberty Link® cotton cultivars allows growers to use postemergence applications of glufosinate in cotton, corn, and soybean. Widestrike® cotton varieties (Dow AgroSciences, Indianapolis, IN), which convey glyphosate resistance and dual *Bacillus thuringiensis* Berliner genes for protection from lepidopteran pests, also contain the phosphinothricin acetyltransferase (*pat*) gene that confers partial resistance to glufosinate (Culpepper et al. 2009). With the increased ability to make postemergence applications of glufosinate to cotton, tailoring applications of this compound for twospotted spider mite management would reduce total pest management costs, preserve beneficial insects, and reduce environmental contamination (Ahn et al. 1997).

Effects of Neonicotinoid Insecticides

Multiple reports have indicated that applications of neonicotinoid insecticides result in population increases of several mite species. Several reasons for these findings have been proposed. Sclar et al. (1998) observed that *T. urticae* and honeylocust spider mite, *Platytetranychus multidigituli* (Ewing), densities were significantly greater on field grown marigolds, *Tagetes erecta* L., and honeylocust, *Gleditsia triacanthos* L., respectively, treated with soil applications of imidacloprid. In greenhouse experiments with imidacloprid conducted in the absence of predators, mite densities were not increased. A reduction in the predator minute pirate bug, *Orius tristicolor* (White) on treated plants was believed to allow increases in spider mite populations in outdoor settings. Conversely, James and Price (2002) reported hormoligosis in twospotted spider mite females directly sprayed with imidacloprid and fed leaf disks cut from systemically treated bean leaves. Hormoligosis is the phenomenon of reproductive stimulation by sublethal doses of insecticides or other stresses (Luckey 1968). Hormoligants include chemicals, temperature, radiation, and minor injury (Luckey 1968). In the study reported by James and Price (2002), *T. urticae* treated with imidacloprid immediately began producing 10-26% more eggs than twospotted spider mite treated with water only. Increased egg production lasted ~15 days. Mites that ingested systemically treated bean plants increased egg production at day 6, and continued to express increased fecundity through day 18. Ako et al. (2004) reported contradictory observations from a greenhouse study including four neonicotinoid insecticides at field-relevant and sublethal doses. At field-relevant doses, twospotted spider mite fecundity was lower in neonicotinoid treatments. At sublethal doses there was no significant difference among insecticides and the check.

Other field experiments report that mites are more prevalent after application of neonicotinoid insecticides. Raupp et al. (2004) determined that Canadian hemlock, *Tsuga canadensis* (L.) Carrière, was 9 times more likely to have severe needle damage from spruce spider mite, *Oligonychus ununguis* (Jacobi), on one or more terminals when treated with imidacloprid. The study did not report what caused the increase in damage. Beers et al. (2005) observed that two spotted spider mite populations in Washington apple orchards were 4.6 fold higher when treated with acetamprid rather than organophosphate insecticides. Also, seasonal mite density was positively related to total grams active ingredient of acetamiprid applied. Troxclair (2007) found that percentages of cotton plants infested with twospotted spider mite were significantly greater in plots treated with Cruiser and Gaucho seed treatments than those treated with Temik at 21, 25, and 32 DAP, and higher than the untreated check at 21 and 32 DAP.

With the exception of Ako et al. (2004), multiple reports indicate that increased *Tetranychus* populations are associated with soil and foliar neonicotinoid insecticide applications; however, the causes of these increases are not agreed upon. The phenomenon has been documented in multiple plant species and also from many anecdotal reports. It is possible that neonicotinoid seed treatments could be a factor in the recent early-season outbreaks of twospotted spider mite that have occurred in cotton throughout the Mid-South.

Injury to Cotton and Associated Yield Loss

Spider mites damage cotton by feeding on individual cells on the abaxial leaf surface. The feeding apparatus of twospotted spider mite consists of paired and partially fused cheliceral stylets that are used to pierce mesophyll cells, which occur between the adaxial and abaxial epidermises (Hislop and Jeppson 1976). The mesophyll is divided into two layers of cells: the upper palisade layer and the lower spongy layer. Chloroplasts are contained within the spongy and palisade layers (Bondada et al. 1995). Mite stylets are about 132 $\pm$ 27 µm long (Reddall et al. 2004). Cotton leaves are generally about 255 µm thick (Pettigrew et al. 1993). Mites were recorded to puncture strawberry leaves to a depth of 117.5 $\pm$ 24.9 µm (Sances et al. 1979). Based on those parameters, Reddall et al. (2004) postulated that twospotted spider mite feeding on the abaxial leaf surface should primarily result in damage to the spongy mesophyll. Bondada et al. (1995) determined through electron micrographs that chloroplasts in spongy mesophyll cells in mite infested leaves were deformed and swollen because of large plastoglobuli filling the entire chloroplast. This characteristic was associated with disintegration of the grana, most likely caused by proteolytic enzymes in mite saliva

(Bondada et al. 1995). Eventually, damaged spongy mesophyll cells become necrotic (Bondada et al. 1995). Damage to the spongy mesophyll from twospotted spider mite feeding has been associated with dehydration and a decrease in turgidity of stomatal guard cells, leading to closure of stomata and reduced transpiration (Reddall et al. 2004). Damage is not limited to cells directly punctured. Mites usually feed around the basal leaf portions first then move to more distal portions (Reddall et al. 2004). Feeding in basal areas not only reduces leaf processes in basal portions of the leaf, but also reduces many functions in undamaged distal leaf portions (Reddall et al. 2004). Reddall et al. (2004) linked this effect to damage of vascular tissues, which reduced transport of nutrients, hormones, and water to distal leaf portions, and ultimately caused water stress and progressive closure of stomata. Once damaged, there is no within-leaf compensation; however, it is possible that within-plant compensation could occur (Reddall et al 2004).

Bondada et al. (1995) determined that the final impact of mite injury to the leaf was a reduction of photosynthesis. Stomatal conductance, transpiration and chlorophyll content were also reduced to lesser degrees (Bondada et al. 1995). In peppermint leaves damaged by twospotted spider mite, the predominant factor that reduced photosynthesis has been linked to inhibition of gas exchange (DeAngelis et al. 1983). Park and Lee (2002) reported that net photosynthetic rate, total chlorophyll content, and leaf greenness of cucumber, *Cucumis sativus* L., were significantly affected by twospotted spider mite feeding.

Sadras and Wilson (1997a) determined that yield losses in cotton were ultimately caused by reductions in radiation-use efficiency followed by accelerated leaf senescence and reduced light interception in extensively damaged plants. Reductions of those physiological processes caused decreases in the amount of dry matter production, lint yield, seed cotton, and number of open bolls, depending on when damage occurred (Sadras and Wilson 1997b). Damage sustained during fruit set periods has been associated with decreases in the number and size of bolls, whereas late-season damage during the boll-fill period generally only reduces boll size and weight (Wilson 1993).

Twospotted spider mite damage can cause yield losses in cotton (McGregor and McDonough 1917, Furr and Pfrimmer 1968, Leigh et al. 1968, Wilson et al. 1987, Wilson et al. 1991, Wilson 1993, Sadras and Wilson 1997b). Yield losses have been reported to range from minimal to severe, depending on environmental conditions and when the damage occurred. In 1917, McGregor and McDonough (1917) estimated that spider mites caused damage to 8,100 ha of cotton in South Carolina and decreased production by 40%. Furr and Pfrimmer (1968) measured 30 and 35% yield losses from cotton infested with mites between 1st square to bloom and before quarter sized bolls were present, respectively, in Mississippi; however, a late season infestation (bolls larger 1.9 cm diam.) caused no yield decrease. Wilson (1993) infested mites during early, mid and late season during a three year study and reported yield losses of 1-16, 7-29, and 13-78%, respectively. Sadras and Wilson (1997b) reported an extreme yield loss of 97% in cotton infested 59 DAP (1st bloom). In the same experiment, infestations of similar densities initiated at 80 and 93 DAP resulted in yield losses of 93 and 84%, respectively. In general, the literature suggests that twospotted spider mite cause greater yield loss when infestations are initiated before or during flowering periods. However, infestations developing late season can significantly reduce yield if twospotted spider mite populations develop rapidly and environmental conditions are not conducive to plant growth.

Most *Tetranychus* spp. are closely related and damage cotton similarly, except for the strawberry spider mite, *Tetranychus atlanticus* McGregor, which is most damaging because of toxin-induced injury (Brito et al. 1986). Infestations of strawberry spider mite initiated at flowering, 4-wk after flowering and 8-wk after flowering resulted in yield reductions of 63, 41, and 18%, respectively, in North Carolina (Mistric 1969). Carmine spider mite, *Tetranychus cinnabarinus* (Boisduval) reduced seed cotton yields by 14-44% in Alabama (Canerday and Arant 1964a). Canerday and Arant (1964b) measured yield losses of 13-22% caused by feeding damage from the strawberry spider mite.

It is well established in the literature that twospotted spider mite can cause yield losses in cotton. However, previous research has investigated yield loss in production systems very different from those currently present in the southern United States. Also, previous research did not fully investigate yield losses caused by late-season twospotted spider mite infestations or define yield loss by the amount of injury at specific growth stages.

Currently, little information exists about the population dynamics of twospotted spider mite in mid-southern U. S. or the potential for injury and subsequent yield losses in cotton. The focus of this dissertation is to present data that will contribute to our knowledge about twospotted spider mite management in cotton. To address twospotted spider mite infestations in the mid-South, the following objectives were proposed:

I. Document major weed hosts of twospotted spider mite

II. Determine effects of neonicotinoid seed treatments to twospotted spider mite in cotton

III. Determine if preplant applications of glufosinate-ammonium can be used to manage twospotted spider mite in cotton

IV. Measure cotton yield-loss caused by twospotted spider mite injury

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CHAPTER II

EFFECTS OF ALDICARB AND NEONICOTINOID SEED TREATMENTS ON TWOSPOTTED SPIDER MITE, *TETRANYCHUS URTICAE*, KOCH, ON COTTON

Abstract

Twelve field experiments and one laboratory experiment were conducted to determine the effects of furrow applied aldicarb and seed treatments of thiamethoxam, imidacloprid, Avicta (thiamethoxam + abamectin), Aeris (imidacloprid + thiodicarb), and acephate on twospotted spider mite (TSSM), *Tetranychus urticae* Koch, on cotton, *Gossypium hirsutum* L. For the field experiments, data were pooled across all experiments and analyzed with analysis of variance. Aeris, thiamethoxam, and imidacloprid treatments resulted in twospotted spider mite densities greater than those in the untreated check, aldicarb, and acephate treatments. However, cotton treated with Avicta (thiamethoxam + abamectin) had 34% fewer mites than other neonicotinoid seed treatments when infestations occurred near cotyledon stage. Untreated check and aldicarb treatments had the lowest mite densities. Only aldicarb reduced mite densities below that in the untreated check. In a laboratory trial, the fecundity of TSSM was measured. While neonicotinoid seed treatments increased mite densities in the field, they did not increase fecundity in the laboratory experiment. Foliar applied thiamethoxam

slightly elevated average fecundity in the laboratory experiment. Increased use of neonicotinoid seed treatments instead of furrow applied aldicarb is likely at least partly responsible for recent increased twospotted spider mite infestations in seedling cotton across the Mid-South.

Introduction

Twospotted spider mite, *Tetranychus urticae* Koch, (TSSM) has traditionally been considered an occasional late season pest of cotton, *Gossypium hirsutum* L., across the Mid-South. However, the percentage of acres in Mississippi requiring acaricide applications targeting twospotted spider mite has increased by at least two-fold in recent years (Williams 2009). Before 2005, most acaricide applications were made during the late season, but from 2006-2008 a small percentage of seedling cotton in Mississippi has been heavily damaged by mites as well.

Several factors may have contributed to the increasing frequency of mites in seedling cotton, one of which is a shift in production practices from furrow applied aldicarb to neonicotinoid seed treatments for thrips control. Multiple reports have indicated that applications of neonicotinoid insecticides have resulted in population increases of *Tetranychus* species (Sclar et al. 1998, Van Duyn et al. 1998, James and Price 2002, Beers et al. 2005, and Troxclair 2007). Soil applications of imidacloprid resulted in higher densities of twospotted spider mite and honeylocust spider mite, *Platytetranychus multidigituli* (Ewing), on field grown marigolds, *Tagetes erecta* L., and honeylocust, *Gleditsia triacanthos* L., respectively, compared to untreated plants (Sclar et al. 1998). Beers et al. (2005) observed that twospotted spider mite populations in Washington apple orchards were 4.6-fold higher when treated with acetamprid compared to organophosphate insecticides. Also, seasonal mite density was positively correlated to total grams AI of acetamiprid applied. Troxclair (2007) found that percentages of cotton plants infested with twospotted spider mite were significantly greater in plots treated with thiamethoxam and imidacloprid seed treatments than those treated with aldicarb or untreated.

Several theories have been proposed to explain the relationship between neonicotinoid insecticides and twospotted spider mite population increases. James and Price (2002) reported a hormoligant effect in twospotted spider mite females that were either directly sprayed with imidacloprid or fed leaf disks cut from systemically treated bean leaves. Hormoligosis is the phenomenon of reproductive stimulation or increased fecundity from sublethal doses of insecticides (Luckey 1968).   Sclar et al. (1998) determined that increased densities of two-spotted spider mite were related to reductions of predators. In contrast, Ako et al. (2004) reported that four neonicotinoid insecticides caused lower fecundity. At sublethal doses, there was no significant difference among the twospotted spider mites exposed to neonicotinoid insecticides and those that were not exposed to neonicotinoid insecticides. The impact of seed-applied and foliar-applied neonicotinoids on *Tetranychus* spp. has been documented in multiple plant species. The increased use of neonicotinoid seed treatments in cotton may be a factor in the recent early-season outbreaks of twospotted spider mite that have occurred throughout the Mid-South.

Most research studying the effects of neonicotinoid insecticides on twospotted spider mite has been conducted on plants or crops other than cotton. To this point there has not been a comprehensive experiment that examined the effects of neonicotinoid seed treatments on twospotted spider mite on cotton. In the current experiment, the effects of the six most widely used insecticide seed treatments on twospotted spider mite were examined. Multiple field experiments were conducted over three years, allowing subtle differences and trends between treatments to be identified. The differences between these treatments with regard to mite densities and possible explanations are discussed.

Materials and Methods

From 2007 through 2009, a total of 12 field trials and one lab experiment were conducted. Twospotted spider mites were artificially infested in each trial from a colony maintained on green bean, *Phaseolus vulgaris* L., at Mississippi State University, Mississippi State, MS. The colony was originally established in 2007 from field populations in the Mississippi Delta.

Field Experiments. Field experiments were conducted as a randomized complete block with 4-6 replications. Plot size was four rows wide (96.5 cm centers) by 6.1 or 9.1 m long. In most trials, Phytogen 485 WRF cotton seed (Dow AgroSciences, Indianapolis, IN), containing only a fungicide treatment [Maxim (fludioxinil) and Apron XL (mefenoxam)] was treated in the laboratory with appropriate insecticide seed treatments. Base treatments in all trials included thiamethoxam (Cruiser 5 FS, Syngenta Crop Protection) at 0.34 mg ai/seed, imidacloprid (Gaucho Grande 5 FS, Bayer CropScience) at 0.375 mg ai/seed, and acephate (Orthene 90 S, Valent) at 0.709 kg/45.4 kg seed, aldicarb (Temik 15 G, Bayer CropScience) at 0.841 kg ai/ha placed in furrow at planting, and untreated. Avicta (28.1% thiamethoxam and 12.4% abamectin, Syngenta

Crop Protection) and/or Aeris (24% imidacloprid and 24% thiodicarb, Bayer CropScience) were included in two trials conducted in 2007 and 4 trials conducted in 2009. Rates of the insecticide seed treatments and aldicarb were the same in all trials. Planting dates, infestation dates, plant stages of cotton when infested with twospotted spider mite, and treatments included are shown in Table 2.1. All experiments were conducted in Starkville, MS, except tests 2, 10, and 12, which were conducted in Stoneville, MS.

Seedling cotton plants were inoculated with twospotted spider mites by stapling one infested green bean leaf from the laboratory colony onto one cotyledon of each plant within a 1-2 m row foot section in the center two rows of each plot. Cotton was infested between the 1st and 5th true leaf stages. Twospotted spider mites were sampled by pulling the uppermost fully expanded leaf from 5 plants in 2007 and five or ten leaves in 2008 and 2009, usually two nodes below the terminal. Leaves were placed in plastic bags and immediately transported to the laboratory where adult mites, immature mites, and/or mite eggs were counted with aid of a stereo microscope under 80X magnification. Trials were generally sampled at ~7 and 14 days after infestation (DAI).

Field experiment 8 also included three foliar treatments, including: thiamethoxam (Centric 40 WG, Syngenta Crop Protection) at 0.056 kg ai/ha, imidacloprid (Trimax Pro 4.43 SC, Bayer CropScience) at 0.071 kg ai/ha, and acephate (Orthene 90 S, Valent) at 0.22 kg ai/ha. Foliar insecticides were applied with a tractor-mounted sprayer calibrated to deliver 93.5 l/ha at 413.7 kpa through TX-6 hollow cone nozzles (2 per row). Foliar treatments were applied directly after infestation. The number of adult, immature, and mite eggs were counted. Plots were also visually rated on a 1-10 scale with 10 being no damage and 1 equal to severe damage.

Field experiments 9-12 were conducted in Starkville and Stoneville, Mississippi during May and June 2009. All four experiments had identical designs and treatments. One trial was planted in each location during the early period of the optimum planting window (22 April in Starkville and 27 April in Stoneville) and during the later period of the optimum planting window (20 May in Starkville and 21 May in Stoneville). All seed treatments previously listed were included in the trials. In an effort to further explain treatment differences, estimates of thrips densities were determined by cutting and washing the 3 uppermost nodes at 21 DAI in the early planted tests and 14 DAI in the late planted tests.

Laboratory Experiment. A laboratory experiment was conducted in the insect rearing facility in Clay Lyle Entomology at Mississippi State University to determine if seed treatments or applications of foliar insecticides impacted twospotted spider mite fecundity. Treatments were identical to those in field experiment 8, including: three seed treatments, three foliar treatments, aldicarb applied in-furrow, and an untreated check. Seed treatments were thiamethoxam, imidacloprid, and acephate. Foliar treatments were thiamethoxam (Centric 40 WG) at 0.056 kg ai/ha, imidacloprid (Trimax Pro 4.43 SC) at 0.071 kg ai/ha, and acephate (Orthene 90 S) at 0.22 kg ai/ha. Cotton was grown in pots (14-cm diameter, 15-cm depth) in a greenhouse. The experiment contained four replications. Each replication included eight treatments, totaling 32 pots in the experiment. Soil was collected from a field on the R. R. Foil Plant Science Research Center where previous field trials had been conducted. Four cotton seeds were planted per pot. A furrow was dug across each pot, and seed were evenly spaced across it, and then covered. In the aldicarb treatment, Temik 15 G was placed into the furrow with the seed. Each pot was watered at 2-3 day intervals. Although water volume was not measured, the volume poured in each pot was limited to prevent it from running out the bottom of the pot. When plants reached the second true leaf stage, the first true leaf from one plant per pot was removed and placed directly in individual petri dishes. Leaves were positioned with the abaxial surface facing upward on saturated cotton wool. A small piece of saturated cotton wool was placed over the leaf petiole at the point it was severed to protect against desiccation.

To standardize mite age, mated females were collected from the colony described previously, and placed on untreated green bean leaves. Leaves were placed on top of saturated cotton wool in a plastic bowl covered with cheese cloth. Photoperiod was 16:8 LD and temperature was 27°C. Female mites were allowed to lay eggs for 24 h before being either removed or killed. Eggs began to hatch 2.5 d later. Mating in the offspring was observed eight d after oviposition. Nine d after oviposition, all females had begun to oviposit. Two adult female mites were placed on each cotton leaf with a fine hair brush. Foliar applications were made to individual leaves and mites of the foliar treatments in a closed spray chamber calibrated to deliver 46.75 l/ha with a TeeJet 8015E nozzle at 220.6 kpa. Mortality and fecundity were measured daily for 14 d. Eggs were counted and removed daily by touching them with a fine hair brush that was lightly coated with

Tangle Foot adhesive. Water was added to the cotton wool each day to maintain saturation of cotton wool.

Analyses. Interactions between field experiments and treatments were first tested. Because interactions were not significant, a pooled analysis was then performed including all replicates of all trials. There was considerable variation in mite densities between different trials so each replicate was standardized as percent of the untreated control and a log base 10 transformation was taken of this percentage. Because some trials did not include all treatments, the design was unbalanced, so analysis was conducted with mixed model ANOVA using SAS (SAS Institute of America). Trial, replicate, and replicate within trial were set as random variables. Data were analyzed by: all observations combined, observations grouped within days after infestation (DAI) when sampled, observations grouped by stage of cotton at time of infestation, neonicotinoid treatments grouped and compared against other treatments, and only experiments 9-12. Each trial was also analyzed individually with ANOVA using ARM (Gyling Data Management). In Experiments 9-12, thrips counts were included as a covariant; however, thrips did not significantly affect mite treatment differences, so the covariant was removed in subsequent analyses.

Results

Field Experiments. Only three of nine individual field experiments resulted in significant differences for eggs (Table 2.2), and two of six for immature mites (Table 2.3). Six of the 12 individual field experiments resulted in significant treatment differences of total mites (Tables 2.4). Interactions between experiments and treatments were not significant at 7 DAI for total mites (df = 35, F = 1.34, P = 0.1185) or 14 DAI (df = 28, F = 1.21, P = 0.2385). Pooled analyses of data from all experiments resulted in significant treatment differences. In the simplest model, densities of adults, immatures, eggs, and total mites were compared by treatment across all replicates and sampling intervals of all experiments. Densities of each life stage and total mites were significantly less ($P \leq 0.05$) in cotton treated with aldicarb in-furrow than cotton with all other seed treatments. Adult and total mite densities in the aldicarb treatment were lower than the untreated check (Table 2.5). Densities of all life stages and total mites were lower in the untreated check than in the seed treatments with two exceptions: adults in Avicta treatment and total mites in acephate treatment. Thiamethoxam, imidacloprid, and Aeris treatments generally had similar mite densities across all life stages. However, Avicta treatments had significantly fewer adult and total mites than other neonicotinoid treatments. Mite densities in acephate and Avicta seed treatments were similar. Treatment differences were observed with egg densities. In general, aldicarb and untreated checks contained significantly fewer eggs than other treatments. All of the seed treatments contained similar egg densities.

To segment treatment differences over time, data were categorized based on the number of days after infestation (DAI) that the experiments were sampled. The three sampling interval categories included 5-8 DAI (1 wk), 12-15 DAI (2 wk), and 16+ DAI (3 wk). Only total mite densities are presented because combining immature and adult mite densities was representative of both life stages independently. Treatment differences varied over these sampling intervals (Table 2.6). When cotton was sampled 1 wk after infestation, aldicarb had fewer mites than all other treatments. Mite densities in the untreated check and Avicta treatments were significantly less than acephate and other neonicotinoid treatments. Acephate ranked as the median treatment. There were no significant differences between thiamethoxam, imidacloprid, or Aeris. At 2 wk after infestation, mite densities in untreated check treatments were below all other treatments except aldicarb. Avicta, Aeris, imidacloprid, thiamethoxam, and acephate treatments were similar. By 3 wk after infestation, untreated check, acephate, and aldicarb treatments had lower mite densities than all four neonicotinoid treatments.

Data were further partitioned by growth stage of cotton when mites were infested, including 1st, 3rd, and 4th true leaf stages. Each DAI category within each growth stage at infestation was analyzed independently. When cotton was infested at 1st true leaf and sampled 1 wk after (~3rd leaf stage), many of the trends apparent in the overall analysis were magnified (Table 2.7). Aldicarb, Avicta, and untreated check had significantly fewer mites than neonicotinoid treatments. However, when cotton was sampled 2 wk after infestation at 1st true leaf stage (5-6th leaf stage), mite densities in Avicta treatments were similar to those in the thiamethoxam treatment. Three wk after infestation at first true leaf, acephate had mite densities similar to aldicarb and untreated check, and less mites than all other neonicotinoid treatments. Aldicarb and untreated check treatments contained statistically fewer mites than most treatments at all sampling intervals. Treatments were not statistically different when infested at 3rd or 4th true leaf.

Because thiamethoxam, imidacloprid, and Aeris were statistically similar in overall analyses, those treatments were combined into a neonicotinoid category and compared against Avicta, Acephate, aldicarb and untreated check. In this analysis, treatments ranked similar to other analyses (Table 2.8). Avicta contained 34% fewer mites than other neonicotinoids. Aldicarb and untreated check had 57 and 53% fewer mites than the neonicotinoid category, respectively.

Experiments 9-12 A separate pooled-analysis was performed on experiments 9-12 because those 4 experiments were conducted identically and could be analyzed in a balanced design. Results were once again similar to other analyses. Imidacloprid, Aeris, and thiamethoxam contained statistically more mites than all other treatments when sampled at 1 and 2 wk post infestation and across all time intervals (Table 2.9). Also, Avicta contained fewer mites than other neonicotinoid seed treatments and aldicarb had fewer mites than all other treatments. By 3 wk after mite infestation, aldicarb, acephate, and untreated check had ~60% fewer mites than the neonicotinoid seed treatments.

Foliar vs. Seed Treatment. Experiment 8 contained treatments with seed applied and foliar applications of thiamethoxam, imidacloprid, and acephate in addition to aldicarb in-furrow and an untreated check. Overall, there were very few differences between seed applied and foliar applications of thiamethoxam, imidacloprid, and acephate (Table 2.10). Aldicarb contained fewer mites than all other treatments at 7 and 14 DAI. Visual injury ratings followed closely with mite densities. Cotton in aldicarb treatments was least injured and cotton treated with foliar applications of acephate was most injured.

Lab Fecundity Experiment. Fecundity of female mites was measured when fed cotton leaves from plants with an at-planting insecticide (seed treatment or granular) or foliar applications of imidacloprid, thiamethoxam, and acephate, or an untreated check. Only foliar applied thiamethoxam significantly increased twospotted spider mite fecundity above the untreated check (df = 41, F = 2.30, P = 0.0489) (Fig. 1). All other foliar and systemic neonicotinoid treatments resulted in similar average fecundity to the untreated check. Aldicarb had the lowest fecundity because nearly all mites either crawled off the leaves or died within three days.

Discussion

Aeris, thiamethoxam, and imidacloprid treatments resulted in twospotted spider mite densities greater than those in the untreated check, aldicarb, and acephate treatments. However, cotton treated with Avicta (thiamethoxam + abamectin) had 34% fewer mites than other neonicotinoid seed treatments. Efficacy of Avicta against mites was only apparent when mites were infested close to cotyledon stage and the effect became less apparent as cotton grew larger. Foliar formulations of abamectin are highly effective against twospotted spider mite (Price et al. 2009, Smith and Catchot 2009).

Abamectin is not systemic within plant tissues, but may be deposited on cotyledons during germination and plant emergence from the soil (Christoph Crimm, Syngenta Crop Protection AG, personal communication). This may explain why Avicta reduced mite densities for only a brief period after cotyledon stage. As a seed treatment, acephate consistently ranked as the median treatment, and this may be related to less activity against thrips than the other seed treatments. Thrips are a known predator of twospotted spider mites (Agrawal et al. 1999, Colfer et al. 2000). Lindquist and Wolgamott (1980) reported that neither foliar nor systemic applications of acephate caused significant twospotted spider mite mortality. It is generally believed that systemic applications of acephate begin to diminish just after cotyledon stage. Predator populations may have rebounded quicker in acephate treatments than in neonicotinoid treatments. As a result, increased predation may partly explain why twospotted spider mite densities were lower in the acephate and untreated treatments. Untreated and aldicarb treatments had the lowest mite densities of twospotted spider mite. Aldicarb was the only treatment that reduced twospotted spider mite densities below the untreated check. Van Duyn et al. (1998) and Troxclair (2007) reported that on cotton with neonicotinoid seed treatments twospotted spider mite populations were significantly higher compared to untreated or aldicarb treated cotton, and that densities in untreated and aldicarb treated cotton were similar.

Twospotted spider mite densities on cotton treated with neonicotinoid seed treatments were consistently greater than those on untreated cotton or cotton treated with aldicarb or acephate. These results corroborate reports from Van Duyn et al. (1998), Sclar et al. (1998), James and Price (2002), Raupp et al. (2004), and Beers et al. (2005). Authors have postulated several theories explaining why mite populations increase after neonicotinoid applications. First, neonicotinoids have a hormoligant effect on mites, causing increased fecundity (James and Price 2002). Second, neonicotinoid insecticides reduce interspecific competition and promote mite population growth (Ako et al. 2004). Third, neonicotinoid insecticides reduce predation by killing predatory insects and mites (Sclar et al. 1998).

In the current experiment, systemically applied imidacloprid and thiamethoxam did not increase twospotted spider mite fecundity above that in the untreated check, but foliar applied thiamethoxam did increase fecundity. The current experiment did not show hormoligosis when mated females were exposed to treated leaves, but the results may be different if mites were allowed to develop on treated leaves. The second theory, that neonicotinoid seed treatments increase mite densities by reducing interspecific competition and plant injury, cannot be ruled out. Several thrips species are pests of seedling cotton, and in the absence of insecticides, can injure plants and reduce leaf area. It is possible that untreated cotton sustained more thrips injury and as a result was a less suitable host than cotton treated with insecticides. It is important to point out that 3 of the 12 experiments did receive enough thrips injury to reduce leaf area in untreated cotton, but, although some injury was evident, large differences in leaf area were not visually apparent among treatments in other experiments. The theory that neonicotinoid seed treatments caused mortality in predators, thus flaring twospotted spider mite populations is also plausible. Studies by Steinkraus et al. (1999) showed that immature thrips are often found in the center of mite colonies underneath leaves. *Orius insidiosus* (Say), *Geocoris punctipes* (Say), and *Frankliniella occidentalis* (Pergande), are other omnivorous insects that are frequently found on seedling cotton (Colfer et al. 2000, Studebaker and Kring 2003, Tillman and Mullinix 2003). All three species are reported to be important predators of twospotted spider mite (Lincoln et al. 1953, Wilson et al. 1991, Agrawal et al. 1999, and Rondon et al. 2004), and have been documented to reduce populations by 76-99% (Colfer et al. 2000). Neonicotinoid insecticides have been reported to be deleterious to these and many other omnivorous predators (Sclar et al. 1998, Van Duyn et al. 1998, Elzen 2001, Studebaker and Kring 2003). Sclar et al. (1998) suggested that a reduction in minute pirate bug, *Orius tristicolor* (White), densities on plants treated with imidacloprid resulted in higher spider mite populations. Systemic soil-drench applications of thiamethoxam and imidacloprid also have been reported to be highly toxic to the omnivorous Brazilian spined soldier bug, *Podisus nigrispinus* (Dallas) (Torres and Ruberson 2004, Torres et al. 2003). Smith and Krischik (1999) found that the coccinellid predator *Coleomegilla maculata* (DeGeer) expressed higher mortality, and decreased mobility and oviposition when exposed to flowers after systemic applications of imidacloprid. Neonicotinoid insecticides used as seed treatments in cotton may have similar effects on omnivorous insects. Although other factors cannot be completely ruled out, predation was likely an important factor impacting the results of the current experiment.

Aldicarb generally suppressed mite densities across all field experiments, but did not eliminate populations. Although control was variable among experiments, most aldicarb treatments resulted in mite populations that would have required further management. Knowles et al. (1988) determined that aldicarb was highly toxic to twospotted spider mite, and that a LC_{50} of 21 ppm was less (> 4 fold) than for other carbamates, organophosphates, pyrethroids, and organochlorines tested, except for bifenthrin. Aldicarb was also found to be effective at reducing twospotted spider mite populations in large-seeded Virginia-type peanuts (Smith and Mozingo 1983). It is important to emphasize that a higher density of mites was placed on the seedling cotton plants using artificial infestations than would usually occur under natural conditions. Aldicarb may provide adequate control of twospotted spider mite under natural infestations where densities are low. The difference in the effects of neonicotinoid seed treatments and aldicarb on twospotted spider mite is explained by the fact that both are deleterious to predators, however only aldicarb is effective against twospotted spider mite.

Overall, these trials indicated that twospotted spider mite densities are higher on cotton with a neonicotinoid seed treatment than on untreated cotton, or cotton treated with acephate as a seed treatment or aldicarb. All treatments except aldicarb resulted in higher mite densities than those on untreated cotton. Thrips are a major pest of cotton across the United States and require at-planting insecticides in nearly all situations. Despite widespread use of neonicotinoid seed treatments on most cotton acres in Mississippi, mite outbreaks in seedling cotton occur on only a small percentage of acres. Another factor that may impact twospotted spider mite densities in seedling cotton is weed management. Outbreaks on seedling cotton are often the result of alternate hosts remaining within or next to field borders. In situations where mite populations exist along field borders or on vegetation within fields, using a neonicotinoid seed treatment could further promote mite population growth. If there is a known risk of mite infestation, aldicarb would likely reduce the risk of economic infestations occurring.

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Table 2.1. Planting date, infestation date, and treatments for each field experiment from 2007-2009.

	Planting Date	Infestation Date	Plt Stage (Infest)[a]	UTC	Aldicarb	Thiamethoxam	Imidacloprid	Avicta	Aeris	Acephate
Test 1	4/27/2007	5/23/2007	3	X	X	X				
Test2	5/4/2007	5/29/2007	4	X	X			X	X	
Test 3	6/7/2007	6/27/2007	1	X	X			X		
Test 4	6/5/2007	7/6/2007	3	X	X			X		
Test 5	6/22/2007	7/12/2007	3	X	X	X	X			
Test 6	4/23/2008	5/20/2008	1	X	X			X	X	
Test 7	5/5/2009	5/29/2008	1	X	X	X		X		
Test 8*	6/5/2008	6/18/2008	1	X	X	X	X			X
Test 9	4/22/2009	5/12/2009	1	X	X	X	X	X	X	X
Test 10	4/27/2009	5/18/2009	1	X	X	X	X	X	X	X
Test 11	5/20/2009	6/8/2009	1	X	X	X	X	X	X	X
Test 12	5/21/2009	6/8/2009	1	X	X	X	X	X	X	X

[a] Plant Stage when infested (number of true leaves).

* Three foliar insecticide treatments were included in experiment 8. They included thiamethoxam (Centric 40 WG, Syngenta Crop Protection), Imidacloprid (Trimax Pro 4.43 SC, Bayer Crop Science), and acephate (Orthene 90 S, Valent).
Base treatments in all experiments included an untreated control (UTC), aldicarb (Temik 15 G, Bayer CropScience), and at least one neonicotinoid seed treatment. Five trials included an acephate seed treatment (Orthene 90 S, Valent). Neonicotinoid seed treatments included: thiamethoxam (Cruiser 5 FS, Syngenta Crop Protection), imidacloprid (Gaucho Grande 5 FS, Bayer CropScience), aldicarb (Temik 15 G, Bayer CropScience), Avicta (28.1% thiamethoxam and 12.4% abamectin, Syngenta Crop Protection), and Aeris (24% imidacloprid and 24% thiodicarb, Bayer CropScience).

Table 2.2. Mean number of twospotted spider mite eggs and statistical values for each trial and sample date.

	Test 1		Test2		Test 4	Test 7	Test 8		Test 9		Test 10		Test 11		Test 12	
	7 DAI	**20 DAI**	**6 DAI**	**20 DAI**	**6 DAI**	**6 DAI**	**7 DAI**	**14 DAI**	**8 DAI**	**15 DAI**	**8 DAI**	**14 DAI**	**8 DAI**	**15 DAI**	**7 DAI**	**14 DAI**
Thiamethoxam	25.4 a	16.1 a	-	-	-	40.5 a	29.3 a	45.5 c	14.3 a	15.6 a	0.65 a	57.9 ab	21.5 a	85.2 a	45.8 a	71.0 a
Imidacloprid	-	-	-	-	-	-	25.7 a	105.6 a	14.1 a	19.7 a	2.43 a	54.4 ab	9.5 c	66.8 a	41.48 a	92.4 a
Avicta	-	-	29.3 a	14.2 a	1.5 a	17.0 a	-	-	13.6 a	14.0 a	1.5 a	62.1 ab	7.2 c	36.3 bc	20.18 a	189.9 a
Aeris	-	-	23.6 a	23.2 a	-	-	-	-	12.5 a	24.9 a	0.58 a	42.25 bc	16.6 ab	67.2 a	56.1 a	90.5 a
Acephate	-	-	-	-	-	-	18.6 a	86.5 ab	8.6 a	16.25 a	1.1 a	42.78 bc	13.4 bc	44.1 b	39.3 a	44.48 a
Aldicarb	3.1 a	2.9 a	32.5 a	16.3 a	3.4 a	22.3 a	3.4 a	38.7 c	12.9 a	9.9 a	1.7 a	74.9 a	8.0 c	23.3 c	30.45 a	66.93 a
Untreated	12.3 a	12.8 a	14.1 a	9.6 a	0.8 a	14.0 a	32 a	50.1 c	10.6 a	14.7 a	0.33 a	19.6 c	9.5 c	34.2 bc	23.3 a	58.95 a
N	12	12	16	16	12	40	50	50	70	70	70	70	70	70	70	70
F-value	2.51	1.46	0.587	0.555	1.219	1.231	1.713	2.737	0.608	1.04	2.017	2.877	3.334	7.181	1.507	2.137
P	0.1618	0.305	0.6402	0.6577	0.34	0.354	0.1602	0.0348	0.7212	0.4325	0.1163	0.0381	0.0218	0.0005	0.232	0.1021

Means followed by the same letter within a column are not significantly different (LSD with $\alpha = 0.05$).
N = total number of observations (treatment x replications)

Table 2.3. Mean number of twospotted spider mite immatures and statistical values for each trial and sample date.

	Test 7	Test 8		Test 9		Test 10		Test 11		Test 12	
		7 DAI	14 DAI	8 DAI	15 DAI	8 DAI	14 DAI	8 DAI	15 DAI	7 DAI	14 DAI
Thiamethoxam	26.0 a	25.7 ab	33.2 bc	10.4 a	5.7 ab	1.2 a	5.6 a	14.8 a	15.8 a	20.6 a	18.0 a
Imidacloprid	-	26.0 ab	55.6 a	12.5 a	4.8 b	3.3 a	5.6 a	8.4 a	15.2 a	19.7 ab	34.2 a
Avicta	26.0 a	-	-	13.6 a	3.5 b	1.2 a	3.7 a	7.4 a	5.7 b	8.2 cd	42.8 a
Aeris	-	-	-	8.6 a	7.5 a	1.1 a	3.0 a	13.6 a	17.2 a	15.5 abc	48.4 a
Acephate	-	19.9 ab	24.7 bcd	8.4 a	4.4 b	1.3 a	6.4 a	8.7 a	12.7 a	15.6 abc	17.1 a
Aldicarb	33.8 a	18.8 c	82.8 d	7.3 a	2.7 b	1.0 a	7.4 a	8.9 a	3.6 b	6.9 d	20.3 a
Untreated	28.5 a	18.0 b	17.5 cd	7.9 a	3.1 b	1.0 a	2.0 a	6.7 a	4.5 b	11.5 bcd	10.2 a
N	40	50	50	70	70	70	70	70	70	70	70
F-value	0.042	2.525	3.614	0.737	2.475	1.814	1.218	1.457	6.491	2.319	1.545
P	0.9879	0.0473	0.0103	0.627	0.0635	0.1529	0.3421	0.2481	0.0009	0.0779	0.2232

Means followed by the same letter within a column are not significantly different (LSD with $\alpha = 0.05$).
N = total number of observations (treatment x replications)

Table 2.4. Mean number of twospotted spider mite adults and immatures, and statistical values for each trial and sample date.

	Test 1		Test2		Test 3		Test 4	Test 5	Test 6	Test 7	Test 8		Test 9		Test 10		Test 11		Test 12	
	7 DAI	20 DAI	6 DAI	13 DAI	6 DAI	9 DAI	6 DAI	14 DAI	8 DAI	6 DAI	7 DAI	14 DAI	8 DAI	15 DAI	8 DAI	14 DAI	8 DAI	15 DAI	7 DAI	14 DAI
Thiamethoxam	4.4 a	1.5 a	-	-	-	-	-	10.7 a	-	40.8 a	29.9 ab	41.0 b	14.3 a	9.3 b	2.8 b	11.2 a	20.0 a	24.7 a	31.5 a	30.2 bcd
Imidacloprid	-	-	-	-	-	-	-	7.5 a	-	-	31.3 ab	64.2 a	16.4 a	10.1 b	4.6 a	11.2 a	11.5 a	21.5 ab	29.2 a	60.6 ab
Avicta	-	-	8.8 a	7.4 a	11.1 a	12.9 a	4.2 a	-	29.9 b	30.8 a	-	-	17.0 a	9.0 b	2.1 b	9.8 a	9.1 a	9.4 c	12.3 c	53.6 abc
Aeris	-	-	5.7 a	11.7 a	-	-		-	71.1 a	-	-	-	11.4 a	14.5 a	2.1 b	7.5 a	16.3 a	24.9 a	27.3 a	68.4 a
Acephate	-	-	-	-	-	-	-	-	-	-	24.2 b	39.5 b	10.0 a	7.2 bc	2.6 b	10.4 a	12.4 a	16.9 b	25.3 ab	23.1 cd
Aldicarb	0.83 ab	2.1 a	4.4 a	12.3 a	7.1 a	6.92 a	2.05 a	2.8 a	48.5 b	39.0 a	27.5 c	11.5 c	10.5 a	4.5 c	1.4 b	16.0 a	11.6 a	6.3 c	10.7 c	26.3 cd
Untreated	2.9 b	2.75 a	2.7 a	4.9 a	12 a	3.97 a	3.4 a	6.0 a	41.8 b	33.5 a	22.6 b	29.9 bc	11.1 a	6.7 bc	1.3 b	4.2 a	8.9 a	7.9 c	16.9 bc	18.5 d
N	12	12	16	16	12	12	12	16	16	16	50	50	70	70	70	70	70	70	70	70
F-value	6.47	0.45	1.394	1.709	1.53	2.07	0.991	2.21	3.693	0.048	1.713	3.051	0.774	3.544	2.329	1.848	1.794	8.414	5.616	2.291
P	0.0318	0.6585	0.3135	0.2342	0.2679	0.1769	0.4083	0.1185	0.0239	0.9851	0.1602	0.0223	0.6005	0.0171	0.0769	0.146	0.157	0.0002	0.002	0.0836

Means followed by the same letter within a column are not significantly different (LSD with $\alpha = 0.05$).
N = total number of observations (treatment x replications)

Table 2.5. Mean number of adult, immature, total mites (adult + immature), and eggs averaged across all experiments.

	Adult				Immatures				Total Mites				Eggs			
TRT	**N**	**Mean**		**SEM**	**N**	**Mean**		**SEM**	**N**	**Mean**		**SEM**	**N**	**Mean**		**SEM**
Aeris	32	7.0	ab	1.5	32	16.3	ab	3.5	58	17.3	a	3.2	40	31.0	a	8.0
Avicta	36	4.2	c	1.4	42	12.4	b	3.3	67	11.2	b	3.2	49	30.9	a	7.5
Thiamethoxam	44	5.9	a	1.4	44	13.9	ab	3.3	66	14.9	a	3.2	52	29.0	a	7.5
Imidacloprid	39	6.6	a	1.4	39	17.3	a	3.4	53	18.6	a	3.3	39	33.0	a	8.0
Acephate	40	4.8	bc	1.4	40	11.2	ab	3.3	48	10.2	bc	3.3	40	22.4	ab	8.0
Aldicarb	44	2.9	d	1.4	50	6.5	c	3.2	89	7.2	d	3.1	65	18.7	c	7.1
Untreated	44	4.1	c	1.4	50	7.7	c	3.2	90	7.9	c	3.1	66	17.0	bc	7.1
df (num, den)		6, 249				6, 264				6, 411				6, 322		
F-value		8.68				9.54				16.23				3.31		
P		<.0001				<.0001				<.0001				0.004		

Means followed by the same letter within a column are not significantly different (LSD with α = 0.05).

Table 2.6. Mean number of total mites (adult + immature), by days after infestation (DAI) averaged across all experiments.

	5-8 DAI				12-15 DAI				16+ DAI			
TRT	**N**	**Mean**		**SEM**	**N**	**Mean**		**SEM**	**N**	**Mean**		**SEM**
Aeris	30	12.6	a	2.4	20	26.5	a	6.4	8	18.3	a	4.1
Avicta	39	8.0	b	2.3	20	18.9	ab	6.4	8	12.6	ab	4.1
Thiamethoxam	28	14.8	a	2.4	26	18.3	a	6.2	12	14.9	a	3.8
Imidacloprid	20	15.4	a	2.6	25	25.1	a	6.3	8	19.3	a	4.1
Acephate	20	11.8	ab	2.6	20	15.0	a	6.4	8	3.5	c	4.1
Aldicarb	47	6.5	c	2.3	30	11.3	c	6.1	12	6.1	bc	3.8
Untreated	48	8.3	b	2.3	30	10.8	bc	6.1	12	5.4	bc	3.8
# Experiments		11				7				3		
df (num, den)		6, 178				6, 135				6, 50		
F-value		7.83				6.98				5.25		
P		<.0001				<.0001				0.0003		

Means followed by the same letter within a column are not significantly different (LSD with α = 0.05).

Table 2.7. Mean number of total mites (adult + immature), when infested at 1st, 2nd, or 3rd true leaf and sampled at 5-9, 12-14, and 16+ days after infestation (DAI). Includes data across all reps of all experiments.

	1st True Leaf												3rd True Leaf									4th True Leaf					
	5-9 DAI (3)[a]				12-14 DAI (5)				16+ DAI (7)				5-9 DAI (5)			12-14 DAI (7)			16+ DAI (9)			5-9 DAI (6)			12-14 DAI (8)		
	N	Mean		SEM	N	Mean		SEM	N	Mean		SEM	N	Mean	SEM	N	Mean	SEM	N	Mean	SEM	N	Mean	SEM	N	Mean	SEM
Aeris	26	15.17	a	2.93	16	32.84	ab	7.88	8	21.35	a	2.77	-	-	-	-	-	-	-	-	-	4	5.65	2.22		11.7	3.43
Avicta	30	9.5	b	2.9	16	24.5	c	7.9	8	15.7	a	2.77	6	4.17	0.9	-	-	-	-	-	-	3	9.1	2.6	4	7.4	3.43
Thiamethoxam	24	17.5	a	2.9	20	23.3	abc	7.6	8	21.6	a	2.77	4	4.4	1.1	6	2.1	0.4	4	1.5	1.1	-	-	-	-	-	-
Imidacloprid	20	17.5	a	3.0	19	32.5	a	7.7	8	22.4	a	2.77	-	-	-	6	1.5	0.4	-	-	-	-	-	-	-	-	-
Acephate	20	13.8	ab	3.0	20	19.4	bc	7.7	8	6.6	b	2.77	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Aldicarb	34	8.3	c	2.8	20	12.9	d	7.7	8	8.1	b	2.77	9	1.7	0.7	6	0.6	0.4	4	2.1	1.1	4	4.4	2.22	4	12.3	3.43
Untreated	34	10.6	bc	2.8	20	13.4	d	7.7	8	6.8	b	2.77	10	3.2	0.7	6	1.2	0.4	4	2.8	1.1	4	2.7	2.22	4	4.9	3.43
# experiments		8				5				2				2			1			1			1			1	
df (num, den)		6, 148				6, 105				6, 42				3, 16			3, 15			2, 6			3, 8			3, 9	
F-value		7.3				7.46				10.84				2.3			2.44			0.56			0.3			2.59	
P		<.0001				<.0001				<.0001				0.1198			0.1			0.6006			0.8034			0.1173	

Means followed by the same letter within a column are not significantly different (LSD with $\alpha = 0.05$).
[a] (3) – approximate growth g stage or number of nodes at time of sampling

Table 2.8. Mean number of total mites (adult + immature), averaged across all experiments. Aeris, Gaucho, and Cruiser categorized into neonicotinoid class for analysis.

	All Timing Intervals				5-8 DAI				12-15 DAI				16+ DAI			
TRT	**N**	**Mean**		**SEM**	**N**	**Mean**		**SEM**	**N**	**Mean**		**SEM**	**N**	**Mean**		**SEM**
Avicta	67	11.1	b	3.2	39	8.1	b	2.4	20	18.7	bc	6.4	8	12.2	ab	4.3
Untreated	90	7.8	c	3.1	48	8.4	b	2.3	30	10.8	cd	6.1	12	5.4	bc	4.1
Neonicotinoid	177	16.7	a	3.0	78	14.1	a	2.2	71	23.1	a	5.8	28	16.9	a	3.8
Acephate	48	10.1	bc	3.3	20	11.6	ab	2.6	20	15.0	ab	6.4	8	3.1	c	4.3
Aldicarb	89	7.1	d	3.1	47	6.6	c	2.3	30	11.3	d	6.1	12	6.1	c	4.1
df (num, den)	4, 413				4, 180				4, 137				4, 52			
F-value	24.4				11.83				10.62				7.56			
P	<.0001				<.0001				<.0001				<.0001			

Means followed by the same letter within a column are not significantly different (LSD with α = 0.05).

Table 2.9. Mean number of total mites (adult + immature), averaged across all experiments 9-12. Experiments 9-12 each contain all treatments.

	All Timing Intervals				5-8 DAI				12-15 DAI				16+ DAI			
TRT	**N**	**Mean**		**SEM**	**N**	**Mean**		**SEM**	**N**	**Mean**		**SEM**	**N**	**Mean**		**SEM**
Aeris	40	22.0	a	5.4	16	14.3	a	4.3	16	28.8	a	7.9	8	21.4	a	2.8
Avicta	40	15.9	b	5.4	16	10.1	b	4.3	16	20.5	ab	7.9	8	15.7	ab	2.8
Thiamethoxam	40	19.2	a	5.4	16	17.1	a	4.3	16	18.8	a	7.9	8	21.6	a	2.8
Imidacloprid	39	20.5	a	5.5	15	15.4	a	4.3	16	24.4	a	8.0	8	22.4	a	2.8
Acephate	40	12.6	bc	5.4	16	12.6	ab	4.3	16	14.4	a	7.9	8	6.6	c	2.8
Aldicarb	40	10.8	d	5.4	16	8.5	c	4.3	16	13.3	c	7.9	8	8.1	c	2.8
Untreated	40	9.4	c	5.4	16	9.5	b	4.3	16	9.3	bc	7.9	8	6.8	bc	2.8
df (num, den)	6, 257				6, 90				6, 89				6, 42			
F-value	12.8				6.02				5.31				10.84			
P	<.0001				<.0001				<.0001				<.0001			

Means followed by the same letter within a column are not significantly different (LSD with α = 0.05).

Table 2.10. Mean number of immatures, adults, eggs, and total mites per leaf on cotton treated with foliar and systemically applied insecticides in experiment 8.

	7 DAI				14 DAI				Visual
	Immatures	Adults	Eggs	Total Mites	Immatures	Adults	Eggs	Total Mites	Rating [a]
Thiamethoxam (Sd Trt)	25.65 a	4.2 a	29.25 a	29.85 a	33.23 b	7.8 a	45.53 cd	41.03 ab	4.5 b
Imidacloprid (Sd Trt)	25.95 a	5.3 a	25.73 a	31.25 a	55.55 a	8.63 a	105.6 a	64.18 a	4.0 bc
Acephate (Sd Trt)	19.83 a	4.35 a	18.63 a	24.18 a	24.68 bc	14.85 a	86.5 abc	39.53 ab	4.0 bc
Thiamethoxam (Foliar)	19.93 a	4.98 a	31.63 a	24.9 a	33.78 ab	5.78 a	65.23 a-d	39.55 ab	4.8 b
Imidacloprid (Foliar)	26.45 a	5.55 a	23.78 a	32 a	37.98 ab	11.15 a	87.13 ab	49.13 ab	4.3 b
Acephate (Foliar)	33.1 a	7.08 a	38.83 a	40.18 a	36.48 ab	10.25 a	63.93 bcd	46.73 ab	3.3 c
Aldicarb	1.88 b	0.88 a	3.43 a	2.75 b	8.28 c	3.23 a	38.65 d	11.5 c	8.3 a
Untreated	17.98 ab	4.58 a	31.95 a	22.55 a	17.45 bc	12.43 a	50.18 bcd	29.88 bc	4.3 b
df (num, den)	7, 24	7, 24	7, 24	7, 24	7, 24	7, 24	7, 24	7, 24	7, 24
LSD (α=0.05)	171.21	37	241.51	189.31	221.47	83.81	415.77	256.91	0.81
F-value	2.525	1.964	1.713	2.884	3.614	1.706	2.737	3.051	30.19
P	0.0473	0.1094	0.1602	0.0282	0.0103	0.162	0.0348	0.0223	0.0001

Means followed by the same letter within a column are not significantly different (LSD with $\alpha = 0.05$).

* Sd Trt = Seed Treatment

[a] Visual rating on a 1-10 scale, 10 = no damage

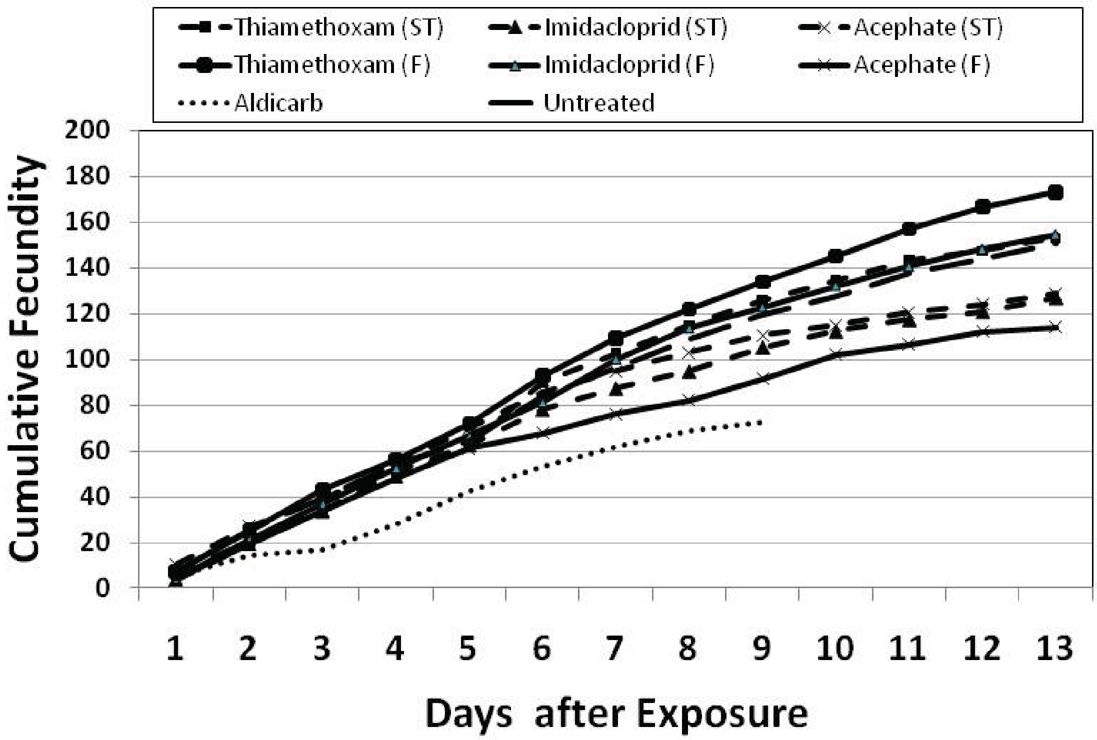

Figure 2.1. Cumulative fecundity of twospotted spider mite females placed on cotton leaves treated with foliar and systemically applied insecticides. ST = seed treatment, F = foliar.

CHAPTER III

SURVEY OF TWOSPOTTED SPIDER MITE HOST PLANTS IN THE MISSISSIPPI DELTA

Abstract

A survey of twospotted spider mite, *Tetranychus urticae* Koch, hosts was conducted during the spring months of 2007 through 2009 in Mississippi. Uncultivated field borders that supported a diverse flora of herbaceous plants and adjacent in-field weeds were sampled from late-March through May for the presence of twospotted spider mite. Twospotted spider mite preference for each plant species was determined and ranked in a 0-3 scale. Henbit, *Lamium amplexicaule* L., was the most consistent and preferred host of twospotted spider mite in Mississippi. Carolina geranium, *Geranium carolinianum* L., cutleaf geranium, *Geranium dissectum* L., vetch, *Vicia* spp., volunteer soybean, *Glycine max* L., purple deadnettle, *Lamium purpureum* L., and spiny sowthistle, *Sonchus asper* (L.) Hill, were other frequently infested dicotyledonous species. Of the monocotyledonous species sampled, only rescuegrass, *Bromus catharticus* Vahl, johnsongrass, *Sorghum halepense* (L.) Pers., and volunteer corn, *Zea mays* L., appeared to be major hosts of twospotted spider mite during spring months. Italian ryegrass, *Lolium perenne* (L.) spp. multiflorum (Lam.), did not appear to be an important host of twospotted spider mite at any location, which is a benefit considering glyphosate resistant

biotypes are very common in many Mississippi fields. Equally important, twospotted spider mite was not found on annual bluegrass, *Poa annua* L., which occurs in all Mississippi fields during winter and spring. The host list generated from this study can be directly used to refine early-season twospotted spider mite management, and also help support future research.

Introduction

The twospotted spider mite, *Tetranychus urticae* Koch, is a polyphagous plant feeder and pest of many crops. In cotton, *Gossypium hirsutum* L., twospotted spider mite has traditionally been considered an occasional pest of cotton in the southern United States. However, from 2005 through 2008, the number of cotton acres treated for mites in Mississippi increased by 2-fold above historic levels (Williams 2009). Other southern states also experienced increases in mite densities, compared to previous years. Twospotted spider mite management will likely continue to be an annual economic problem for cotton production in southern United States, so effective management of the pest will continue to be important.

One strategy used to control polyphagous pests is to disrupt host plant synchrony by eliminating alternate hosts that are utilized before crops become suitable. Snodgrass et al. (2006) was able to reduce populations of tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois), and insecticide applications in cotton by minimizing host plants around field borders during early-spring. Removal of hosts with a selective herbicide in February and March limited the ability of tarnished plant bugs to increase population densities around field perimeters. Similar reductions in twospotted spider mite populations may be possible using similar procedures. However, before such projects are initiated, host plants of twospotted spider mite in the southern cotton belt need to be identified. Previous literature has documented many hosts of twospotted spider mite

(Cagle 1949, Brandenburg and Kennedy 1981, Brandenburg and Kennedy 1982, Takafuji and Kamibayashi 1984, Margolies and Kennedy 1985, Flexner et al. 1991, Wilson 1995, Steinkraus et al. 1999, Hardman et al. 2005). However, these studies were either not conducted in the southern U. S. cotton belt or did not extensively sample weeds during the early-spring critical time period. Steinkraus et al. (1999), conducted a host survey in Arkansas, but sampled during June and July. Brandenburg and Kennedy (1981 and 1982) identified several primary hosts in North Carolina, but did not conduct an exhaustive host survey. Flexner et al. (1991) and Wilson (1995) observed mite preference for many plants, but conducted the studies in Oregon and Australia, respectively.

The following manuscript describes a three year host survey that was conducted across the Mississippi River alluvial plain 'Delta' in Mississippi. The current results were compared to previous reports and an extensive host list is included.

Materials and Methods

A twospotted spider mite host survey was conducted during the spring months of 2007 through 2009. Uncultivated field borders that supported a diverse flora of herbaceous plants and adjacent in-field weeds were sampled from late-March through May for the presence of twospotted spider mites. Extensive sampling was used to collect data from multiple sites and all weed species present. Sample sites were located across the Mississippi Delta in areas with a history of spider mite infestations in cotton. Sites were chosen both at random and, when possible, near fields of seedling cotton experiencing twospotted spider mite outbreaks. Sampling was conducted by examining entire plants using a 10X hand lens for the presence or absence of mites. Spider mites were categorized by species and life stage (egg, immature, or adult) and recorded as present or absent on each weed species. Densities on each host were determined by counting the number of mites on ten leaves or shoots.

During 2007, 16 locations adjacent to fields that had been planted to cotton the previous year were sampled from March through May. During 2008, 14 fields and adjacent weedy areas were sampled for mites from 28 March to 9 May. Sample sites were near locations where populations had existed the previous season. Thirteen locations were sampled in 2009, adjacent to current cotton fields or fields planted to cotton the previous year.

Twospotted spider mite preference for each plant species was determined and ranked in a 0-3 scale (Flexner et al. 1991) (Table 3.1), where: 0 = No mites were observed on the plant species, 1= very few mites were found on the plant and no reproduction was evident, 2= mites and reproduction was commonly found, but densities were generally low, and 3= when mite populations were located, the species was always infested and supported high populations relative to other plant species present. Classification of plant preference was based primarily on spider mite densities. However, not all plant species were present at all sample sites, so some subjectivity exist in the ranking of spider mite preference for certain species. There were also a couple of instances where high populations were found on a plant species in one location, but in other areas the species did not host mites. Common plant species were identified in the field. Field identification was confirmed by comparing plant specimens to published descriptions. Specimens of less common plant species were transported to the laboratory for identification and confirmed by a trained weed scientist at Mississippi State University. The same rating scale was also applied to hosts plants documented in previous reports. Classification of plant preference was based on previous preference ranking or descriptions in published reports.

Results

Mites were detected at eight locations sampled in 2007. Population densities were variable among those locations. On 7 May, two areas in Sunflower Co. and one field in Leflore Co. were sampled for mites. Two sites in Sunflower Co. contained mites. At the first site, a weedy area around a shop yard, twospotted spider mites were found on henbit, *Lamium amplexicaule* L., hairy vetch, *Vicia villosa* Roth, Carolina geranium, *Geranium carolinianum* L., Brazilian vervain, *Verbena brasiliensis* Vell, and white clover, *Trifolium repens* L (Table 1). Average density on henbit was 3.4 twospotted spider mites per stem. Carolina geranium and Brazilian vervain had 3.0, and 3.1 twospotted spider mites per leaf, respectively. Eggs and immature twospotted spider mites were present on all three species. No twospotted spider mites were found on johnsongrass, *Sorghum halepense* (L.) Pers., spotted spurge, *Chamaesyce maculata* (L.) Small, curly dock, *Rumex crispus* L., pigweeds, *Amaranthus* spp., bermudagrass, *Cynodon dactylon* (L.) Pers., rescuegrass, *Bronus catharticus* Vahl, field corn, *Zea mays* L., cutleaf eveningprimrose, *Oenothera laciniata* Hill, and several unidentified grass species. At the second location in Sunflower Co., twospotted spider mites were found on ivyleaf morningglory, *Ipomoea hederacea* (L.) Jacq., (1.7 mites/leaf), honeyvine milkweed, *Cynanchum laeve* (Michx.) Pers., (0.57 mites/leaf), and dewberry, *Rubus* spp., (0.4 mites/leaf).   No mites were found on yellow woodsorrell, *Oxalis stricta* L., horsenettle, *Solanum carolinense* L., giant ragweed, *Ambrosia trifida* L., buttercup, *Ranunculus* spp., Virginia creeper, *Parthenocissus quinquefolia* (L.) Planch., or Pennsylvania smartweed, *Polygonum pensylvanicum* L. Three fields, with varying twospotted spider mite populations, were sampled on 16 May. Among the species sampled, Brazilian vervain, johnsongrass, *Sorghum halepense* (L.) Pers., coneflower, *Dracopis amplexicaulis* (Vahl) Class, henbit, entireleaf morningglory, redvine, *Brunnichia ovata* (Walt.) Shinners, honeyvine milkweed, and cotton were hosting twospotted spider mite. At one location, 66 % of henbit stems within a cotton field were infested and damaging twospotted spider mite populations had developed in adjacent cotton. Three cotton fields (2-4 leaf stage) containing heavy twospotted spider mite infestations were sampled on 21 May. No mites were found in fallow areas around the fields, but henbit that persisted within each field after herbicide applications was heavily infested. Volunteer field corn within one of the fields was also heavily infested. Infestations were scattered in an aggregated distribution across the fields and recently killed or living henbit was found within each infestation. Areas of the field that did not have henbit were not infested. On June 29, johnsongrass growing around a utility pole within a cotton field in Washington Co. supported high twospotted spider mite densities. Cotton adjacent to the area was infested also.

In 2008, mite densities were low throughout the spring and mites were found in only two locations. At the two locations, very low densities of twospotted spider mite were found on only crimson clover, *Trifolium incarnatum* L., and honeyvine milkweed. On 28 July, twospotted spider mites were found on Palmer amaranth, *Amaranthus palmeri* S. Wats, and cotton at one site. This corroborates with findings of Steinkraus et al. (1998) that Palmer amaranth is a major host for twospotted spider mite during summer months.

Twospotted spider mites were found at five locations in 2009 and two were heavily infested. On 30 March, a large population of twospotted spider mite were found in a producer's equipment yard in Leflore Co., MS, with a diverse flora of plants. Twospotted spider mites were found on cutleaf evening primrose, hairy vetch, rescue grass, *Bronus catharticus* Vahl, spotted bur clover, *Medicago arabica* (L.) Huds., henbit, rabbit tobacco, *Pseudognaphalium obtusifolium* (L.) Hilliard & B.L. Burtt ssp. *Obtusifolium,* shepherd's purse, *Capsella bursa-pastoris* (L.) Medik., Caroliana geranium, Brazilian vervain, horseweed, *Conyza canadensis* (L.) Cronq., American black elderberry, *Sambucus nigra* L. ssp. *canadensis* (L.) R. Bolli, purple deadnettle, *Lamium purpureum* L., and common pokeweed, *Phytolacco americana* L. Twospotted spider mite adults were found at low levels on Italian ryegrass, *Lolium perenne* (L.) spp. multiflorum (Lam.), wild carrot, *Daucus carota* L., and common pokeweed, *Phytolacco americana* L. Henbit, purple deadnettle, and hairy vetch supported the highest densities of twospotted spider mite (>100 mites/leaf or stem) and 100% of these plants were infested. Carolina geranium and American black elderberry also supported high densities of twospotted spider mite. Cutleaf evening primrose (4.8 mites/leaf), rescue grass (7 mites/leaf), spotted bur clover (7.9 mites/leaf), Brazilian vervain (0.25 mites/leaf), Shepherd's purse (0.25 mites/leaf), wild carrot (0.5 mites/leaf), and horseweed (21 mites/leaf) supported moderate twospotted spider mite densities. No mites were found on daisy fleabane, *Erigeron annuus* (L.) Pers., curly dock, or mouseear chickweed, *Cerastium fontanun* Baumg. ssp. Vulgare. The area was sampled again on 4 May to determine mite host preference on later emerging species. Spiny sowthistle, *Sonchus asper* (L.) Hill, henbit, vetch, Carolina geranium, cutleaf evening primrose, and cutleaf geranium were all heavily infested with twospotted spider mite. Horseweed, broadleaf signalgrass, *Urochloa platyphylla* (Munro ex C. Wright) R.D. Webster, Brazilian vervain, daisy fleabane, and spotted bur clover supported low densities of twospotted spider mite. No mites were found on curly dock, yellow woodsorrell, Italian ryegrass, or Virginia pepperweed, *Lepidium virginicum* L.

On 4 May, a ditch bank adjacent to a soybean field was sampled in Humphreys Co. Mites were found on hairy vetch, spiny sowthistle, Carolina geranium, johnsongrass, henbit, honeyvine milkweed, green pigweed, *Amaranthus viridis* L., goldenrod, *Solidago* L. spp., common chickweed, S*tellaria media* (L.) Vill, white clover, soybean, *Glycine max* (L.) Merr. in the adjacent field, and cutleaf geranium, *Geranium dissectum* L. Henbit (numerous mites present), cutleaf geranium (10 mites/ leaf), and prickly sowthistle (~75 mites/leaf) supported the highest densities of twospotted spider mite at the location. Hairy vetch (3.5 mites/leaflet), soybean (3.5 mites/leaf), Carolina geranium (1.5 mites/leaf), johnsongrass (1mite/seedling plant, one plant with ~50 mites), common chickweed (1 mite/stem), honeyvine milkweed (2-4 mites/seedling), pigweeds (1.5 mites/leaf), goldenrod (1mite/seedling), and white clover (0.25 mite/leaf) supported moderate twospotted spider mite densities. No mites were found on yellow woodsorrell, crabgrass, *Digitaria* spp., nutsedges, *Cyperus* spp., common pokeweed, prostrate spurge, *Chamaesyce humistrata* (Engelm. ex A. Gray) Small, briar, *Rubus* spp., and several unidentified grass spp.

On 13 May, twospotted spider mite colonies were identified on ~ 10% of Pennsylvania smartweed leaves in fallow areas adjacent to a cotton field in Humphreys Co. No other plant species were infested around the field. Low densities of twospotted spider mite were also identified on kudzu in Washington Co. on 28 May. On 16 July, twospotted spider mites were found on field corn and volunteer soybean in Tallahatchie Co. Pitted morningglory, *Ipomoea lacunusa* L., Johnsongrass, hemp sesbania, *Sesbania herbacea* (Mill.) McVaugh, and spiny pigweed were also infested (5-10/leaf). Densities of twospotted spider mite on horseweed were ~1 per plant. No mites were found on barnyardgrass, *Echinochloa crus-galli* (L.) Beauv., broadleaf signalgrass, horse purslane, *Trianthema portulacastrum* L., and Palmer amaranth.

Discussion

Henbit appears to be the most consistent and preferred spring host of twospotted spider mite in Mississippi. Previous research has noted twospotted spider mite preference for henbit and the plant's suitability as a host from fall through spring (Brandenburg and Kennedy 1981, Margolies and Kennedy 1985, Wilson 1995). Henbit was infested at nearly every location where twospotted spider mites were found from March through May in the current study. Furthermore, nearly all twospotted spider mite infestations sampled in seedling cotton were linked to nearby henbit. Purple deadnettle was present at only one location where mites were found, but appeared to support twospotted spider mite populations similar to those on henbit. Henbit is a common winter annual weed across Mississippi and, in the absence of herbicides or tillage, can be found within and around most fields.

Many other dicotyledonous plant species were found to be hosts for twospotted spider mite. Carolina and cutleaf geranium, vetch, volunteer soybean, and spiny sowthistle were frequently infested and often supported high densities of twospotted spider mite. Brazilian vervain, honeyvine milkweed, 'hairy' (entireleaf and ivyleaf) morningglory, cutleaf evening primrose, pigweeds, and clover spp. were also generally infested with low densities of twospotted spider mite. Horseweed was heavily infested at one site, but overall was only occasionally infested with low densities of twospotted spider mite relative to other nearby hosts. Curly dock was not found to be a host of two spotted spider mite at any sample sites. Mouseear and common chickweed, common pokeweed, and daisy fleabane were minor hosts of twospotted spider mite.

Of the monocotyledonous species sampled, only rescuegrass, johnsongrass, and volunteer corn appeared to be major hosts during spring months. Few, if any mites, were found on other grass or sedge species. Italian ryegrass was not a major host of mites at any location. This is important because glyphosate resistant Italian ryegrass is common in many Mississippi fields (Robinson 2008). Equally important, twospotted spider mite was not found on annual bluegrass, *Poa annua* L., which occurs frequently in all Mississippi fields during winter and spring.

Early-season populations of twospotted spider mites were variable from year to year, likely due to several factors including environmental conditions and population densities entering overwintering. Recent, heavy-rainfall events lowered population densities and increased the difficulty of locating populations. After rain, webbing was sometimes present, but no mites were observed. It is likely mites were present at some locations at densities below those we were able to detect. For example, no mites were found after inspecting over 100 plants in a cotton field just after being planted. The field was untilled, covered with winter annual weeds and no herbicides had been applied. However, 3 wk later twospotted spider mite populations exceeded threshold across the field of seedling cotton and required treatment. This situation exemplifies the difficulty of detecting low mite populations on weeds, and that populations can increase quickly.

Previous workers have documented many host plants of twospotted spider mite (Table 3.2). In many cases, these reports corroborate observations made in this research. As in this survey, henbit served as an important host of twospotted spider mite host in many areas from fall through spring months (Brandenburg and Kennedy 1981, Margolies and Kennedy 1985, and Wilson 1995). Purple deadnettle is a preferred cool weather host in Japan (Takafuji and Kamibayashi 1984). Margolies and Kennedy (1985) reported that vetch, henbit, and Carolina geranium were the primary winter and early-spring hosts of twospotted spider mite in North Carolina. Flexner et al. (1991) determined that vetch, cutleaf geranium, and bur clover were suitable hosts of twospotted spider mite in Oregon.

Our results support previous findings that these plant species are also highly preferred host plants in Mississippi. However other reported host plants contradict observations made in Mississippi. Brandenburg and Kennedy (1982) and Flexner et al. (1991) reported that red and white clover, respectively, can support high populations of twospotted spider mite. Although twospotted spider mite was found on white and crimson clover in this survey, only spotted bur clover appeared to be a preferred host relative to henbit, geranium, and vetch. Flexner et al. (1991) concluded that ryegrass was a suitable host in Oregon, but in Mississippi, Italian ryegrass did not seem to be a suitable host. Steinkraus et al. (1999) did not observe twospotted spider mite on geranium during early-summer, however it was found to be a primary host during spring months in Mississippi. The differences in host suitability and preference of twospotted spider mite observed in this study and other reports demonstrate that the pest may utilize many different host plants under different climatic or temporal conditions, or in different geographical regions (Flexner et al. 1991).

The host list generated from this study can be used to refine early-season twospotted spider mite management. If cotton is to be planted into or adjacent to weedy areas, it would be prudent to determine if spider mites are present before planting. It appears that henbit, geranium, vetch, cutleaf evening-primrose, and most likely purple deadnettle are primary spring hosts of twospotted spider mite in Mississippi and can be used as indicator species to determine if twospotted spider mite is present. The presence or absence of twospotted spider mites on these primary hosts can be used to determine whether additional management strategies should be applied before planting. This host survey should also help support future research focused on early-season management of twospotted spider mite. Twospotted spider mites often migrate from alternative hosts to cultivated crops (Brandenburg and Kennedy 1982, Wilson 1995, Steinkraus et al. 1999). By eliminating specific weeds that were identified as primary hosts, it may be possible to delay or reduce seasonal population growth of twospotted spider mite with methods similar to those Snodgrass et al. (2006) used to control tarnished plant bug.

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Table 3.1. List of plant species sampled during host survey. Twospotted spider mite host preference is estimated using a 0-3 scale.

Common Name of Weed	**Scientific Name**	**Family**	**TSSM Host Preference**
Carolina geranium	*Geranium carolinianum*	Geraniaceae	3
coneflower	*Dracopis amplexicaulis*	Asteraceae	3
cotton	*Gossypium hirsutum*	Malvaceae	3
cutleaf evening-primrose	*Oenothera laciniata*	Onagraceae	3
cutleaf geranium	*Geranium dissectum*	Geraniaceae	3
field corn	*Zea mays*	Poaceae	3
hairy vetch	*Vicia villosa*	Fabaceae	3
henbit	*Lamium amplexicaule*	Lamiaceae	3
ivyleaf morningglory	*Ipomoea hederacea*	Convolvulaceae	3
Palmer amaranth	*Amaranthus palmeri*	Amaranthaceae	3
purple deadnettle	*Lamium purpureum*	Lamiaceae	3
soybean	*Glycine max*	Fabaceae	3
spiny sowthistle	*Sonchus asper*	Asteraceae	3
spotted burclover	*Medicago arabica*	Fabaceae	3
vetch	*Vicia* spp.	Fabaceae	3
Brazilian Vervain	*Verbena brasiliensis*	Verbenaceae	2
crimson clover	*Trifolium incarnatum*	Fabaceae	2
dewberry	*Rubus* spp.	Rosaceae	2
giant ragweed	*Ambrosia trifida*	Asteraceae	2
green pigweed	*Amaranthus viridis*	Amaranthaceae	2
honeyvine milkweed	*Ampelamus albidus*	Asclepiadaceae	2
johnsongrass	*Sorghum halepense*	Poaceae	2
Pennsylvania smartweed	*Polygonum pensylvanicum*	Polygonaceae	2
pigweeds	*Amaranthus* spp.	Amaranthaceae	2
pitted morningglory	*Ipomoea lacunusa*	Convolvulaceae	2
rabbit tobacco	*Pseudognaphalium obtusifolium*	Asteraceae	2
rescuegrass	*Bromus catharticus*	Poaceae	2
hemp sesbania	*Sesbania herbacea*	Fabaceae	2*
barnyardgrass	*Echinochloa crus-galli*	Poaceae	1
broadleaf signalgrass	*Urochloa platyphylla*	Poaceae	1
common chickweed	*Stellaria media*	Caryophyllaceae	1
common pokeweed	*Phytolacco americana*	Phytolaccaceae	1
horseweed	*Conyza canadensis*	Asteraceae	1

Table 3.1 continued.

Common Name of Weed	Scientific Name	Family	TSSM Host Preference
Italian ryegrass	*Lolium perenne*	Poaceae	1
mouseear chickweed	*Cerastium fontanun*	Caryophyllaceae	1
purple cudweed	*Gnaphalium purpureum*	Asteraceae	1
redvine	*Brunnichia ovata*	Polygonaceae	1
shepherd's purse	*Capsella bursa-pastoris*	Brassicaceae	1
tall goldenrod	*Solidago canadensis*	Asteraceae	1
white clover	*Trifolium repens*	Fabaceae	1
wild carrot	*Daucus carota*	Apiaceae	1
briars	*Rubus* spp.	Rosaceae	1*
daisy fleabane	*Erigeron annuus*	Asteraceae	1*
goldenrod	*Solidago*	Asteraceae	1*
kudzu	*Pueraria montana*	Fabaceae	1*
Virginia pepperweed	*Lepidium virginicum*	Brassicaceae	1*
annual bluegrass	*Poa annua*	Poaceae	0
bermudagrass	*Cynodon dactylon*	Poaceae	0
common purslane	*Portulaca oleracea*	Portulacaceae	0
curly dock	*Rumex crispus*	Polygonaceae	0
prostate spurge	*Chamaesyce humistrata*	Euphorbiaceae	0
purple nutsedge	*Cyperus rotundus*	Cyperaceae	0
spotted spurge	*Chamaesyce maculata*	Euphorbiaceae	0
wild garlic	*Allium vineale*	Liliaceae	0
yellow nutsedge	*Cyperus esculentus*	Cyperaceae	0
yellow woodsorrel	*Oxalis stricta*	Oxalidaceae	0
buttercup	*Ranunculus* spp.	Ranunculaceae	0*
Virginia creeper	*Parthenocissus quinquefolia*	Vitaceae	0*
crabgrass	*Digitaria* spp.	Poaceae	0*
horse purslane	*Trianthema portulacastrum*	Aizoaceae	0*
horsenettle	*Solanum carolinense*	Solanaceae	0*

* Indicates that rating is based on limited data.
Spider mite preference for each plant species was determined and ranked in a 0-3 scale. Rankings were as follows: 0 – No mites were observed on the plant species, 1- Very few mites were found on the plant and no reproduction was evident, 2- mites and reproduction was commonly found, but densities were generally low, 3- when mite populations were located, the species was always infested and supported high populations relative to other species present.

Table 3.2. List of published twospotted spider mite host plants found within the United States.

Hosts	Sci. name	Family	Publication [a]	Location	TSSM Host Preference[b]
burclover	*Medicago polymorpha*	Fabaceae	4	OR	3
bush vetch	*Vicia sativa*	Fabaceae	8	Japan	3
Carolina geranium	*Geranium carolinianum*	Geraniaceae	1, 6	NC	3
commom chickweed	*Stellaria media*	Caryophyllaceae	8	Japan	3
common mallow	*Malva neglecta*	Malvaceae	3, 4	VA , OR	3
crabgrass	*Digitaria sanguinalis*	Poaceae	4	OR	3
cutleaf geranium	*Geranium dissectum*	Geraniaceae	4	OR	3
dead-nettle	*Lamium purpureum*	Lamiaceae	8	Japan	3
henbit	*Lamium amplexicaule*	Lamiaceae	1, 6, 9	NC, AU	3
nightshade	*Solanum nodiflorum*	Solanaceae	4	OR	3
Palmer Amaranth	*Amaranthus palmeri*	Amaranthaceae	7	AR	3
pitted morniingglory	*Ipomoea lacunosa*	Convulvulaceae	7	AR	3
red clover	*Trifolium pratense*	Fabaceae	1, 2, 3	NC, VA	3
showy milkweed	*Asclepias speciosa*	Asclepiadaceae	4	OR	3
switchgrass	*Panicum virgatum*	Poaceae	1	NC	3
vetch	*Vicia* spp.	Leguminosae	6,4	NC, OR	3
white clover	*Trifolium repens*	Fabaceae	3, 4, 5	VA*, OR, NS	3
wild rose	*Rosa* spp.	Rosaceae	4	OR	3
blackberry	*Rubus* spp.	Rosaceae	1, 2, 4, 6	NC , OR	2-3
violet	*Viola* spp.	Violaceae	1	NC	2-3
trumpet creeper	*Campsis radicans*	Bignoniaceae	6	NC	1-3
common dandelion	*Taraxacum officinale*	Asteraceae	4	OR	2
false dandelion	*Hypochaeris radicata*	Asteraceae	4	OR	2
Japanese honeysuckle	*Lonicera japonica*	Caprifoliaceae	6	NC	2
lambsquarters	*Chenopodium album*	Chenopodiaceae	3, 7	VA*, AR	2
minerslettuce	*Montia perfoliata*	Polygonaceae	4	OR	2
orchard grass	*Dactylis glomerata*	Poaceae	4	OR	2
red root pigweed	*Amaranthus retroflexes*	Amaranthaceae	4	OR	2
ryegrass	*Lolium multiflorum*	Poaceae	4	OR	2
smartweed	*Polygonum persicaria*	Polygonaceae	4	OR	2
thymeleaf speedwell	*Veronica serpyllifolia*	Scrophulariceae	4	OR	2
trefoil	*Lotus corniculatus*	Fabaceae	4	OR	2
velvetgrass	*Holcus lanatus*	Poaceae	4	OR	2
barnyardgrass	*Echinocloa crus-galli*	Poaceae	4, 7	OR, AR	1-2

Table 3.2 continued.

Hosts	Sci. name	Family	Publication [a]	Location	TSSM Host Preference[b]
cocklebur	*Xanthium stumarium*	Compositae	7	AR	1-2
curled dock	*Rumex crispus*	Polygonaceae	7	AR	1-2
entireleaf morningglory	*Ipomoea hederacea*	Convulvulaceae	7	AR	1-2
goosegrass	*Elusine indica*	Poaceae	7	AR	1-2
hedge bindweed	*Convolvulus arvensis*	Convulvulaceae	4, 7	OR, AR	1-2
horsenettle	*Solanum carolinense*	Solanaceae	7	AR	1-2
purple vetch	*Vicia american*	Leguminosae	7	AR	1-2
smartweed	*Polygonum pensylvanicum*	Polygonaceae	7	AR	1-2
spotted spurge	*Euphorbia maculata*	Euphorbiaceae	7	AR	1-2

Abbreviations: AR-Arkansas, AU-Australia, NC-North Carolina, OR-Oregon, NS-Nova Scotia, VA-Virginia

[*] Data from Japan, but plant species also found in United States

[a] Publications

1 - Brandenburg, R. L., and G. G. Kennedy. 1981.
2 - Brandenburg, R. L., and G. G. Kennedy. 1982.
3 - Cagle, L. R. 1949.
4 - Flexner, J. L., P. H. Westigard, P. Gonzalves, and R. Hilton. 1991.
5 - Hardman, J. M., K. I. N. Jensen, J. L. Franklin, and D. L. Moreau. 2005.
6 - Margolies, D. C. and G. C. Kennedy. 1985.
7 - Steinkraus, D., J.Zawislak, G. Lorenz, and J. Welch. 1999.
8 - Takafuji, A. and M. Kamibayashi. 1984.
9 - Wilson, L. J. 1995.

[b] Spider mite preference for each plant species was determined and ranked in a 0-3 scale similar to that used by Flexner et al. (1991). Rankings were as follows: 0 – No mites were observed on the plant species, 1- Very few mites were found on the plant and no reproduction was evident, 2- mites and reproduction was commonly found, but densities were generally low, 3- when mite populations were located, the species was always infested and supported high populations relative to other plant species present. Classification of plant preference was based on previous preference ranking or descriptions in published reports, but also remained somewhat subjective.

CHAPTER IV

TWOSPOTTED SPIDER MITE, *TETRANYCHUS URTICAE* KOCH, OVERWINTERING ON WILD HOSTS AND MANAGEMENT USING GLUFOSINATE AND HERBICIDE BURNDOWN PROGRAMS

Abstract

A series of experiments were conducted from 2007 through 2009 to determine the overwintering characteristics of twospotted spider mite, *Tetranychus urticae* Koch, in Mississippi, compare field efficacy of glufosinate (Ignite 280 SL, Bayer CropScience) to miticides in cotton, *Gossypium hirsutum* L., and determine the value of glufosinate for control of twospotted spider mite when applied as part of a preplant herbicide program. Twospotted spider mites proved to be capable of overwintering as active adults and immatures in Mississippi. From Dec. through Feb., all life stages (adults, immatures and eggs) were found on henbit, *Lamium amplexicaule* L., and cutleaf evening-primrose, *Oenothera laciniata* Hill, on all sample dates. The herbicide glufosinate was efficacious against twospotted spider mite. The 0.58 kg ai/ha rate of glufosinate provided 48-80% control of field populations of twospotted spider mite on cotton and was comparable to low- to mid- rates of labeled acaricides. In the burndown experiments, timing was not critical, provided weeds were removed from plots before cotton emerged. However, if

weeds remained in plots at the time of planting, glufosinate did control remaining twospotted spider mite populations. These data illustrate that in a situation where cotton is planted into fields containing weeds, applying glufosinate instead of other herbicides will provide control of twospotted spider mite. With the current increased use of glufosinate and glufosinate tolerant cotton varieties, the ability to control both weeds and twospotted spider mite with a single application gives producers an additional method to reduce economic costs.

Introduction

Twospotted spider mite, *Tetranychus urticae* Koch, is a major pest of dozens of crops across the world. In the many regions of the United States, twospotted spider mite is a serious pest of cotton, *Gossypium hirsutum* L. Traditionally, in the mid-south (AR, LA, MO, MS, TN), twospotted spider mite has been considered a late-season pest during hot and dry years. However in recent years, the number of cotton acres treated for twospotted spider mite in Mississippi increased by over 2 fold above historic levels (Williams 2009). Also, twospotted spider mite outbreaks have occurred on seedling cotton earlier in the growing season, which historically is uncommon in this region. Other southern states also experienced increases in twospotted spider mite infestations, well above those seen in previous years (Williams 2009). It is suspected that changes in cotton production could be responsible for these early-season twospotted spider mite outbreaks. One hypothesis is that a shift from pre-plant tillage to conservation tillage or no-till cropping system has resulted in increased winter-annual weeds at planting that serve as hosts for twospotted spider mite. Current recommendations in conservation or no-till systems are to apply a preplant herbicide burndown in February through early-March, ~ 2 months before planting. Burndown applications are sometimes delayed due to environmental conditions or provide inadequate weed control, leaving weed hosts in fields at planting. Also, herbicide-resistant varieties allow producers to apply non-selective herbicides after emergence, thereby making burndown timing less critical.

Twospotted spider mites can utilize these in-field weeds as a 'green bridge' and move directly onto cotton when the weeds are killed (Wilson 1995).

It is probable that twospotted spider mite management will continue to be a frequent economic expense of cotton production in southern states, therefore effective management strategies for this pest will be valuable. One option may be to select pre- or post-plant herbicides that offer activity against twospotted spider mite. Glufosinate is a non-selective, postemergence herbicide that controls a broad spectrum of grasses and broadleaf weeds (Sensemen 2007). Ahn et al. (1997, 2001) reported that glufosinate-ammonium caused high mortality to twospotted spider mite nymphs and adults on kidney beans under laboratory conditions. Ahn et al. (1997) also found that the use of glufosinate for control of weeds in apple orchards could aid in suppression of twospotted spider mite. In fact, when glufosinate was substituted for other herbicides, miticide treatments were reduced from six to one per season (Ahn et al. 1997). The development of glyphosate resistant (GR) in Palmer amaranth, *Amaranthus palmeri* S. Wats, and horseweed, *Conyza canadensis* L., since 2005 in southeastern and mid-south states has led to increased use of glufosinate and glufosinate tolerant crops for weed control. Glyphosate resistant Palmer amaranth has become so difficult to manage in some states that Culpepper et al. (2009) suggested that selecting cotton varieties with glufosinate tolerance may be more important than selecting varieties for yield. Glufosinate can also be used to control GR horseweed (Steckel et al. 2006). The release of glufosinate-resistant cotton cultivars (Liberty Link®, Bayer CropScience) allows growers to utilize postemergence applications of glufosinate. Widestrike® cotton varieties (Dow

AgroSciences, Indianapolis, IN), which convey glyphosate resistance and dual *Bacillus thuringiensis* Berliner genes for protection from lepidopteran pests, also contain the phosphinothricin acetyltransferase (*pat*) gene that confers resistance to glufosinate (Culpepper et al. 2009). The *pat* gene was inserted into Widestrike® varieties as a selectable marker, and conveys tolerance to postemergence glufosinate applications. Although neither the company producing glufosinate (Bayer CropScience) nor Widestrike (Dow AgroSciences) recommend this practice (Culpepper et al. 2009), it has been adopted by growers because of the flexibility to apply both glyphosate and glufosinate postemergence. By applying a herbicide that controls twospotted spider mite, it may be possible to control twospotted spider mite and weeds with the same application, thereby reducing total pest management costs, preserving beneficial insects, and reducing environmental contamination (Ahn et al. 1997). Although glufosinate has been shown to control twospotted spider mite in Korean apple orchards, the efficacy of this compound and its value for twospotted spider mite control as a component of a weed control program has not been tested on cotton. Because glufosinate has become an integral tool in managing GR weeds in cotton, also tailoring this compound for twospotted spider mite management could be valuable. The objectives of this study were to determine the overwintering characteristics of twospotted spider mite in Mississippi, compare field efficacy of glufosinate to miticides, and determine the value of glufosinate for control of mites when applied as part of a pre and postemergence herbicide regime.

Materials and Methods

Overwintering Study. Cotton Variety 'Phytogen 485 WRF' was planted on 6 September 2007 at the R. R. Foil Plant Science Research Facility in Starkville, MS. A total of sixteen plots were artificially infested with twospotted spider mite on 1 October by stapling infested green bean, *Phaseolus vulgaris* L., leaves onto cotton cotyledons. Mites used in the experiment were from a laboratory colony originating from natural populations collected during June 2007 on cotton in the Mississippi Delta. Plot size was 6 rows (96.5 cm rows) by 6.1 m, of which only the center 1m of the two center rows were infested. In mid-November, frost killed the cotton. At that time, twospotted spider mite populations moved to henbit, *Lamium amplexicaule* L. that was growing naturally across the study area. Mite densities were sampled on 7 December, 15 January, 20 February, 17 March, and 8 April. Henbit was sampled on the first four sample dates, and cutleaf eveningprimrose, *Oenothera laciniata* Hill, on the final two dates. Estimates of density were determined by counting the number of twospotted spider mites on 10 stems of henbit from each plot. Plants were gently bent over without injury to the stems, and the underside of leaves examined with a 10X hand lens. To determine the amount of reproduction occurring, ten randomly selected stems with at least 5 visible adult twospotted spider mites present were collected, transported to the laboratory and the densities of eggs, immature, and adults were counted with aid of a microscope.

Efficacy of Glufosinate. The efficacy of glufosinate against twospotted spider mite was tested in three field trials. Although Ahn et al. (1997, 2001) reported glufosinate was active against twospotted spider mite in lab experiments, the possible relevance of using glufosinate in cotton pest management warranted further research. Twospotted spider mites tested in these trials originated from the colony previously described.

Field experiment 1 was planted with cotton variety 'Phytogen 485 WRF'on 6 September 2007. Twospotted spider mites were artificially infested on 1 October in each of the plots by stapling green bean leaves infested with twospotted spider mites onto the cotyledons of cotton plants at the one leaf stage of growth. Consecutive plants in 1 m sections of the two center rows in each plot were infested. Treatments were applied 7 d following infestation on 8 October. Three chemical treatments, each at recommended field rates, and an untreated check were included. Chemical treatments included glufosinate (Ignite 280 SL, Bayer CropScience, Research Triangle Park, NC) @ 0.47 kg ai/ha (0.42 lb ai/A) and 0.58 kg ai/ha (0.52 lb ai/A), and dicofol (Kelthane 4 MF, Dow AgroSciences, Indianapolis, IN) @ 1.12 kg ai/ha (1.0 lb ai/A). Dicofol is a miticide that was used as a standard for comparison. All treatments were applied at a spray volume of 93.49 L/ha with a tractor mounted sprayer, using TX-6 hollow cone spray tips and a pressure of 427.5 kpa. The sprayer traveled at 5.6 km/hr to achieve the desired spray volume. Treatments were replicated four times in a randomized complete block design. Plots were 6 rows wide (96.5 cm rows) by 6.1 m long. Only the center four rows were treated. The experiment was rated 2 days after treatment (DAT) on 10 October.

Sampling was conducted by pulling the second true leaf from 10 plants in each plot. The total number of twospotted spider mites was counted under a stereo microscope in the laboratory. Dead mites were not counted. Data were analyzed with ANOVA and means were separated using a Fisher's Protected LSD ($P \leq 0.1$). (ARM, Gylling Data Management, Inc., Brookings, SD).

Field experiment 2 was planted on 22 April 2009. Cotton was infested with mites on 13 May, using procedures identical to those used in field experiment 1. Treatments were applied on 7 July using identical procedures and equipment as was used in field experiment 1. Field Experiment 2 was conducted on larger cotton during early bloom stage. Twospotted spider mite populations were high and cotton leaves were severely injured at the time of application. Treatments included glufosinate (Ignite 280 SL) @ 0.47 kg ai/ha (0.42 lb ai/A) and 0.58 kg ai/ha (0.52 lb ai/A), etoxazole (Zeal 72 WSP, Valent USA Corporation, Walnut Creek, CA) at 0.0504 kg ai/ha, fenpyroximate (Portal 0.4, Nichino America, Inc., Wilmington, DE) at 0.0560 kg ai/ha, spiromesifen (Oberon 4 SC, Bayer CropScience, Research Triangle Park, NC) at 0.21 kg ai/ha, abamectin (Agrimek 0.15 EC, Syngenta Crop Protection, Greensboro, NC) at 0.0053 and 0.0105 kg ai/ha, and an untreated check. Estimates of twospotted spider mite density were determined by counting the number of mites in a 2.5 cm^2 square grid on the bottom side of 5 randomly selected leaves per plot three nodes down from the terminal using a 10X hand lens at 3 and 7 DAT. Data were analyzed with ANOVA and means were separated using a Fisher's Protected LSD ($P \leq 0.1$)

A third field trial was conducted at Jackson, TN. Cotton variety 'Phytogen 375 WFR' was planted on 29 April 2009. Plot size was 4 rows wide (96.5 cm rows) by 16.1 m long. Cotton was infested with mites in July by placing infested green bean plants on the cotton. This experiment was conducted late-season when cotton was approaching physiological maturity. Foliar applications were made on 1 August using a tractor mounted sprayer equipped with two 8001 flat fan nozzles per row. Treatments were applied at a volume of 74.8 l/ha and 317.2 kpa. Treatments included: bifenthrin (Brigade 2 EC, FMC Corporation, Philadelphia, PA) at 0.112 kg ai/ha, dicofol (Dicofol 4 E, MANA Inc., New York, NY) at 1.68 kg ai/ha, propargite (Comite II, Chemtura USA Corporation, Middlebury, CT) at 1.9 kg ai/ha, fenpyroximate (Portal 0.4) at 0.056 kg ai/ha, etoxazole (Zeal 72 WSG) at 0.0504 kg ai/ha, abamectin (Zephyr, Syngenta Crop Protection, Greensboro, NC) at 0.00526 and 0.0158 kg ai/ha, spiromesifen (Oberon 4 SC) at 0.14 and 0.28 kg ai/ha, glufosinate (Ignite 280 SL) at 0.112 kg ai/ha, and an untreated check. Estimates of spider mite density were determined by counting spider mites in a 2.5 cm^2 grid on the bottom side of 10 randomly selected leaves per plot three nodes down from the terminal using a 10X hand lens at 3, 8 and 13 DAT. Data were analyzed with ANOVA and means were separated using a Fisher's Protected LSD ($P \leq 0.1$).

Herbicide Programs to Control *T. urticae*. During 2008 and 2009, two experiments were conducted to determine the impact of herbicide and tillage regimes on controlling mites in seedling cotton. In 2008, only late burndown applications (April and May) were tested. Treatments were designed to examine the value of glufosinate (Ignite

280 SL) in pre-plant herbicide burndown programs. On 17 and 27 March, henbit was artificially infested with twospotted spider mites by placing infested green bean plants in henbit foliage. Mites were obtained from a colony described in field experiment 1. The experiment was conducted as a randomized complete block with four replications. Plots were 8 rows wide (96.5 cm centers) x 12.2 m long. Mites were infested in a 2 m section of the two center rows, allowing 10.4 m between each infested area. Treatments included tillage (hipping rows at-planting), no tillage or herbicides (check), glyphosate (Roundup Weathermax, Monsanto Company, St. Louis, MO) at 870 g ae/ha and dicamba (Clarity, DuPont, Wilmington, DE) at 280 g ai/ha five wk prior to planting, glyphosate at 870 g ae/ha plus dicamba at 280 g ai/ha five wk prior to planting plus glufosinate (Ignite 280 SL, Bayer CropScience, Research Triangle Park, NC) at 595 g ai/ha at-planting, paraquat at 840 g ai/ha 12 d prior to planting, and glufosinate at 595 g ai/ha 12 d prior to planting. Cotton variety 'Stoneville 4554 BG2RF' was planted on 7 May. The entire test area was sprayed with glyphosate at a rate of 1260g ae/ha at planting and at pinhead square to prevent weed competition. Henbit was beginning to senesce at time of planting, but twospotted spider mite populations remained on living henbit. When cotyledons began to unfurl on the 15 May, all weeds in the test area were dead. Cotton was sampled weekly from emergence until first-square. Estimates of twospotted spider mite density were determined by counting the number of mites in a 2.5 cm^2 grid on the bottom side of 10 randomly selected leaves per plot using a 10X hand lens. The first true leaf was sampled until cotton reached four total nodes, and then the third node from the terminal was sampled. The test was harvested with a mechanical cotton picker.

In 2009, a similar experiment was conducted, but selected treatments were applied one month earlier. The test area was infested with mites on 17, 24, and 30 March. The entire area was infested with mites instead of infesting individual foci. Three flats of green beans, infested with twospotted spider mites, were spread across each plot. Plot size was identical to the 2008 study and the experiment was conducted as a randomized complete block. Treatments included no tillage or herbicides (check), glyphosate at 870 g ae/ha and dicamba at 280 g ai/ha 45 d prior to planting, glyphosate at 870 g ae/ha and dicamba at 280 g ai/ha 45 d prior to planting plus glufosinate at 595 g ai/ha 5 d post-plant prior to emergence, paraquat 840 g ai/ha 8 d prior to planting, glufosinate at 595 g ai/ha 8 d prior to planting, and glufosinate at 595 g ai/ha 5 d post-plant prior to emergence. The cotton variety 'FiberMax 1845 LLB2' (Bayer CropScience, Research Triangle Park, NC) was planted on 20 May. Planting was delayed because of repeated rainfall, and as a result, henbit had completely senesced before planting. Chickweed, *Stellaria media* (L.) Vill, annual bluegrass, *Poa annua* L., and entireleaf morningglory, *Ipomoea hederacea* var. integriuscula, were the primary species present in untreated plots at planting. Twospotted spider mite populations were low across the study area. Because the cotton was not glyphosate tolerant, the entire test area was treated with sethoxydim (Poast Plus, BASF Corporation, Research Triangle Park, NC) at 0.31 kg ai/ha and pyrithiobac sodium (Staple LX, DuPont, Wilminton, DE) at 0.11 kg ai/ha at the fifth leaf stage to kill remaining weeds. Repeated rainfall events lowered twospotted spider mite populations after cotton emerged. Because mite densities were low, the experiment was sampled by counting the number of cotton plants with visible mite injury in the center two rows of each plot at the fifth leaf stage of growth. At the fifth leaf stage of growth, twospotted spider mite populations had completely crashed and no subsequent sampling was conducted or yield measured.

Results

Twospotted Spider Mite Overwintering. On 7 December 2007, an active infestation of twospotted spider mite that included all life stages was found on henbit in the field, although densities were not determined. Thirty percent of henbit stems were infested with twospotted spider mite on the 15 January (Table 4.1). Twospotted spider mite populations increased to 70% infested henbit stems on 17 March 2008. Additionally, 51% of cutleaf evening primrose leaves were infested on 17 March. Henbit completely senesced by the end of March. Densities on cutleaf eveningprimrose leaves had increased 8% by the end of April from those found on 17 March. All life stages of twospotted spider mites were found throughout the winter and spring on henbit and cutleaf eveningprimrose (Fig. 4.1). Densities of eggs and immatures increased with successive months. Both winter active (normal appearance) and orange (diapausing) (Parr and Hussey 1965) female twospotted spider mites were found on each sample date. The percentages of orange colored females decreased from 39% on 20 February to 14 and 1.2% on 17 March and 8 April, respectively.

Glufosinate Efficacy. In field experiment 1, glufosinate (Ignite 280 SL) at 0.593 kg ai/ha and dicofol (Kelthane 4 MF) at 1.12 kg ai/ha significantly reduced twospotted spider mite densities below those in the untreated check at 2 DAT (Table. 4.2). Glufosinate at 0.45 kg ai/ha did not significantly reduce densities of twospotted spider mite below the untreated check. Efficacy of lowest labeled rate of dicofol (1.12 kg ai/ha) and glufosinate at 0.593 kg ai/ha against twospotted spider mite were nearly identical, providing 80% control. It is important to point out that this experiment was conducted on seedling cotton and allowed for very good spray coverage of plant foliage.

In field Experiment 2, both rates of glufosinate were not different than abamectin at 0.0053 kg ai/ha or the untreated check (Table 4.3). Additionally, glufosinate at 0.5930 was not different than abamectin at 0.0105 kg ai/ha, etoxazole at 0.05 kg ai/ha, or spiromesifen at 0.21 kg ai/ha. The high rate of glufosinate (0.58 kg ai/ha) was comparable to the low rate of abamectin (0.0053 kg ai/ha) at 3 DAT, providing about 40% control. At 7 DAT, all treatments significantly reduced twospotted spider mite densities lower than those in the untreated check. Both rates of glufosinate were not different than abamectin at 0.0053 kg ai/ha or spiromesifen at 0.21 kg ai/ha. Additionally glufosinate at 0.5930 kg ai/ha was not different than any other treatment, providing 54% control.

In Field experiment 3, glufosinate at the 0.58 kg ai/ha significantly reduced twospotted spider mite densities at 3 and 8 DAT compared to the untreated check (Table 4.4). There were no differences among treatments at 13 DAT. There were no significant differences between glufosinate and the other acaricide treatments at 3 or 8 DAT. At 3 and 8 DAT, glufosinate provided 48 and 72% control.

Controlling *T. urticae* Using Herbicides. Weather conditions were more conducive to mite population growth during 2008 than 2009. During 2008, twospotted spider mite populations were high on henbit remaining in the study area at the time of planting. Other weed species present, such as chickweed spp., annual blue grass, and Italian rye grass, *Lolium perenne* (L.) spp. multiflorum (Lam.), hosted very few twospotted spider mites. The glyphosate and dicamba herbicide treatments applied 5 wk before planting controlled >95% of vegetation before planting. Tillage removed and buried all vegetation before planting. The paraquat and glufosinate ammonium treatments that were applied 12 d before planting were also effective and killed nearly all vegetation. Large Italian ryegrass was not completely controlled, however no twospotted spider mites were found on Italian ryegrass. There were significantly more twospotted spider mites found on cotton in the untreated treatment than all other treatments on all sample dates from cotyledon through match-head square (Figure 4.2). Twospotted spider mite densities averaged between 81-570 fold higher in untreated plots than in treatments where weeds were removed or killed. No treatment completely eliminated twospotted spider mite populations, but densities in all herbicide and tillage treatments were low and statistically similar. The low densities of twospotted spider mites that occurred in plots which received herbicide and tillage treatments could have been the result of physical translocation by workers or equipment or natural migration. On 27 May, cotton was at the 2nd leaf stage and twospotted spider mite populations were primarily located in untreated plots. By 3 June, mites could be found in most of the test area, regardless of treatment. However, twospotted spider mite densities remained significantly higher in untreated plots through the 17 June. By first bloom, twospotted spider mite populations had spread across the entire study area from the untreated check and severely injured all plots. Differences in early season injury between untreated plots and other treatments were apparent, but severe injury of all plots during bloom stages likely equalized yields. Although yield was reduced 39-50% in the untreated plots, differences were not significant (df = 23, F = 0.661, p =0.6584). If twospotted spider mite populations had been controlled before they spread across the entire test area, yield differences between treatments may have been realized.

Repeated rainfall events in April and May delayed planting and reduced twospotted spider mite populations in the 2009 experiment. High twospotted spider mite populations were initially established on succulent henbit across the entire area. Henbit began to senesce in late April and died by mid-May. Relatively low twospotted spider mite populations remained on mouseear chickweed and entireleaf morningglory in untreated plots at planting. The two treatments using glyphosate plus dicamba 45 d before planting initially controlled >95% of all weeds, although there was reemergence of grasses, sedges, *Cyperus* spp., and entireleaf morningglory in those treatments before planting. At the time of planting, low densities of twospotted spider mite were found only on entire leaf morningglory in those plots. Paraquat and glufosinate treatments applied 8 d pre-plant controlled all weeds except for sedges, which hosted no twospotted spider mite. The two treatments that included a glufosinate treatment post-planting and pre-emergence also controlled all weeds except for sedges and grasses, on which no twospotted spider mites were found. Twospotted spider mite injury was measured at the

5th leaf stage. Because continual rainfall caused twospotted spider mite populations to completely crash before this date, only visible injury could be rated and no further sampling was conducted. Only the untreated check and glyphosate plus dicamba 45 d pre-plant treatments contained twospotted spider mite injury (Table 4.5). The number of plants with injury in the untreated check was ~2.5 fold greater than in plots where glyphosate plus dicamba was applied 6 wk pre-plant. In this experiment, two treatments consisted of an early burndown of glyphosate plus dicamba, but one of those treatments also included a glufosinate application post-plant, but before crop emergence. Plots receiving the post-plant application of glufosinate contained no twospotted spider mite injury, whereas the treatment without glufosinate post plant did contain twospotted spider mite injury. The treatment that consisted of only a glufosinate application post-plant, but before crop emergence also had no injury. Treatments that included applications of paraquat or glufosinate 8 d before planting completely eliminated twospotted spider mite injury.

Discussion

Twospotted spider mites are capable remaining active and reproductive throughout winter in Mississippi. From Dec. through Feb., all life stages (adults, immatures and eggs) were found on henbit and cutleaf evening-primrose on all sample dates. Brandenburg and Kennedy (1981) also observed active twospotted spider mite in North Carolina fields throughout winter months on blackberry, *Rubus* spp., red clover, *Trifolium pretense* L., violet, *Viola* spp., henbit, and senesced switchgrass, *Panicum* *virigatum*. Both orange (diapause) and green-colored (winter active) forms were found on those hosts in the study. The authors proposed that in the presence of moderate temperatures and continual food sources, diapause may be unnecessary in North Carolina and other southern states. Wilson (1995) corroborates those results by reporting that twospotted spider mite remained active on green vegetation throughout winter months in Australia. The ability to overwinter as active life forms in-field is an important aspect of twospotted spider mite ecology and enhances this pest's ability to infest seedling cotton. After harvest, there are very few weeds present in fields, causing a decline in twospotted spider mite populations. Winter annual weeds generally emerge from fall through spring, creating an alternate food source. By reproducing on these weeds throughout winter and spring months, twospotted spider mite populations can increase. Winter active twospotted spider mites are also able to disperse across fields in early-spring before crops are planted. This ability of twospotted spider mite to build populations during winter months and disperse across fields makes it critical to remove weeds well in advance of planting cotton.

The herbicide glufosinate (Ignite 280 SL) proved to provide control of twospotted spider mite in these experiments, which corroborates previous reports by Ahn et al. (1997 and 2001). The 0.58 kg ai/ha (29 oz Ignite 280 SL/A) rate provided 48-80% control of field populations of twospotted spider mite on cotton and was comparable to low- to mid-rates of labeled acaricides. The suitability of glufosinate as a miticide when applied as part of a herbicide program was also examined. The herbicide treatments were designed to answer two questions: 1) is early-burn down critical for twospotted spider mite control, and 2) does a pre-emergence application of glufosinate control twospotted spider mites better than other herbicides. In the 2008 experiment, both burndown timing and herbicide treatment were critical. Regardless of the method used, removal of the weeds from the plots before cotton emerged significantly reduced spider mite densities. Ahn et al. (1997) found that glyphosate and paraquat caused no twospotted spider mite mortality. The fact that plots treated with paraquat eight days pre-plant contained no mite injury suggests that twospotted spider mite populations on in-field weeds can be controlled if weeds are completely killed before planting. In the 2009 experiment glufosinate did contribute to overall twospotted spider mite control. When glyphosate and dicamba were applied 45 d preplant, twospotted spider mite injury was found on a small percentage of cotton; however, when those treatments were followed by glufosinate postplant, no cotton was injured by twospotted spider mite. These data illustrate that if all weeds are removed or controlled before planting, the addition of glufosinate provides little benefit for twospotted spider mite control. However, in a situation where cotton is planted into fields containing weeds, applying glufosinate instead of or in combination with other herbicides will control or suppress twospotted spider mite populations that are surviving on winter annual weeds.

Glufosinate can effectively control both GR horseweed and Palmer amaranth (Steckel et al. 2006, Norsworthy et al. 2008, and Culpepper et al. 2009). However, effective control of weeds depends on two requirements: day time air temperatures of at least 24°C (Steckel 2010) and applications timed before weeds exceed a height of 7.6 to 15.2 cm (Koger 2009). To meet these requirements, applications generally have to be timed as either a late burndown (April or May), rescue treatment for a failed burndown (April or May), or early postemergence (< 6 node cotton). These requirements also tailor the use of glufosinate for controlling twospotted spider mite during the early-season because the greatest value of a glufosinate application would be when both weeds and mites could be controlled with a single application. During early-spring (Feb-March), any effective herbicide or tillage can be used to remove weeds and control twospotted spider mite populations. Additionally, because miticides are a costly input during the early-season, secondary control of twospotted spider mite from a herbicide application would be appealing for many producers.

In plants, glufosinate inhibits the activity of glutamine synthetase, the enzyme that converts glutamate and ammonia to glutamine (Senseman 2007). Plant death is caused by a buildup of ammonia, which destroys cells, and inhibits photosystem I and II reactions (Senseman 2007). The acaricidal mode of action (MOA) of glufosinate is unknown. Ahn et al. (1997) suggested that twospotted spider mite mortality was likely a direct effect. Because immature twospotted spider mites were killed within 24 h, inhibition of chitin synthesis could be ruled out. The MOA is also different from that of some acaricides because the herbicide was effective against biotypes resistant to miticides (Ahn et al. 1997). It is possible that inhibition of glutamine synthetase could also kill twospotted spider mite. Glutamine synthetase is present in all organisms (Stryer 1981). Without glutamine synthetase to sequester ammonium ions, ammonia could possibly buildup in mites as well. The blank formulation of Ignite 280 SL, which does not contain glufosinate, was tested and did not kill mites (data not shown). Future research should focus on understanding glufosinate MOA and uptake in arthropods.

This research demonstrates that twospotted spider mite can remain active on annual weeds throughout the winter and increase populations during early-spring in Mississippi. Management of these spring populations before planting is required to prevent outbreaks in seedling cotton. Besides being used to control GR weeds, the increasing presence of glufosinate tolerant varieties should also be utilized to control twospotted spider mite with glufosinate in seedling cotton. This will allow producers to reduce input costs and the total number of applications to control pests.

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Table 4.1. Percent henbit and cutleaf evening primrose infested with twospotted spider mite in Oktibbeha Co. Mississippi, during winter/spring 2007-2008.

Date	% Henbit Stems Infested	% Cutleaf Eveningprimrose Leaves Infested
7-Dec	[a]	-
15-Jan	30%	-
20-Feb	58%	-
17-Mar	70%	51%
8-Apr	(senesced)	59%

[a] Densities were not determined on 7 Dec.

Table 4.2. Average number of mites per 32 cm^2 on cotton 2 days after treatment (DAT). Trial was conducted on Sept.-planted seedling cotton in Starkville, MS.

Common Name (AI)	**Trade Name**	**kg AI/ha**	**# Mites**
dicofol	Kelthane 4 MF	1.120	4.3 b
glufosinate	Ignite 280 SL	0.450	17.4 a
glufosinate	Ignite 280 SL	0.593	4.6 b
Untreated Check	-	-	22.6 a
LSD			9.926
F-value			5.777
P			0.0175

Means followed by the same letter within a column are not significantly different (LSD with $\alpha = 0.1$).

Table 4.3. Average number of mites per 32 cm^2 on cotton 3 and 7 days after treatment (DAT). Trial was conducted at first bloom in Starkville, MS during 2009.

Common Name (AI)	Trade Name	kg AI/ha	3 DAT	7 DAT
abamectin	Agrimek 0.15 EC	0.0053	144.5 bcd	54.3 b
abamectin	Agrimek 0.15 EC	0.0105	85.0 cd	16.0 c
etoxazole	Zeal 72 WSP	0.0504	57.8 cd	8.8 c
fenpyroximate	Portal	0.0560	36.3 d	9.0 c
glufosinate	Ignite 280 SL	0.4500	206.3 ab	54.5 b
glufosinate	Ignite 280 SL	0.5930	156.5 abc	40.5 bc
spiromesifen	Oberon 4 SC	0.2100	95.5 cd	30.0 bc
Untreated Check			262.5 a	92.8 a
LSD			109.12	38.17
F-value			4.309	4.907
P			0.0043	0.002

Means followed by the same letter within a column are not significantly different (LSD with α = 0.1).

Table 4.4. Average number of mites per 64 cm^2 on cotton 3, 8, and 13 days after treatment (DAT). Trial was conducted late-season in Jackson, TN during 2009.

Common Name (AI)	Trade Name	kg AI/ha	3 DAT	8 DAT	13 DAT
abamectin	Agrimek 0.15 EC	0.0053	26.0 bcd	27.8 b	46.8
abamectin	Agrimek 0.15 EC	0.0158	35.3 ab	6.0 de	29.0
bifenthrin	Brigade 2 EC	0.112	13.0 cd	18.0 b-e	31.3
dicofol	Dicofol 4	1.68	16.8 bcd	24.5 bc	17.5
etoxazole	Zeal 72 WSP	0.0504	7.0 d	7.8 cde	19.3
fenpyroximate	Portal	0.056	19.8 bcd	5.3 e	48.5
glufosinate	Ignite 280 SL	0.593	27.5 bcd	13.5 b-e	27.5
propargite	Comite II 6	1.90	28.3 bcd	26.8 b	37.8
spiromesifen	Oberon 4 SC	0.140	34.5 abc	23.3 bcd	68.0
spiromesifen	Oberon 4 SC	0.280	31.3 bc	3.3 e	37.3
Untreated Check			53.0 a	49.0 a	98.5
	LSD		21.6	17.7	
	F-value		1.9350	3.3820	1.2470
	P		0.0793	0.0047	0.3029

Means followed by the same letter within a column are not significantly different (LSD with α = 0.1).

Table 4.5. Average number of mite damaged plants at the 5th leaf stage per 24 row m following various herbicide regimes in 2009.

Treatment	# Damaged Plants
Untreated Check	13.8 a
Glyphosate + Dicamba (45 d pre)	5.3 b
Glyphosate + Dicamba (45 d pre) + glufosinate (5 d post plt)	0 b
Paraquat (8 d pre-plt)	0 b
Glufosinate (8 d pre-plt)	0 b
Glufosinate (5 d post plt)	0 b
LSD	10.85
F-value	2.416
P	0.0851

Means followed by the same letter within a column are not significantly different (LSD with $\alpha = 0.1$).

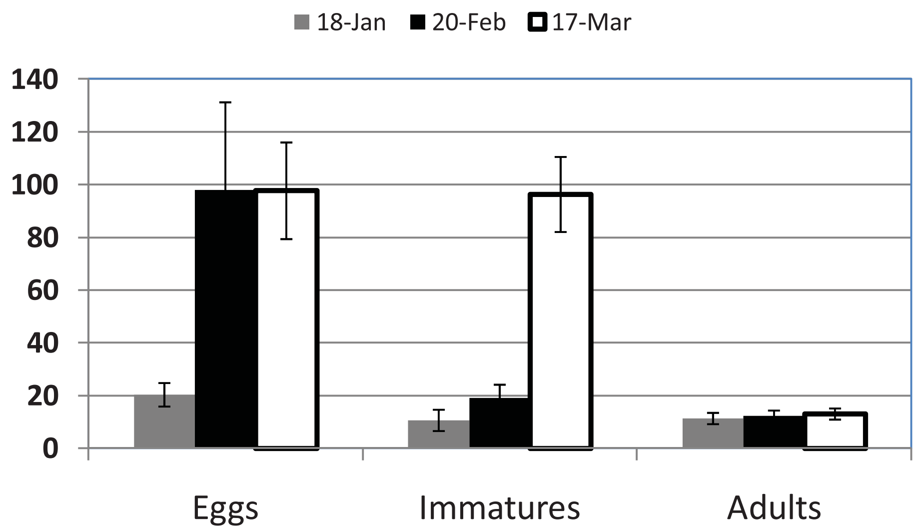

Figure 4.1. Average densities of twospotted spider mite eggs, immatures, and adults per henbit stem during three winter months in 2008-2009. Densities were measured from 10 infested stems.

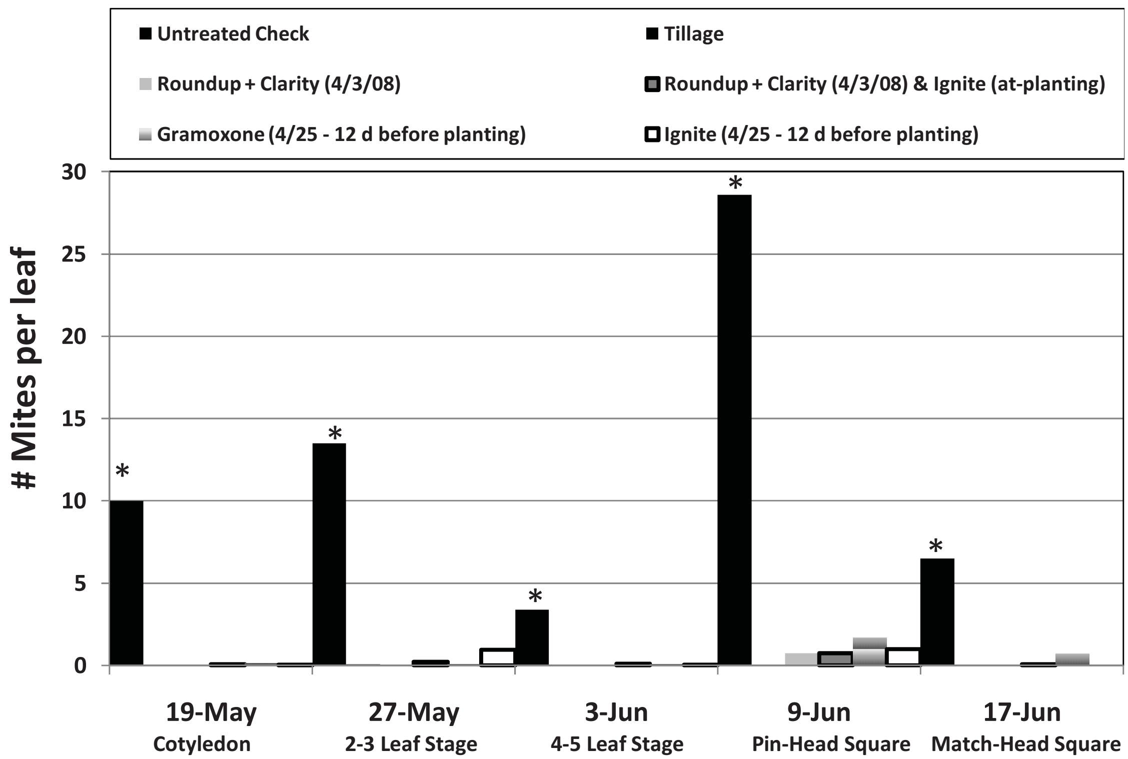

Figure 4.2. Average number of mites per leaf by treatment on cotton following various herbicide regimes in 2008. * Indicates that there were significantly more mites ($P < 0.05$) in the untreated check than other herbicide treated plots on all sample dates. There were no differences among other treatments.

CHAPTER V

EFFECTS OF TWOSPOTTED SPIDER MITE, *TETRANYCHUS URTICAE* KOCH, INJURY ON COTTON YIELD LOSS

Abstract

During 2007, cotton, *Gossypium hirsutum* L., yield loss was measured at sites where naturally occurring populations of twospotted spider mite, *Tetranychus urticae* Koch, had injured cotton. Six uninjured areas and six areas containing twospotted spider mite injury were identified within an irrigated and non-irrigated field. Uninjured plots were chosen directly adjacent to injured plots, often within 3 m and in the same row. Two row m sections from each area were box mapped at harvest. During 2008 and 2009, cotton was artificially infested with high densities of mites at 3^{rd} true leaf, first bloom, and at 200 heat unit intervals from first bloom until cutout + 650 heat units (HU), resulting in a total of ~6-7 infestation-timing treatments plus an uninfested check. Naturally occurring infestations caused more yield loss in the non-irrigated field than in the irrigated field. In the irrigated field, there was a 48% total yield loss in mite damaged areas as compared to undamaged areas. Yield loss was caused by both fruit abortion and reduced boll weight. In the irrigated field, yield was reduced by 10% by *T. urticae* injury. Yield loss in the irrigated field was due to reduction in boll weight. Artificial infestation experiments were adversely affected by unseasonably wet and cool weather

during 2008 and 2009. During 2009, experiments were successfully conducted at three locations. Infestations established at the third true leaf resulted in an average yield loss of 45%. It is difficult to make any conclusions about infestations made from first bloom and later because of the difficulty in establishing mite population later in the season.

Introduction

Beginning in 2005, Arkansas, Louisiana, Mississippi, Missouri, and Tennessee experienced a surge of twospotted spider mite outbreaks in cotton, *Gossypium hirsutum* L. Spider mites have traditionally been considered occasional pests that occurred at or near maturity during hot dry years. However, since 2005, post-bloom twospotted spider mite infestations have been more common across the Mid-South. The percentage of cotton acres requiring treatment for *T. urticae* across the Mid-South has increased by over two-fold in recent years and twospotted spider mites are currently ranked as the 3rd most damaging pest of cotton, behind plant bugs and bollworms (Williams 2008). In years without excessive rainfall, many cotton fields in Mississippi reach and exceed threshold densities late in the season. These infestations are likely the result of migration of twospotted spider mite from senescent field corn, *Zea mays* L (Margolies and Kennedy 1985). Repeated applications of organophosphates, pyrethroids, and neonicotinoids targeting tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois), made after first bloom in an 8-9 wk time frame also reduces beneficial insects and late-season predation of *T. urticae*. Tarnished plant bug accounted for an average of 7.5, 5.5, and 6.5 insecticide applications per acre in Mississippi-delta cotton during 2007, 2008, and 2009 respectively (Williams 2008, 2009, 2010). Because infestations of twospotted spider mite often occur late in the growing season, it is often difficult to decide whether chemical control of the pest is economically advisable. To compound this problem, little research has been done to determine when to terminate foliar applications for this pest.

Spider mites damage cotton by feeding on individual cells on the abaxial leaf surface. The feeding apparatus of twospotted spider mite consists of paired and partially fused cheliceral stylets that are used to pierce mesophyll cells (Hislop and Jeppson 1976). Damage to the spongy mesophyll from feeding has been associated with closure of stomata and reduced transpiration (Reddall et al. 2004). Damage is not limited to cells directly punctured. Feeding in basal areas not only reduces leaf processes in that portion of the leaf, but also reduces many functions in undamaged distal leaf portions (Reddall et al. 2004). Once damaged, there is no within-leaf compensation; however, it is possible that within-plant compensation could occur (Reddall et al. 2004). Sadras and Wilson (1997a) determined that yield losses in cotton were ultimately caused by reductions in radiation-use efficiency followed by accelerated leaf senescence and reduced light interception in extensively damaged plants. Reductions of those physiological processes caused decreases in the amount of dry matter production, lint yield, seed cotton, and number of open bolls, depending on when damage occurred (Sadras and Wilson 1997b). Damage sustained during fruit set periods has been associated with decreases in the number and size of bolls, whereas late-season damage during the boll-fill period generally only reduces boll size and weight (Wilson 1993).

Twospotted spider mite damage has been widely reported to cause yield losses in cotton (McGregor and McDonough 1917, Furr and Pfrimmer 1968, Leigh et al. 1968, Wilson et al. 1987, Wilson et al. 1991, Wilson 1993, Sadras and Wilson 1997b). Yield losses have been reported to range from minimal to severe, depending on environmental conditions and when the damage occurred. Nearly a century ago, McGregor and McDonough (1917) estimated that spider mites caused damage to 8,100 ha of cotton in South Carolina and decreased production by 40%. Furr and Pfrimmer (1968) measured 30 and 35% yield losses from cotton infested with mites between 1st square to bloom and before quarter sized bolls were present, respectively, in Mississippi. In that experiment, a late season infestation (bolls larger than 1.9 cm diam.) caused no yield decrease. Wilson (1993) infested mites during early, mid and late season over three years and reported yield losses of 13-78%, 7-29%, and 1-16%, respectively. Sadras and Wilson (1997b) reported an extreme yield loss of 97% in cotton infested 59 DAP (~1st bloom). In the same experiment, infestations of similar densities initiated at 80 and 93 DAP resulted in yield losses of 93 and 84%, respectively. In general, the literature suggests that twospotted spider mites cause greater yield loss when infestations begin before or during flowering periods. However, infestations developing late season can significantly reduce yield if twospotted spider mite populations develop rapidly and environmental conditions are not conducive to plant growth (Wilson 1993).

Currently, economic thresholds in Mississippi and other southern states recommend chemical control of twospotted spider mites in cotton when 30-50% of plants are infested and populations are increasing (Catchot 2010, Stewart et al. 2010, Studebaker 2010). These thresholds are static throughout the season and don't account for potential differences in yield loss at different growth stages. Also, recommendations generally do not define when chemical controls can be terminated. Expected yield loss tables have been developed in Australia (Maas 2009); however, these tables are based on *T. urticae* population increase (proportion leaves infested) and require repeated, extensive sampling. Although this procedure is likely accurate, it has not been adopted in the United States, likely because of the required sampling time. Twospotted spider mites are very small, difficult to count, and population densities can fluctuate rapidly, making thresholds based on density difficult. Similar to other small pests that cause indirect injury, economic injury levels are difficult to determine and thresholds are often somewhat vague. It seems a more efficient and accurate method would be to utilize thresholds and expected yield loss on twospotted spider mite injury to cotton at specific growth stages. Mite injury to cotton is very characteristic and progressive over time. This injury could be categorized into a simple injury index scale. For example, injury could be classified into 5 levels on a 0-5 scale, where 0 = no injury and 5 = complete leaf reddening and/or defoliation. Although classifying injury is subjective, this approach should be as accurate as current defoliation thresholds used in soybean and cotton, which requires estimation of defoliation. By determining the amount of injury that caused economic damage at a range of growth stages, a more user friendly and accurate twospotted spider mite threshold should be determined.

Although previous research has investigated yield loss effects from spider mite feeding, those trials were conducted in production systems very different from those currently present in the southern United States. Previous research did not fully investigate yield losses caused by late-season twospotted spider mite infestations or define yield loss by the amount to injury at specific growth stages. During the first year of the study, yield loss, caused by naturally occurring twospotted spider mite infestations, was measured. The objectives of this study during 2008 and 2009 were to measure yield loss caused by mites when infestations were established pre-bloom, at bloom, and at 200 heat unit (HU) intervals from bloom through harvest. Heat units are derived from degree days above 15.6°C (60° F) (Supak 1984). Also, a second objective was to rate injury through the season and correlate yield loss to injury at specific growth stages. The overall objective is to refine twospotted spider mite thresholds and chemical control termination.

Materials and Methods

Research investigating late-season cotton yield loss from twospotted spider mite injury was conducted in Mississippi during 2007. In this study, six uninjured areas and six areas containing twospotted spider mite injury were identified within the same field. Plants within the field averaged five nodes above uppermost, first-position white flower. Uninjured plots were chosen directly adjacent to injured plots, often within 3 m and in the same row. An irrigated and non-irrigated field was included. Two row m sections from each area were box mapped at harvest. Box-mapping requires that lint from bolls on each node and position within each node be harvested independently and determine which plant portions contribute to overall yield. Box mapping allowed for determination of when damage occurred and whether it was due to fruit abortion or decrease in boll weight. Yield was categorized by bottom (nodes 5-10), middle (nodes 11-15), or top (nodes 16+) portions of the plant for analysis. In both fields, uninjured plots were chosen as close to injured plots as possible, but in areas containing no or only minor injury. Data were analyzed separately using PROC MIXED (SAS Institute 1998). Protected LSD (P = 0.05) was used to separate treatment means when appropriate.

To account for time of infestation and amount of injury, experiments using artificial infestation were conducted in 2008 and 2009. In these experiments, cotton was artificially infested with high densities of mites at 3rd true leaf, first bloom, and at 200 heat unit intervals (based on °F) from first bloom until node above white flower five + 650 heat units (HU), resulting in a total of ~6-7 infestation-timing treatments plus an uninfested check. Node above white flower is a term that describes the number of nodes above the uppermost first position white flower on a cotton plant. Plot size was 4 rows (96.5-cm centers) by 6.1 m long. The experiment was arranged as a randomized complete block with 4 replications. Plots were separated by 2 unplanted rows and 3 m alleys consisting of unplanted bare ground to reduce migration of mites between plots. Dual *Bacillus thuringiensis* Berliner gene cotton varieties were planted to minimize the impact of lepidopteran insects. Either heavily infested cotton leaves or entire plants, or green bean plants were used to infest cotton with mites. Cotton was infested by placing infested cotton or green bean plants leaves across the canopy of cotton plants within plots. Applications of insecticides and miticides were used to maintain appropriate infestation levels and timings. All plots were sprayed with acephate at 0.57 kg/ha or a pyrethroid at a minimum rate (excluding bifenthrin), prior to 3rd true leaf and first bloom infestations to reduce natural enemy populations and allow the mites to become established. Once infested, every effort was made to maintain damaging densities of mites on the cotton until defoliation. If densities began to decline in previously infested cotton, plots were re-infested and/or treated with acephate to reduce predatory insects. When an insecticide was applied, all plots were sprayed to ensure yield differences were the result of mite injury. Bifenthrin and dicofol were applied on a few occasions when mites were detected in plots before the time of scheduled infestation. However, no miticide was applied to plots less than 7 days before infestation. Plots were harvested with a mechanical picker at harvest. When uninfested plots reached first bloom, mites were removed from the 3rd true leaf treatment by applying a high rate of etoxazole, spiromesifen, or abamectin.

Visual damage ratings were taken to capture and describe the physical damage caused by twospotted spider mites within the growing season. Three separate ratings were taken at bloom, each subsequent infestation date, and after the final infestation but before defoliation. The first visual rating was symptomology or leaf reddening index: on a 0-5 scale where 0 = no damage and 5 = complete reddening and/or defoliation on nearly all leaves. Rankings were assigned as follows: 1) light stippling occurring on sporadic leaves, 2) stippling and reddening present on 15-20% of leaves, 3) 50% of leaves have very apparent reddening on basal portions of leaf, 4) > 50% of leaves contain extensive reddening of entire leaves and area where leaves begin to excise. The second rating was a stunting index on 0-100% scale that estimated stunting in infested plots compared to uninfested plots. The third rating was a defoliation rating (0-100%).

One artificial infestation trial was conducted in Starkville, MS during 2008. Cotton variety ‘Stoneville 4554 BG2RF’ was planted on 5 May at the R. R. Foil Plant

Science Research Farm at Starkville, MS. First-bloom, first bloom + 200, and 400 HU infestations were made on 7, 17, and 29 July, respectively. Cotton was infested by placing two infested cotton leaves against the main stem three nodes below the terminal. During 2009, the project was expanded to include cooperators in AR, LA, MO, and TN. The trial was conducted in 10 total locations during 2009. At the Starkville, MS location, cotton variety 'Phytogen 375 WRF' was planted on 19 May at the R. R. Foil Plant Science Research Farm. Infestations in 2009 were made by placing entire infested green bean plants or cotton plants across the foliage of plots. Placing entire infested plants in plots allowed the introduction of a higher number of mites at infestation, which helped to minimize the effects of environmental mortality and accelerated population growth. First bloom infestations were made in early- to mid-July and subsequent infestations were made at 200 HU intervals or about 10 days thereafter. However, because of unseasonably wet and cool weather, successful experiments were conducted at only three locations. Wet weather either prevented mites from being established or caused populations to crash prematurely in some locations, whereas other locations could not be properly harvested. Locations with successful trials included Stoneville, MS, Macon Ridge, LA, and Portageville, MO.

Results and Discussion

Yield loss was first measured in naturally occurring twospotted spider mite infestations in production fields during 2008. Yield loss was greatest in the non-irrigated field. In the non-irrigated field, there was a 48% total yield loss in mite damaged areas as compared to undamaged areas (Table 5.1). Yield losses in the bottom, middle and top portions of the plant were 22, 48, and 73%, respectively. The total number of bolls in that field was reduced by 30% in mite damaged areas as compared to undamaged areas. The number of bolls in the bottom portion of plants was similar in injured and uninjured plots, whereas boll reduction in the middle and top portions of plants was 31 and 45%, respectively, in mite injured plots compared to uninjured plots. Yield loss was caused by both fruit abortion and reduced boll weight in this field. Although it cannot be determined exactly when these infestations began, it is likely that extensive injury did not occur until after bolls on nodes 5-10 had bloomed, since number of bolls was similar on the bottom plant portion in injured and uninjured plots. Premature defoliation and fruit abortion seemed to be more prevalent in the non-irrigated field. Mite injured plots in the non-irrigated field (mite injured areas) contained severe twospotted spider mite injury, which resulted in > 50% premature defoliation of plants compared to other areas of the field. These severely injured areas were scattered across the field with varying levels of minor injury between them. Twospotted spider mite injury in damaged areas of the irrigated field consisted of leaf reddening, but no defoliation. Extensive leaf reddening was more widespread in the irrigated field, however areas with minor injury was scattered throughout.

Yield loss in the irrigated field was less severe. Total yield of seed cotton was reduced by 10% in the damaged plots as compared to plots containing no mite injury. Although not statistically different, bottom portions of plants in mite injured plots yielded 18% more than uninjured plots. However, in the middle and top portions of plants in mite injured plots yield was reduced by 23 and 68%, respectively. Numbers of bolls were statistically similar in the mite injured and uninjured plots, signifying that yield loss in mite injured areas of this field was most likely due to reduction in boll weights. Because yield loss was only observed in middle and top plant portions (nodes $\geq$11), twospotted spider mite injury presumably occurred later in the growing season, most likely between bloom and cutout. Although the severity of leaf reddening was similar in the irrigated and non-irrigated fields, premature defoliation was most evident in the non-irrigated field. This likely indicates that irrigated cotton is more capable of compensating for twospotted spider mite injury, by retaining leaves with mite injury and not aborting bolls.

Artificial infestations at first bloom, first bloom + 200 HU, and first bloom + 400 HU were successfully established in Starkville, MS during 2008. Although yield differences were statistically similar (df = 15, F = 0.198, P = 0.8950), yields trended to be lower for earlier infestation timings (Fig. 5.1). On 3 August, mite damage was significantly higher in the first bloom and first bloom +200 HU treatments than the first bloom + 400 HU or uninfested treatments (Table 5.2). Additionally, injury from twospotted spider mites was significantly higher in the first flower infestation than the first flower + 200 HU infestation. Measureable rainfall was recorded at the R. R. Foil Plant Science Research Facility on five of nine days, beginning five days following the first bloom + 200 HU infestation. Soon thereafter, tropical storm Fay and hurricane Gustav resulted in additional days of heavy rain and cloudy weather. The unseasonably wet conditions caused twospotted spider mite populations to completely crash ~ 1 August across the entire test area and no further infestations were successful. The adverse weather conditions in 2008 likely impacted the yield results in this experiment. Excessive rainfall and cloudy conditions resulted in high levels of fruit abscission and boll rot from pathogenic organisms.

Experiments in 2009 were also negatively impacted by the unseasonably cool and wet weather. Rainfall totals in crop production regions of AR, MS, MO, and TN were 2-fold above normal during the months of July, August, and September (Fenimore 2009). As a result, establishment of twospotted spider mite populations and cotton harvest was only successful at three of ten locations, including Macon Ridge, LA, Stoneville, MS, and Portageville, MO. Presence of the pathogenic fungus *Neozygites floridana* was verified at the Starkville, MS location during the first week of August. Seven artificial infestation timings were established at the Macon Ridge, LA location. Cotton yield was significantly reduced compared to the uninfested check by infestations initiated from third true leaf through first bloom + 400 HU (df = 31, F = 17.6, $P < 0.0001$) (Figure 5.2). Infestations established at first bloom + 600, 800, and 1000 HU did not statistically reduce yield. Yield was reduced by 38.2, 24.3, 25.0, and 11.1% by infestations established at 3rd true leaf, first bloom, and first bloom + 200, and 400 HU, respectively. Although twospotted spider mite injury did cause damage, mite populations were also continually hampered at this location by rainfall and crashed during the late season. Yield response from infestations established after first bloom + 400 HU likely do not represent maximum yield loss that twospotted spider mite can cause during those growth stages. At the Stoneville, MS location, the 3rd true leaf and subsequent first bloom, first bloom + 200 and 400 HU infestations were made. Only the 3rd true leaf infestations resulted in a significant yield loss (42.8%) compared to the untreated check (df = 19, F = 12.088, P = 0.0004) (Fig. 5.3). Mite populations were not successfully established or maintained in infestations made after first bloom. At later infestation timings, visible mite injury was minimal and similar among treatments. At the Portageville, MO location, mites were successfully established at the 3rd true leaf and first bloom timings. Yield was statistically reduced by infestations established at 3rd true leaf and first bloom (df = 27, F = 22.141, P = 0.0001) (Fig. 5.4). Cotton yields from infestations made after first bloom were similar to the untreated check. Mite populations were not successfully established or maintained after the first bloom infestation timing.

The 3rd true leaf infestation was also successfully established at Starkville, MS and Jackson, TN locations. However, continuous rain delayed harvest in Starkville, MS and prevented harvest at the Jackson, TN location. At the Starkville location, mite injury from the 3rd true leaf infestation caused significantly more defoliation (57.5%) (df = 15, F = 529, P = 0.0002) stunting on cotton plants (20%) (df = 15, F = 96, P = 0.0023), and a higher injury index score (5.0%) (df = 15, F = 116.52, P = 0.0001). The infestation established at 3rd true leaf also caused ~100% fruit shed on all branches below node 13 and delayed maturity by at least 30 d. On 19 October, cotton in the 3rd leaf infestation treatment had only reached 10% cracked bolls, whereas in other treatments, bolls were 100% open. Rainfall delayed harvest, eventually causing cotyledons to sprout, hard lock, and boll rot on a large percentage of bolls in all treatments except the 3rd true leaf treatment, which at the time of rainfall had not opened. At harvest there were no differences among treatments (df = 27, F = 1.056, *P* = 0.4235). At the Jackson TN site, twospotted spider mites caused visible injury in early infestations, but the experiemnt was not harvested.

Despite inclement conditions, pre-bloom infestations (3rd true leaf) of twospotted spider mites caused significant cotton yield losses in three trials. On average, infestations established at 3rd true leaf caused a yield loss of 45%. Mite populations were removed from this treatment when surrounding treatments reached first bloom, which allowed populations to persist ~4 weeks. Yield losses observed from pre-bloom mite infestations in this experiment corroborate those reported by Furr and Pfrimmer (1968) at Stoneville, MS. Furr and Pfrimmer (1968) reported a yield loss of 30% when twospotted spider mite infestations were initiated ~ 3 wk later than the 3rd true leaf treatment in this trial. Conclusions cannot be made about infestations made from first bloom and later because of the difficulty in establishing mite population later in the season. In the one trial at Macon Ridge, LA where post-bloom populations of twospotted spider mites were established, yields were significantly reduced. However, even in this trial, mite populations were impacted by rainfall and yield losses may have been more severe in a normal dry year. Other research has shown that substantially higher yield loss can occur when conditions are more favorable. Wilson (1993) reported yield losses ranging from 1-29% when mites were infested during mid and late season. Sadras and Wilson (1997b) reported an extreme yield loss of 84-97% in cotton infested during blooming periods. These data suggest that twospotted spider mite can cause a wide range of yield loss depending on environmental conditions. Given adequate data, it should be possible to use regression analysis to determine the relationship between damage index score and cotton yield loss at given growth stages. Unfortunately, because of failed experiments, this relationship could only be determined for the 2008 experiment. Regression analysis resulted in a R^2 of 0.61 (df = 16, F = 3.1192, P = 0.0593), but minimal damage resulted in very little yield loss.

It is important to further determine how much yield loss *T. urticae* can cause in the high insecticide input production system of the Mid-South. Future experiments should continue to use artificial infestation procedures similar to those used in the current experiments to further define the impact of twospotted spider mite infestation timing on cotton. This research should be very valuable to producers and consultants once completed.

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Table 5.1. Seed cotton yield (kg lint/ha) and number of bolls in irrigated and non-irrigated cotton plots containing twospotted spider mite injury and no injury.

		Non-Irrigated Field				Irrigated Field			
Portion of plant	Treatment	Seed Cotton Yield	(P > t)	Number of Bolls	(P > t)	Seed Cotton Yield	(P > t)	Number of Bolls	(P > t)
Total	Mite injury	1026.8	(0.0015)	79.8	(0.0190)	3093.8	(0.0528)	157.7	(0.3273)
	No mite injury	1970.4		113.2		3454.1		168.0	
Bottom	Mite injury	374.6	(0.2418)	23.3	(0.4089)	1651.1	(0.0965)	72.2	(0.9001)
	No mite injury	479.0		26.5		1353.0		73.0	
Middle	Mite injury	523.9	(0.0027)	41.3	(0.0241)	1321.9	(0.0126)	73.5	(0.6183)
	No mite injury	1010.7		59.0		1721.4		77.8	
Top	Mite injury	128.3	(0.0079)	15.2	(0.1143)	120.9	(0.0532)	12.0	(0.5010)
	No mite injury	480.7		27.7		379.8		17.2	

Table 5.2. Injury caused by twospotted spider mite infestations on cotton at different timings during 2008 in Starkville, MS.

Treatment	Date Infestation	Damage Rating[a]	
First Bloom	7 July*	2.88	a
First Bloom + 200 HU	17 July*	2.13	b
First Bloom + 400 HU	29-Jul	0.50	c
Uninfested check		0.00	c
LSD		0.592	
F value		35.00	
P		0.0001	

* Plots were also re-infested on 21 July.
[a] Injury rating was on a 0-5 scale, (0 = no damage and 5 = complete reddening and defoliation)

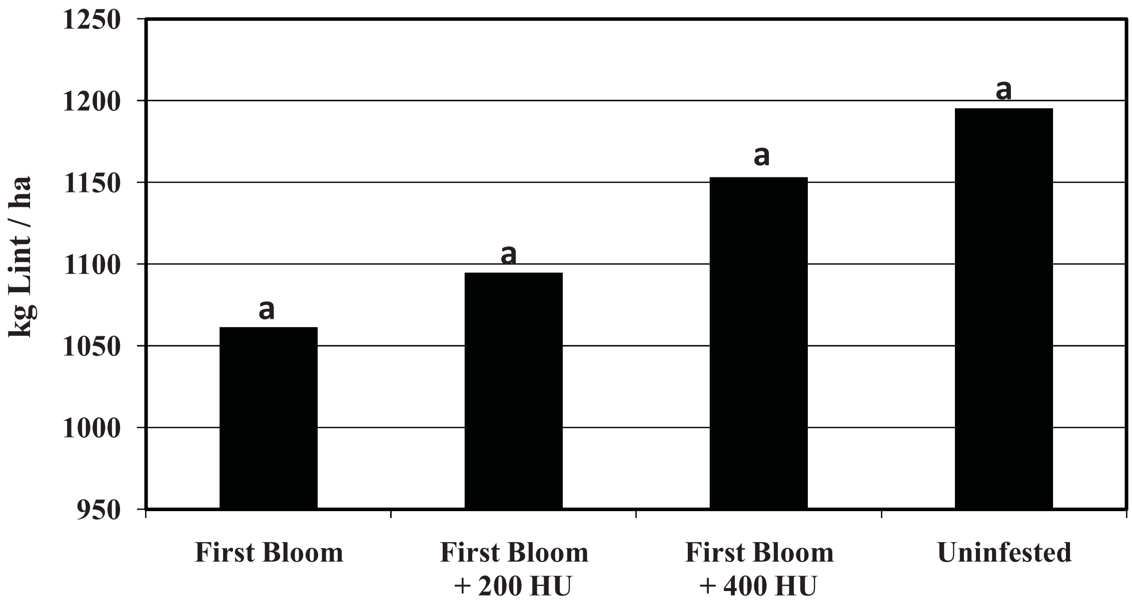

Figure 5.1. Impact of twospotted spider mite infestation timing on cotton yields at Starkville, MS in 2008. Means followed by the same letter are not significantly different ($\alpha = 0.05$).

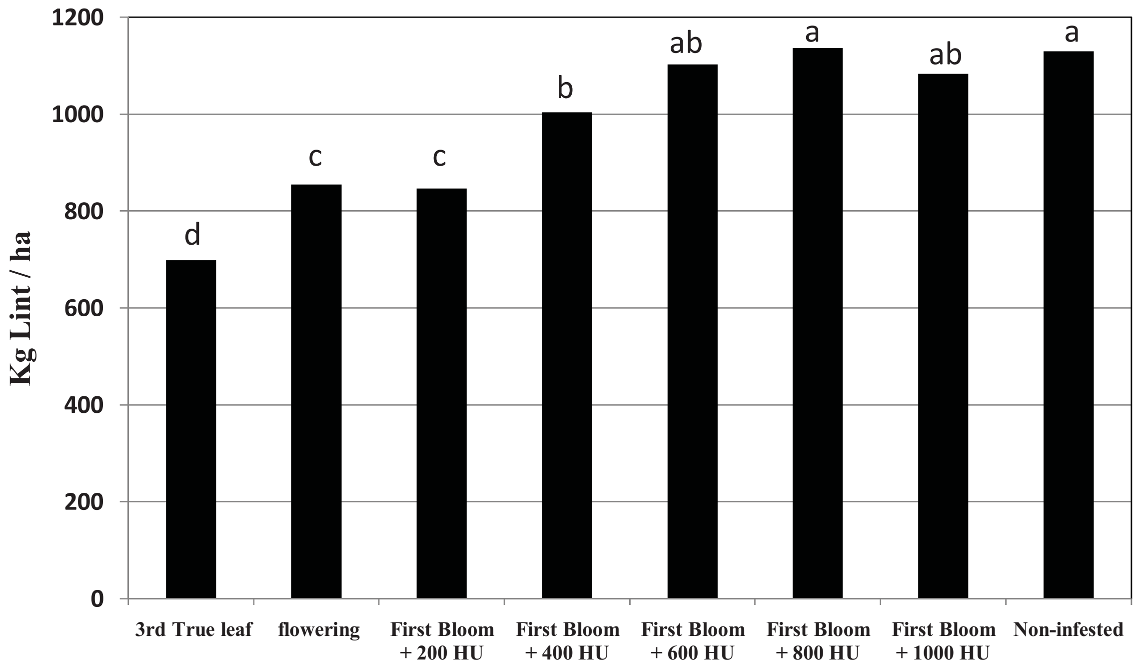

Figure 5.2. Impact of twospotted spider mite infestation timing on cotton yields at Macon Ridge, LA in 2009. Means followed by the same letter are not significantly different ($\alpha = 0.05$).

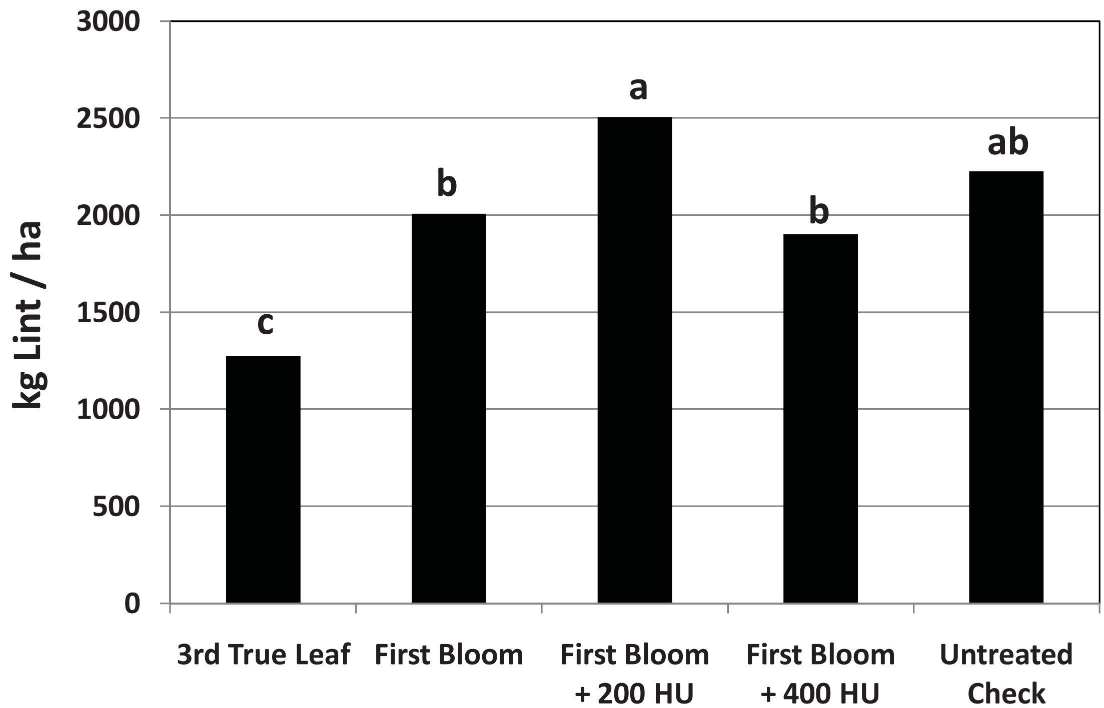

Figure 5.3. Impact of twospotted spider mite infestation timing on cotton yields at Stoneville, MS in 2009. Means followed by the same letter are not significantly different ($\alpha = 0.05$).

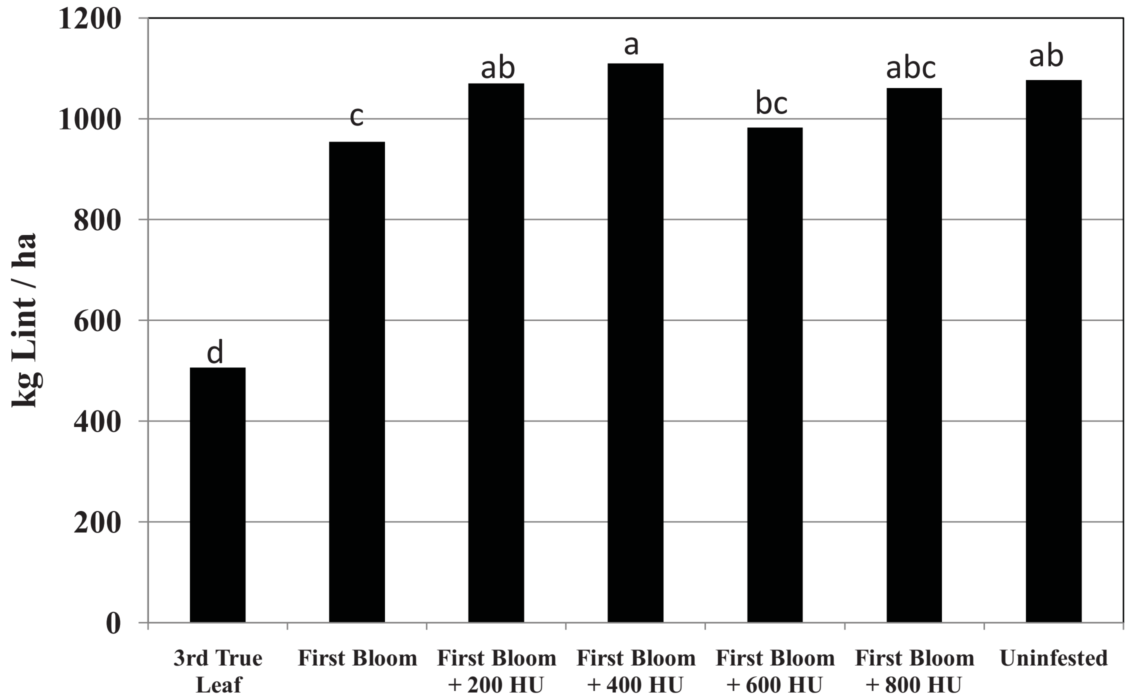

Figure 5.4. Impact of twospotted spider mite infestation timing on cotton yields at Portageville, MO in 2009. Means followed by the same letter are not significantly different (α = 0.05).

CHAPTER VI

SUMMARY

Data from a series of field experiments, conducted from 2007-2009, suggests that changes in production practices may be partly responsible for the elevated frequency of twospotted spider mite, *Tetranychus urticae* Koch, outbreaks in seedling cotton. Neonicotinoid seed treatments (thiamethoxam and imidacloprid) increased twospotted spider mite densities on seedling cotton by ~ 2-fold compared to aldicarb and untreated treatments. These results indicate that in fields with a high risk of twospotted spider mite outbreak, aldicarb would likely delay infestations or decrease the likelihood of infestations reaching damaging levels. Although neonicotinoid seed treatments are not the only factor that has increased twospotted spider mite outbreaks, it is possible that the number and severity of infestations in seedling cotton would be lower if aldicarb were applied at planting. Another factor that impacts twospotted spider mite outbreaks on seedling cotton is weed management. A higher percentage of cotton acres are managed with no-till or reduced- tillage practices than in the past, where weeds are controlled with herbicides instead of tillage. Throughout the study, it was commonly observed that henbit was nearly always present when natural infestations occurred on seedling cotton in production fields. Data from experiments in 2008 and 2009 suggest that burndown timing was not critical, provided all weeds were completely controlled prior to planting.

However, when weeds that hosted mites remained in plots, cotton was infested and severely injured soon after emergence. The addition of glufosinate as a burndown treatment was only beneficial to twospotted spider mite control when applied to weeds post-plant and preemergence of cotton. Glufosinate efficacy against twospotted spider mite was comparable to low- to mid-rates of labeled miticides. With the increased use of glufosinate tolerant cotton varieties and occurrence of glyphosate resistant weeds, glufosinate will likely be applied to an increasing number of cotton acres in Mississippi and other mid-south states. Integrating glufosinate to manage twospotted spider mite as well as weeds should allow producers to reduce total pesticide applications in fields where mites are present.

During 2007, ~ 10 and 50% yield losses were measured from cotton injured by naturally occurring infestations in non-irrigated and irrigated cotton, respectively. Box-mapping data suggest that these infestations were initiated during blooming periods. Artificial yield loss experiments demonstrated that pre-bloom infestations of twospotted spider mite in cotton can cause ~ 50% yield loss. It was not possible to draw any conclusions from post-bloom infestations due to difficulty in establishing populations. However, previous literature and data from 2007 experiments indicate that mite injury can result in substantial yield losses. It is important for this work to be continued into future years. Hopefully, more accurate, dynamic thresholds and miticide termination can be developed from this research.

The data generated from these from these experiments will be important for refining management practices for twospotted spider mite across the Mid-South. Future research should continue to focus on refining twospotted spider mite thresholds and insecticide termination for cotton in the Mid-South.