Evaluation of Tillage, At-Planting Treatment, and Nematicide on Tobacco Thrips (Thysanoptera: Thripidae) and Reniform Nematode (Tylenchida: Hoplolamidae) Management in Cotton

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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, acephate 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 of nematicide on thrips control or damage. The main effects 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. Early-season plant response was impacted by tillage and at-planting insecticide treatment; however, that did not result in significant yield differences. In regard to nematicide treatment, the use of 1,3-dichloropropene resulted in lower yields than the untreated.

Keywords: cotton; tobacco thrips; reniform nematodes

1. Introduction

The complexity of early-season pest management in cotton, *Gossypium hirsutum* L., production systems can 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 [1]. Cotton is susceptible to thrips injury from emergence until the fourth or fifth true leaf, or approximately 28 days after emergence under optimal conditions [2]. 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 [1–3]. Additionally, several studies suggest that seedling root growth and development can be negatively impacted by thrips feeding [4–7]. 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 the injury and environmental conditions [6,8,9].

The reniform nematode is a semi-endoparasitic nematode that penetrates and feeds on the cortex of cotton roots. Nematode infestation and feeding impact cotton root development by limiting effective water and nutrient uptake, as well as increasing the susceptibility of plants to soil-borne diseases [10]. 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 [11,12]. Feeding of the 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 [12–14]. Yield losses from both thrips and nematodes can be variable depending on environmental conditions and compounding stresses. Individually, the 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 [15–18]. Cotton losses in Mississippi due to thrips in 2016 were estimated at 16,129 bales of the 1,074,896 total bales harvested [19].

Yield losses associated with early-season pests can generally be minimized by various cultural and chemical practices. Conservation tillage has been reported to influence both thrips densities and damage, and nematode densities [20]. Reduced thrips densities and damage have been associated with conservation tillage systems compared to conventional tillage systems [16,20–22]. Thrips densities were lower in plots where strip-till practices were implemented compared to those with conventional tillage [2]. However, less is known regarding the impact of tillage systems on nematodes. Bauer et al. [20] reported that root-knot nematode, *Meloidogyne incognita*, densities were reduced in some years following conservation tillage practices. Although Minton [23] suggested that tillage system and nematode species may be dependent on one another; conservation tillage practices lowered populations of some plant-parasitic species, while populations of 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 [10,24]. Deep tillage in clay soils, or in the presence of a hardpan, has been beneficial for tap root growth and soil penetration in the presence of lance nematode, *Hoplalaimus galeatus*, infestations [25].

While tillage practice may aid in reducing populations, 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 [26–28]. 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 [23,29]. However, Roberts et al. [30] reported that the positive effects of a nematicide in regards to early root growth may be affected by thrips injury, which has the potential to impact root development. 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. While this research may be similar to previously conducted research, it is important to remember that with limited control options for thrips due to resistance, how other factors such as tillage or nematode stress could positively or negatively impact a production system.

2. 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 9 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 [31]. Applications of 1,3-dichloropropene were made 30 to 35 cm in depth on 5 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 (Counter 15G, AMVAC Chemical Corporation, Los Angeles, CA) at 75.7 g ai ha^{-1} (2015) or aldicarb (AgLogic 15G, AgLogic LLC, Chapel Hill, NC) at 340.5 g ai ha^{-1} (2016), and an untreated control [32–38]. All seed were treated with a base fungicide (ipconazole at 0.01 mg ai seed^{-1} + metalaxyl at 0.002 mg ai seed^{-1} plus myclobutanil 0.06 mg ai seed^{-1} plus 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. While some Stoneville cotton varieties are considered to have resistance to root-knot nematode, including those used in this study, they are not considered to have any tolerance to reniform nematode nor was there any indication of root-knot nematode populations. Standard production practices were followed according to the 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; and then identified to species [39,40]. Reniform nematode thresholds are 2000 nematodes per pint of soil during summer (July–August) months and 5000 nematodes per pint of soil during winter (September to February) months (Mississippi State University Extension).

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 [41] where 98% of thrips species in Mississippi were determined to be tobacco thrips [42,43]. 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 weighed to determine dry biomass. The 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, location, 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.

3. Results

3.1. Reniform Nematode Control

When evaluating the effect of 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 =1365; $p < 0.01$). 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 = 1332; p = 0.13), nematicide (F = 0.05; df = 1332; p = 0.83), or at-planting insecticide treatment (F = 0.94; df = 6332; p = 0.47). At the post-harvest sample date, there was no significant three-way interaction among any factors (F = 0.89; df = 6332; p = 0.50) and there was not a significant effect of at-planting insecticide (F = 1.73; df = 6332; p = 0.11). There was a significant interaction between tillage and nematicide (F = 4.13; df = 1332; p = 0.04). No differences were observed among nematicide treatments in the no-tillage treatments. However, the number of nematodes per 500 cm^3 of soil were reduced by 36% with the use of 1,3-dichloropropene compared to no nematicide in the conventional tillage system (Table 1).

Table 1. Interaction of tillage treatment and nematicide application on the post-harvest nematode populations in cotton in Hamilton, MS during 2015 and 2016.

Treatment		Density per 500 cm^3 [a] (±SE)
No Tillage	No 1,3-dichloropropene	3879ab (672)
No Tillage	1,3-dichloropropene	4278ab (560)
Conv. Tillage	No 1,3-dichloropropene	5102a (679)
Conv. Tillage	1,3-dichloropropene	3278b (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.

3.2. Tobacco Thrips Densities and Damage

There were no significant interactions among factors for thrips densities (F > 0.03; df = 6341; $p > 0.21$) or damage (F > 0.03; df = 6338; $p > 0.09$). Nematicide did not have a significant effect on the density of immature or adult thrips at any sampling period (F > 0.03; df = 1341; $p > 0.58$). 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 = 1341; $p > 0.40$). At the 3–4 leaf stage, there were 33% fewer immature thrips and 29% fewer adult tobacco thrips per five plants in the no-tillage plots compared to conventional tillage (F > 4.08; df = 1341; p <0.04) (Table 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 = 6341; $p < 0.01$) (Table 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 = 6341; $p < 0.01$) (Table 2). At the 3–4 leaf stage, immature thrips (F = 10.89; df = 6341; $p < 0.01$) 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 = 6341; $p < 0.01$) (Table 2).

Table 2. Impacts of tillage treatment and at-planting insecticide treatment on thrips populations at the 1–2 and 3–4 cotton 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)
Conv. 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.

When evaluating main effects for thrips damage, nematicide did not have a significant effect at the 1–2 leaf stage (F = 10.51; df = 6341; *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 =1335; *p* = 0.05) (Table 3). Thrips damage was significantly reduced at both rating intervals in the no-tillage system (F > 15.99; df = 1335; *p* < 0.01) compared to the conventional tillage system (Table 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 protection from thrips damage at both rating intervals, while the greatest level of damage was in the untreated control and thiamethoxam treatments (F > 113.26; df = 6335; *p* < 0.01) (Table 3).

Table 3. Impact of tillage, nematicide, and at-planting insecticide treatment on tobacco thrips damage and cotton 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)
Conv. 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.

3.3. Effect on Plant Vigor, Biomass, and Cotton Yield

No significant interactions were observed for plant vigor (F > 0.75; df = 6339; *p* > 0.61), biomass (F > 1.24; df = 6316; *p* > 0.28), or cotton yield (F > 0.60; df = 6333; *p* > 0.73). There was a significant

interaction (F = 5.56; df = 1339; *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 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 4).

Table 4. Interaction of tillage and nematicide on plant vigor at the 1–2 cotton leaf stage in Hamilton, MS during 2015 and 2016.

Treatment		Vigor (±SE) [ab]
No Tillage	No 1,3-dichloropropene	5.83c (0.12)
Conv. Tillage	1,3-dichloropropene	6.81a (0.15)
No Tillage	1,3-dichloropropene	6.11b (0.13)
Conv. 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. [b] lant vigor ratings are based on a 1 (poor, uniform stand) to 10 (excellent, uniform stand) scale.

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 = 6339; *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 3). When evaluating plant vigor at the 3–4 leaf stage, there were no significant interactions between factors (F > 0.48; df = 6339; *p* > 0.44), nor a significant difference for nematicide (F = 1.14; df = 1339; *p* = 0.29). Again, cotton vigor was greater when grown in the conventional tillage plots compared to the no-tillage plots (F = 283.34; df = 1339; *p* < 0.01) (Table 3).

Tillage (F = 4.08; df = 1, 341; *p* < 0.01), nematicide (F = 0.06; df = 1341; *p* = 0.01), and at-planting insecticide treatments (F = 8.73; df = 6341; *p* < 0.01) had significant effects on total dry plant biomass per five plants (Table 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 was no differences in cotton yield associated with tillage (F = 1.99; df = 1333; *p* = 0.16) or at-planting treatment (F = 0.62; df = 1333; *p* = 0.71). However, nematicide treatments significantly impacted yield (F = 15.91; df = 1333; *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).

Table 5. Impact of tillage, nematicide, and at-planting insecticide seed treatment on the total dry plant biomass at the 4th cotton 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.

4. Discussion

In this research, there were no significant interactions between tillage, nematicide, and 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 [23,44–47]. Numerous studies support both the benefit of conventional and minimum tillage systems in the management of nematodes. For example, Thomas [48] 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. [49] 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 root's 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 [23]. 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 [23]. 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 options in nematode management 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. Numerous studies support 1,3-dichloropropene, aldicarb, and terbufos as effective chemical options for suppressing nematode populations and protecting yields [13,50].

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 to 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 [26]. North et al. [51] found an average increase of 115 kg lint ha^{-1} across 100 mid-south test locations when utilizing an insecticide seed treatment compared to the fungicide alone. 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 [52,53]. 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 [7,54]. There are a number of factors that influence the plant's ability to compensate, including but not limited to soil fertility, damage timing and severity, and environmental conditions [55–57]. Optimal environmental conditions over the course of the study aided in the plant's ability to compensate for 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.

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