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The Compounding Stresses of Tobacco Thrips, Frankliniella fusca (Hinds), and Reniform Nematode, Rotylenchulus reniformis (Linford & Oliveira), on the Growth and Development of Cotton, Gossypium hirsutum L

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By

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The objectives of this research were to evaluate management options for tobacco thrips, *Frankliniella fusca* (Hinds), and reniform nematode, *Rotylenchulus reniformis* (Linford & Oliverira), in cotton productions systems. When evaluating tillage practices for pest control, conservational tillage reduced thrips densities and damage, while the impact on nematode densities is less understood and in this study had no impact. Insecticide seed treatments remain a vital resource for controlling thrips in Mid-South cotton production systems. When incorporating an early season herbicide application for weed control, systems with an insecticide seed treatment generally tolerated herbicide injury better than those with early season stress from thrips and nematodes. When using foliar applications as an alternative option for thrips management, early season automatic applications at the cotyledon stage followed by one or two sequential applications provided similar efficacy to the insecticide seed treatment. For reniform nematode management, 1, 3-dichloropropene reduced densities lower than that of the untreated control or aldicarb; however, depending on environmental conditions this practice may

not result in yield increases great enough to warrant the cost of application. These data highlight the importance of effective control of thrips whether it be via at-planting or foliar applications. 1, 3-dichloropropene reduced nematode densities and is an effective option in nematode management; however, nematodes are a stress pathogen and the ability to minimize other seasonal stresses ,such as water stress, will determine if a nematicide application may be needed. While environmental conditions may be optimal to allow for plant recoverability, effective early season pest management decreases the potential for delayed crop maturity which could lead to increased input cost or reduced yield later in the season.

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"For I know the plans I have for you," declares the lord, "plans to prosper you and not to harm you, plans to give you hope and a future."

Jeremiah 29:11

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER I

EVALUATION OF TILLAGE, AT-PLANTING TREATMENT, AND NEMATICIDE ON TOBACCO THRIPS (THYSANNOPTERA: THRIPIDAE)) AND RENIFORM NEMATODE (TYLENCHIDA: ROTYLENCHULIDAE) MANAGEMENT

1.1 Abstract

There are numerous early season pests of cotton, *Gossypium hirsutum* L., that are economically important, including tobacco thrips, *Frankliniella fusca* (Hinds), and reniform nematode, *Rotylenchulus reniformis* (Linford & Oliveira). Both of these species have the potential to reduce plant growth and delay crop maturity, ultimately resulting in reduced yields. A field study was conducted during 2015 and 2016 to evaluate the influence of tillage, at-planting insecticide treatment, and nematicide treatment on pest management, cotton development, and yield. Treatment factors consisted of two levels of tillage, (no- tillage and conventional tillage); seven levels of at-planting insecticide treatments, (imidacloprid, imidacloprid plus thiodicarb, thiamethoxam, thiamethoxam plus abamectin, aceptate plus terbufos, aldicarb, and an untreated control); and two levels of nematicide, (no nematicide and 1, 3- dichloropropene). There were no significant interactions between tillage, at-planting insecticide treatment, or nematicide for any parameters nor was there a difference in the main effect treatment of nematicide on thrips control or damage. Main effect treatments of tillage and at-planting insecticide treatment impacted thrips densities and damage. The no-tillage treatments and aldicarb in-furrow or

acephate seed treatment plus terbufos in-furrow significantly reduced thrips populations. There was a significant main effect of tillage or at-planting insecticide treatment on cotton yield. Plots that did not receive a nematicide application yielded greater than plots treated with 1, 3-dichloropropene. This was likely due to compensation from stress. There were no differences in tillage or at-planting treatment with respect to yield.

1.2 Introduction

The complexity of early season pest management in cotton, *Gossypium hirsutum* L., production systems can be may be impacted by both tobacco thrips, *Frankliniella fusca* (Hinds), and reniform nematode, *Rotylenchulus reniformis* (Linford and Oliveira). Tobacco thrips are a consistent and predictable pest of seedling cotton across the United States (Cook et al. 2011). Cotton is susceptible to thrips injury from emergence until the fourth or fifth true leaf, or approximately 28 days after emergence under optimal conditions (Toews et al. 2010). The common symptomology of thrips damage includes ragged or wrinkled leaves, a silvery appearance to cotyledons and leaves, distorted or malformed leaves after expansion, and/or loss of apical dominance when injury is severe enough to damage the apical meristem (Telford and Hopkins 1957, Reed and Reinecke 1990, Cook et al. 2011). Additionally, several studies suggest that seedling root growth and development can be negatively impacted by thrips feeding (Roberts and Rechel 1996, Sadras and Wilson 1998, Brown et al. 2008). Damage caused by thrips may lead to reduced plant height, delayed maturity, and/or reduced yield. Cotton does have the ability to compensate for thrips damage depending on the severity of injury and environmental conditions (Watts 1937, Carter et al. 1989, Roberts and Rechel 1996).

Reniform nematode is a semi-endoparasitic nematode that penetrates and feeds on the cortex of cotton roots. Nematode infestation and feeding impacts cotton root development by limiting effective water and nutrient uptake, as well as, increasing the susceptibility of plants to soil-borne diseases (Koenning et al. 2004). Nematode damage is often confused with nutrient deficiencies due to above-ground symptomology including stunted growth, premature plant wilt, and/or non-uniform plant stand (Lawrence and McLean 2001, Monfort 2005). Feeding from reniform nematode may also reduce or stunt the developing root system which could lead to fewer blooms, reduced leaf area or boll size, increased fruit shed, delayed crop maturity, or plant death (Gazaway and Edisten 1993, Kirkpatrick 2001, Monfort 2005). Yield losses from both thrips and nematodes can be variable depending on environmental conditions and compounding stresses. Individually, reniform nematode is a stress pathogen that causes an estimated yield loss between 7 and 8%, but may cause much greater yield losses under adverse conditions (Davis et al. 2003, Blasingame et al, 2006, 2009, Birchfield and Jones 1961). Cotton losses in Mississippi due to thrips in 2016 were estimated at 16,129 bales (Williams 2016).

Yield losses associated with early season pests can generally be minimized by various cultural and chemical practices. Conservational tillage has been reported to influence both thrips densities and damage, and nematode densities (Bauer et. al., 2010). Reduced thrips densities and damage have been associated with conservational tillage systems compared to conventional tillage systems (All et al. 1992, Bauer et al. 2010). Thrips densities were lower in plots where strip-till practices were implemented compared to those with conventional tillage (Towes et al. 2010). However, less is known regarding the impact of tillage systems on nematodes. Bauer et al. (2010) reported that root-knot nematode, *Meloidogyne incognita*, densities were reduced in some years following conservational tillage practices. Although Minton (1986) suggested that tillage system and nematode species may be dependent on one another; conservation tillage practices lowered populations of some plant parasitic species, while other species increased with the remaining plant residues. However, conventional tillage systems that incorporated plant residues and destroyed roots prevented additional nematode reproduction. Conversely, other studies reported that conventional tillage had minimal impact on reducing nematode populations (Davis et al. 2000, Koenning et al. 2003). Deep tillage in clay soils, or in the presence of a hardpan, has been beneficial for tap root growth and soil penetration with lance nematode, *Hoplalaimus galeatus*, infestations (Hussey 1977).

While tillage practice may aid in control, seed treatments and at-planting in-furrow pesticides are the most commonly used control method for thrips, and are generally more effective than foliar applications in preventing yield losses (Reed et al., 2001, Layton and Reed 2002). While nematode management options are limited, some seed treatments are packaged with an insecticide and nematicide targeting thrips and nematodes. Generally, seed treatments are not as effective at suppressing nematode populations as soil fumigants or aldicarb (Starr et al. 2007). However, Roberts et al. (2009) reported that positive effects of a nematicide in regards to early root growth may be affected by thrips injury. Therefore to better understand the effect of thrips and nematodes on cotton growth and development, studies were conducted to evaluate the influence of tillage, at-planting insecticide treatments, and nematicide use on pest control and cotton yield.

1.3 Materials and Methods

Field experiments were conducted in Hamilton, MS during 2015 (two locations) and in 2016 (two locations) to evaluate the influence of tillage, at-planting insecticides, and nematicide on tobacco thrips and reniform nematode control. The field study was implemented as a randomized complete block design with a split-split plot treatment arrangement with four replications. The main-plot factor included two levels of land preparation: conventional tillage and no-tillage. Conventional tillage plots were subsoiled 48 to 51-cm on 09 Apr 2015 and 16 Apr 2016. Immediately following subsoiling, tilled plots were bedded with a four row hipper/bedding implement. The sub-plot factor included two levels of a nematicide: 1, 3-dichloropropene (Telone II, Dow AgroSciences, Indianapolis, IN) applied at 28 L ha^{-1} and no nematicide. Applications of 1, 3-dichloropropene were made on 05 May 2015 and 19 Apr 2016 using a four-row coulter injection system. The sub-sub-plot factor included seven levels of at-planting insecticide: imidacloprid (Gaucho 600, Bayer CropScience, Research Triangle Park, NC) at 0.375 mg ai $seed^{-1}$, imidacloprid plus thiodicarb (Aeris, Bayer CropScience, Research Triangle Park, NC) at 0.375 plus 0.75 mg ai $seed^{-1}$, thiamethoxam (Cruiser 5FS, Syngenta Crop Protection Inc., Greensboro, NC) at 0.34 mg ai $seed^{-1}$, thiamethoxam plus abamectin (Avicta Duo Cotton, Syngenta Crop Protection Inc., Greensboro, NC) at 0.34 plus 0.49 mg ai $seed^{-1}$, acephate (Orthene 97, AMVAC Chemical Corporation, Los

Angeles, CA) at 3.9 g ai kg^{-1} of seed plus terbufos 75.7 g ai ha^{-1} (2015) (Counter 15G, AMVAC Chemical Corporation, Los Angeles, CA) or aldicarb (AgLogic 15G, AgLogic LLC, Chapel Hill, NC) at 340.5 g ai ha^{-1} (2016), and an untreated control. All seed were treated with a base fungicide (ipconazole at 0.01 mg ai seed $^{-1}$ + metalaxyl at 0.002 mg ai seed $^{-1}$ + myclobutanil 0.06 mg ai seed $^{-1}$ + penflufen at 0.02 mg ai seed $^{-1}$) to minimize any effects from seedling disease. Granular insecticides terbufos and aldicarb were applied directly into the seed furrow at the time of planting by planter mounted granular insecticide boxes. All other at-planting insecticides were applied as seed treatments. Sub-sub-plots were four 3.6-m rows measuring 15.2-m in length. Stoneville 4946 (Bayer CropScience, Research Triangle Park, NC) cotton seed were planted at a depth of approximately 2-cm at a population of 135,850 seed ha^{-1} on 12 May 2015 and Stoneville 6448 (Bayer CropScience, Research Triangle Park, NC) on 10 May 2016. Standard production practices were followed according to Mississippi State University Extension Service recommendations.

Nematode samples were collected prior to the nematicide application, at first square, and post-harvest. Nematode populations were determined by collecting ten, 20-cm deep soil cores from individual plots using a 2.5 cm diameter soil sampling probe. Cores were combined, and a sub-sample of 300 cm^3 was processed by the Mississippi State University Extension Plant Diagnostic Laboratory in Starkville, MS using a semi-automatic elutriator and sucrose extraction (Byrd et al. 1976, Jenkins 1964).

Thrips damage ratings and thrips densities were evaluated at the 1-2 and 3-4 leaf stage of cotton growth. Damage ratings were recorded on a scale of 0 (no injury) to 5 (severe injury). Thrips densities were estimated by randomly cutting five plants from each plot at ground level and placing them into a 0.47-L glass jar with a 50% ethanol solution. Plants were rinsed with a 50% ethanol solution and the remaining solution was poured through a Buchner funnel. Thrips adults and nymphs were collected on filter paper and that paper was placed into a Petri dish for counting under a microscope. Adult thrips darker in color were considered to be tobacco thrips based on the observations of Stewart et.al (2013) where 98% of thrips species in Mississippi were determined to be tobacco thrips. Immature thrips were not identified to species and pooled.

Plant vigor was assessed at 1-2 and 3-4 leaf stages on a scale of 1 (poor stand) to 10 (excellent, uniform stand). Total above- and below-ground biomass samples were evaluated by uprooting five random plants from the outer two rows at the 4-leaf stage. Above- and below-ground portions of the five uprooted plants were placed into paper bags and dried in a forced air dryer for 48 hours at 38°C. After drying, samples were weighted to determine dry biomass. Cotton yield was determined by harvesting the center two rows of each plot with a modified spindle-type cotton picker for small plot research.

Data were analyzed using analysis of variance (PROC GLIMMIX, SAS 9.4; SAS Institute; Cary, NC). Year and replication were considered to be random effects, and tillage, nematicide, and at-planting treatments were considered to be fixed effects. Means were separated using Fisher's Protected LSD procedure at the 0.05 level of significance.

1.4 Results

Reniform nematode control. When evaluating tillage system on nematode populations prior to nematicide applications, conventional tillage plots had significantly lower population of 1178 nematodes per 500 cm^3 of soil compared to that of the no-tillage plots which had 1704 nematodes (F=13.90; df=1,365; *P*<0.01). No differences in nematode populations were observed at first square for any interaction (F>0.01; df= 6, 332; *P*>0.13) or the main effects of tillage (F=2.31; df= 1,332; *P*=0.13), nematicide (F=0.05; df= 1, 332; P=0.83), or at-planting insecticide treatment (F=0.94; df= 6,332; *P*= 0.47). At the post-harvest sample date, there was no significant three-way interaction among any factors (F=0.89; df= 6, 332; *P*=0.50); however, there was a significant interaction between tillage and nematicide (F=0.01=4.13; df= 1, 332; *P*=0.04), while no significant differences were observed for at-planting insecticide treatments (F=1.73; df= 6, 332; *P*=0.11) in regards to nematodes per 500 cm^3 of soil. When comparing the use of nematicide in tillage practice, there were no observed significant differences between tillage practice and nematicide. However,, the number of nematodes per pint of soil were reduced by 36% with the use of 1, 3-dichloropropene compared to no nematicide in the conventional tillage system (Table 1.1).

Tobacco thrips densities and damage. There were no significant interactions among factors for thrips densities (F>0.03; df= 6, 341; *P*>0.21) or damage (F>0.03; df= 6, 338; *P*>0.09). Nematicide did not have a significant effect on the density of immature or adult thrips at any sampling period (F>0.03; df= 1, 341; *P*>0.58). At the 1-2 leaf stage, tillage system did not have an effect on the density of immature or adult thrips, (F>0.13; df= 1, 341; *P*>0.40). At the 3-4 leaf stage, there were 33% fewer immature and 29% fewer adult tobacco thrips per five plants in the no-tillage plots compared to conventional tillage (F>4.08; df= 1, 341; *P*<0.04) (Table 1.2). Applications of acephate plus terbufos and imidacloprid plus thiodicarb followed by aldicarb and imidacloprid provided greater control of immature thrips than both thiamethoxam treatments as well as the untreated control at the 1-2 leaf stage (F=10.51; df= 6, 341; *P*<0.01) (Table 1.2). Acephate plus terbufos provided the greatest control of adults thrips at the 1-2 leaf stage, followed by all other at-planting treatments which provided greater control than the untreated (F=14.64; df= 6, 341; *P*<0.01) (Table 1.2). At the 3-4 leaf stage, immature thrips (F=10.89; df= 6, 341; *P*<0.01) densities were significantly reduced by aldicarb applications compared to all other treatments, while acephate plus terbufos applications resulted in the greatest level of adult control (F=8.73; DF= 6, 341; *P*<0.01) (Table 1.2).

When evaluating main effects for thrips damage, nematicide did not have a significant effect at the 1-2 leaf stage (F=10.51; df= 6, 341; *P*=0.57). However, minor reductions in thrips damage from the 1,3-dichlorpropene treatments were observed compared to no nematicide at the 3-4 leaf stage (F=3.99; df=1, 335; *P*=0.05) (Table 1.3). Thrips damage was significantly reduced at both rating intervals in the no-tillage system (F>15.99; df= 1, 335; *P*<0.01) compared to the conventional tillage system (Table 1.3). When comparing at-planting insecticide treatments, there was a wide range of thrips damage. Furthermore, applications of acephate plus terbufos or aldicarb provided the greatest level of thrips control at both rating intervals, while the lowest level of control was in the untreated control and thiamethoxam treatments (F>113.26; df= 6, 335; *P*<0.01) (Table 1.3).

Effect on plant vigor, biomass, and cotton yield. No significant interactions were observed for plant vigor (F>0.75; df= 6,339; *P*>0.61), biomass (F>1.24; df= 6,316; *P*>0.28), or cotton yield (F>0.60; df= 6,333; *P*>0.73). There was a significant interaction (F=5.56; df= 1,339; *P*=0.02) between tillage and nematicide at the 1-2 leaf stage for plant vigor, where plants in the conventional tillage plots regardless of nematicide had greater vigor than those in the no-tillage plots (Table 1.4). However, there was a significant difference between nematicide treatment in the no-tillage systems, where treatments containing 1, 3-dichloropropene had greater vigor than those in no-tillage plots with no nematicide (Table 1.4). When evaluating at-planting insecticide treatments on plant vigor at both rating intervals, applications of aldicarb or acephate plus terbufos resulted in greater observed plant vigor, followed by imidacloprid plus thiodicarb ($F>49.19$; df= 6, 339; $P<0.01$). There were no differences between plots treated with imidacloprid or thiamethoxam plus abamectin, yet they had an increased amount of plant vigor compared to thiamethoxam alone and the untreated control (Table 1.3). When evaluating plant vigor at the 3-4 leaf stage, there were no significant interactions between factors ($F>0.48$; df= 6, 339; $P>0.44$), nor a significant difference for nematicide ($F=1.14$; df= 1, 339; $P=0.29$). Again there was increased cotton vigor when grown in the conventional tillage plots compared to the no-tillage plots ($F=283.34$; df= 1, 339; $P<0.01$) (Table 1.3). Tillage ($F=4.08$; df= 1, 341; $P<0.01$), nematicide ($F=0.06$; df= 1,341; $P=0.01$), and at-planting treatments ($F=8.73$; df= 6, 341; $P<0.01$) had significant effects on total dry plant biomass per five plants (Table 1.5). The greatest plant biomass resulted from conventional tillage compared to no-tillage; applications of 1, 3-dichloropropene compared to no nematicide; and applications of aldicarb or acephate plus terbufos compared to all other at-planting insecticide treatments. While there were indications of early season plant response in regard to tillage and at-planting insecticide treatment, there were no differences in cotton yield associated with tillage ($F=1.99$; df= 1,333; $P=0.16$) or at-planting treatment ($F=0.62$; df= 1,333; $P=0.71$). However, nematicide treatments significantly impacted yield (F=15.91; df= 1,333; *P*<0.01), where the no nematicide applications resulted in greater yield (1252 kg ha) than applications of 1, 3-dichloropropene (1180 Kg Ha). There was a negative correlation between nematode population and yield, for every increase per 500 cm^3 soil in nematode population there is a 0.3688 ha kg decrease in yield (*P*<0.0001).

1.5 Discussion

In this research, there were no significant interactions between tillage, nematicide, at-planting insecticide treatment for any parameter measured, nor did at-planting insecticide treatment impact nematode densities. Lower nematode populations were observed prior to planting in conventional tillage plots, but populations rebounded by first square to similar levels as in the no-tillage plots. While tillage did not influence post-harvest nematode densities, 1, 3-Dichloropropene applications to conventional tillage plots reduced nematodes densities. Currently, there is limited understanding of the impact of tillage on nematode persistence and survival. Both conventional tillage and no-tillage practices have positive and negative attributes in regard to nematode management. Different tillage practices may have variable impacts depending on nematode species. In previous research, the form of tillage did not impact nematode populations, while in other cases, minimum tillage and root residue resulted in the opportunity for increasing populations (Caveness 1979; Tyler et al. 1983; Forthnum and Karlen 1985; Minton 1986). Numerous studies support both the benefit of conventional and minimum tillage systems in the management of nematodes. For example, Thomas (1978) reported that when comparing various tillage practices, the highest densities of *Helicotylenchus pseudorobustus, Pratylenchus* spp., and *Xiphinema americanum* were in no-tillage systems while the lowest densities of these nematode species were observed in spring and fall plowed systems. Alby et al. (1983) reported higher densities of *Pratylenchus scribneri* in conventional tillage soybean, *Glycine max*, systems compared to no-tillage systems. Reduced tillage or no-tillage systems have the potential to limit the roots ability to penetrate into the soil profile, especially in fields with soil compaction issues, which increases the potential for negative impacts on plant development under nematode stress (Minton 1986). Conventionally tilled systems might aid in plant root development; however, there is greater potential for the spread of nematodes throughout the field. While tillage systems can play a vital role in nematode management by minimizing other stresses, such as water or nutrient stress, crop rotation and chemical control options largely aid in minimizing the losses associated with nematodes (Minton 1986). An increase in populations of some species is possible in the presence of root residue, adequate moisture, and warmer winter temperatures even after harvest. The main strategy for chemical control of nematode suppression is to target early season root growth. In a previous study, there were no differences in nematode populations at first square, but there was an early season response in the total dry plant biomass per five plants when using nematode control practices (Sasser 1972). Numerous studies support 1,3-dichloropropene, aldicarb, and terbufos as effective chemical options for suppressing nematode populations and protecting yields (Gazaway et al. 2001, Robinson 2007). The use of 1,3-dichloropropene had no impact on thrips densities or damage. The current study in addition to other research shows that implementing no-tillage systems can reduce the amount of damage sustained from tobacco thrips. This decrease is likely due to a reduced infestation of thrips due the lessened ability to detect the cotton plant within the previous crop residue which would result in reduced damage. Seed treatments are one of the most effective control measures for reducing thrips populations and damage on seedling cotton (Layton and Reed 2002). Of the at-planting treatments that were evaluated, applications of aldicarb and acephate plus terbufos were the best options for controlling thrips populations and reducing damage. Studies have previously reported a reduction in the efficacy of tobacco thrips management with thiamethoxam and imidacloprid, and thiamethoxam performed similarly to the untreated control in the current study (Huseth et al. 2016, Darnell 2017). When evaluating plant vigor and biomass, there was an early season plant growth response to tillage, nematicide, and at-planting treatment. Plant growth was increased following conventional tillage, the presence of a nematicide, or the use of effective at-planting treatments; however, none of those responses resulted in yield differences. While at-planting treatment and tillage had no significant impact on yield, the absence of nematode control resulted in greater yields.

Cotton, unlike other crops, has the ability to compensate to some degree from early season damage sustained from pests such as thrips or nematodes (Sadra and Wilson 1998, Wilson et al. 2003). There are a number of factors that influence the plants ability to compensate, including but not limited to soil fertility, damage timing and severity, and environmental conditions (Hearn and Rosa, 1984 Cox et al. 1990, Sadras 1995). Optimal environmental conditions over the course of the study (A.1.1; A.1.2) aided in the plant's ability to compensate from the early season stress of tobacco thrips and reniform nematode infestations. Ultimately, the goal in any production system is to minimize stressors that can reduce yield.

Given the data, we conclude that there are positive benefits to both no-tillage and conventional tillage systems, as well as, applications of a nematicide and at-planting treatment; however, the best management practices for controlling thrips and nematodes in cotton production systems should be considered on a field-by-field basis and considering field history, risk aversion, and economics. Additional research is needed to evaluate the influence of tobacco thrips and reniform nematodes in cotton production systems and what other stress factors might compound damage from the pest and ultimately reduce yields.

1.1 Interaction of tillage treatment and nematicide application on the post-harvest nematode populations in Hamilton, MS during 2015 and 2016.

Treatment		Density per 500 cm^{3}[a] (±SE)
No Tillage	No 1,3-dichloropropene	3,879ab (672)
No Tillage	1,3-dichloropropene	4,278ab (560)
Tillage	No 1,3-dichloropropene	5,102a (679)
Tillage	1,3-dichloropropene	3,278b (600)
P-value		0.043

[a]Means within the column that are followed by the same letter are not different according to Fisher's Protected LSD with an alpha of 0.05.

1.2 Impacts of tillage treatment and at-planting insecticide treatment on thrips populations at the 1-2 and 3-4 leaf stage in Hamilton, MS during 2015 and 2016.

Treatment	Densities per five plants[a]			
	1-2 Leaf Stage		3-4 Leaf Stage	
	Immatures (±SE)	Adults(±SE)	Immatures(±SE)	Adults (±SE)
No Tillage			12.91b (1.3)	5.28b (0.8)
Tillage			19.27a (1.6)	7.46a (1.2)
P-values			0.0004	0.0442
Untreated Control	11.35a (2.6)	3.32b (0.4)	16.98cd (2.4)	7.94ab (2.0)
Thiamethoxam	13.4a (1.8)	4.78a (0.7)	25.73a (2.9)	9.84a (1.9)
Thiamethoxam plus abamectin	10.15a (1.3)	3.52b (0.5)	24.65ab (2.9)	10.3 a (1.9)
Imidacloprid	5.47b (5.4)	3.42b (0.7)	19.97bc (2.9)	5.70b (1.2)
Imidacloprid plus thiodicarb	3.62bc (0.4)	3.03b (0.4)	12.86de (2.1)	7.74ab (2.2)
Acephate plus terbufos	1.09c (0.4)	1.34c (0.2)	8.56ef (0.4)	1.34c (0.4)
Aldicarb	5.24b (0.7)	3.12b (0.1)	3.86f (2.6)	7.45ab (0.3)
P-values	0.0001	0.0001	0.0001	0.0001

[a]Means within the column that are followed by the same letter are not different according to Fisher's Protected LSD with an alpha of 0.05.

1.3 Impact of tillage, nematicide, and at-planting insecticide treatment on tobacco thrips damage and plant vigor at the 1-2 leaf stage and the 3-4 leaf stage in Hamilton, MS during 2015 and 2016.

Treatment	1-2 Leaf Stage[a]		3-4 Leaf Stage	
	Damage (±SE)[b]	Vigor (±SE)[c]	Damage(±SE)	Vigor(±SE)
No Tillage	2.57b (0.07)		2.69b (0.2)	5.08b (0.07)
Tillage	2.83a (0.06)		2.79a (0.1)	6.12a (0.06)
P-values	0.0001		0.0001	0.0001
No 1,3-dichloropropene			2.62b (0.1)	
1,3-dichloropropene			2.87a (0.2)	
P-values			0.0466	
Untreated Control	3.48a (0.06)	5.7d (0.16)	4.04a (0.52)	4.90e (0.11)
Thiamethoxam	3.4a (0.08)	5.81d (0.16)	3.55a (0.05)	4.81e (0.09)
Thiamethoxam plus abamectin	3.22b (0.09)	6.07c (0.15)	3.25b (0.07)	5.13d (0.10)
Imidacloprid	3.04b (0.08)	6.25c (0.16)	2.89c (0.06)	5.33d (0.09)
Imidacloprid plus thiodicarb	2.84c (0.07)	6.55b (0.15)	2.71c (0.06)	5.61c (0.09)
Acephate plus terbufos	1.78d (0.07)	7.33a (0.15)	1.79d (0.07)	6.24b (0.18)
Aldicarb	1.12e (0.13)	7.05a (0.12)	0.95e (0.09)	7.18a (0.12)
P-values	0.0001	0.0001	0.0001	0.0001

[a]Means within the column that are followed by the same letter are not different according to Fisher's Protected LSD with an alpha of 0.05. [b]Damage ratings are based on a 0 (no injury) to 5 (plant death) scale. [c]Plant vigor ratings are based on a 1 (poor, uniform stand) to 10 (excellent, uniform stand) scale.

1.4 Interaction of tillage and nematicide on plant vigor at the 1-2 leaf stage in Hamilton, MS during 2015 and 2016.

Treatment		Vigor (±SE)[a]
No Tillage	No 1,3-dichloropropene	5.83c (0.12)
Tillage	1,3-dichloropropene	6.81a (0.15)
No Tillage	1,3-dichloropropene	6.11b (0.13)
Tillage	No 1,3-dichloropropene	6.83a (0.11)
P-value		0.019

[a]Means within the column that are followed by the same letter are not different according to Fisher's Protected LSD with an alpha of 0.05.

1.5 Impact of tillage, nematicide, and at-planting insecticide seed treatment on the total dry plant biomass at the 4th leaf stage in Hamilton, MS during 2015 and 2016.

Treatment	Total Biomass[a] Grams (±SE)
No Tillage	3.55b (0.11)
Tillage	5.29 a (0.14)
P-values	0.0001
No 1,3-dichloropropene	4.21 b (0.13)
1,3-dichloropropene	4.63 a (0.14)
P-values	0.0076
Untreated Control	3.61 c (0.21)
Thiamethoxam	3.77 c (0.21)
Thiamethoxam plus abamectin	4.35 b (0.26)
Imidacloprid	4.12 bc (0.24)
Imidacloprid plus thiodicarb	4.41 b (0.20)
Acephate plus terbufos	5.46 a (0.44)
Aldicarb	5.24 a (0.29)
P-values	0.0001

[a]Means within the column that are followed by the same letter are not different according to Fisher's Protected LSD with an alpha of 0.05.

References

Alby, T., J. M. Ferris, and V. R. Ferris. 1983. Dispersion and distribution of *Pratylenchus scribneri* and *Hoplolaimus galeatus* in soybean fields. J. Nematol.. 15:418 426.

All, J. N., B. H. Tanner, and P. M. Roberts. 1992. Influence of no-tillage practices on tobacco thrips infestations in cotton, pp. 77–78. *In* M. D. Mullen and B. N. Duck (eds.), Proceedings Southern Conservation Tillage Conference. Jackson and Milan, TN. University of Tennessee Special Publication, University of Tennessee, Knoxville, TN.

Anonymous. Aeris seed applied insecticide/nematicide label. Available at http://www.cdms.net. Assessed on 12 Oct 2017.

Anonymous. AgLogic15G insecticide label. Available at http://www.aglogicchemical.com/ Assessed on 12 Oct 2017.

Anonymous. Avicta duo cotton nematicide/insecticide seed treatment label. Available at http://www.cdms.net. Assessed on 15 Oct 2017.

Anonymous. Counter 15G insecticide label. Available at http://www.cdms.net. Assessed on 12 Oct 2017.

Anonymous. Cruiser 5FS insecticide label. Available at http://www.cdms.net. Assessed on 12 Oct 2017.

Anonymous. Gaucho 600 insecticide label. Available at http://www.cdms.net. Assessed on 12 Oct 2017.

Anonymous. Orthene 97 insecticide label. Available at http://www.cdms.net. Assessed on 12 Oct 2017.

Anonymous. Telone II soil fumigant label. Available at http://www.cdms.net. Assessed on 12 Oct 2017.

Bauer, P. J., B. A. Fortnum, and J. R. Frederick. 2010. Cotton responses to tillage and rotation during the turn of the century drought. Agron. J. 1145-1148

Birchfield, W., and J. E. Jones. 1961. Distribution of the reniform nematode in relation to crop failure of cotton in Louisiana. Plant Dis Rep 45:671-673.

Blasingame, D., M. V. Patel, W.Gazaway, M. Olsen, T. Kirkpatrick, M. Davis, R. K. Sprenkel, B. Kemerait, P. Colyer, A. Wrather, N. Goldberg, S. Koenning, J. C. Banks, J. Muller, M. Newman, J. Woodward, and P. Phipps. 2006. Cotton disease loss estimate committee report. Proceedings of the Beltwide Cotton Conferences of the Natil Cot Coun of Am http://www.cotton.org/beltwide/proceedings/ 2007.

Blasingame, D., Gazaway, W., Lawrence, K. S., Wrather, A., Olsen, M., Kirkpatrick, T., Koenning, S. R., Goldberg, N., Banks, J.C., Sprenkel, R., Muller, J., Davis, M., Kemerait, R. C., Newman, M. A., Colyer, P. D., Woodward, J. E., Sciumbato, G. L., and Phipps, P. M. 2009. Cotton disease loss estimate committee report. Proceedings of the Beltwide Cotton Conferences of the Natl Cot Counc of Am 1:94–96.

Bourland, F. M., D. M. Oosterhuis, N. P. Tugwell. 1992. Concept for monitoring the growth and development of cotton plants using main- stem node counts. J. Prod. Agric.5: 532- 538.

Brown, S. M., P. M. Roberts, and R. C. Kemerait. 2008. Potential implications of thrips control for nematode management, p. 258. *In* S. Boyd, M. Huffman, D. Richter, and B. Robertson (eds.), Proceedings 2008 Beltwide Cotton Conferences. Natl Cott Counc, Memphis, TN.

Byrd, D. W., Jr., K. R. Barker, H. Ferris, C. J, Nusbaum, W. E. Griffin, R. H. Small, and C. A. Stone. 1976. Two Semi-automatic elutriatiors for extracting nematodes and certain fungi from soil. J. Nematol. 8:206-212.

Carter, F. L., N. P. Tugwell, and J. R. Phillips. 1989. Thrips control strategy: effects on crop growth, yield, maturity, and quality, pp. 295–297. *In* J. M. Brown and D. A. Richter (eds.), Proceedings 1989 Beltwide Cotton Conferences, Natl Cot Counc, Memphis, TN.

Caveness, F. E. 1979. Nematode populations under no-tillage soil management regime. Pp. 133- 145 in R. Lal, ed. Soil tillage and crop production. Ibadan, Nigeria: International Institute of Tropical Agriculture.

Cook, D., A. Herbert, D. S. Akin, and J. Reed. 2011. Biology, Crop Injury, and Management of Thrips (Thysanoptera: Thripidae) Infesting Cotton Seedling in the United States. J. Integ. Pest. Mgmt. 2:2011.

Cox, P. G., S. G. Marsden, K. D. Brook, H. Talpaz, and A. B. Hearn. 1990. Economic optimization of Heliothis thresholds on cotton using the SIRATAC pest management model. Agric. Syst. 35:157–171.

Darnell. C. H. 2017. Evaluation and management of neonicotinoid resistant tobacco thrips (*Frankliniella fusca*) in cotton. Mississippi State University Thesis

Davis, R. F., S. R. Koenning, R. C. Kemerait, T. D. Cummings, and W. D. Shurley. 2003. *Rotylenchulus reniformis* management in cotton with crop rotation. J. Nematol. 35:58-64

Davis R. F., R. E. Baird, R. D. McNeill. 2000. Efficacy of cotton root destruction and winter crops for suppression of *Hoplolaimus columbus* . Supplement to the J. Nematol. 32:550-555.

Davis, R., S. Koenning, R. Kemerait, T. Cummings, and W. Shurley. 2003. *Rotylenchulus reniformis* management in cotton with crop rotation. J. Nematol. 35:58-64.

Fortnum, B. A., and D. L. Karlen. 1985. Effects of tillage system and irrigation on population densities of plant nematodes in field corn. J Nematol. 17:25-28.

Gazaway, W., D. Rush, and K. Edmisten. 1992. An evaluation of various Temik and Telone rates for controlling reniform nematodes in cotton. Fungicide and Nematicide Test 47:161.

Hearn, A. B., and G. D. Rosa. 1984. A simple model for crop management application for cotton (*Gossypium hirsutum L*.). Field Crops Res. 12:49–69.

Herbert, D.A., Jr. 1998. Evaluation of thrips damage on maturity and yield of Virginia cotton, p. 1177-1180. *In* Proc. Beltwide Cotton Conf., San Diego, CA. 5-9 Jan. Natl. Cotton. Counc. Am., Memphis, TN.

Huseth, A.S., T. M. Campbell, K. Langdon, S. C. Morsello, S. Martin, J. K. Greene, A. Herbert, A. L. Jacobson, F. P. F. Reay-Jones, T. Reed, D. D. Reisig, P .M. Roberts, R. Smith, and G. G. Kennedy. 2016. Frankliniella fusca resistance to neonicotinoid insecticides: an emerging challenge for cotton pest management in the eastern United States. Pest Mgmt Sci. 72:1934-1945.

Hussey R. S. 1977. Effect of subsoiling and nematicides on *Hoplolaimus columbus* populations and cotton yield. J. Nematol.. 9:83–86.

Jenkins W R. 1964. A rapid centrifugal-flotation technique for separating nematodes from soil. Plant Dis. Rep. 48:692.

Kirkpatrick, T. 2001. Nematodes, hidden enemy of cotton. Delta Farm Press 58 (16):28 29

Koenning S. R., K. L. Edmisten, K. R. Barker, D. E. Morrison. 2003. Impact of cotton production system on *Hoplolaimus columbus* . J. Nematol.. 35:73–77.

Koenning, S., T. Kirkpatrick, J. Starr, J. Wrather, N. Walker, and J. Mueller. 2004. Plant parasitic nematodes attacking cotton in the United States: old and emerging production challenges. Plant Dis. 88:100-113.

Lawrence, G. W., and K. S. McLean. 2001. Reniform nematodes. *In* Compendium of Cotton Diseases, Second Edition. T. L. Kirkpatrick and C. S. Rothrock (eds.), APS Press pp. 42-43.

Layton, B. and J. T. Reed. 2002. Biology & Control of Thrips on Seedling Cotton, ppx Mississippi State University. Mississippi State, MS. *Mississippi State University Extension Service*. Publication 2302.

Minton, N. A. 1986. Impact of Conservation Tillage on Nematode Population. J. Nematol. 18:135-140.

Monfort, W. 2005. Potential for remote identification of within-field problem zones associated with *Meloidogyne incognita* and *Thielaviopsis basicola* for site specific control in cotton. Doc. Dissertation. University of Arkansas Fayetteville.

Reed, J. T., and J. Reinecke. 1990. Western flower thrips on cotton: plant damage and mite predation - preliminary observations, pp. 309–310. *In* J. M. Brown and D. A. Richter(eds.), Proceedings 1990 Beltwide Cotton Conferences, Natil Cot Counc, Memphis, TN.

Reed, J. T., E. Burris, C. Allen, R. Bagwell, D. Cook, B. Freeman, G. Herzog, G. Lentz, R. Leonard. 2001. Thrips (Thysanoptera: Thripidae) A Multi-State Survey: Mississippi. *Mississippi State University Extension Service*. Vol.22 No.15.

Roberts, B. A., and E. A. Rechel. 1996. Effects of early season thrips feeding on root development, leaf area, and yield, pp. 939–941. *In* P. Dugger and D. A. Richter (eds.), Proceedings 1996 Beltwide Cotton Conferences, National Cotton Council, Memphis, TN.

Roberts, P. M., M. Toews, and B. Kemerait. 2009. Impact of early season thrips control on root development and nematode management, p. 1140. *In* S. Boyd, M. Huffman, D. Richter, and B. Robertson (eds.), Proceedings 2009 Beltwide Cotton Conferences. National Cotton Council, Memphis, TN.

Robinson, A. F., A. A Bell, P. Augudelo, C. A. Avila, J. M. Stewart, F. E. Callahan, R. W. Hayes, J. N. Jenkins, J. C. Mccarty, M. J. Wubben, C. G. Cook, N. D. Dighe, M. A. Menz, C. W. Smith, D. M. Stelly, O. A.Gutierrez, T. P. Wallace, J. T. Johnson, R. Kantety, G. W. Lawrence, K. S. Lawrence, L. Mangineni, D. B. Weaver, W. A. Meredith, E. Sacks, B. Scheffler, S. R. Stetina, L.D Young, R. L.Nichols, R. T. Robbins, G. L. Sciumbato, P. M. Thaxton, and J.L Starr. 2008. Development of reniform nematode resistance in Upland cotton. In: Proceedings of the World Cotton Research Conference-4, September 10-14, 2007, Lubbock, Texas.

Sadras, V. O., and L.J. Wilson. 1998. Recovery of cotton crops after early season damage by thrips (Thysanoptera). Crop Sci. 38: 399–409.

Sadras, V. O. 1995. Compensatory growth in cotton after loss of reproductive organs. Field Crops Res. 40:1–18.

Starr, J. L., S. R. Koenning , T. L. Kirkpatrick, A. F. Robinson, P. A. Roberts, R. L. Nichols. 2007. The future of nematode management in cotton. J. Nematol.. 39:283–294

Stewart, S., S. D. Akin, J. Reed, J. Bacheler, A. Catchot, D. Cook, J. Gore, J. Greene, A. Herbert, R. Jackson, D. Kerns, B. R. Leonard, G. Lorenz, S. Micinski, D Reisig, P. Roberts, G. Stude Baker, K. Tindall, and M. Toews. 2013. Survey of Thrips Species Infesting Cotton across the Southern U.S. Cotton Belt. J. Cot. Sci. 17(2): 1-7.

Telford, A. D., and L. Hopkins. 1957. Arizona cotton insects. Arizona Agricultural Experiment Station Bulletin 286. University of Arizona, Tucson, AZ.

Thomas, S. H. 1978. Populations densities of nematodes under seven tillage regimes. J. Nematol. 10:24-27.

Toews, M. D., R. S. Tubbs, D.Q . Wann, and D. Sullivan. 2010. Thrips (Thysanoptera:Thripidae) mitigation in seedling cotton using strip tillage and winter cover crops. Pest Mgmt. Sci. 66: 1089–1095.

Tyler, D. D., J. R. Overton, and A. Y. Chambers. 1983. Tillage effects on soil properties, diseases, cyst nematodes, and soybean yields. Journal of Soil and Water Conservation 38:374-376.

Watts, J. G. 1937. Reduction of cotton yield by thrips. J. of Econ. Ent. 6: 860–863.

Wilson, L. J., V. O. Sadras, S. C. Heimoana, and D. Gibb. 2003. How to succeed by doing nothing: Cotton compensation after simulated early season pest damage. Crop Sci. 43:2125–2134.

CHAPTER II

EVALUATION OF SEED TREATMENT, HERBICIDE, AND NEMATICIDE ON TOBACCO THRIPS (THYSANNOPTERA: THRIPIDAE)) AND RENIFORM NEMATODE (TYLENCHIDA: ROTYLENCHULIDAE) CONTROL

2.1 Abstract

There are numerous pests that infest cotton early in the season. Some of the most economically important are Palmer amaranth, *Amaranthus palmeri* (S. Wats); tobacco thrips *Frankliniella fusca*;(Hinds) and reniform nematode, *Rotylenchulus reniformis* (Linford and Oliveira). Thrips and weed management are essential to prevent delayed maturity and reduced crop yield. A field study was conducted during 2015 and 2016 to evaluate the influence of insecticide seed treatment, herbicide, and nematicide on tobacco thrips and reniform nematode control as well as impact on cotton growth, development and yield. Treatments consisted of insecticide seed treatment (insecticide seed treatment and an untreated control); herbicide application (*S*-metolachlor, glufosinate, *S*-metolachlor plus glufosinate, and no herbicide); and nematicide application (1, 3-dichloropropene and no nematicide). There were no significant interactions between seed treatment, herbicide, and nematicide for any parameter. Nor were there any interactions in respect to nematode densities, thrips densities, thrips injury, herbicide injury, or biomass. Nematode densities were reduced with the use of 1,3-dichloropropene when sampled at first square and post-harvest. Thrips densities and damage were reduced at

the 1-2 leaf stage sample timing with an insecticide seed treatment, but not at the 3-4 leaf stage sample timing. Herbicide injury was the greatest following *S*-metolachlor plus glufosinate applications (<12%). A significant interaction between nematicide and seed treatment was observed for cotton yield, where the use of 1,3-dichloropropene and the insecticide seed treatment resulted in greater yields than all other treatments.

2.2 Introduction

Cotton, *Gossypium hirsutum* L., producers face a number of early season pests that may impact crop growth and limit yields. These potentially compounding stress factors include tobacco thrips, *Frankliniella fusca* (Hinds), glyphosate-resistant weeds, and reniform nematode, *Rotylenchulus reniformis* (Linford and Oliveira). As the prevalence of glyphosate-resistant (GR) weeds, predominantly Palmer amaranth, *Amaranthus palmeri* (S. Wats.), increases across the midsouthern region of the United States (Arkansas, Mississippi, Louisiana, Tennessee, and Missouri) there is an increased need for preemergent herbicides and early-postemergence herbicide applications during the thrips management window to minimize weed competition (Steckel et al. 2012, Norsworthy et al. 2016). Many of these herbicides have the potential to cause cotton injury and slow seedling development which may intensify injury associated with other early season stresses including thrips and nematodes (Steckel et al. 2012, Stewart et al. 2013). One of the main tools used in controlling GR Palmer amaranth has been glufosinate; however, co-applications with residual herbicides are often needed to provide effective control (Steckel et al. 1997). Coapplication of glufosinate and *S*-metolachlor has not been observed to increase crop injury on glufosinate-resistant cotton varieties, and has provided effective weed control (Culpepper et al. 2007, 2009; Whitaker et al. 2008, Everman et al. 2009). However, one to two glufosinate applications to Widestrike® (Dow AgroSciences, Indianapolis, IN) cotton varieties can result in 15 to 25% crop injury with no yield reduction (Culpepper et al. 2009, Barnett et al. 2011, Dodds et al. 2011, Whitaker et al. 2011). Widestrike cotton varieties have conferred tolerance to glufosinate like that of LibertyLink varieties; however, this tolerance is incomplete (OECD 2002, Tan et al. 2006). Many cotton producers utilize combinations of glufosinate and residual herbicides despite the injury potential within their weed control programs to better manage troublesome weeds.

Tobacco thrips is one of the primary pests of seedling cotton annually throughout the Midsouthern United States with estimated yield losses between 10 to 304 kg ha^{-1} (Layton and Reed 1996, Reed and Jackson 2002, Cook et al. 2003, Stewart et al. 2013, North 2016). Thrips feeding on developing leaves and meristematic tissue of cotton seedlings can result in leaf malformation, poor growth and vigor, and/or loss of apical dominance (Watts 1937, Cook et al. 2011, Stewart et al. 2013). Seed treatments or at-planting in-furrow insecticide treatments are used to prevent thrips injury and reduced the associated yield losses (Stewart et al. 2013).

While limited information is known about the interactions of nematodes in a system stressed from thrips and herbicide injury, the reniform nematode results in restricted root development limiting the plant’s ability to effectively uptake water and nutrients (Koenning et al. 2004). The common above-ground symptomology in reniform nematode infested fields includes stunted growth, interveinal chlorosis, and non-uniform plant stand (Lawrence and McLean 2001, Monfort 2005). Outside of crop rotation, nematicides, including soil fumigants, seed treatments or in-furrow at-planting insecticides, are the most common control options for nematode management (Westphal and Smart 2003, Robinson et al. 2008). The reniform nematode is considered to be a stress pathogen, as stress increases from other sources so does the associated yield losses from reniform nematode. The average estimated yield losses as a result of the reniform nematode are generally between 7 and 8% (Birchfield and Jones 1961, Davis et al. 2003, Blasingame et al. 2006, 2009).

Early season stress factors including tobacco thrips, reniform nematode, and herbicide injury all have the potential to cause chlorosis, reduced plant growth and vigor, delayed plant maturity, or reduced crop yield (Davidson et al. 1979, Gasaway and Edisten 1993, Leonard et al. 1999, Monfort 2005). Little is known about the impacts of multiple stresses, such as tobacco thrips, reniform nematode, and herbicide injury on cotton development and yield versus the individual stresses. To better understand the compounding stress of multiple early season factors, studies were conducted to evaluate the influence of seed treatment, herbicide application, and nematicide use on early season pest management, as well as, cotton growth ,development, and yield.

2.3 Materials and Methods

A field experiment was conducted at the R.R. Foil Plant Science Research Center in Starkville, MS in 2015 and 2016, with two additional locations in 2016 in Hamilton, MS to evaluate the influence of herbicide injury on tobacco thrips and reniform nematode stressed verses non-stressed cotton. The experiment was implemented as a randomized complete block design with a split-split plot arrangement of treatments with four replications.

Whole-plot treatment consisted of two levels of a nematicide: 1, 3-dichloropropene (Telone II, Dow AgroSciences, Indianapolis, IN) at 28 L ha^{-1} using a four-row coulter injection system and no nematicide. Sub-plot factor A consisted of four levels of herbicide treatment: glufosinate (Liberty 280L, Bayer CropScience, Research Triangle Park, NC) at 595 g ai ha^{-1}, *S*-metolachlor (Dual Magnum, Syngenta Crop Protection, Greensboro, NC) at 1068 g ai ha^{-1}, glufosinate at 595 g ai ha^{-1} plus *S*-metolachlor at 1068 g ai ha^{-1}, and an untreated control. Sub-plot factor B consisted of two levels of at-planting insecticide in the form of a seed treatment: imidacloprid (Gaucho 600, Bayer CropSciences) at 0.375 mg ai $seed^{-1}$ and an untreated control. All seed were treated with a fungicide (ipconazole at 0.01 mg ai seed $^{-}$1 + metalaxyl at 0.002 mg ai seed $^{-1}$ + myclobutanil 0.06 mg ai seed $^{-1}$ + penflufen at 0.02 mg ai seed $^{-1}$) to minimize the effects of seedling disease. Individual plots consisted of four 3.7-m rows measuring 12.2-m (Starkville, MS location) or 15.2m (Hamilton, MS location) in length. On 01 May 2015, 12 Apr 2016 and 22 Apr 2016, 1, 3- dichloropropene was applied to the designated plots using a four-row injection coulter system. Phytogen 499 (Dow AgroSciences, Indianapolis, IN) cotton was planted at a depth of approximately 2-cm at a population of 135,850 seed ha^{-1} on 12 May 2015 and Phytogen 333 (Dow AgroSciences, Indianapolis, IN) on 09 May 2016, and 10 May 2016. Herbicide applications were made to cotton between the 2- and 3-leaf stage using a tractor mounted sprayer calibrated to deliver 93.5 L ha^{-1} using TX-6 hollow cone nozzle at 276 kPa.

Nematode samples were collected prior to the nematicide application, at first square, and post-harvest. Nematode populations were determined by collecting ten, 20-cm deep soil cores from individual plots using a 2.5 cm diameter soil sampling probe.

Cores were combined, and a sub-sample of 300 cm^3 was processed by the Mississippi State University Extension Plant Diagnostic Laboratory in Starkville, MS using a semi-automatic elutriator and sucrose extraction (Byrd et al. 1976, Jenkins 1964).

Thrips damage ratings and thrips densities were evaluated at the 1-2 and 3-4 leaf stage of cotton growth. Damage ratings were recorded on a scale of 0 (no injury) to 5 (severe injury). Thrips densities were estimated by randomly cutting five plants from each plot at ground level and placing them into a 0.47-L glass jar with a 50% ethanol solution. Plants were rinsed with a 50% ethanol solution and the remaining solution was poured through a Buchner funnel. Thrips adults and nymphs were collected on filter paper and that paper was placed into a Petri dish for counting under a microscope. Adult thrips darker in color were considered to be tobacco thrips based on the observations of Stewart et.al (2013) where 98% of thrips species in Mississippi were determined to be tobacco thrips. Immature thrips were not identified to species and pooled.

Plant vigor was assessed at 1-2 and 3-4 leaf stages on a scale of 1 (poor stand) to 10 (excellent, uniform stand). Herbicide injury was evaluated 7 days after application (DAA) using a scale of 0 (no injury) to 100 (death) based on visual estimates comparing the treated to the non-treated control. Total above- and below-ground biomass samples were evaluated by uprooting five random plants from the outer two rows at the 4-leaf stage. Above- and below-ground portions of the five uprooted plants were placed into paper bags and dried in a forced air dryer for 48 hours at 38°C. After drying, samples were weighted to determine dry biomass. Cotton yield was determined by harvesting the center two rows of each plot with a modified spindle-type cotton picker for small plot research.

Data were analyzed using analysis of variance (PROC GLIMMIX, SAS 9.4; SAS Institute; Cary, NC). Year and replication were considered to be random effects, and herbicide, seed treatment and nematicide were considered to be fixed effects. Means were separated using Fisher's Protected LSD procedure at the 0.05 level of significance.

2.4 Results

Reniform nematode control. Prior to any treatment implementation, the number of nematodes ranged from 675 to 1300 per 500 cm^3 of soil. There were no significant interactions (F>0.52; df= 3,224; *P*= 0.31) among any factors, nor were there any significant main effects of herbicide (F>0.91; df= 3, 224; *P*>0.23) or seed treatment (F>1.55; df= 1, 225; *P*>0.20) at first square or post-harvest. However, significantly fewer nematodes per pint of soil were observed following application of 1, 3-dichloropropene treatments at first square (F= 25.40; df= 1, 224; *P*<0.01) and post-harvest (F= 1.55; df= 1, 225; *P*=0.03) (Table 2.1).

Tobacco thrips densities and damage. There were no significant interactions among factors with respect to tobacco thrips populations (F>0.35; df=3,225; *P*>0.47) or damage (F>1.00; df=3,224; *P*= 0.39), nor were there any significant main effect treatments of herbicide (F=0.26; df= 3, 225; *P*=0.82), seed treatment (F>2.03; df= 1, 224; *P*=0.13), or nematicide (F>0.26; df= 1, 225; *P*=0.60) on immature thrips at the 1-2 or 3-4 leaf stage. Herbicide (F>0.70; df= 1, 225; *P*=0.50) and nematicide application (F>0.09; df= 1, 225; *P*>0.06) had no impact on thrips damage at either sample date. Use of insecticide seed treatments reduced the amount of thrips damage at the 1-2 and 3-4 leaf stage (F>3.72; df= 1, 224; *P*>0.01) (Table 2.2).

Cotton injury. No significant interactions were observed among factors for herbicide injury (F>2.39; df= 3,225; *P*>0.07), nor was there a significant difference for nematicide (F>0.05; df= 1,225; *P*= 0.82); however, there were significant main effects of herbicide (F=17.25; df= 3, 225; *P*<0.01) and insecticide seed treatment (F=6.51; df= 1, 225; *P*= 0.01). Applications of *S*-metolachlor plus glufosinate resulted in more injury than other herbicide treatments. Also, glufosinate alone resulted in more injury than *S*-metolachlor (Table 2.3). Additionally, plants in plots that received an insecticide seed treatment had significantly less herbicide injury compared to those in plots that did not receive an insecticide seed treatment (Table 2.3).

Effect on plant vigor, biomass, and cotton yield. No significant interactions were observed between nematicide, insecticide seed treatment, and/or herbicide for plant vigor (F>0.41; df= 3, 223; *P*>0.74), biomass (F>0.36; df= 3, 224; *P*>0.78), or yield (F>0.81; df= 3, 220; *P*>0.49). At the 1-2 leaf stage the use of an insecticide seed treatment resulted in greater plant vigor compared to the untreated control (F=9.24; df= 1, 223; *P*<0.01). However, no differences were observed at the 3-4 leaf stage (F=1.11; df= 1, 225; *P*=0.29) (Table 2.2). There was no impact of herbicide treatment (F>1.44; df= 3, 224; P>22), seed treatment (F> 1.73; df= 1, 224; *P*> 0.18), or nematicide treatment (F> 3.15; df= 1, 224; *P*> 0.07) on above- or below-ground biomass at the 4- leaf stage. No significant differences among herbicide treatment were observed in cotton yield (F=0.10; df= 3, 227; *P*=0.96). However, there was a significant interaction between nematicide treatment and insecticide seed treatment for yield where applications of 1, 3-dichlorpropene along with an insecticide seed treatment resulted in higher yields compared to all other treatment combinations (F=3.98; df= 1, 227; *P*=0.05) (Table 2.4).

2.5 Discussion

Nematodes have the potential to interact with both soilborne diseases and early season insect pests such as thrips, to reduce cotton yield (Burris et al. 2010). Seed treatments containing a nematicide are the most widely used treatment for nematode control; however, such practices generally require a supplemental foliar thrips application (Burris et al. 2010). In this study, applications of 1, 3-dichloropropene reduced nematode densities; however, this product is expensive and requires special application equipment. Substantial yield increases are necessary for this practice to be cost effective.

While thrips damage was only reduced with the use of an insecticide seed treatment at the 1-2 leaf stage, thrips management did not impact yield. Historically, yield responses to thrips management have been variable and depend on the severity of infestation and the environmental conditions during the remainder of the growing season. Numerous studies have shown yield increases when thrips were effectively controlled in seedling cotton (Watts 1937, Davis et al. 1966, Burris et al. 1989, Carter et al. 1989, Lentz and Van Tol 2000). Prior to documented resistance, thiamethoxam and imidacloprid have been shown to increase cotton yield 15 to 20% compared to untreated cotton (Reed and Jackson 2000).

With the continued spread of glyphosate resistant Palmer amaranth across the cotton belt, early season applications of glufosinate and residual herbicides are becoming more common. Herbicide injury in this study was minor and did not impact cotton yield. Barnett et al. (2011) found that Wikestrike cotton varieties can withstand 15 to 25% glufosinate injury from one to two applications with no maturity delay or yield losses. However, delayed maturity and yield losses have resulted from co-applications of herbicide and insecticide applications to Widestike cotton already damaged by thrips (Stewart et al. 2013). Depending on environmental conditions, the impact of early season co-applications is likely to be variable. Although herbicide injury was minor, herbicide injury was lower when an insecticide seed treatment was used.

Cotton yield was greater following the use of an insecticide seed treatment and 1, 3-dichloropropene. These results suggest that compounding stress factors have the potential to limit yield compared to individual stress alone. However, the yield increase may not be enough to justify the cost of a soil fumigant for reniform nematode control.

While injury from herbicide applications and thrips injury alone did not seem to be limiting factors, both have the potential to delay crop maturity and/or reduce yield. Thrips are an annual pest in Mississippi cotton production systems and with the spread of herbicide resistant Palmer amaranth, reducing early season stress from these factors may be beneficial later in the season. Delayed crop maturity early season resulting from damage may expose the crop to late season pest for a long period of time potentially increasing management costs. Also, there is increased potential for exposure to adverse environmental conditions that may reduce lint quality and yield (Barker et al 1976; Williford et al 1995; Stewart et al. 2013) (A.1.1; A.1.2). The use of at-planting insecticide and preemergence herbicide can reduce the need for co-applications of herbicide and insecticides to cotton seedlings, thus reducing the potential for crop injury. Phototoxicity as a result of early season postemergence herbicide applications seems to be decreased when stress from pests such as, thrips and/or nematodes were reduced, suggesting the importance of reducing early-stress plant stresses were applicable.

Additional, research is needed to better understand the relationship between early season herbicide applications on cotton damaged by thrips.

2.1 Impact of nematicide application on nematode populations in cotton at first square and post-harvest in Starkville, MS and Hamilton, MS during 2015 and 2016.

Treatment	Density per 500 cm^3 [a]	
	1st Square (±SE)	Post Harvest (±SE)
No 1,3-dichloropropene	1,072a (129.7)	3,581a (384.6)
1,3-dichloropropene	409b (52.9)	2,488b (347.4)
P-Value	0.0012	0.0290

[a]Means within the column that are followed by the same letter are not different according to Fisher's Protected LSD with an alpha of 0.05.

2.2 Impact of insecticide seed treatment on thrips damage and plant vigor at the 1-2 leaf stage in Starkville, MS and Hamilton, MS during 2015 and 2016.

Treatment	1-2 Leaf[a]	
	Damage (±SE)[b]	Vigor (±SE)[c]
Insecticide Seed Treatment	3.1b (0.04)	6.6a (0.11)
Untreated Control	3.3a (0.04)	6.3b (0.11)
P-Value	0.0148	0.0026

[a]Means within the column that are followed by the same letter are not different according to Fisher's Protected LSD with an alpha of 0.05. [b]Damage ratings are based on a 0 (no injury) to 5 (plant death) scale. [c]Plant vigor ratings are based on a 1 (poor, uniform stand) to 10 (excellent, uniform stand) scale.

2.3 Impacts of herbicide application on cotton seven days after application in Starkville, MS and Hamilton, MS during 2015 and 2016.

Treatment	Herbicide Injury 7 DAA (±SE)[ab]
Insecticide Seed Treatment	4.4b (0.74)
Untreated Seed	7.1a (0.79)
P-Value	0.0114
S-metolachlor	2.1c (0.4)
Glufosinate	6.9b (1.1)
S-metolachlor plus glufosinate	11.26a (1.5)
P-Value	0.0001

[a]Means within the column that are followed by the same letter are not different according to Fisher's Protected LSD with an alpha of 0.05. [b]Damage ratings of visual herbicide injury estimate on scale 0 (no injury) to 100 (plant death).

2.4 Interaction between nematicide application and at-planting insecticide treatment on cotton yields in Starkville, MS and Hamilton, MS during 2015 and 2016.

Treatment		Lint [ab] kg ha (±SE)
No 1,3-dichloropropene	Untreated Seed	931b (31.1)
	Insecticide Seed Treatment	928b (39.87)
1,3-dichloropropene	Untreated Seed	936b (34.5)
	Insecticide Seed Treatment	1,012a (39.9)
P-Value		0.0473

[a]Means within the column that are followed by the same letter are not different according to Fisher's Protected LSD with an alpha of 0.05. [b]Cotton yield was taken from the center two rows of each plot.

References

Anonymous. Dual Magnum herbicide label. Available at http://www.cdms.net. Assessed on 15 Oct 2017.

Anonymous. Gaucho 600 insecticide label. Available at http://www.cdms.net. Assessed on 15 Oct 2017.

Anonymous. Liberty 280SL herbicide label. Available at http://www.aglogicchemical.com/ Assessed on 15 Oct 2017.

Anonymous. Telone II soil fumigant label. Available at http://www.cdms.net. Assessed on 15 Oct 2017.

Baker, G. L, R. W. McClendon, J. W. Jones, and R. F. Colwick. 1976. Effects of field weathering [rainfall, relative humidity, and temperature on cotton fiber quality [Mississippi|. P. 122-123. *In* Proc. Beltwide Cotton Prod. Res. Conf. Las Vegas, NV. 5-7 Jan. Natl. Cotton Counc. Am., Memphis, TN.

Barnett, K. A., L. E. Steckel, A. C. York, and A. S. Culpepper. 2011. Influence of glufosinate timing on cotton growth and yield. p. 1562. *In* Proc. Beltwide Cotton Conf., Atlanta, GA. 4-7 Jan. 2011. Natl. Cotton Counc. Am., Memphis, TN.

Birchfield, W., and J. E. Jones. 1961. Distribution of the reniform nematode in relation to crop failure of cotton in Louisiana. Plant Dis45:671-673.

Blasingame, D., M.V. Patel, W. Gazaway, M. Olsen, T. Kirkpatrick, M. Davis, R.K. Sprenkel, B. Kemerait, P. Colyer, A. Wrather, N. Goldberg, S. Koenning, J. C. Banks, J. Muller, M. Newman, J. Woodward, and P. Phipps. 2006. Cotton disease loss estimate committee report. Proceedings of the Beltwide Cotton Conferences of the Natl. Cott Counc. of Am. http://www.cotton.org/beltwide/proceedings/ 2007.

Blasingame, D., Gazaway, W., Lawrence, K. S., Wrather, A., Olsen, M., Kirkpatrick, T., Koenning, S. R., Goldberg, N., Banks, J. C., Sprenkel, R., Muller, J., Davis, M., Kemerait, R .C., Newman, M. A., Colyer, P. D., Woodward, J. E., Sciumbato, G. L., and Phipps, P. M. 2009. Cotton disease loss estimate committee report. Proceedings of the Beltwide Cotton Conferences of the Natl. Cotton Counc. of Am 1:94–96.

Bourland, F. M., D. M. Oosterhuis, N. P. Tugwell. 1992. Concept for monitoring the growth and development of cotton plants using main- stem node counts. J. Prod. Agric.5: 532- 538.

Burris, E., D. Burns, K. S. McCarter, C. Overstreet, M. Wolcott, and E. Clawson. 2010. Evaluation of the effects of Telone II (fumigation) on nitrogen management and yield in Louisiana delta cotton. Prec. Agric. 11:239-257.

Burris, E., K. J. Ratchford, A. M. Ratchford, D. J Pavloff, B. R. Williams, and R. L. Rogers. 1989. Thrips on seedling cotton: related problems and control. Louisiana Agric. Experiment Sta. Bull. 811. LSU AgCenter, Baton Rouge, LA.

Byrd, D. W., Jr., K. R. Barker, H. Ferris, C. J, Nusbaum, W. E. Griffin, R. H. Small, and C. A. Stone. 1976. Two Semi-automatic elutriatiors for extracting nematodes and certain fungi from soil. J. Nematol. 8:206-212.

Carter, F. L., N .P. Tugwell, and J. R. Phillips. 1989. Thrips control strategy: effects on crop growth, yield, maturity, and quality, p.295-297. *In* Proc. Beltwide Cotton Prod. Res.Conf. Nashville, TN. 2-7 Jan. 1989. Natl. Cotton Counc. Am. Memphis, TN.

Cook, D. R., C. T. Allen, E. Burris, B. L. Freeman, G. A. Herzog, G. L. Lentz, B. R. Leonard, and J. T. Reed. 2003. A survey of thrips (Thysanoptera) species infesting cotton seedlings in Alabama, Arkansas, Georgia, Louisiana, Mississippi, and Tennessee. J. Econ. Entomol. Sci. 38: 669-681.

Cook, D., A. Herbert, D. S. Akin, and J. Reed. 2011. Biology, Crop Injury, and Management of Thrips (Thysanoptera: Thripidae) Infesting Cotton Seedling in the United States. J. Integ. Pest. Mgmt. 2:2011.

Culpepper, A. S., A. C. York, P. Roberts, and J. R. Whitaker. 2009. Weed control and crop response to glufosinate applied to 'PHY 485 WRF' cotton. Weed Technol. 23:356–362.

Culpepper, A. S., A. C. York, A. W. MacRae, J. Kichler, J.Whitaker, and A. L. Davis. 2007. Managing glyphosate resistant Palmer amaranth in conventional and strip till Roundup Ready cotton. p. 1230–1231. *In* Proc. Beltwide Cotton Conf., New Orleans, LA. 9-12 Jan. 2007. Natl. Cotton Counc. Am., Memphis, TN.

Davis, R. F., S. R. Koenning, R. C. Kemerait, T. D. Cummings, and W. D. Shurley. 2003. *Rotylenchulus reniformis* management in cotton with crop rotation. J. Nematol. 35:58-64.

Davis, J. W., W. C. Watkins, Jr., C. B. Cowan, Jr., R. L. Ridgeway, and D. A. Lindquist. 1966. Control of several cotton pests with systemic insecticides. J. Econ. Entomol. 159-162.

Davidson, R. H., L. M. Peairs, and W. F. Lyon. 1979. Insect pests of farm, garden, and orchard, 7th ed. Wiley, New York.

Dodds, D. M., L. T. Barber, N. W. Buehring, G. D. Collins, and C. L. Main. 2011. Tolerance of WideStrike cotton to glufosinate. p. 1542. *In* Proc. Beltwide Cotton Conf., Atlanta, GA. 4-7 Jan. 2011. Natl. Cotton Counc. Am., Memphis, TN.

Everman, W. J., S. B. Clewis, A. C. York, and J. W. Wilcut.2009. Weed control and yield with flumioxazin, fomesafen, and s-metolachlor systems for glufosinate resistant cotton residual weed management. Weed Technol.23:391–397.

Gazaway, W., D. Rush, and K. Edmisten. 1992. An evaluation of various Temik and Telone rates for controlling reniform nematodes in cotton. Fungicide and Nematicide Test 47:161.

Jenkins W. R. 1964. A rapid centrifugal-flotation technique for separating nematodes from soil. Plant Dis. Rep. 48:692.

Koenning, S., T. Kirkpatrick, J. Starr, J. Wrather, N. Walker, and J. Mueller. 2004. Plant parasitic nematodes attacking cotton in the United States: old and emerging production challenges. Plant Dis 88:100-113.

Lawrence, G. W., and K. S. McLean. 2001. Reniform nematodes. *In* compendium of cotton Diseases, Second Edition. T. L. Kirkpatrick and C. S. Rothrock (eds.), APS Press pp. 42-43.

Layton, B. and J. T. Reed. 1996. Biology and control of thrips on seedling cotton. Mississippi State Extension Publication 2302.

Leonard, B. R., J. B. Graves, and P. C. Ellsworth. 1999. Insect and mite pests of cotton.p. 489 551. In C. W. Smith and J. T. Cothren (eds.) Cotton: Origin, History, Technology and Production. John Wiley and Sons, Inc., New York, NY.

Lentz, G. L. and N. B. Van Tol. 2000. Early season insect control: Adage vs recommended standards. P 1113-1115. *In* Proc. Beltwide Cotton Conf. San Antonio, TX. 4-8 Jan. 2000. Natl Cotton Counc. Am., Memphis, TN.

North, J. H. 2016. Impact of neonicotinoids in mid-south row crop systems. Master of Science in Agriculture Life Science, Mississippi State University

Norsworthy, J. K., L. M. Schwartz, L. T. Barber. 2016. The incidence and ramifications of glyphosate resistance in cotton. Outlooks on Pest Mmgt.

Monfort, W. 2005. Potential for remote identification of within-field problem zones associated with *Meloidogyne incognita* and *Thielaviopsis basicola* for site specific control in cotton. Doc. Dissertation. University of Arkansas Fayetteville.

Organisation for Economic Co-operation and Development [OECD]. 2002. Module II: Herbicide biochemistry, herbicide metabolism and the residues in glufosinateammonium (phosphinothricin)-tolerant transgenic plants [Online]. Ser. Harmonization of Regulatory Oversight in Biotechnology 25. Available at http://www.oecd.org/ officialdocuments/displaydocumentpdf/?cote=env/jm/ mono(2002)14&doclanguage=en (verified 3 July 2013).

Reed, J. T., and C. S. Jackson. 2002. Thrips on Mississippi Seedling Cotton: Pest overview and 15-Year Summary of Pesticide Evaluation. Mississippi State University Extension Service. Bulletin 1124.

Robinson, A. F., A. A Bell, P. Augudelo, C. A. Avila, J. M. Stewart, F. E. Callahan, R. W. Hayes, J. N. Jenkins, J. C. Mccarty, M. J. Wubben, C. G. Cook, N. D. Dighe, M. A. Menz, C. W. Smith, D. M. Stelly, O. A.Gutierrez, T. P. Wallace, J. T. Johnson, R. Kantety, G. W. Lawrence, K. S. Lawrence, L. Mangineni, D. B. Weaver, W. A. Meredith, E. Sacks, B. Scheffler, S. R. Stetina, L. D Young, R. L.Nichols, R. T. Robbins, G. L. Sciumbato, P.M . Thaxton, and J .L Starr. 2008. Development of reniform nematode resistance in Upland cotton. In: Proceedings of the World Cotton Research Conference-4, September 10-14, 2007, Lubbock, Texas.

Steckel, L. E., D. Stephenson, J. Bond, S. D. Stewart, and K. A. Barnett. 2012. Evaluation of WideStrike Flex Cotton Response to Over-the-Top Glufosinate Tank Mixtures. J. Cot. Sci. 16:88-95.

Steckel, G J., L. M. Wax, F. W. Simmons, and W. H. Phillips II.1997. Glufosinate efficacy on annual weeds is influenced by rate and growth stage. Weed Technol. 11:484–488.

Stewart, S., S. D. Akin, J. Reed, J. Bacheler, A. Catchot, D. Cook, J. Gore, J. Greene, A. Herbert, R. Jackson, D. Kerns, B. R. Leonard, G. Lorenz, S. Micinski, D. Reisig, P. Roberts, G. Studebaker, K. Tindall, and M. Toews. 2013. Survey of Thrips Species Infesting Cotton across the Southern U.S. Cotton Belt. J. Cot. Sci. 17(2): 1-7.

Stewart, S. D., L. E. Steckel, and S. Steckel. 2013. Evaluation of WideStrike Cottom (*Gossypium hirsutum* L.) Injury from Early Season Herbicide and Insecticide Tank Mixes. J. Cot. Sci. 17:219-226

Tan, S., R. Evans, and B. Singh. 2006. Herbicidal inhibitors of amino acid biosynthesis and herbicide-tolerant crops. Amino Acids 30:195–204.

Watts, J. G. 1937. Reduction of cotton yields by thrips. J. Econ. Entomol. 30:860–862.

Westphal, A. and J. Smart. 2003. Depth distribution of *Rotylenchulus reniformis* under different tillage and crop sequence systems. Phytopathology 93:1182-1189

Whitaker, J. R., A. C. York, and A. S. Culpepper. 2008. Management systems for glyphosate resistant Palmer amaranth. p. 693. *In* Proc. Beltwide Cotton Conf., Nashville, TN. 8-11 Jan. 2008. Natl. Cotton Counc. Am., Memphis, TN.

Williford, J. R., F. T. Cooke, Jr, D. F. Caillouet, and S. Anothony. 1995. Effect of harvest timing on cotton yiled and quality. p. 633-638. *In* Proc. Beltwide Cotton Conf., San Antonio, TX. 4-7 Jan. 1995. Natl. Cotton Counc. Am., Memphis, TN.

Williams, M. R. 2016. Cotton Insect Losses 2016. Available at http://www.entomology.msstate.edu/resources/croplosses/pdf/2016/table17.pdf

CHAPTER III

EVALUATION OF ALTERNATIVES TO NEONICOTINOID SEED TREATMENTS FOR THRIPS (THYSANOPTERA: THRIPIDAE*)* MANAGEMENT IN COTTON

3.1 Abstract

Tobacco thrips, *Frankliniella fusca* (Hinds), is a consistent and predictable pest of cotton production systems in the United States. Damage from these pests can delay maturity and reduce crop yields. On average, insecticide seed treatments have resulted in increases of 128 kg ha^{-1}. Thiamethoxam and imidacloprid were two of the mostly widely used insecticide seed treatments for thrips management. With the decline in efficacy of thiamethoxam, it is vital to identify alternative control measures for effective tobacco thrips control. Therefore, the objective of this study was to evaluate foliar insecticide applications at various timings as alternative management strategies for thrips. Studies were conducted during 2015 and 2016, in Arkansas, Mississippi, Louisiana, and Tennessee using a randomized complete block design with four replications. Treatments included foliar applications of acephate at the following intervals: cotyledon, cotyledon plus two weeks post emergence, cotyledon plus two and three weeks post emergence, and only week two and week three post emergence. All treatments were compared to an untreated check and an imidacloprid seed treatment. There were no differences in cotton yield among any treatments, but early management decisions decreased the overall amount of thrips damage sustained.

3.2 Introduction

Tobacco thrips, *Frankliniella fusca* (Hinds), is an annual pest of seedling cotton in the midsouthern region of the United States. Unlike other row crops, cotton is more susceptible to injury caused by thrips due to its slow development during the seedling stage (Layton and Reed 2002). Thrips feed on the fluids of the epidermal tissue causing the penetration of air into damaged cells resulting in a silvery appearance of the leaves (Layton and Reed 2002, Cook et al. 2011). Damage becomes more apparent as leaves continue to develop and leaf area increases causing tearing and malformation (Layton and Reed 2002). Feeding damage may result in reduced size of the first few true leaves, crinkled leaves, stunted growth, loss of apical dominance, delayed fruiting, reduced plant stand, delayed crop maturity, and reduced yields (Davidson et al. 1979, Reed et al. 2001, Layton and Reed 2002). In instances where crop maturity is delayed, the susceptibility of cotton to other insect pests throughout the growing season is prolonged and may lead to increased input costs (Stewart et al. 2013). Studies have reported that large infestations of thrips can delay crop maturity more than two weeks (Gaines 1934, Dunham and Clark 1937, Bourland et al. 1992, Parker et al. 1992). In addition to insect susceptibility, the crop may be exposed to adverse environmental conditions including late-season cool temperatures or increased rainfall (Morris 1963, Gipson and Joham 1968). Studies have reported increased cotton yield when the early season impacts of thrips have been minimized (Davis et al. 1966, Herbert 1998, Cook et al. 2011). Yield losses as a result of thrips has previously been estimated to range from 10 to 304 kg ha^{-1} in Mississippi (Layton and Reed 2002). During 2016, yield losses of approximately 16,129 bales due to thrips damage were reported in Mississippi. (Williams 2016).

Generally, thrips and other insect pests of cotton seedlings have been managed through the use of at-planting insecticide treatments applied to the seed or in-furrow as liquid sprays or granular applications (Cook et al. 2011). On average, the at-planting insecticides provide acceptable thrips control for two to four weeks after planting (Cook et al. 2011). Across the Cotton Belt, seed treatments (thiamethoxam or imidacloprid) have been widely adopted by growers and have been reported to provide effective control of tobacco thrips (Greene et al. 2002, Stewart et al. 2013). Both thiamethoxam and imidacloprid are neonicotinoid insecticides that act on the nervous system of a broad spectrum of insects by blocking the postsynaptic nicotinic acetylcholine receptor, resulting in overstimulation of nerves leading to paralysis and death (Wollweber and Tietjen 1999, Zhang et al. 2000, Nauen et al. 2001). Other preventative at-planting insecticide treatments include aldicarb and acephate. However, the extensive use on neonicotinoid seed treatments in cotton and other crops has resulted in a recent decrease in their efficacy (Catchot et al. 2013). Previous research has demonstrated a reduction in the susceptibility of tobacco thrips to thiamethoxam and imidacloprid in the Mid-South region. (Huseth et al. 2016, Darnell 2017). Because resistant populations of tobacco thrips have been documented in Mississippi, identifying alternatives to neonicotinoid seed treatments is important to minimize injury and losses from thrips. Other thrips management options include various foliar insecticides, as well as, acephate applied as a seed treatment or in-furrow application. To evaluate foliar insecticide strategies as alternatives to neonicotinoid seed treatments, an experiment was conducted across multiple locations in the midsouthern U.S.

3.3 Materials and Methods

Field experiments were conducted during 2015 and 2016 at the Southeast Research and Extension Center in Monticello, AR; Macon Ridge Research Station in Winnsboro, LA; R.R. Foil Plant Science Research Center in Starkville, MS; Delta Research and Extension Center in Stoneville, MS; Lonoke Extension Center in Lonoke, AR, and West Tennessee Research and Education Center in Jackson, TN to determine the best strategy for managing tobacco thrips with various foliar application intervals. The field study was implemented as a randomized complete block design with four replications at each location. Stoneville 4946 (Bayer CropScience, Research Triangle Park, NC) cotton was planted at 135,850 seed ha^{-1} in 2015, and Stoneville 6448 (Bayer CropScience, Research Triangle Park, NC) in 2016. Standard production practices were followed according to the corresponding university extension recommendations in each state.

The treatments included foliar applications of acephate at (1) one week post emergence (cotyledon), (2) cotyledon plus two weeks post emergence, (3) cotyledon plus two and three weeks post emergence, and (4) two and three weeks post emergence. The foliar insecticide applications were compared to an insecticide seed treatment consisting of (5) imidacloprid (Gaucho 600, Bayer CropScience, Research Triangle Park, NC) applied at a rate of 0.375 mg ai $seed^{-1}$ and 6) an untreated control. Foliar applications of acephate (Orthene 97, AMVAC Chemical Corporation, Los Angeles, CA) were made at 0.27 kg ai ha^{-1} using a tractor mounted sprayer calibrated to deliver 93.5 L ha^{-1} using TX-6 hollow cone nozzles at 275.8 kPa. Plots were four 3.6-m rows measuring 12.2-m in length.

Thrips damage ratings and thrips densities were evaluated at the 1-2 and 3-4 leaf stage of cotton growth. Damage ratings were recorded on a scale of 0 (no injury) to 5 (severe injury). Thrips densities were estimated by randomly cutting five plants from each plot at ground level and placing them into a 0.47-L glass jar with a 50% ethanol solution. Plants were rinsed with a 50% ethanol solution and the remaining solution was poured through a Buchner funnel. Thrips adults and nymphs were collected on filter paper and that paper was placed into a Petri dish for counting under a microscope. Adult thrips darker in color were considered to be tobacco thrips. Immature thrips were not identified to species and pooled. Cotton yield was determined by harvesting the center two rows of each plot with a modified spindle-type cotton picker for small plot research.

Data were analyzed using analysis of variance in PROC GLIMMIX (SAS 9.4; SAS Institute; Cary, NC). Year and replications were considered to be random effects and treatments were considered to be fixed effects. Means were separated using Fisher's Protected LSD procedure at the 0.05 level of significance.

3.4 Results and Discussion

Significantly fewer immature (F=5.85; df= 5, 128; P<0.01) and adult (F= 4.43; df= 5, 168; P<0.01) thrips per five plants were observed for the treatments that had an automatic cotyledon application or an insecticide seed treatment when compared to the untreated control at the cotyledon sampling three to five days after the cotyledon application (Table 3.1). For thrips damage, the insecticide seed treatment resulted in significantly less damage compared to the untreated control (F= 3.66; df= 5, 135; P<0.01) (Table 3.1).

At the week two sampling, the untreated plots had significantly (F= 8.86; df= 5, 111; *P*<0.01) more immature thrips than plots that received any of the treatments, while foliar applications at the cotyledon stage had significantly reduced thrips compared to the insecticide seed treatment (Table 3.2). Adult thrips were significantly (F= 7.62; df= 5, 141; *P*<0.01) decreased by foliar applications at cotyledon plus week two and at cotyledon plus weeks two and three compared to the other foliar application timings, insecticide seed treatment, and untreated control (Table 3.2). The insecticide seed treatment did not reduce thrips populations below that of the automatic treatments, however, it did provide the greatest amount of protection from thrips injury (F= 12.51; df= 5, 195; *P*<0.01) (Table 3.2). Foliar applications at cotyledon had significantly reduced thrips damage compared to the untreated control and the foliar application at the week two and three timings.

All insecticides reduced the number of thrips compared to the untreated control at week three (F>9.13; df= 5, 119; *P*<0.01). All of the insecticide treatments reduced immature thrips densities compared to the untreated control, foliar applications at cotyledon plus weeks two and three significantly reduced immature thrips densities compared to all other treatments except foliar applications at cotyledon plus week two (Table 3.3) (F= 15.95; df= 5, 119; *P*<0.01). All foliar applications, except those at cotyledon alone reduced immature thrips populations below that of the insecticide seed treatment and all treatments. (Table 3.3). The foliar applications at cotyledon plus week two and cotyledon plus week two and three significantly reduced adult thrips compared to the insecticide seed treatment, foliar applications at cotyledon, and the untreated control. Additional foliar applications at weeks two and three (cotyledon plus weeks two and three) did not result in greater reductions in thrips adults compared to a single foliar application at the cotyledon stage (Table 3.3) ($F=9.13$; df= 5, 119; $P<0.01$). Thrips damage was significantly lower in plots that received an insecticide seed treatment or foliar applications at cotyledon stage compared to the untreated control or foliar applications at week two and three (Table 3.3) ($F= 22.53$; df= 5, 175; $P<0.01$).

In this study, thrips management did not significantly impact cotton yield ($F= 2.01$; df= 5, 210; $P=0.08$). While there were no differences in yield among treatments, damage sustained from thrips was reduced with early management decisions, and early foliar applications were comparable to the insecticide seed treatment in reducing thrips densities and damage. Foliar applications at the cotyledon stage are especially important in situations where the use of an insecticide seed treatment is not implemented. Furthermore, at-planting treatments tend to be more effective in preventing yield loss than foliar applications. It is important to understand how alternative foliar applications compare to these at-planting treatments, especially with documented thiamethoxam resistance (Layton and Reed 2002; Darnell, 2017). However, thrips damage levels following foliar applications at the cotyledon stage were comparable to those where an insecticide seed treatment was used. With foliar applications, it is important to time applications shortly after crop emergence to minimize damage from thrips because damage was much greater when foliar applications were delayed until to week two. In the event that a seed treatment is not used, early foliar applications can provide similar control to at planting insecticides; however, foliar insecticide usage has the potential to reduce beneficial insect populations and flare secondary pests. Not to mention that adverse environmental conditions may impact or delay the timeliness of a foliar insecticide application thus compromising thrips control which may lead to yield losses. Therefore, at-planting insecticides are generally a more consistent control option than foliar applications alone.

3.1 Impact of foliar application timing intervals on thrips population and plant damage at the cotyledon stage across the Mid-South during 2015 and 2016**.**

Treatment		Cotyledon	
	Immature(±SE)[ab]	Adult(±SE)[ab]	Damage(±SE)[c]
Untreated Control	14.3a (3.4)	18.6a (6.7)	1.5ab (0.18)
Cotyledon	8.8bc (2.2)	10.0b (3.9)	1.3bc (0.17)
Cotyledon followed by week two	6.9cd (1.8)	9.5b (2.8)	1.3bc (0.17)
Cotyledon followed by week two and three	7.3cd (2.1)	7.4b (2.4)	1.4a (0.20)
Week Two and Three	10.7ab (2.3)	14.0a (4.3)	1.6a (0.21)
Insecticide Seed Treatment	7.8bcd (2.2)	10.9b (3.2)	1.3c (0.19)
P-Value	0.0016	0.0008	0.0039

[a]Means within the column that are followed by the same letter are not different according to Fisher's Protected LSD with an alpha of 0.05. [b] Samples were taken at the cotyledon stage by randomly cutting five plants per plot. [c]Damage ratings are based on a 0 (no injury) to 5 (plant death) scale.

3.2 Impact of foliar application timing intervals on thrips population and plant damage at two weeks after emergence across the Mid-South during 2015 and 2016.

Treatment		Week Two	
	Immature(±SE)[ab]	Adult(±SE)[ab]	Damage(±SE)[c]
Untreated Control	16.6a (4.1)	23.2a (9.4)	2.4a (0.17)
Cotyledon	4.2cd (0.8)	14.1a (5.6)	1.9b (0.15)
Cotyledon followed by week two	4.4cd (1.1)	10.9b (5.1)	1.9b (0.16)
Cotyledon followed by week two and three	3.1d (0.7)	8.1b (3.6)	1.9b (0.15)
Week Two and Three	5.3bc (1.1)	26.6a (11.7)	2.3a (0.17)
Insecticide Seed Treatment	8.5b (2.4)	14.9a (5.5)	1.8c (0.15)
P-Value	0.0001	0.0001	0.0001

[a]Means within the column that are followed by the same letter are not different according to Fisher's Protected LSD with an alpha of 0.05. [b] Samples were taken two week after emergence by randomly cutting five plants per plot. [c]Damage ratings are based on a 0 (no injury) to 5 (plant death) scale.

3.3 Impact of foliar application timing intervals on thrips population and plant damage at three weeks after emergence across the Mid-South during 2015 and 2016.

Treatment	Week Three		
	Immature(±SE)[ab]	Adult(±SE)[ab]	Damage(±SE)[c]
Untreated Control	38.1a (8.2)	6.3a (1.0)	2.9a (0.09)
Cotyledon	10.3bc (2.1)	3.9ab (0.5)	2.2c (0.08)
Cotyledon followed by week two	5.7cd (1.1)	2.6c (0.5)	2.0cd (0.07)
Cotyledon followed by week two and three	3.9d (0.9)	1.6c (0.4)	1.9d (0.08)
Week Two and Three	14.4c (3.8)	2.8bc (0.7)	2.5b (0.11)
Insecticide Seed Treatment	18.7b (4.1)	4.6a (0.8)	1.9d (0.10)
P-Value	0.0001	0.0001	0.0001

[a]Means within the column that are followed by the same letter are not different according to Fisher's Protected LSD with an alpha of 0.05. [b] Samples were taken three weeks after emergence by randomly cutting five plants per plot. [c]Damage ratings are based on a 0 (no injury) to 5 (plant death) scale.

References

Anonymous. Gaucho 600 insecticide label. Available at http://www.cdms.net. Assessed on 16 Oct 2017

Anonymous. Orthene 97 insecticide label. Available at http://www.cdms.net. Assessed on 16 Oct 2017

Bourland, F. M., D. M. Oosterhuis, N. P. Tugwell. 1992. Concept for monitoring the growth and development of cotton plants using main- stem node counts. J. Prod. Agric.5: 532- 538.

Catchot, A., J. Gore and D. Cook. (2013). "Tobacco thrips in mid-south resistant to thiamethoxam" Retrieved 10 Oct. 2014, from http://www.mississippicrops.com/2013/11/07/tobacco-thrips-in-mid-south resistant-to thiamethoxam/.

Chaudlhry, M. Rafiq and Andrei Guitchounts. 2003. Cotton Facts. Common Fund for Commodities Technical paper No. 25: pp. 35-83

Cook, D., A. Herbert, D. S. Akin, and J. Reed. 2011. Biology, Crop Injury, and Management of Thrips (Thysanoptera: Thripidae) Infesting Cotton Seedling in the United States. J. Integ. Pest. Mgmt. 2:2011.

Darnell. C. H. 2017. Evaluation and management of neonicotinoid resistant tobacco thrips (*Frankliniella fusca*) in cotton. Mississippi State University Thesis

Davis, J. W., W. C. Watkins, Jr., C. B. Cowan, Jr., R. L. Ridgway, and D. A. Lindquist. 1966. Control of several cotton pests with systemic insecticides. J. Econ. Entomol. 59: 159-162. Davidson, R. H., L. M. Peairs, and W. F. Lyon. 1979. Insect pests of farm, garden, and orchard, 7th ed. Wiley, New York.

Dunham, E. W., and J. C. Clark. 1937. Thrips damage to cotton. J. Econ. Entomol. 30:855 857.

Greene, J. K., C. Capps, B. Myers, J. Reed. 2002. Control Options for Thrips in Southeast Arkansas. Summaries of Arkansas Cotton Research. pp. 254-258

Gaines, J. C. 1934. A preliminary study of thrips on seedling cotton with special reference to the population, migration, and injury. J. Econ. Entomol. 27:740-743.

Gipson, J. R. and H. E. Joham. 1968. Influence of night temperature on growth and development of cotton *Gossypium hirsutum* (L.) II. Fiber properties. Agron. J. 60: 296-298.

Herbert, D. A., Jr. 1998. Evaluation of thrips damage on maturity and yield of Virginia cotton, p. 1177-1180. *In* Proc. Beltwide Cotton Conf., San Diego, CA. 5-9 Jan. Natl. Cotton. Counc. Am., Memphis, TN.

Huseth, A. S., T. M. Campbell, K. Langdon, S. C. Morsello, S. Martin, J. K. Greene, A. Herbert, A. L. Jacobson, F. P. F. Reay-Jones, T. Reed, D. D. Reisig, P. M. Roberts, R. Smith, and G. G. Kennedy. 2016. Frankliniella fusca resistance to neonicotinoid insecticides: an emerging challenge for cotton pest management in the eastern United States. Pest Mgmt Sci. 72:1934-1945.

Layton, B. and J. T. Reed. 2002. Biology & Control of Thrips on Seedling Cotton. *Mississippi State University Extension Service*. Publication 2302.

Morris, D. A. 1963. Variation in the boll maturation period of cotton. Empire Cotton Grow. Rev. 40: 114-123.

Nauen, R., U. Ebbinghaus-Dintscher, A. Elbert, P. Jeschke, K. Tietjen. 2001. Acetylcholine receptors as sites for developing neonicotinoid insecticides. In: Ishaaya I, editor. Biochemical sites important in insecticide action and resistance. New York: Springer Verlag. P 77-105.

Parker, R. D., S. D. Livingston, R. L. Huffman, and D. A. Dromgoole. 1992. Evaluation on cotton of Orthene applied in-furrow at-planting with and without starter fertilizer in the Texas coastal bend. p. 818-819. *In* Proc. Beltwide Cotton Conf., Nashville, TN. 6-10 Jan. Natl. Cotton. Counc. Am., Memphis, TN.

Reed, J. T., E. Burris, C. Allen, R. Bagwell, D. Cook, B. Freeman, G. Herzog, G. Lentz, R. Leonard. 2001. Thrips (Thysanoptera: Thripidae) A Multi-State Survey: Mississippi. *Mississippi State University Extension Service*. Vol.22 No.15.

Stewart, S., S. D. Akin, J. Reed, J. Bacheler, A. Catchot, D. Cook, J. Gore, J. Greene, A. Herbert, R.Jackson, D. Kerns, B. R. Leonard, G. Lorenz, S. Micinski, D. Reisig, P. Roberts, Studebaker, K. Tindall, and M. Toews. 2013. Survey of Thrips Species Infesting Cotton across the Southern U.S. Cotton Belt. J. Cot. Sci. 17(2): 1-7.

Wollweber D., and K. Tietjen. 1999. Chloronicotinyl insecticides: a success of the new chemistry. In: Yamamoto I, Casida JE, editors. Neonicotinoid Insecticides and the nicotinic acetylcholine receptor. Tokyo: Springer Verlag. P 109-125.

Zhang, A., H. Kayser, P. Maienfisch, and J. E. Casida. 2000. Insect nicotinic acetylcholine receptor: conserved neonicotinoid specificity of [3 H] imidacloprid binding site. J Neurochem 75:1294-1303.

CHAPTER IV

EVALUATION OF VARIETY AND AT-PLANTING NEMATICIDE ON SEASONAL POPULATIONS OF RENIFORM NEMATODE (TYLENCHIDA: ROTYLENCHULIDAE)

4.1 Abstract

Many cotton growing regions across the southern United States are impacted by renifrom nematode, *Rotylenchulus reniformis* (Linford and Oliveira), a semiendoparasitic nematode with the potential to stunt growth, delay maturity, and reduce crop yields. A study was conducted during 2017 in Hamilton, MS and two locations in Tchula, MS to evaluate the response of cotton varieties to aldicarb and 1, 3-dichloropropene nematicides applied for nematode suppression. No significant interactions between cotton variety and nematicide were observed. Nematode densities were suppressed with the use of 1,3-dichloropropene compared to aldicarb and the untreated control. The use of 1,3-dichloropropene resulted in positive early season plant growth responses however, these responses did not translate into higher yields.

4.2 Introduction

Reniform nematode, *Rotylenchulus reniformis* (Linford and Oliveira), is a primary semiendoparasitic nematode pest of cotton production systems in the southern U.S. (Lawrence et al. 2008). Estimated yield losses associated with this nematode pest average between 7 and 8% annually, however, the potential for yield reductions of 40 to 60% under adverse environmental conditions exists (Birchfield and Jones 1961,Davis et al. 2003, Blasingame et al, 2006 and 2009). Reniform nematode populations are generally a 1:1 ratio of males to females, yet only the females are parasitic (Weaver 2015). The vermiform female penetrates the cortex of the root to establish a feeding site within the stele. As the female feeds, her reproductive system matures resulting in the familiar kidney shaped body form characteristic of reniform nematode. The life cycle of reniform nematode can be rapid under optimal soil conditions and population densities can rapidly increase in the presence of an adequate host (Weaver 2015). Unlike other species, reniform nematode tends to be more uniformly distributed across the field that have established infestations with more irregular distributions in fields recently infested (Robinson 2008). Symptomology of reniform nematode includes reduced plant vigor which may manifest as irregular plant growth, plant wilt, interveinal chlorosis, delayed plant maturity, or even reduced yields (Lawrence and McLean 2001, Monfort 2005). In addition to above ground symptoms that may be perceived as nutrient deficiencies, nematode damage may also stunt or reduce the root system, slowing root development and limiting water and nutrient uptake. Nematode infestations are also known to increase the susceptibility of cotton seedlings to other diseases (Koenning et al. 2004). The main impact of reniform nematode on cotton production systems is through reductions in boll size and lint percentages that often lead to reduced yields (Jones et al 1959, Cook et al. 1997).

Soil fumigants or aldicarb (AgLogic™ 15G or AgLogic™ 15GG, AgLogic Chemical LLC, Chapel Hill, NC), an in-furrow insecticide with nematicide properties, are the most common chemical control options for nematode management (Robinson et al 2008, Westphal and Smart 2003). The use of both aldicarb and 1, 3-dichloropropene (Telone, Dow AgroSciences, Indianapolis, IN) can reduce populations and preserve cotton yield potential (Newman and Stebbins 2002, Robinson et al. 2005). The main goal of nematode management using nematicides is protection of seedling plants and promotion of rapidly growing and healthy root system for better tolerance of other environmental stresses (Robinson 2008). Other alternatives to chemical nematode management include crop rotation, cover crops, or soil amendments. While crop rotation is a beneficial strategy for nematode management, reniform nematode has the ability to enter into an anhydriobiotic state for up to two years allowing prolonged survival in soils left fallow or planted to a non-host crop (Weaver 2015). Host plant resistant genes to reniform nematode have been identified in cotton, but the incorporation into commercial cultivars has been mostly unsuccessful. As a result, there are currently no reniform resistance cultivars available (Yik and Birchfield 1984, Jones et al. 1988, 1984, Gaur and Perry 1991, Cook et al. 1997, Davis et al. 2003, Blessitt et al. 2012). With no commercially varieties resistant to reniform nematode, studies were conducted to evaluate the response of two commonly used cotton varieties grown in soils with reniform nematodes infestation using aldicarb or 1, 3-dichloropropene.

4.3 Materials and Methods

A field experiment was conducted in Hamilton, MS and two locations in Tchula, MS during 2017 to evaluate reniform nematode control using aldicarb and 1, 3-dichloropropene on two common cotton varieties. The field study was implemented as a randomized complete block design with a factorial arrangement of treatments and four replications.

Factor A consisted of two levels of nematicide: aldicarb (AgLogic 15G, AgLogic, LLC, Chapel Hill, NC) at 340.5 g ai ha in-furrow, 1, 3-dichloropropene (Telone, Dow AgroSciences, Indianapolis, IN) at 28 L ha^{-1}, and an untreated control. Factor B consisted of two levels of cotton variety: Stoneville 4949 and Stoneville 4946 (Bayer CropScience, Research Triangle Park, NC). All seed were treated with a base fungicide (ipconazole at 0.01 mg ai $seed^{-1}$ + metalaxyl at 0.002 mg ai $seed^{-1}$ + myclobutanil 0.06 mg ai $seed^{-1}$ + penflufen at 0.02 mg ai seed

$^{-1}$) and imidacloprid (Gaucho 600, Bayer CropScience, Research Triangle Park, NC) applied at a rate of 0.375 mg ai seed^{-1} to minimize the effects of seedling disease and thrips. Plots were four 3.6-m rows measuring 12.2-m in length. Nematicide applications using 1, 3-dichloropropene were applied using a four-row coulter injection system on 13 Apr 2017 and 17 Apr 2017. Aldicarb applications were applied in-furrow by a tractor mounted granular insecticide box at planting. Cotton was planted at a depth of approximately 2-cm at a population of 135,850 seed ha^{-1} on 04 May 2017, 11 May 2017, and 19 May 2017. Standard production practices were followed according to Mississippi State University Extension Service recommendations.

Nematode samples were collected prior to the nematicide application, at first square, and post-harvest. Nematode populations were determined by collecting ten, 20-cm deep soil cores from individual plots using a 2.5 cm diameter soil sampling probe. Cores were combined, and a sub-sample of 300 cm^3 was processed by the Mississippi State University Extension Plant Diagnostic Laboratory in Starkville, MS using a semi-automatic elutriator and sucrose extraction (Byrd et al. 1976, Jenkins 1964).

Above- and below-ground biomass samples were evaluated by uprooting five random plants from the outer two rows at the 4-leaf stage. Above- and below-ground portions of the five uprooted plants were placed into paper bags and dried in a forced air dryer for 48 hours at 38°C. After drying, samples were weighted to determine dry biomass. Plant heights and total node counts were taken at first square, first bloom, and at harvest. Heights were determined by measuring from the ground to the apical meristem. Nodes above white flower (NAWF) were determined by counting the nodes above the uppermost first position white flower when the majority of plants were flowering (Bourland et al. 1992). Nodes above cracked boll (NACB) were determined by counting the nodes between the uppermost first position cracked boll and the uppermost first position harvestable boll prior to defoliation. Cotton yield was determined by harvesting the center two rows of each plot with a modified spindle-type cotton picker for small plot research.

Data were analyzed using analysis of variance (PROC GLIMMIX, SAS 9.4; SAS Institute; Cary, NC). Location and replications were considered to be random effects, and nematicide and cotton variety were considered to be fixed effects. Means were separated using Fisher's Protected LSD procedure at the 0.05 level of significance.

4.4 Results

Seasonal populations of reniform nematode. There were no significant differences among varieties for nematode densities on any sample date ($F>0.01$; df= 1, 55; $P>0.06$). Also, there were no significant differences among nematicide treatments for sample dates one, three, four, and nine to 12 ($F>0.79$; df= 2, 55; $P>0.13$) (Table 4.1). At sample date two, 1, 3-dichloropropene significantly reduced nematode densities compared to the untreated control. On sample dates five through eight, significantly lower nematode densities were observed in the 1,3-dichloropropene treated plots compared to both the untreated control and aldicarb treated plots ($F>0.16$; df= 1,55; $P<0.01$). Aldicarb did not significantly reduce nematode densities compared to the untreated control on any sample date ($F=4.12$; df= 2, 55; $P=0.04$).

Varietal response. No significant interactions between variety and nematicide were observed for plant height ($F>0.05$; df= 2, 55; $P>0.94$) or number of nodes ($F>1.28$; df= 2, 55; $P>0.28$) at 1st square, 1st bloom, or harvest, nor were there any interactions for NAWF ($F=0.02$; df= 2, 55; $P=0.98$), NACB ($F=0.00$; df= 2, 55; $P=0.99$), or above-($F=0.10$; df= 2, 55; $P=0.90$) and below- ground biomass ($F= 0.19$; df= 2, 55; $P= 0.82$). At first square, Stoneville 4946 had a significantly greater plant height ($F=6.90$; df= 1, 55; $P=0.04$) and number of nodes ($F=13.38$; df=

1, 55; *P*=0.02) than Stoneville 4949 (Table 4.2). At first bloom, there were no significant differences between varieties for plant height (F=1.34; df= 1, 55; *P*=0.59) or NAWF (F=6.51; df= 1, 55; *P*=0.23) (Table 4.2). Also, there were no significant differences in plant heights (F=0.18; df= 1, 55; *P*=0.71) or NACB (F=2.10; df= 1, 55; *P*=0.662) between varieties at maturity (Table 4.2). Stoneville 4946 had significantly higher above- (F= 8.28; df= 1, 55; *P*= 0.02) and below- (F= 6.91; df= 1, 55; *P*= 0.04) ground plant biomass compared to the Stoneville 4946 (Table 4.3). Stoneville 4946 produced significantly higher cotton yields compared to Stoneville 4646 (F=4.93; df= 1, 55; *P*=0.03) (Table 4.3).

Plant response to nematicide treatment. 1,3-dichloropropene resulted in greater above- ground biomass compared to untreated control or aldicarb (F=11.03; df= 2, 55; *P*<0.01) and more below-ground biomass compared to the untreated control (F=6.45; df= 2, 55; *P*=0.02) (Table 4.3). 1,3-dichloropropene resulted in significantly greater plant height at 1st square (F=20.83; df= 2, 55; *P*<0.01) and 1st bloom(F=29.91; df= 2, 55; *P*<0.01), as well as, total nodes at 1st square (F=7.27; df= 2, 55; *P*<0.01) and 1st bloom (F=17.23; df= 2, 55; *P*=0.002) compared to all other nematicide treatments(Table 4.2). Also, 1, 3-dichloropropene resulted in significantly more main stem modes at 1st square compared to aldicarb. No significant differences among nematicide treatment were observed for NAWF (F=1.85; df= 2, 55; *P*=0.46), NACB (F=0.62; df= 2, 55; *P*=0.89), or plant heights (F=5.21; df= 2, 55; *P*=0.17) at harvest (Table 4.2). 1, 3-dichloropropene resulted in significantly higher yields compared to aldicarb (F=3.18; df= 2, 55; *P*=0.05) (Table 4.3).

4.5 Discussion

Currently, there are no commercially available cotton varieties with reniform nematode tolerance, therefore a varietal response to nematode infestation stress would be unlikely.

Differences in plant performance are likely due to varietal responses to various biotic and abiotic stresses throughout the season. The early season biomass and plant growth response to nematode control did not translate into increased cotton yields. The advantage of aldicarb is that this product also provides control of important insect pests, including tobacco thrips. Numerous studies demonstrated effective nematode suppression and increased yield with both 1, 3-dichloropropene and aldicarb, with soil fumigants generally being more effective than other chemical nematicide options (Lawrence et al., 1990, Gazaway et al. 2001, Robinson 2008). Therefore, it is important to weigh the cost of nematicide usage to cotton yield responses in Mississippi. Yield losses associated with reniform nematode in the United States are <10% on average annually, however, with additional stresses, such as water-stress, yield losses >50% have been observed (Robinson 2008). Generally, nematicide applications are warranted when yield losses are expected to be > 5%, however it is not possible to accurately predict the environmental conditions for the remainder of the growing season and the amount of yield loss that might occur cannot be predicted (Robinson 2008). To determine the potential benefit of nematicide usage be in Mississippi cotton production systems, a knowledge of production history and the ability to minimize other environmental stresses, such as water stress, would be needed. While 1, 3-dichloropropene did suppress nematode densities early-season, and resulted in an early season plant response, yield responses were not great enough to warrant the cost. Late season environmental conditions during this study were favorable to plant compensation, and the amount of stress throughout the season was relatively low resulting in yields that were comparable (A.1.3). If the environmental stresses had been greater increased, yield responses great enough to warrant nematicide use may have been observed (A.1.3). Further research is needed to better understand the relationship between reniform nematode infestation and environmental conditions and soil properties to allow for development of the best management practices for reniform nematode in Mississippi cotton production systems.

4.1 Impacts of nematicide applications on the number of nematodes per pint soil at various seasonal sampling dates during the growing season in Tchula, MS and Hamilton, MS during 2017.

Treatment	Reniform nematodes per 550 cm of soil[a]						
	One(±SE)	Two (±SE)	Three(±SE)	Four (±SE)	Five (±SE)	Six (±SE)	Seven(±SE)
Untreated Control	2,149a (359)	3492a (706)	2,992a (689)	9,026a (2539)	2,999a (592)	1,802a (521)	2,090a (307)
1,3- Dichloropropene	2,496a (560)	1,295b (352)	1,097a (198)	5,163a (2043)	1,160b (344)	6,80b (186)	7,57b (158)
Aldicarb	1,799a (361)	2,305ab (346)	2,666a (729)	7,636a (2221)	2,390a (684)	2,221a (538)	2,751a (590)
P-value	0.561	0.043	0.278	0.554	0.006	0.010	0.006

[a]Means within the column that are followed by the same letter are not different according to Fisher's Protected LSD with an alpha of 0.05.

Continued. Impacts of nematicide applications on the number of nematodes per pint of soil at various seasonal sampling dates during the growing season in Tchula, MS and Hamilton, MS during 2017.

Treatment	Reniform nematodes per 550 cm^3 of soil[a]					
	Eight (±SE)	Nine (±SE)	Ten(±SE)	Eleven(±SE)	Twelve(±SE)	Seasonal (±SE)
Untreated Control	1,969a (439)	5,441 a (1004)	3,230a (693)	4,005a (875)	3,588a (644)	3,524a (359)
1,3-Dichloropropene	6,87b (129)	3,629a (750)	1,518a (252)	3,189a (674)	2,985a (821)	2,065a (281)
Aldicarb	1,554 (230)	5,988a (904)	2,421a (528)	5,544a (832)	4,152a (735)	3,490a (363)
P-value	0.005	0.230	0.133	0.174	0.628	0.020

[a]Means within the column that are followed by the same letter are not different according to Fisher's Protected LSD with an alpha of 0.05.

4.2 Impacts of cotton variety and nematicide treatment on plant growth at 1st square, 1st bloom, and harvest in Tchula, MS and Hamilton, MS during 2017.

Treatment	1st Square		1st Bloom			Harvest	
	Height(±SE)	Nodes(±SE)	Height(±SE)	Nodes(±SE)	NAWF(±SE	Height(±SE	NACB(±SE)
	Centimeter	Total	Centimeter	Total	Total	Centimeter	Total
Stoneville 4946	27.5a (0.63)	8.1a (0.11)	79.3a (1.06)	14.9a (0.12)	6.9a (0.15)	106.5a	6.5a (0.41)
Stoneville 4949	25.7b (0.61)	7.6b (0.12)	77.6a (1.04)	14.2b (0.11)	7.2a (0.17)	107.6a	6.9a (0.47)
P-value	0.0411	0.017	0.2711	0.0009	0.232	0.800	0.622
Untreated Control	24.7b (0.71)	7.8ab (0.14)	73.9b (1.21)	14.3b (0.15)	6.8a (0.20)	102.9a	6.6a (0.52)
1,3-Dichloropropene	29.9a (0.81)	8.2a (0.16)	86.6a (1.38)	15.1a (0.16)	7.1a (0.19)	112.8a	6.5a (0.60)
Aldicarb	25.1b (0.75)	7.6b (0.13)	74.9b (1.28)	14.2b (0.13)	7.1a (0.19)	105.5a	6.9a (0.51)
P-value	0.0001	0.016	0.0001	0.003	0.456	0.172	0.888

[a]Means within the column that are followed by the same letter are not different according to Fisher's Protected LSD with an alpha of 0.05. [b]Nodes above white flower. [c]Nodes above cracked boll.

4.3 Impact of cotton variety and nematicide treatment on above and below dry plant biomass at the 4th leaf stage and cotton yield in Tchula, MS and Hamilton, MS during 2017.

Treatment	Biomass [ab]		Yield[c]
	Above (±SE)	Below (±SE)	Lint(±SE)
	Grams		$kg\ ha^{-1}$
Stoneville 4946	19.5 a (0.85)	3.1 a (0.14)	1,356 a (31.3)
Stoneville 4949	16.6 b (0.82)	2.6 b (0.16)	1,274 b (30.0)
P-value	0.017	0.038	0.031
Untreated Control	15.5 b (0.95)	2.4 b (0.16)	1,326 ab (33.3)
1,3-Dichloropropene	23.3 a (0.85)	3.2 a (0.16)	1,367 a (41.3)
Aldicarb	17.3 b (1.03)	2.0 ab (0.21)	1,251 b (38.3)
P-value	0.002	0.022	0.050

[a]Means within the column that are followed by the same letter are not different according to Fisher's Protected LSD with an alpha of 0.05. [b]Dried plant biomass at the 4th leaf stage. [c]Cotton yield was taken from the center two rows of each plot.

References

Anonymous. AgLogic15G insecticide label. Available at http://www.aglogicchemical.com/. Assessed on 17 Oct 2017

Anonymous. Telone II soil fumigant label. Available at http://www.cdms.net. Assessed on 17 Oct 2017

Birchfield, W., and J. E. Jones. 1961. Distribution of the reniform nematode in relation to crop failure of cotton in Louisiana. Plant Dis 45:671-673.

Blasingame, D., M.V. Patel, W. Gazaway, M. Olsen, T. Kirkpatrick, M. Davis, R.K. Sprenkel, B. Kemerait, P. Colyer, A. Wrather, N. Goldberg, S. Koenning, J. C. Banks, J. Muller, M. Newman, J. Woodward, and P. Phipps. 2006. Cotton disease loss estimate committee report. Proceedings of the Beltwide Cotton Conferences of the Natl Cot Counc of Am. http://www.cotton.org/beltwide/proceedings/ 2007.

Blasingame, D., Gazaway, W., Lawrence, K. S., Wrather, A., Olsen, M., Kirkpatrick, T., Koenning, S. R., Goldberg, N., Banks, J. C., Sprenkel, R.,Muller, J., Davis, M., Kemerait, R. C., Newman, M. A., Colyer, P. D., Woodward, J. E., Sciumbato, G. L., and Phipps, P. M. 2009. Cotton disease loss estimate committee report. Proceedings of the Beltwide Cotton Conferences of the Natl Cot Counc of Am. 1:94–96.

Blessitt, J. A. S. R. Stetina, T. P. Wallace, P. T. Smith, and G. L. Sciumbato. 2012. Cotton (*Gossypium hirsutum*) cultivars exhibiting tolerance to the reniform nematode (*Rotylenchulus reniformis*). Inter. J. Agro. doi:10.1155/2012/893178

Byrd, D. W., Jr., K. R. Barker, H. Ferris, C. J, Nusbaum, W. E. Griffin, R. H. Small, and C. A. Stone. 1976. Two Semi-automatic elutriatiors for extracting nematodes and certain fungi from soil. J. Nematol. 8:206-212.

Cook, C. G., A. F. Robinson, and L. N. Namken. 1997. Tolerance of *Rotylenchulus reniformis* and resistance to *Meloidogyne incognita* race 3 in high-yielding breeding lines of upland cotton. J. Nematol..29:322–328.

Davis, R., S. Koenning, R. Kemerait, T. Cummings, and W. Shurley. 2003. *Rotylenchulus reniformis* management in cotton with crop rotation. J. Nematol.35:58-64.

Gaur, H. S., and R. N. Perry. 1991. The biology of the plant parasitic nematode *Rotylenchulus reniformis.* Agricultural Zoology Reviews 4:177–212.

Gazaway, W., D. Rush, and K. Edmisten. 1992. An evaluation of various Temik and Telone rates for controlling reniform nematodes in cotton. Fungicide and Nematicide Test 47:161.

Koenning, S., T. Kirkpatrick, J. Starr, J. Wrather, N. Walker, and J. Mueller. 2004. Plant parasitic nematodes attacking cotton in the United States: old and emerging] production challenges. Plant Dis 88:100-113.

Lawrence, K. S., A. J. Price, G. W. Lawrence, J. R. Jones, and J. R. Akridge. 2008. Weed hosts for *Rotylenchulus reniformis* in cotton fields rotated with corn in the southeast of the United States. Nematropica 38:13-22.

Lawrence, G. W., and K. S. McLean. 2001. Reniform nematodes. *In* compendium of cotton Diseases, Second Edition. T. L. Kirkpatrick and C. S. Rothrock (eds.), APS Press pp. 42-43.

Jenkins W. R. 1964. A rapid centrifugal-flotation technique for separating nematodes from soil. Plant Dis. Rep. 48:692.

Jones, J. E., J. P. Beasley, J. I. Dickson, and W. D. Caldwell. 1988. Registration of four cotton germplasm lines with resistance to reniform and root-knot nematodes. Crop Sci 28:199–200.

Jones, J. E., L. D. Newsom, and E. L. Finley. 1959. Effect of the reniform nematode on yield, plant characters, and fiber properties of upland cotton. Agron. J. 51:353 356.

Newman, M. A., and Stebbins, T. C. 2002. Recovery of reniform nematodes at various depths in cotton. Proceedings of the Beltwide Cotton Conferences of the Natl Cot Counc of Am.:254–255.

Robinson, A. F., Cook, C. G., Westphal, A., and Bradford, J. M. 2005. Rotylenchulus reniformis below plow depth suppresses cotton yield and root growth. J. Nematol. 37:285–291.

Robinson, A. F., A. A Bell, P. Augudelo, C. A. Avila, J. M. Stewart, F. E. Callahan, R. W. Hayes, J. N. Jenkins, J. C. Mccarty, M. J. Wubben, C. G. Cook, N. D. Dighe, M. A. Menz, C. W. Smith, D. M. Stelly, O. A.Gutierrez, T. P. Wallace, J. T. Johnson, R. Kantety, G. W. Lawrence, K .S. Lawrence, L. Mangineni, D.B. Weaver, W.A. Meredith, E. Sacks, B. Scheffler, S.R. Stetina, L. D Young, R. L.Nichols, R. T. Robbins, G. L. Sciumbato, P. M. Thaxton, and J. L Starr. 2008. Development of reniform nematode resistance in Upland cotton. In: Proceedings of the World Cotton Research Conference-4, September 10-14, 2007, Lubbock, Texas.

Starr. 2008. Development of reniform nematode resistance in Upland cotton. In: Proceedings of the World Cotton Research Conference-4, September 10-14, 2007, Lubbock, Texas.

Robinson A. F. Nematode management in cotton. 2008. In: Ciancio A, Mukerji K, editors. Integrated management and biological control of vegetable and grain crops nematodes. Berlin: Springer; 2008. pp. 149–182.

Weaver, D. B. 2015. Cotton Nematodes. In: Cotton, 2nd ed., Agron. Monogr. 57. ASA, CSSA, and SSSA, Madison, WI. p. 547-570. doi:10.2134/agronmonogr57.2013.0045

Westphal, A. and J. Smart. 2003. Depth distribution of *Rotylenchulus reniformis* under different tillage and crop sequence systems. Phytopath. 93:1182-1189

Yik, C. P., and W. Birchfield. 1984. Resistant germplasm in *Gossypium* species and related plants to *Rotylenchulus reniformis.* J. Nematol. 16:146–153.

CHAPTER V

SUMMARY

The overall objective of this research was to evaluate management options for tobacco thrips, *Frankliniella fusca* (Hinds), and reniform nematode, *Rotylenchulus reniformis* (Linford & Oliveira), in cotton production systems. This included evaluation of tillage practice, at-planting insecticide treatments, and nematicides on thrips and nematode management. Numerous studies have demonstrated that conservational tillage systems can reduce thrips infestations and damage. While tillage impact is less understood for nematode management, depending on species both positive and negative responses to management have been observed. In this study, tillage practice did not have an impact on nematode densities. At-planting insecticide treatments are generally the most effective option for managing thrips, and in this study aldicarb or acephate plus terbufos provided the greatest control. For the plant growth parameters of total biomass and plant vigor, the greatest responses resulted from the usage of conventional tillage, 1,3-dichloropropene, and acephate plus terbufos or aldicarb treatments. Tillage and nematicide did not impact post-harvest nematode densities, there were no differences; however, in the conventional tillage systems the use of a nematicide reduced densities compared to the untreated. There was an increase in cotton yield with the no nematicide treatment over the nematicide treatment possibly due to over compensation.

The second part of this research evaluated how weed control and herbicide injury can impact a system that has both effective control of thrips and nematodes, as well as, a stressed system. The use of an insecticide seed treatment reduces thrips densities and damage, while the use of a nematicide decreased nematode densities. When making early season herbicide applications, all herbicides provided <12% percent crop injury, but overall, systems with an insecticide seed treatment had less herbicide injury than the untreated. Yield was the highest with an insecticide seed treatment and 1,3-dichloropropene compared to all other treatments.

Due to thrips resistance, automatic foliar applications were evaluated to determine how they compared to the current standard control method of an insecticide seed treatment. Generally, seed treatments are more effective for thrips management than foliar applications. However, with the increase of imidacloprid resistance and the already widespread thiamethoxam resistance, understanding the timing of foliar applications on thrips control relative to an insecticide seed treatment is becoming more important. Early automatic cotyledon applications plus continual foliar applications reduced thrips densities and damage similar to that of an insecticide seed treatment. When implementing foliar applications for thrips management, it is important to make applications at crop emergence.

Lastly, with the reintroduction of aldicarb into the market, a nematode study was conducted to compare aldicarb to 1, 3-dichloropropene for nematode management. 1,3-dichloropropene effectively reduced reniform nematode densities below that of aldicarb or an untreated check. Depending on the environmental conditions, the crops recoverability would determine whether a yield increase is high enough to warrant a nematicide application. In this study, the 1,3-dichloropropene treatment yielded higher than the aldicarb but was not significantly different than the untreated check. Because nematodes are a stress pathogen, in production situations where other environmental stresses like water stress might be minimized nematode management may be less critical and the use of a nematicide may not prove to be beneficial.

Many of the factors evaluated in these studies are well known independently to reduce yield of cotton. Across the three years of this research, we were successfully able to effect cotton growth and development with many of the factors tested, however, yield was not impacted in many of the studies. As others have shown previously, cotton has a tremendous ability to compensate and even overcompensate for early season stress provided ideal conditions later in the growing season (A.1.1; A.1.2; A.1.3). The hypothesis of compounding stresses from multiple pests such as studied here need to addressed further in years where adverse environmental conditions exist to fully understand potential for yield loss in cotton production systems across the midsouthern region where these pests commonly occur together (A.1.1; A.1.2; A.1.3).

APPENDIX A

ENVIRONMENTAL DATA

A.1.1 Average monthly temperatures, total rainfall, and 30 year average temperatures for Tuscaloosa, AL.

	High	Low	Total Rain
	ºC		cm
	2015		
Apr	58.2	38.2	17.7
May	65.2	43.2	12.9
Jun	72.2	52.2	7.8
Jul	75.2	56.2	10.3
Aug	73.2	51.2	5.0
Sep	70.2	46.2	3.8
Oct	60.2	36.2	6.3
Nov	50.2	30.2	21.2
	2016		
Apr	58.2	35.2	11.0
May	64.2	42.2	8.2
Jun	54.2	52.2	9.9
Jul	76.2	55.2	9.0
Aug	75.2	55.2	8.8
Sep	75.2	49.2	7.0
Oct	67.2	37.2	0.1
Nov	55.2	24.2	8.8
	2017		
Apr	62.2	36.2	10.8
May	63.2	41.2	15.4
Jun	67.2	49.2	23.3
Jul	74.2	54.2	9.6
Aug	71.2	52.2	19.6
Sep	68.2	46.2	12.3
Oct	61.2	35.2	5.6
Nov	50.2	24.2	2.9
	30 Year		
Apr	56.6	31.7	
May	64.0	40.9	
Jun	70.4	49.0	
Jul	73.4	53.0	
Aug	73.2	52.1	
Sep	67.4	45.4	
Oct	57.5	33.3	
Nov	47.1	23.5	

(NOAA)

A.1.2 Average monthly temperatures, total rainfall, and 30 year average temperatures for Starkville, MS.

	High	Low	Total Rain
	ºC		cm
	2015		
Apr	58.2	38.2	23.0
May	66.2	44.2	5.9
Jun	73.2	52.2	4.3
Jul	77.2	55.2	7.4
Aug	74.2	52.2	11.3
Sep	69.2	47.2	2.3
Oct	60.2	36.2	9.3
Nov	52.2	31.2	13.9
	2016		
Apr	58.2	34.2	10.0
May	65.2	41.2	1.8
Jun	73.2	51.2	10.9
Jul	75.2	54.2	10.5
Aug	75.2	55.2	7.3
Sep	75.2	49.2	0.8
Oct	67.2	35.2	0.0
Nov	55.2	24.2	6.4
	2017		
Apr	63.2	37.2	19.2
May	64.2	41.2	8.9
Jun	68.2	50.2	31.5
Jul	74.2	55.2	8.7
Aug	70.2	54.2	16.4
Sep	68.2	46.2	4.1
Oct	60.2	37.2	11.4
Nov	51.2	26.2	2.6
	30 Year		
Apr	59.4	33.8	
May	66.3	43.2	
Jun	72.4	50.7	
Jul	74.9	54.3	
Aug	74.8	53.8	
Sep	69.9	47.5	
Oct	59.9	35.7	
Nov	49.9	26.3	

(NOAA)

A.1.3 Average monthly temperatures, total rainfall, and 30 year average temperatures for Belonzi, MS.

	2017		
	High	Low	Total Rain
	ºC		cm
Apr	60.2	39.2	17.4
May	65.2	46.2	11.3
Jun	68.2	52.2	17.0
Jul	72.2	54.2	11.8
Aug	65.2	53.2	3.0
Sep	67.2	41.2	8.3
Oct	61.2	34.2	4.1
Nov	50.2	28.2	9.2
	30 Year		
Apr	56.7	54.0	
May	64.8	63.8	
Jun	71.2	70.9	
Jul	73.5	73.3	
Aug	73.9	72.2	
Sep	69.0	65.3	
Oct	58.8	54.7	
Nov	47.4	45.6	

(NOAA)

References

National Oceanic and Atmospheric Administration (NOAA). Climate Data Online: Dataset Discovery. https://www.ncdc.noaa.gov/cdo-web/datasets#GHCND. Assessed on 19 Feb 2018.

National Oceanic and Atmospheric Administration (NOAA). Supplemental Monthly Temperature Normals. https://www.ncdc.noaa.gov/normalsPDFaccess. Assessed on 19 Feb 2018.