Studies on the Use of Soil Edaphic Factors for the Development of Site Specific Management Strategies for *Rotylenchulus reniformis* on Cotton

by

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Abstract

The reniform nematode, *Rotylenchulus reniformis*, is currently one of the most limiting factors to cotton production in the United States. With no available commercial host plant resistance, options for management of *R. reniformis* are limited to the use of rotations with non-hosts and the use of nematicides, each of which varies greatly in cost-savings and effectiveness. Site-specific application is used for a wide variety of agricultural practices, and successful programs for other species of nematodes in cotton, such as *Meloidogyne incognita* and *Hoplolaimus columbus,* are currently in use. The future of site-specific management for *R. reniformis* in cotton depends on determining which soil factors can be utilized to predict damage and the development of reliable recommendations based on this knowledge. The first half of this dissertation focuses on soil texture distribution and its effect on the cotton/*R. reniformis* interaction both directly and with respect to its influence on soil moisture availability. The second half focuses on utilizing soil texture to create management zones within cotton production systems for maximum yield and cost savings. Through these studies, a greater understanding of the differential effects of soil texture on the cotton/*R. reniformis* interaction is achieved as well as solutions for production scale management of *R. reniformis* in cotton.

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Chapter 1

Rotylenchulus reniformis in Cotton: Current Methods of Management and the Future of Site-Specific Management

Abstract

The reniform nematode, *Rotylenchulus reniformis*, is currently one of the most limiting factors to cotton production in the United States. With no available commercial host plant resistance, options for management of *R. reniformis* are limited to the use of rotations with non-hosts and the use of nematicides, each of which varies greatly in cost-savings and effectiveness. Multiple research groups are currently pursuing the goal of site-specific management for *R. reniformis* in cotton. Site-specific application is used for a wide variety of agricultural practices, and successful programs for other species of nematodes in cotton, such as *Meloidogyne incognita and Hoplolaimus columbus*, are currently in use. Within this manuscript, future possibilities for the use of site-specific management for *R. reniformis* in cotton as well as potential limitations of current techniques are discussed.

Cotton, *Gossypium hirsutum* Linnaeus, is one of the most economically important crops in the United States. In 2010, cotton was grown in 17 states with 11 million acres devoted to cotton production valued at more than $7.3 billion (USDA-NASS, 2011).

The reniform nematode, *Rotylenchulus reniformis* Linford & Oliveira, is a semi-endoparasite of roots that occurs in tropical and sub-tropical regions (Robinson *et al*., 1997) and is a major pathogen affecting U. S. cotton. Currently, *R. reniformis* can be found in 11 of the 17 cotton producing states and is estimated to have caused a loss of nearly 2% annually in the past decade (Blasingame *et al*., 2002 – 2012).

Rotylenchulus reniformis is easily introduced into cotton fields on contaminated equipment and other means of soil transport. Once there, it can be spread throughout the field by tillage and water flow (Monfort *et al*., 2008; Moore *et al*., 2011a); however, in no-till systems, *R. reniformis* can spread independently both horizontally and vertically (Moore *et al*., 2010a). Vertical distribution has been well documented at depths of up to 1.5 m (Lee *et al*., 2002; Moore *et al*., 2010a; Robinson *et al*., 2005a; Westphal & Smart, 2003; Westphal *et al*., 2004), and populations below the plow layer can greatly affect cotton yields (Newman & Stebbins, 2002; Robinson *et al*., 2005b).

Currently, there are no commercial cotton cultivars with resistance or consistent tolerance to *R. reniformis* (Usery *et al*., 2005; Robinson, 2007). As such, management options for *R. reniformis* fall into two major categories: pesticides and crop rotation. There are many forms of pesticides available for the management of *R. reniformis.* Each varies in effectiveness and each has its limitations. Fumigants such as 1,3-dichloropropene (Telone II) and metam sodium (Vapam) are generally highly effective for management of *R. reniformis* (Kinloch & Rich, 2001; Koenning *et al*., 2007; Lawrence *et al*., 1990; Rich & Kinloch, 2000). They are often limited by cost, high risk to applicators, special application equipment, soil texture, and temperature and moisture requirements.

An assortment of granular pesticides have been proven effective for the management of *R. reniformis*, including aldicarb (Temik 15G) (Lawrence *et al*., 1990; Lawrence & McLean, 2000, Rich & Kinloch, 2000), fenamiphos (Nemacur) (Koenning *et al*., 2007; Lawrence *et al*., 1990), and terbufos (Counter) (Lawrence *et al*., 1990). Of the granular pesticides, aldicarb has been the most widely used in cotton production, and its continual use has resulted in reports of enhanced degradation by soil microbes thus decreasing its overall efficacy (Lawrence *et al*., 2005). Furthermore, the future of this pesticide is currently unknown due to the discontinuance of its production (Bayer CropScience, 2010). Similarly, fenamiphos is no longer labeled for use in the United States (EPA, 2002), and terbufos is not currently labeled for use in cotton production.

Seed applied pesticides such as abamectin and thiodicarb have recently become widely used in cotton production as a part of Avicta Complete Cotton and Aeris Seed Applied System, respectively, and have been reported to provide adequate management of *R. reniformis* (Faske & Starr, 2006; Lawrence & Lawrence, 2007). Their protection of the root is limited (Faske & Starr, 2007) as is their ability to provide adequate protection against high populations of *R. reniformis* (Moore *et al*., 2010b).

Oxamyl (Vydate C-LV) is a foliar applied pesticide that also provides adequate management of *R. reniformis*, often in conjunction with previously mentioned pesticides (Baird et al., 2000; Lawrence & McLean, 2000), but has been reported to be less effective in dry conditions (Koenning *et al*., 2007). Additional options for *R. reniformis* management in the form of biological organisms, such as *Bacillus firmus* (Poncho/VOTiVO) and *Paecilomyces lilacinus* strain 251 (Nemout) as seed applied formulations (Castillo *et al*., 2011), have been reported to have efficacy against *R. reniformis*. Furthermore, there are multiple known nematophagous fungi with high levels of effectiveness in greenhouse studies (Wang *et al*., 2004; Castillo *et al*., 2009) that could prove useful in the future. Overall, the number of pesticides for the management of *R. reniformis* is decreasing, resulting in increased challenges for producers.

Crop rotation to non-hosts, such as corn or peanuts or highly resistant varieties of soybean, is also an effective strategy for the management of *R. reniformis*. A one year rotation with corn and resistant soybean effectively increases cotton yields (Davis *et al*., 2003; Moore *et al*., 2010c); however, populations of *R. reniformis* quickly rebound to pre-rotational crop levels by mid-season. A two year or longer rotation with corn or resistant soybean or a one year or longer rotation with peanuts can result in *R. reniformis* populations remaining below current economic thresholds throughout the subsequent cotton crop (Stetina *et al*., 2007; Moore *et al*., 2010c). Many native weed species are host of *R. reniformis* to some degree and can confound the aforementioned positive effects of crop rotation if not properly controlled (Davis & Webster, 2005; Jones *et al*., 2006; Lawrence *et al*., 2008; Wang *et al*., 2003).

The methods currently used to manage *R. reniformis* in cotton can be economically beneficial if utilized intelligently and with forethought. For a problem that is consistently increasing, further management strategies are needed. Site specific, or precision, management (SSM) is a concept that is increasingly utilized since being made possible by the integration of global positioning systems (GPS) technologies into agriculture. The use of SSM based on soil variability as a strategy to enhance the management of *R. reniformis* has developed into a subject of great interest in recent years. In this review, the current methods of zone delineation for SSM and their uses will be discussed along with the potential for use of known factors affecting *R.*

reniformis and its interaction with cotton. The pitfalls of SSM in regards to its use for *R. reniformis* management also will be addressed, as will an evaluation of the feasibility of using current methods of SSM for *R. reniformis*. Finally, we will determine what information is still required to facilitate a workable guideline for implementing SSM for *R. reniformis*.

The delineation of management zones for SSM based on soil variability has been a topic of research for decades. A management zone can be defined as a sub-region of a field that expresses a homogeneous combination of yield limiting factors for which a single rate of a specific crop input is appropriate (Doerge, 1999). The development of management zones requires the use of some form of geostatistical analysis. There are many different methods of geostatistical analysis, both descriptive and predictive, that can be used alone or in combination, depending on the situation. Descriptive methods of geostatistical analysis allow for the detection and quantification of the major scales of spatial variability (Goovaerts, 1998). Examples of such descriptive methods include the experimental correlogram, which plots the estimated correlation coefficients of one variable as a function of the separation distance, and the experimental semivariogram, which plots the semivariances of ordered data versus distance (Goovaerts, 1998). Predictive methods are utilized in the estimation of soil properties at un-sampled places between or near collected data points. Examples of predictive methods of geostatistical analysis include ordinary kriging, which estimates the value of an un-sampled location as a linear combination of neighboring observations, and factorial kriging, which estimates and maps different sources of spatial variability identified by experimental semivariograms (Wackernagel 1988, 1995; Goovaerts, 1992).

Prescription maps began development based on soil type (Carr *et al*., 1991) or topography (Fiez *et al*., 1994). Further research has developed prescription maps on a collection of characteristics including soil type, soil color, topography, yield, aerial photos, and producer experience (Ostergaard, 1997; Fleming *et al*., 2004). The use of soil apparent electrical conductivity (EC) has become one of the most frequently used methods of management zone delineation based on soil variability. Apparent electrical conductivity has been found to correlate highly with soil texture (Williams & Hoey, 1987). It also relates closely with a variety of other characteristics including: cation exchange capacity and exchangeable Ca and Mg (McBride *et al*., 1990), water content (Kachanoski *et al*., 1988), soil organic C (Jaynes, 1996), herbicide behavior in soil (Jaynes *et al*., 1994), depth to clay pans (Kitchen *et al*., 1999), and crop yield (Sudduth *et al*., 1995; Heermann *et al*., 1999).

The geostatistical analysis of soil properties and the subsequent delineation of management zones have proven effective in a variety of situations worldwide. Casa & Castrignano (2008) demonstrated the spatial relationships between soil and crop variables of durum wheat in Italy. Rab *et al*. (2009) utilized geostatistical modeling of plant-available water capacity and related soil properties to delineate management zones for the enhancement of grain yields in Australia. Liu *et al*. (2006) explored the possibilities of combining ordinary kriging with soil map-delineation to enhance the interpolation of soil properties in a paddy rice/sugarcane rotation in Taiwan. Lopez-Lozano *et al*. (2010) successfully linked leaf area index with soil properties for precision management of abiotic stress of corn in Spain. In the U. S., management zones based on soil characteristics have been used to predict grain yields (Fraisse *et al*., 2001) and determine the risk of iron chlorosis in maize (Kyaw *et al*., 2008).

The use of geostatistical analysis and management zone delineation also has recently been developed for the management of the Columbia lance nematode (*Hoplolaimus columbus*), the root-knot nematode (*Meloidogyne incognita*), and the ring nematode (*Criconemella* spp.)

(Khalilian *et al*., 2001; Khalilian *et al*., 2002; Khalilian *et al*., 2003; Monfort *et al*., 2007; Ortiz *et al*., 2007; Ortiz *et al*., 2008; Wolcott *et al*., 2004; Wolcott *et al*., 2005). Khalilian *et al*. (2003) reported a 5% yield increase using either variable rate aldicarb or 1,3-dichloropropene for Columbia lance management with a 34% and 78% reduction of input, respectively. Monfort *et al*. (2007) observed that the combination of the initial populations of root-knot nematodes and the sand content of the soil explained 65%, 86%, and 83% of the variation in cotton yield over a three-year period, respectively. Similarly, Ortiz *et al*. (2007) observed that a model of root-knot nematode risk of a field over a specific threshold value could be produced through logistic regression using soil electrical conductivity as a predictor variable. Furthermore, it was determined that the use of variable rate application of nematicides could be effectively employed to manage root-knot nematodes in cotton (Ortiz *et al*., 2008).

Although there are several successful examples of site-specific management of nematodes, there are studies that address certain pitfalls of this technique. Wyse-Pester *et al*. (2002) conducted a study to determine the scale of sampling required to obtain correlated observations of density in order to reduce sampling costs for three species of nematodes on corn. The results of the study indicated that correlations between nematode density and soil attributes were inconsistent between field and species, and thus the cost of sampling was not reduced. Similarly, Evans *et al*. (2002) found that coarse sampling grids, which are required to make SSM a commercially viable option for the management of potato cyst nematodes (*Globodera pallida* and *G. rostochiensis*), are likely to produce misleading population distribution maps resulting in yield penalties. Farias *et al*. (2002) were able to construct an accurate distribution model of *R. reniformis* within a cotton field; however, the number of sampling points used (64 points within a 48 x 32 m area) would be cost prohibitive in a commercial setting. In a study assessing sampling grid size for variable rate application of nematicides for the management of *R. reniformis*, Ellis *et al*. (2004) found that fewer rate changes occurred with increasing grid size. This relationship has one of two possible consequences. The first is increased input of nematicides where they are not needed, which would result in a cost penalty. The second consequence would be not applying nematicides where needed, which would result in a yield penalty.

Technological pitfalls are also a possibility in the development of site-specific management. Choosing the correct analysis of spatial data is vital to producing accurate prescription maps. In a study of the accuracy of interpolating elevation data, a measurement commonly used in conjunction with EC for management zone delineation, Weng (2006) determined that accuracy was subject to a number of interpolation parameters that may significantly improve or worsen the accuracy. Similarly, it has been reported that apparent soil electrical conductivity is affected by soil transient properties such as volumetric soil water content and exhibits large changes throughout the season (McCutcheon *et al*., 2006). Factors such as these can result in unreliable data and must be considered during management zone creation.

To create management zones within a field for *R. reniformis*, the factors of influence must first be characterized through quantitative research and then the data can subsequently developed into a useable form. As was discussed earlier, soil texture distribution can be easily measured within a field by utilizing soil apparent electrical conductivity and has been used in management strategies for other species of nematodes. Consequently, this factor has been investigated as a starting point for zone delineation for *R. reniformis*. While *R. reniformis* is known to exist and cause damage in a wide variety of soil types (Gazaway & McLean, 2003), some research has suggested that *R. reniformis* is more prevalent in fine-textured soils (Robinson *et al*., 1987; Starr *et al*., 1993; Monfort *et al*., 2008). Other research on the effects of soil type on *R. reniformis* populations has suggested that the productivity of the soil, not specifically soil texture, is the driving force behind population development (Koenning *et al*., 1996; Herring *et al*., 2010) as well as response to nematicides (Overstreet *et al.*, 2007, 2011, & 2012).

Another consideration for zone delineation is initial populations of *R. reniformis* and economic damage threshold values. More often than not, management decisions and subsequently economic threshold values are based on post-harvest nematode sampling. Although little is known about the overwinter survivorship of *R. reniformis*, it has been observed that overwinter survivorship was lowest in areas of high sand content and increased with increasing clay content (Still & Kirkpatrick, 2006). Studies of overwinter survivorship on *Meloidogyne incognita* have suggested that population density and cultural practices have the greatest impact on overwinter survivorship (Ferris, 1985). Studies have shown that *R. reniformis* populations are adversely affected by post-harvest conventional tillage compared to non-tillage and ridge tillage (Cabanillas, *et al*., 1999). Economic thresholds are established based on the relationships between the degree of control and cost and nematode densities and crop value (Ferris, 1978). Current thresholds are established on a state-by state basis, but it has recently been suggested that different economic thresholds be considered based on soil type and productivity (Moore *et al*., 2011b).

Studies exploring the possibilities of SSM and variable rate nematicide applications for *R. reniformis* have been conducted in recent years. Variable rate application based on populations of *R. reniformis* have been conducted with the fumigant nematicides 1,3-dichloropropene and metam sodium with promising results (Lawrence *et al*., 2002; Ellis *et al*., 2005). Farias *et al*. (2002) created a risk-benefit analysis for the treatment of *R. reniformis* in a Brazilian cotton field by utilizing geostatistical methods to interpolate population distribution over short distances (4-6 m). Another tool in development is the use of remotely sensed hyperspectral data to detect stress levels in cotton. Doshi *et al*. (2010) conducted a study comparing hyperspectral reflectance of cotton plants grown in microplots to *R. reniformis* populations in the plant rhizosphere and determined that this method could accurately estimate *R. reniformis* populations affecting the cotton plant. The use of remote sensing to detect cotton plant stress due to issues with subsurface drip irrigation has also illustrated this tool's ability to detect differences in cotton response to stress in field settings (Fulton *et al*., 2008).

The successful use of site-specific management for *R. reniformis* on cotton is dependent on the resolution of several issues. The first and most important issue is to what spatial scale (single field, soil region, state, etc.) can general recommendations be developed and be reliable? Second, what parameters, or combination of parameters, will provide the most accurate measure of economic risk and subsequent usefulness in management zone creation? Third, can the two aforementioned issues be resolved in a manner which will result in a method that is easily adaptable for producers and will provide them with cost savings?

The issue of the size of the spatial scale upon which to separate recommendations includes two major considerations. *R. reniformis* is known to have geographical variation with respect to reproduction, pathogenicity, morphometrics, temperature effects on embryogenesis, and genetics (Agudelo *et al*., 2001; Agudelo *et al*., 2005; Arias *et al*., 2009; Leach *et al*., 2009; McGawley *et al*., 2010), some of which vary within a single state. A second consideration is the diversity of soils within regions and states. For example, Alabama has six major soil areas where cotton is produced, each with quite different characteristics and levels of in-field variability. It is also well known that certain soils, such as those found in the Mississippi River Delta region, support far greater populations of *R. reniformis* in comparison to the soils found in the Coastal Plain region of the Southeast, yet the amount of yield loss in each region is similar.

The second issue is which parameters provide the best indicators of economic risk and subsequent usefulness in management zone creation? As was detailed earlier, soil texture distribution has been studied quite extensively in relation to predicting which location in a field is more favorable to *R. reniformis* reproduction. While this technique has been used successfully for other species of plant-parasitic nematodes, the success of *R. reniformis* to reproduce and cause damage in a wide variety of soil textural distributions renders this method much less useful. Economic threshold level of *R. reniformis* is another parameter to be considered. Potential soil productivity has been shown to affect this relationship (Moore *et al*., 2011a) as well as the possibilities of additional stress due to the lack of water throughout the growing season (Moore *et al*., 2011c). The use of yield maps from previous years, if they exist, is another strong possibility for guidance of zone creation. Massey *et al*. (2008) determined that utilizing yield maps to assess profitability of corn, soybean, and grain sorghum based on field features and input costs could provide producers with information to assess management options.

Can SSM for *R. reniformis* on cotton become an easily adaptable and cost-saving tool for cotton producers? The answer depends on two major issues; spatial scale and zone creation parameters. Spatial scale and zone creation parameters are currently a focal point of research throughout areas affected by *R. reniformis*. Furthermore, many of the techniques for site-specific management are used for a variety of other issues and could be easily adapted with the correct guidelines. The identification of parameters to quantify economic risk and the understanding of how these parameters will differ over geographical areas will determine if SSM can enable cotton producers to gain an economic advantage over *R. reniformis*.

Chapter 2

The Effect of Soil Texture on the Interaction of *Rotylenchulus reniformis* and Cotton

Abstract

The reniform nematode, *Rotylenchulus reniformis*, is the most damaging nematode pathogen of cotton in Alabama. The use of soil texture is currently being explored as a basis for the development of economic thresholds and management zones within a field. Trials to determine the reproductive potential of *R. reniformis* as influenced by soil type and irrigation were conducted in both microplot and greenhouse settings in 2008 – 2010. Irrigation was found to have a significant effect on *R. reniformis* population in only isolated cases early in the growing season. However, plant parameters were significantly increased by irrigation throughout the growing season. Populations of *R. reniformis* were significantly influenced by soil texture and exhibited a general decrease with increasing median soil particle size. Early season cotton development was significantly affected by increasing *R. reniformis* populations, with plant shoot weight/root weight ratios increasing at low *R. reniformis* populations and declining with increasing *R. reniformis* populations. Soil texture in combination with other soil properties can be a useful tool for developing management strategies for *R. reniformis* on cotton.

Introduction

Site-specific management of the reniform nematode, *Rotylenchulus reniformis* Linford & Oliveira is a developing management strategy for cotton (*Gossypium hirsutum* Linnaeus) growers. This strategy has been successfully employed for other species of nematode such as the southern root-knot (*Meloidogyne incognita*, Kofoid & White) and Columbia lance nematodes (*Hoplolaimus columbus* Sher) by delineating management zones based on various soil edaphic factors and assigning a risk level to each zone. However, for the reniform nematode, which soil characteristic, or combination of characteristics, constitutes a higher or lower risk is not well defined.

One such factor, soil texture, is often used as a starting point for zone delineation for current nematode management. A basic particle size distribution can be determined using apparent soil electrical conductivity and, along with factors such as elevation and slope, be used to create management zones within a field. The use of particle size distribution has been shown to be effective in assessing risk for both the southern root-knot and Columbia lance nematode. Both species exhibit a strong preference to soils with high sand content (Koenning et al. 1996; Lewis and Smith 1976), and as such zone delineation using soil texture as a main factor is highly useful. Alternatively, a 1990 survey of 11 states to determine the agronomic significance of the reniform nematode found no consistent relationship between the reniform nematode's presence and soil texture, soil pH, rainfall, or irrigation regime (Heald and Robinson 1990). Subsequently, the reniform nematode has been observed to prefer soils with less than 40% sand content (Starr et al. 1993); with moderate clay + silt percentages (28%) (Koenning et al. 1996); and with silt percentages ranging from 54 – 60% (Monfort et al. 2008). Within Alabama, the reniform nematode is known to exist above current economic thresholds in a wide variety of soils

(Gazaway and McLean 2003), and although populations are generally observed to be higher in finer texture soils, the impact of these differing populations on cotton yield is difficult to compare due to environmental factors. In order to further our understanding of the effects of soil texture on the reniform/cotton relationship either for management zone delineation or to make management recommendations based on nematode population, a comparison of soils unbiased by environmental factors must be conducted. As such, the objectives of the trials presented here were to evaluate six different soil types representative of the major agronomic regions of Alabama to determine 1) population potential of *R. reniformis* under irrigated and non-irrigated conditions and subsequent effects on cotton yield; and 2) the effects of increasing initial populations of *R. reniformis* on early season cotton growth.

Materials and Methods

Two trials were conducted during 2008 – 2010 in six different soil types from the major field crop cultivated regions of Alabama to evaluate the effect of soil particle size on 1) the reproductive potential of the reniform nematode on cotton over a three-year period from a standardized initial population under both irrigated and non-irrigated conditions; and 2) the reproductive potential of the reniform nematode on cotton and its effects on early season cotton development from differing initial populations. The soil types used in the trials were Decatur silt loam (18-49-33 S-S-C, 1.0% OM, pH = 5.5), Hartsells fine sandy loam (66-21-13 S-S-C, 2.7% OM, pH = 5.4), Vaiden clay (9-53-38 S-S-C, 3.8% OM, pH = 6.1), Lloyd loam (38-35-27 S-S-C, 2.0% OM, pH = 5.5), Dothan sandy loam (82-11-7 S-S-C 0.6% OM, pH = 5.9), and Ruston very fine sandy loam (64-21-15 S-S-C, 1.6% OM, pH = 5.8). Soils were collected from the plow layer (top 12 – 15 cm) of the soil in cultivated fields free of plant parasitic nematodes. Soils were analyzed for nutrient and pH levels and maintained according to standard recommendations set by the Auburn University Soil Testing Laboratory (Adams et al., 1994). Both trials were conducted at the Auburn University Plant Science Research Center in Auburn, AL.

Microplot Trial: The first trial was conducted from 2008 – 2010 in 4,400 cm^3 outdoor microplots arranged in a completely randomized 6 x 2 factorial design replicated 5 times with the first factor designated as soil type and the second factor designated as irrigation. Pots were planted each season with DP161B2RF cotton. Immediately after planting in 2008, 5,000 vermiform life stage *R. reniformis* nematodes were pipetted into to each pot in 10 ml of water into the seed row. Irrigation was added by hand watering the irrigated pots twice a day throughout the season to maintain adequate moisture availability. Cotton plants were evaluated at 60 and 150 days after planting (DAP) for height, and the cotton was hand-picked as bolls matured (120 - 150 DAP) and weighed. The *R. reniformis* nematode populations were evaluated at planting, 60, and 150 DAP by taking four 2.5 x 12 cm core samples from each pot. The four samples were homogenized and the nematodes extracted by combined gravity screening/sucrose centrifugation and enumerated. Eggs were extracted by agitating the root system on an orbital shaker at 150 rpm for 4 minutes in a 0.6% sodium hypochlorite (NaOCl) solution and collected on a 25 µm screen.

Greenhouse Trial: The second set of trials to determine reproductive potential with varying initial nematode populations were conducted in 2010 using 500 cm^3 polystyrene pots placed in the greenhouse. The tests were arranged in a randomized complete block design with four replicates and repeated twice. At planting, six levels of reniform nematodes were added to the designated pots: 0, 500, 1000, 2000, 5000, and 10000 vermiform life stages were pipetted into each pot in 2 ml of water. Pots were planted with DP161B2RF cotton seed. Plant parameters measured included plant height at 30 and 60 DAP as well as root and shoot fresh weight at 60 DAP. Shoot/root ratios indicating plant development were calculated by dividing the shoot fresh weight by the root fresh weight. Reniform nematode populations were extracted and enumerated at 60 DAP using the previously described methods.

Particle Size Analysis: Analysis of soil particle size distribution was conducted using the nested sieving (2.0 – 0.02 mm fraction) and pipette method (< 0.02 mm fraction) (Gee and Bauder, 1994). Median soil particle size (MSPS) of a soil was calculated as: MSPS = ∑ **[**Percent particles of each category (coarse sand, medium sand, fine sand, very fine sand, coarse silt, fine silt, or clay) **X** median size of that category (1.25mm, 0.75mm, 0.175mm, 0.075mm, 0.035mm, 0.011mm, or 0.001mm)**]** / 100. Full particle size analysis and median soil particle size for each soil are presented in Table 1.

Data were analyzed utilizing analysis of variance (ANOVA) within the GLIMMIX procedure or by linear regression within the REG procedure of SAS, version 9.2 (SAS Institute, Cary, NC). Treatment means were determined from the PDIFF option with LSMEANS, where $P \leq 0.05$ was required to be significant. Interactions between the treatment factors of soil and irrigation were not statistically significant for the microplot trials, and data were not analyzed separately. There were also no significant effects of year for the microplot trials, and thus the data for all three years was combined. Soil was a significant factor for the greenhouse trials; therefore, data for each soil type were analyzed separately. Mean populations or *R. reniformis* and shoot:root ratios at 60 DAP were plotted against initial populations of *R. reniformis*. Mean final populations (Pf) of *R. reniformis* were plotted against median soil particle size, and graphics were generated using Microsoft EXCEL.

Results

Microplot Trial: A soil type by irrigation interaction was not observed for nematode counts, plant heights, or seed cotton yields (Table 2). Irrigation did increase mean populations of *R. reniformis*. Irrigated pots averaged 45% higher *R. reniformis* populations at 60 DAP and were significantly higher in the silt loam and sandy loam soils. Irrigated pots averaged 50% higher *R. reniformis* populations at 150 DAP. The overwintering nematode populations were influenced by irrigation; averaging more than double the *R. reniformis* populations at cotton planting the following season and supporting significantly higher initial populations in the clay and silt loam soils.

Soil type also influenced *R. reniformis* populations. Between soil types, the silt loam soil averaged the highest *R. reniformis* populations at each sampling date in both irrigated and non-irrigated pots, respectively. The fine sandy loam soil followed the silt loam soil as the best soil for *R. reniformis* population densities over the three years. Initial, mid-season, and final population densities were consistently lower in the clay soil without irrigation.

Plant parameters were primarily affected by irrigation (Table 2). Plants were significantly shorter in the non-irrigated pots within each soil type at 60 DAP with the exception of the clay soil. The reduction of plant height in the silt loam through the sandy loam soil types averaged 5.35 cm with a range of 4.77 to 6.39 cm. Only the clay soil supported plant growth equally when infested with *R. reniformis* in the irrigated and non-irrigated systems. However, plant heights had equilibrated between all soils at cotton harvest.

Seed cotton yields in *R. reniformis* infested soils were influenced by irrigation (Table 2). Seed cotton yields were significantly higher in the irrigated pots containing the silt loam, the very fine sandy loam, and the sandy loam soils compared to the non-irrigated pots. Irrigation increased yields by 68% in these soils. The irrigated silt loam soil produced the highest yield compared to all soil types. This soil also supported the highest nematode populations throughout the season. No interactions between soil type or nematode populations and seed cotton yield were observed in this trial.

Greenhouse Trial: Cotton growth response to increasing initial populations (Pi) of *R. reniformis* was similar for all six soil types tested (Fig. 1). In each case, both shoot and root weight decreased at lowest inoculation level (Pi = 500) compared to the Pi=0; however, the decrease in root weight was double in magnitude compared to the decrease in shoot weight resulting in higher shoot weight to root weight ratios (Fig 2). As *R. reniformis* populations increased (Pi = 1,000 – 2,000), root weights steadily increased and at Pi = 10,000 averaged 41% higher compared to the root weights in the Pi= 500 treatment (not shown). Inversely, after increasing back to levels at Pi = 2,000 that were similar to the Pi = 0 control, shoot weights decreased with increasing nematode populations resulting in descending shoot weight to root weight ratios. These shoot to root weight ratios were significantly lower at Pi = 10,000 in the silt loam soil, Pi = 1,000 – 10,000 in the loam soil, and Pi = 5,000 – 10,000 in the sandy loam when compared to the Pi = 0 control. Final *R. reniformis* populations (Pf) in the soil increased significantly with increasing Pi. The clay soil supported the highest *R. reniformis* populations, while the very fine sandy loam supported the lowest.

Particle Size Analysis: The effect on soil particle size distribution on average final nematode populations (Pf) for both the microplot and greenhouse trials is shown in Figure 3. A quadratic relationship between final *R. reniformis* population density of a soil and the median particle size of a soil provided an acceptable fit (R^2 = 0.61, P = 0.0001), with the most favorable median particle size for *R. reniformis* population development within these trials being approximately 0.04 mm. In general, as the median soil particle size of a soil increased from 0.04 mm in the clay soil to > 0.30 mm in the very fine sandy loam and sandy loam soils, *R. reniformis* populations decreased. Although the initial classifications for the very fine sandy loam (64-21-15 S-S-C) and fine sandy loam (66- 21-13 S-S-C) used in our trial are very similar, a complete particle size analysis reveals the MSPS of the fine sandy loam (0.165 mm) is less than half that of the very fine sandy loam (0.336 mm). Consequently, *R. reniformis* populations within the fine sandy loam were more than 5x those in the very fine sandy loam. Thus the closer the median particle size of the soil is to 0.04 mm the greater the *R. reniformis* population development within these trials.

Discussion

"Of soil characteristics, texture is one of the most important. It influences many other properties of great significance to land use and management" (Brown 1990). Although within these trials and many others (Heald and Robinson 1990; Robinson et al. 1987; Starr et al. 1993; Koenning et al. 1996) *R. reniformis* has been shown to prefer soils with a smaller soil particle size distribution, the range at which this preference exists is still very wide. Additionally, *R. reniformis* has been reported to cause economic damage to cotton in a wide variety of soil types (Gazaway and McLean 2003). Within these trials, *R. reniformis* was shown to illicit similar plant responses in a wide variety of soils at far different population densities. The results suggests that even if *R. reniformis* prefers, or will reach higher population densities within, a certain soil the damage very well may be no greater than in a soil that is less preferential. Other qualities of a soil that are dictated by soil texture such as water holding capacity, nutrient availability, etc., may offer a beneficial growing environment to the cotton plant in a similar fashion as they provide benefit to the nematode.

The results from the microplot trials indicated that although the availability of water generally increased *R. reniformis* populations, in only the silt loam and sandy loam at 60 DAP were these increases significant. In the case of the silt loam soil, the irrigated pots produced the highest yields even in the presence of the highest nematode populations. However, in the non-irrigated pots, the silt loam again had the highest nematode populations but produced the lowest yields. Although this study did not address the differences of cotton yields in comparison to a nematode free control, the general trend suggests that the interaction of water and nematode stress is an important factor influencing cotton yield.

The growth patterns exhibited by the cotton in our greenhouse trials are consistent with previous findings on the differential effects of low and high *R. reniformis* populations on cotton. Koenning et al. (1996) reported that their findings suggested low Pi of *R. reniformis* may enhance plant maturity while high *R. reniformis* Pi may delay plant maturity. Although our trial focused on early season cotton growth, the effects of Pi produced a marked effect on cotton development.

The use of MSPS may lead to a better understanding of how soil particle size distribution of a soil can be used to predict *R. reniformis* population potential compared to previous methods. While our results are comparable to those previously mentioned (Starr et al. 1993; Koenning et al. 1996; Monfort et al. 2008) in that *R. reniformis* does prefer or possibly has an advantage in finer textured soils, the use of generic soil series information or basic particle size analysis (S-S-C) may not always be sufficient. Within this trial, the use of a basic particle size analysis for the very fine sandy loam and sandy loam suggests that those two soils should similarly affect *R. reniformis* populations. However, using a more in depth particle size analysis and MSPS revealed that they were in fact very different. This is not to suggest that MSPS explains all of the variability. Rather that it is another tool which could provide meaningful information in the attempt to develop management strategies for *R. reniformis.*

Rotylenchulus reniformis is a widely adapted pathogen in cotton production regions and is known to cause economic damage in many environmental conditions. Our results suggest that *R. reniformis* will cause comparable yield declines in a wide range of soil types even though population densities differ significantly. Additionally, the interaction of water stress and *R. reniformis* may be a more significant factor than water stress alone. Using soil texture to create management zones within a field is certainly a useful tool for site-specific management of *R. reniformis*. However, the properties of the soil in each zone, yield potential, the risk of water stress, and initial *R. reniformis* population must be considered and used to develop an economic threshold and management plan for each zone.

Table 1: Particle size analysis and median soil particle size for each soil type.

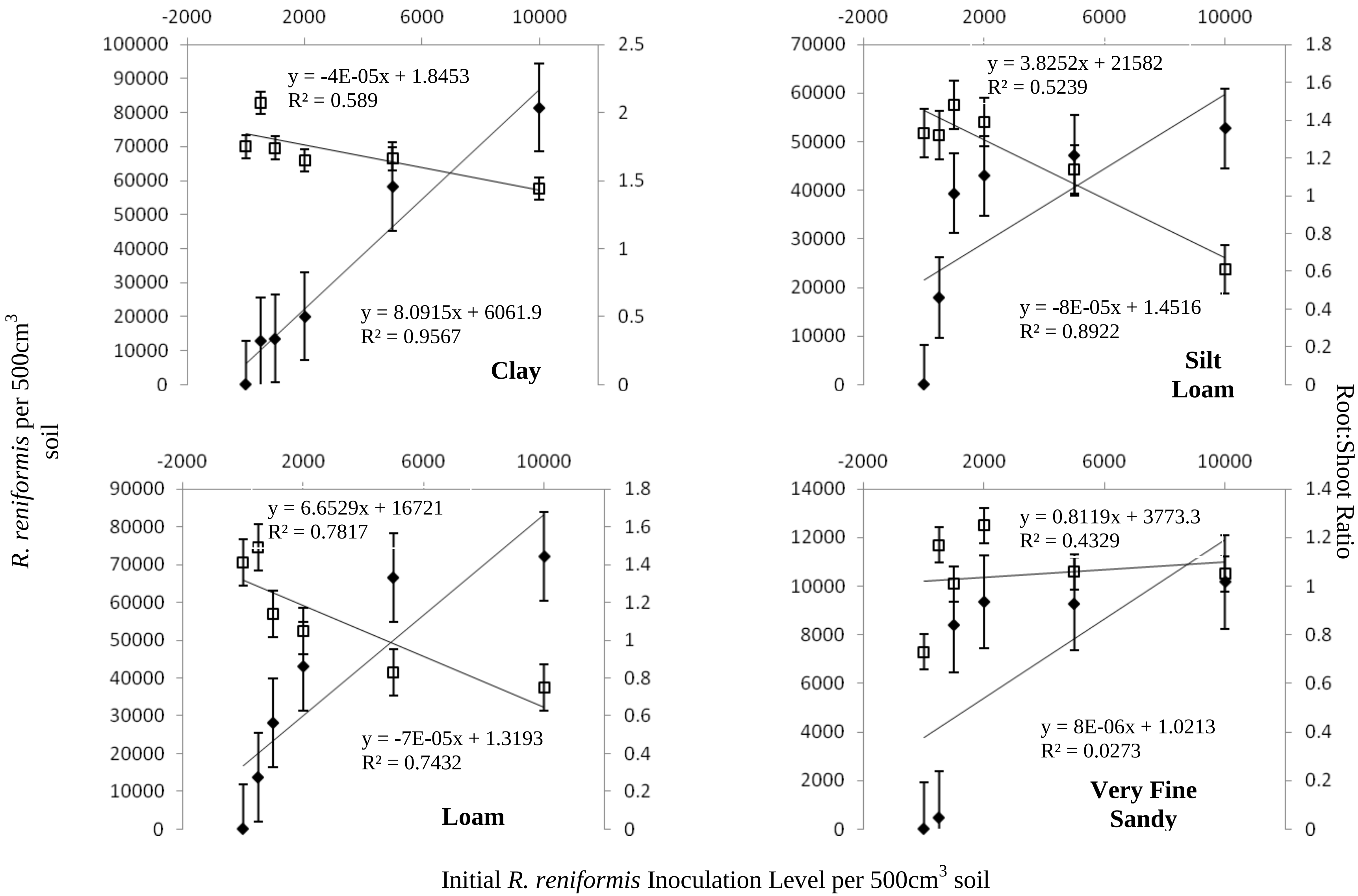
Soil	Particle Size [z]							MSPS (mm) [y]
	Coarse Sand 0.5 – 2.0 mm	Medium Sand 0.25 – 0.50 mm	Fine Sand 0.10 – 0.25 mm	Very Fine Sand 0.05 – 0.10 mm	Coarse Silt 0.02 – 0.05 mm	Fine Silt 0.002 – 0.02 mm	Clay < 0.002 mm	
Clay	1.06	1.14	2.12	5.14	8.78	43.85	37.92	0.038
Silt Loam	2.08	2.45	7.53	5.52	8.61	40.30	33.50	0.070
Loam	6.84	8.78	15.06	7.33	3.98	30.57	27.44	0.188
Very Fine Sandy Loam	8.43	23.96	23.98	7.93	4.47	16.12	15.11	0.336
Fine Sandy Loam	1.29	7.44	45.66	11.85	5.98	15.44	12.35	0.165
Sandy Loam	8.27	29.76	34.59	9.60	2.73	8.30	6.75	0.396

[z] Values are percent of particle size present for each soil.
[y] Median soil particle size calculated as (MSPS) = ∑ **[**Percent particles of each category **X** median size of each category**]** / 100.

Table 2: Mean *R. reniformis* populations at planting, 60 and 150 days after planting (DAP), plant heights at 60 and 150 DAP, and seed cotton yields (grams/plot) for each soil type and irrigation regime from 2008 – 2010.

		Rotylenchulus reniformis / 150 cm^3			Plant height (cm)		
Soil	Irrigation	Planting	60 DAP	150 DAP	60 DAP	150 DAP	Yield (g) [z]
Clay	Yes	865 b [y]	1379 bc	1978 bcd	29.28 abcde	47.31 abc	37.06 abc
	No	278 c	699 c	1011 d	27.92 bcde	45.32 bcd	29.77 bcd
Silt Loam	Yes	2233 a	2433 a	3404 a	31.25 ab	45.21 bcd	43.65 a
	No	950 bc	1661 b	2427 ab	24.86 e	45.19 bcd	22.3 d
Loam	Yes	657 bc	1058 bcd	2092 bc	30.10 abcd	47.27 abc	33.76 abc
	No	355 bc	908 bcd	1089 cd	25.33 e	42.39 cd	33.98 abc
Very Fine Sandy Loam	Yes	935 bc	1085 bcd	1414 bcd	30.35 ab	46.36 bcd	36.01 abc
	No	595 bc	653 c	1357 bcd	25.37 de	40.75 d	21.57 d
Fine Sandy Loam	Yes	1151 b	1321 bc	1628 bcd	32.94 a	49.78 ab	31.46 bcd
	No	479 bc	1020 bcd	1116 cd	27.64 bcde	47.74 abc	28.98 cd
Sandy Loam	Yes	579 bc	618 c	1567 bcd	31.21 ab	52.84 a	41.07 ab
	No	471 bc	545 d	1283 cd	25.88 cde	48.36 ab	28.95 cd
P-value	Soil	0.2973	0.0061	0.8425	0.7653	0.0586	0.8033
	Irrigation	0.0051	0.0196	0.1679	0.0002	0.0260	0.0010
	Soil*Irrigation	0.6035	0.8530	0.3757	0.8049	0.8502	0.1445

[z] Means in the same column followed by the same letter do not differ significantly (*P* ≤ 0.05) according to differences in least squares means.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R² = 0.589
y = 8.0915x + 6061.9
R² = 0.9567
Clay
y = 3.8252x + 21582
R² = 0.5239
y = -8E-05x + 1.4516
R² = 0.8922
Silt Loam
y = 6.6529x + 16721
R² = 0.7817
y = -7E-05x + 1.3193
R² = 0.7432
Loam
y = 0.8119x + 3773.3
R² = 0.4329
y = 8E-06x + 1.0213
R² = 0.0273
Very Fine Sandy
R. reniformis per 500cm3 soil
Root:Shoot Ratio
Initial R. reniformis Inoculation Level per 500cm3 soil

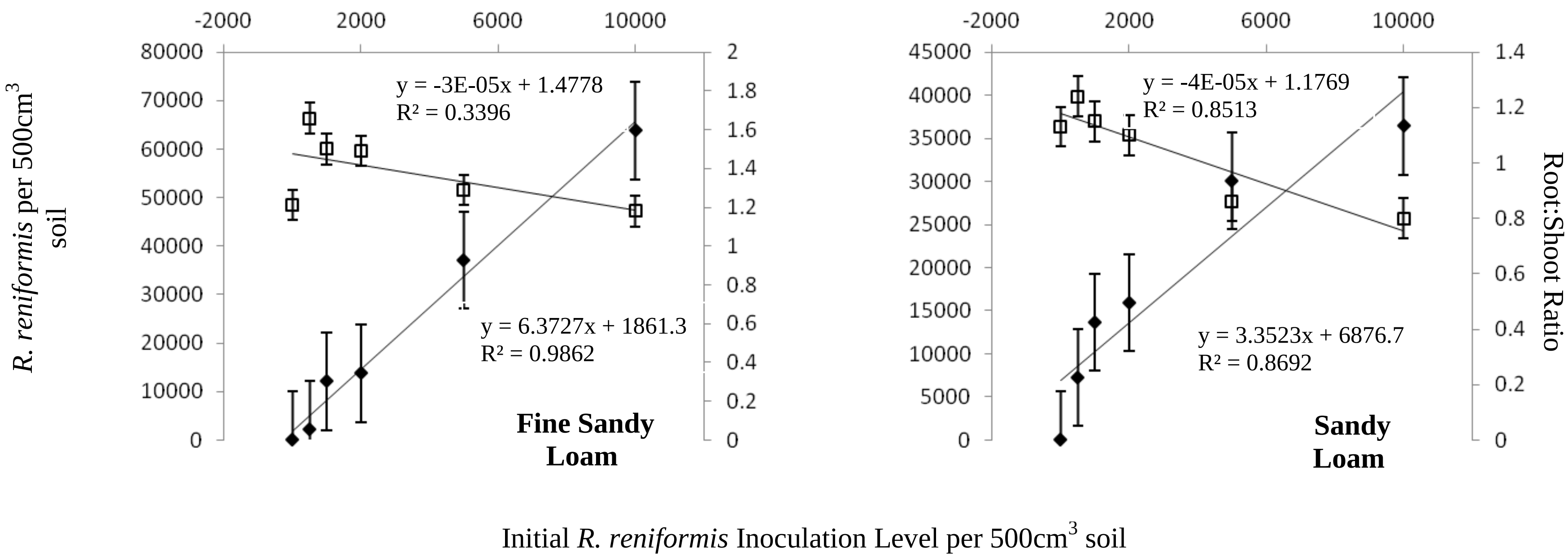

Figure 1. Mean *R. reniformis* populations per 500cm^3 of soil, ◆ , and plant shoot weight: root weight ratios, □, at 60 days after planting for each initial population of *R. reniformis* within each of the six soil types.

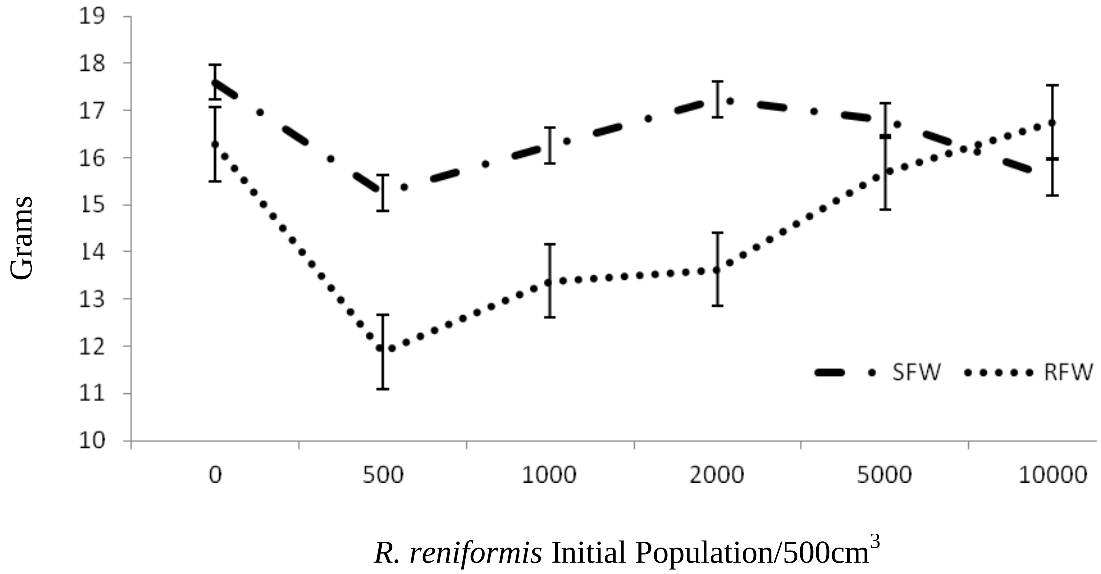

Figure 2. Average shoot fresh weight (SFW) and root fresh weight (RFW) (g) at each initial inoculation level of *R. reniformis* at 60 DAP.

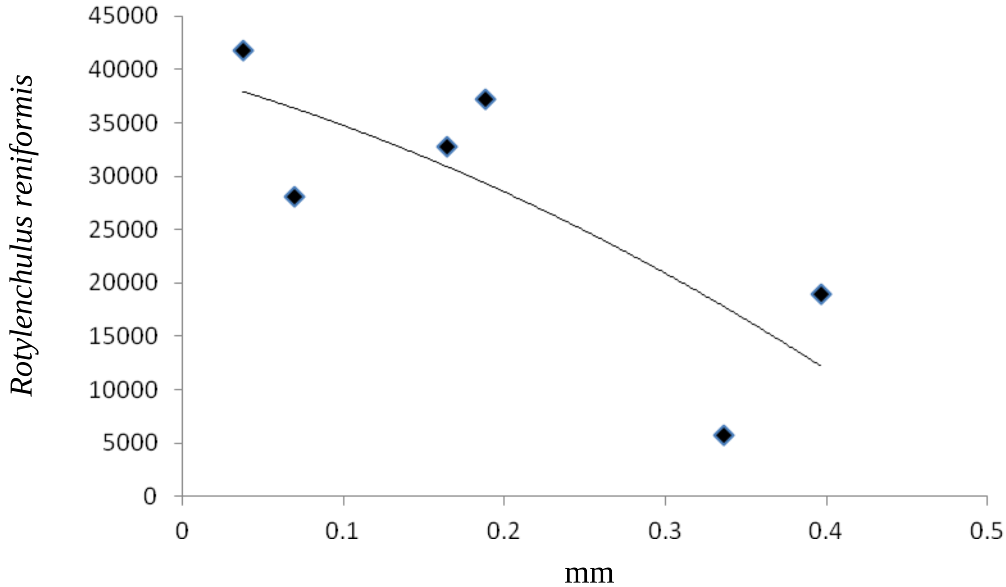

Figure 3. Influence of soil particle size on end of the year cotton harvest population densities of *Rotylenchulus reniformis*/150cm^3 of soil in six different soil types over a three-year period. The relationship between population density of *R. reniformis* (Y) and median soil particle size of a soil (X) was described by the quadratic model Y = 39,571 – 41,363x – 69,707x^2 (R^2 = 0.61, P = 0.0001). Median soil particle size (MSPS) of a soil was calculated as: MSPS = ∑ **[**Percent particles of a category (coarse sand, medium sand, fine sand, very fine sand, coarse silt, fine silt, or clay) **X** median size of that category (1.25mm, 0.75mm, 0.175mm, 0.075mm, 0.035mm, 0.011mm, or 0.001mm)**]** /100.

Chapter 3

The Effect of Soil Water Availability on the Interaction of *Rotylenchulus reniformis* and Cotton in Multiple Soil Types

Abstract

A trial to determine the effect of water availability on the interaction of *Rotylenchulus reniformis* and early season cotton growth was conducted in 2011. The trial was a 6x3x2 factorial design with six different soils (clay, silt loam, loam, very fine sandy loam, fine sandy loam, sandy loam), three different soil moisture potentials (-0.33 bar, - 1.00 bar, - 3.00 bar), and *R. reniformis* present or absent. At 30 days after planting (DAP), each plot was evaluated for *R. reniformis* density per gram of root and plant growth parameters. Water availability affected both *R. reniformis* populations and plant growth; however, the effects were different dependent on soil type. The density of *R. reniformis* per gram of root was significantly higher ($P < 0.05$) at – 3 bar in the fine sandy loam soil compared to – 0.33 bar. Conversely, *R. reniformis* density per gram of root in the sandy loam soil was significantly lower at – 3 bar compared to the other soil moisture potentials. All other soils supported comparable *R. reniformis* populations at each of the three moisture potentials. Plant growth exhibited a general increase with increasing water availability, and plants free of *R. reniformis* were, on average, numerically taller and had higher weights compared to those with *R. reniformis.* Although there were no significant differences in plant growth between nematode present/absent plots, when compared to the nematode free control, all soils presented a general trend of decreasing plant growth with increasing moisture availability in the presence of *R. reniformis*.

Introduction

The reniform nematode, *Rotylenchulus reniformis*, is the most damaging nematode pathogen of cotton in Alabama. Currently, site-specific strategies are being explored for the economic management of this pathogen. One of the many factors to consider when creating management zones is the potential of water stress. Moore et al. (2011c) reported that nematicides to control the reniform nematode resulted in a greater yield increase of cotton where the average seasonal volumetric water content of the soil was the lowest. The root-knot nematode (*Meloidogyne incognita*) can affect the maximum rate and cumulative amount of water flow within a cotton plant (Kirkpatrick et al., 1995) and the interaction of the root-knot nematode and water stress has been observed to negatively impact components of leaf water potential, leaf temperature, transpiration, and stomatal resistance of cotton (Kirkpatrick et al., 1991). Similarly, the interaction of root-knot nematodes and water stress was observed to negatively impact tobacco yields at both low and high water availability (Wheeler, et al., 1991). A study of the response of soybean in soybean cyst nematode (*Heterodera glycines*) infested soil at differing moisture potentials concluded that providing adequate moisture during the growing season may limit yield reductions caused by the soybean cyst nematode (Johnson, et al., 1994). The objective of this trial is to determine the effect of the reniform nematode on cotton crown at varying soil moisture potentials and how this effect may vary within a range of soil types.

Materials and Methods

A trial to determine the effects of soil moisture availability and *Rotylenchulus reniformis* on cotton in six different soil types was conducted in 2011 at the Auburn University Plant Science Research Center, Auburn, AL. The trial was arranged in a completely randomized 6x3x2 factorial design (6 soils, 3 moisture potentials, with and without *R. reniformis*) with four replicates. The soil types used in the trials were Decatur silt loam (18-49-33 S-S-C, 1.0% OM, pH = 5.5), Hartsells fine sandy loam (66-21-13 S-S-C, 2.7% OM, pH = 5.4), Vaiden clay (9-53-38 S-S-C, 3.8% OM, pH = 6.1), Lloyd loam (38-35-27 S-S-C, 2.0% OM, pH = 5.5), Dothan sandy loam (82-11-7 S-S-C 0.6% OM, pH = 5.9), and Ruston very fine sandy loam (64-21-15 S-S-C, 1.6% OM, pH = 5.8). Soils were collected from the plow layer (top 15 cm) of the soil in cultivated fields free of plant parasitic nematodes. Soils were analyzed for nutrient and pH levels and maintained according to standard recommendations set by the Alabama Cooperative Extension System. Three matric potentials, or plant available water, were determined for each soil type by creating a moisture release curve (Figure 4) and selecting the volumetric water content for each soil at matric potentials of -3.0, -1.0, and -0.33 MPa (Table 3), where -3.0 is the least amount of available water and -0.33 is nearing field capacity. Volumetric water content (VWC, m^3/m^3), or the fraction of total volume of soil that is occupied by the water contained in the soil, for each pot was monitored throughout the trial with EC-5 soil moisture sensors and logged with EM-50 dataloggers (Decagon Devices, Pullman, WA). Pots were maintained at the desired volumetric water content with a ¼ inch drip irrigation system controlled by a Rain Bird SST Series Automatic Sprinkler Timer (Rain Bird Corporation).

One thousand cubic centimeter polystyrene pots were planted with DP161B2RF cotton and 10,000 vermiform life stages of *R. reniformis* were added to the designated pots in 5 mL of water. Cotton plants were evaluated at 30 days after planting (DAP) for height, shoot fresh weight and root fresh weight. Populations of *R. reniformis* were appraised at 30 DAP by combined gravity screening/sucrose centrifugation and enumerated. Eggs were extracted by agitating the root system on an orbital shaker at 150 rpm for 4 minutes in a 0.6% sodium hypochlorite (NaOCl) solution and collected on a 25 µm screen. Nutrient content of the leaves and petioles of the cotton plants was conducted at the Auburn University Soil Testing Center in Auburn, AL. Plant material was dry-ashed in a muffle furnace at 500ºC for eight hours and digested using a 1N nitric acid and 1N hydrochloric acid solution. The resulting solution was subsequently filtered and analyzed for nutrient content by Inductively Coupled Plasma Emission Spectroscopy using a Varian Vista-MPX Radial Spectrometer.

Data were analyzed using analysis of variance (ANOVA) within the GLIMMIX procedure of SAS, version 9.2 (SAS Institute, Cary, NC). Treatment means were determined from the PDIFF option with LSMEANS, were $P \leq 0.05$ was required to be significant. There was a significant effect of soil type and as such each soil type was analyzed separately. Treatment means (with or without nematodes) for plant parameters were compared directly within each matric potential for each soil type. Mean numbers of *R. reniformis* per gram of root were compared between matric potentials within each soil type.

Results

Differences in water availability at -3.0, -1.0, and -0.33 MPa in these six soil types had little overall impact on nematode populations produced in one generation within this trial. No significant differences in the numbers of *R. reniformis* per gram of root were observed in the clay, silt loam, loam or very fine sandy loam at any of the three matric potentials (Table 4). Density of *R. reniformis* per gram of root was significantly higher at the -3.0 MPa matric potential compared to the -0.33 MPa matric potential in the fine sandy loam soil; however were significantly lower at -3.0 MPa matric compared to the other two matric potentials in the sandy loam soil.

Plant parameters exhibited a noticeable difference between soils due to the effects of soil moisture and nematode presence. The difference in average plant height between nematode present/absent pots was affected very little by water availability in the clay, silt loam, loam and very fine sandy loam. At each of the three matric potentials, -3.0, -1.0, and -0.33 MPa, the nematode absent pots produced 18, 17 and 20% taller plants in the clay soil compared to the nematode present pots, 13, 15 and 17% taller in the silt loam, 25, 25, and 25% taller in the loam, and 6, 11, and 10% taller in the very fine sandy loam, respectively. Conversely, in the sandy loam soil, plants at the -3.0 MPa moisture potential were taller in the nematode present pots by 13%. As more water became available at the -1.0 and -0.33 MPa matric potentials, the nematode absent pots had increased plant heights by 12 and 14% in the fine sandy loam and 2 and 26% in the sandy loam.

Differences in average shoot fresh weight were higher in the nematode absent pots at all matric potentials in the clay, silt loam, and loam soils by an average of nearly 27%. However, in the very fine sandy loam, the fine sandy loam, and the sandy loam soils, the nematode present pots had increased average shoot fresh weight at the -3.0 MPa matric potential by 7, 14 and 48%, respectively. As with the plant heights, as more water became available at the -1.0 and -0.33 MPa matric potentials, the nematode absent pots had increased shoot fresh weight compared with the nematode present pots. Concentration of nutrients in the cotton leaves and petioles showed no significant differences or trends in this trial (results not shown).

Discussion

The presence of *R. reniformis* within this trial caused early season cotton growth to exhibit a slight decline in overall plant growth as water became more available. However, the differences observed between soils suggests that water available to the plant may not have as much of an effect on *R. reniformis* as volumetric water content of a soil. For example, VWC at -3.0 MPa for the silt loam was 0.33 m^3/m^3 while for the sandy loam was 0.04 m^3/m^3. Although the plant available water is the same, the amount of water within the soil pores or the continuity of the water particles within the soil is not necessarily equal. Further study on the season-long effects of soil moisture availability is needed to determine the how these differences will affect cotton yields.

Table 3. Volumetric water content for each soil at each of the three matric potentials.

	Clay	Silt Loam	Loam	Very Fine Sandy Loam	Fine Sandy Loam	Sandy Loam
MPa	Volumetric Water Content (m^3/m^3)					
- 0.33	0.33	0.33	0.33	0.18	0.23	0.1
- 1.00	0.25	0.26	0.26	0.13	0.18	0.06
- 3.00	0.19	0.22	0.22	0.10	0.09	0.04

Table 4: Average cotton plant height, shoot fresh weight, root fresh weight, and numbers of *R. reniformis* per gram of cotton root for each soil at each matric potential.

Soil	MPa	Nematodes	Plant Height (cm)	95% Confidence Interval	Shoot Fresh Weight (g)	95% Confidence Interval	*R. reniformis*/ gram root	95% Confidence Interval
Clay	-3.00	Yes	9.8 ns*	(7.8, 11.8)	3.2 ns	(1.9, 5.1)	4257 a**	(1174.0, 15438.2)
		No	12.0	(10.0, 14.0)	4.3	(2.4, 7.2)	NA	NA
	-1.00	Yes	13.3	(9.0, 17.7)	5.1	(3.0, 7.2)	3783 a	(1043.1, 13718.5)
		No	16.1	(12.3, 19.8)	6.0	(3.9, 8.1)	NA	NA
	-0.33	Yes	14.5	(10.8, 18.2)	5.8	(2.8, 8.7)	7994 a	(2204.4, 28986.9)
		No	18.2	(14.5, 21.9)	8.2	(5.2, 11.2)	NA	NA
Silt Loam	-3.00	Yes	15.1	(11.5, 18.5)	5.0	(2.3, 7.6)	21772 a	(10624.3, 44613.9)
		No	17.3	(13.4, 21.2)	7.4	(4.5, 10.4)	NA	NA
	-1.00	Yes	17.6	(11.4, 23.8)	6.5	(1.4, 11.6)	18275 a	(8918.7, 37447.8)
		No	20.6	(14.4, 26.8)	9.2	(4.1, 14.3)	NA	NA
	-0.33	Yes	17.7	(11.0, 24.4)	5.6	(1.9, 9.3)	15992 a	(5852.4, 24575.4)
		No	21.4	(14.8, 28.1)	7.4	(3.7, 11.2)	NA	NA
Loam	-3.00	Yes	7.0	(6.0, 8.0)	1.1	(0.83, 1.33)	20906 a	(10201.6, 42843.1)
		No	9.3	(7.9, 10.3)	1.4	(1.15, 1.65)	NA	NA
	-1.00	Yes	7.1	(4.4, 9.7)	1.2	(0.6, 1.7)	20821 a	(10159.9, 42667.8)
		No	9.5	(8.4, 13.7)	1.7	(1.1, 2.2)	NA	NA
	-0.33	Yes	7.1	(5.0, 9.1)	1.2	(0.6, 1.8)	22071 a	(10750.4, 45147.9)
		No	9.5	(6.5, 10.5)	1.8	(1.2, 2.4)	NA	NA
Very Fine Sandy Loam	-3.00	Yes	11.8	(8.4, 15.1)	4.2	(2.5, 5.9)	5619 a	(3613.0, 7625.3)
		No	12.6	(9.2, 15.9)	4.0	(2.3, 5.7)	NA	NA
	-1.00	Yes	15.8	(12.6, 19.0)	5.7	(3.6, 7.8)	4268 a	(2261.5, 6273.7)
		No	17.8	(14.6, 21.0)	5.6	(3.5, 7.7)	NA	NA
	-0.33	Yes	18.1	(14.9, 21.3)	7.2	(5.3, 9.0)	3941 a	(1934.8, 5947.0)
		No	20.1	(16.9, 23.3)	8.7	(6.9, 10.6)	NA	NA
Fine Sandy Loam	-3.00	Yes	16.2	(10.9, 21.5)	9.1	(3.0, 15.2)	4755 a	(2983.9, 7577.2)
		No	16.1	(10.8, 21.4)	8.0	(1.9, 14.1)	NA	NA
	-1.00	Yes	27.4	(20.6, 34.2)	19.8	(13.4, 25.9)	4113 ab	(2581.2, 6554.4)
		No	31.3	(24.4, 38.1)	22.5	(16.2, 28.7)	NA	NA
	-0.33	Yes	26.8	(22.8, 30.8)	19.6	(14.6, 24.5)	2384 b	(1495.9, 3798.6)
		No	31.1	(27.2, 35.1)	25.6	(20.6, 30.6)	NA	NA

Soil	Matric	Nematodes	Plant Height (cm)	95% Confidence Interval	Shoot Fresh Weight (g)	95% Confidence Interval	*R.reniformis*/ gram root	95% Confidence Interval
Sandy Loam	-3.00	Yes	9.4	(5.9, 12.8)	3.1	(1.8, 4.4)	4371 b	(2616.5, 7302.0)
		No	8.3	(4.8, 11.7)	2.1	(0.8, 3.4)	NA	NA
	-1.00	Yes	11.4	(6.7, 16.0)	3.6	(1.6, 5.7)	9939 a	(5949.7, 16604.0)
		No	11.6	(6.9, 16.2)	3.7	(1.6, 5.7)	NA	NA
	-0.33	Yes	12.1	(8.3, 15.9)	4.4	(3.1, 5.7)	14256 a	(8533.0, 23813.3)
		No	16.4	(12.6, 20.2)	6.5	(5.2, 7.8)	NA	NA

*Means for plant parameters are compared directly within each matric potential within each soil type and means followed by the same letter do not differ significantly.

** Means for *R. reniformis* populations are compared between matric potentials within each soil type and means followed by the same letter do not differ significantly.

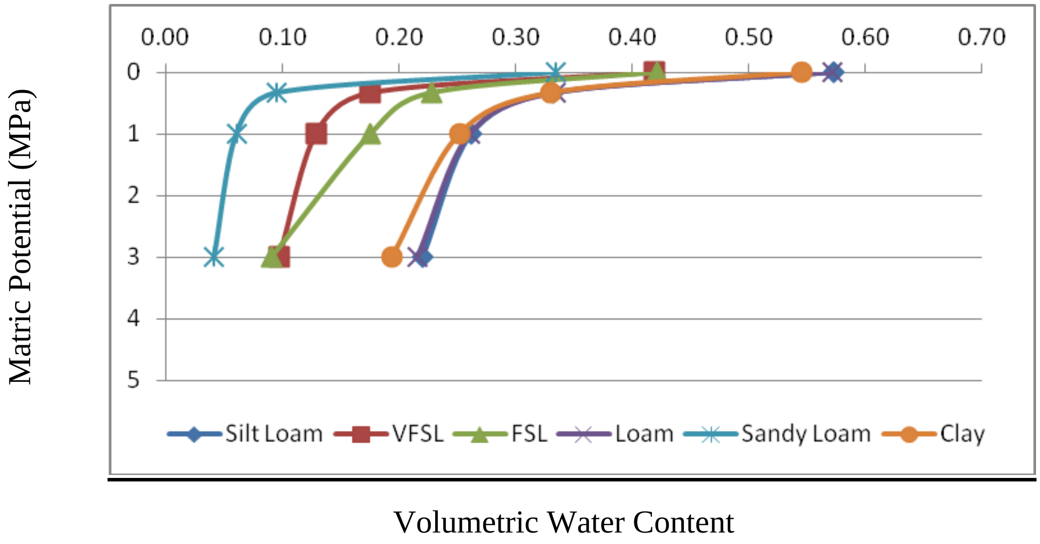

Figure 4. Soil moisture release curves for each soil type (silt loam, very fine sandy loam, fine sandy loam, loam, sandy loam, and clay).

Chapter 4

Evaluation of Nematicides for the Management of *Rotylenchulus reniformis* Across Management Zones Created Using Soil Edaphic Factors

Abstract

Site specific management of *Rotylenchulus reniformis* utilizing management zones delineated by soil attributes is an emerging practice in Southeastern cotton production. A trial to determine differential effects of soil attributes used for management zone delineation on nematicide efficacy was conducted from 2009 – 2011 in a 26 hectare field in the coastal plain of Alabama. Zones were delineated using apparent soil electrical conductivity (EC) and elevation. The nematicides 1, 3-dichloropropene, aldicarb, and Avicta Complete Pak seed treatment exhibited increased yields in the zones where EC values and seasonal moisture were the lowest. The foliar nematicide Oxamyl exhibited reduced efficacy in the management zone where moisture was most limiting. The knowledge of how these nematicides perform across management zones will allow producers to make a more informed decision when choosing nematicides for site specific management of *Rotylenchulus reniformis*.

Introduction

The reniform nematode, *Rotylenchulus reniformis* Linford & Oliveira, is a major pathogen affecting U. S. cotton. Currently, *R. reniformis* can be found in 11 of the 17 cotton producing states and is estimated to have caused a loss of nearly 2% annually in the past decade (Blasingame et al., 2002 – 2012). The presence of *R. reniformis* has been confirmed in at least 30 of the 59 cotton producing counties in Alabama and is responsible for annual yield losses of nearly 7 percent resulting in an estimated $14 million economic loss. Current management strategies rely heavily on chemical nematicides. The most common examples include fumigants such as 1, 3-dichloropropene (Telone II®), granular such as aldicarb (Temik 15G®), seed treatments such as abamectin (Avicta Complete Pak®) or thiodicarb (Aeris Seed Applied System®) and foliar sprays such as oxamyl (Vydate C-LV®).

Site-specific management of nematodes is an emerging practice that has been proven useful for a number of nematode species including the Columbia lance nematode (*Hoplolaimus columbus*), the root-knot nematode (*Meloidogyne incognita*), and the ring nematode (*Criconemella* spp.) (Khalilian *et al*., 2001, 2002, 2003; Monfort *et al*., 2007; Ortiz *et al*., 2007, 2008; Wolcott *et al*., 2004, 2005). Recent studies suggest that nematicide efficacy improves with decreasing electrical conductivity values (Overstreet *et al.* 2012). These techniques are developed based on soil characteristics such as apparent electrical conductivity and terrain attributes and are primarily for the usage of the fumigant nematicide 1, 3-dichloropropene. Site-specific management techniques for *Rotylenchulus reniformis* in cotton based on management zones delineated from soil attributes is currently a topic of interest throughout the cotton growing regions. The objective of this research was to determine the relative efficacy of nematicides, alone and in combination, over three management zones delineated by apparent soil electrical conductivity, elevation, and initial nematode populations.

Materials and Methods

A trial to determine the efficacy of multiple rates of nematicides, alone and in combination, in management zones delineated by soil electrical conductivity and elevation was conducted in 2009-2011 in a 26 hectare field in Escambia County, Alabama (lat, long = 31.073475°, -87.538682°). Continuous apparent soil electrical conductivity and elevation data were collected using a Veris 3100 sensor (Veris Technologies, Inc, Salina, KS) connected to a real-time kinematic (RTK) Trimble GPS receiver mounted to the tractor. The data collected was analyzed using the Mahalanobis distance technique within Management Zone Analyst software (USDA-ARS) to determine the optimal number of management zones (Table 5). Three management zones were chosen and have the following attributes. Management zone 1: Highest sand content, lowest EC, elevation, and seasonal VWC, second highest average nematode population. This zone contains moderately productive soil with adequate moisture. Management zone 2: Highest clay content, EC, and average nematode population, second highest seasonal VWC, average elevation the same as management zone 3. Soils within this zone are considered highly productive agricultural soils. Management zone 3: Highest silt content and seasonal VWC. Second highest EC and average elevation the same as management zone 2. Lowest average nematode population. Soils within this zone considered very productive, but are prone to flooding.

Nine nematicide treatments were selected for evaluation and compared to an untreated (no nematicide) control. All seeds received a base insecticide, thiomethoxam (Cruiser®), and fungicide, azoxystrobin + fludioxanil + mefenoxam (Dynasty CST®). Three rates of 1, 3-

dichloropropene (Telone II®), 42, 28, and 14 L/ha, were applied 30-cm deep to selected rows 14 days prior to planting during the strip-till operation. Two rates of aldicarb (Temik 15G®), 3.9 and 7.8 kg/ha, were applied at planting as an in-furrow granular. The seed treatment abamectin (Avicta Complete Pak®) was applied to the seed and planted alone and in combination with aldicarb at 3.9 kg/ha, aldicarb 3.9 kg/ha + oxamyl (Vydate C-LV®) 1.2 L/ha, and oxamyl 1.2 L/ha. Oxamyl was applied as a foliar spray at 45 days after planting (DAP) at a volume of 94 L/ha. All treatments were applied in 6-row strips (5.5 m) through each management zone. Five replicates, 15.25 m in length, were established within each zone for sampling.

Nematode population densities were evaluated at planting, 30 and 60 DAP, and at harvest by taking 10, 2.5 x 15 cm soil cores from the center two rows of each plot. The soil cores were homogenized and a 150cm^3 subsample was taken for analysis. Nematodes were extracted from the soil by combined gravity screening and sucrose (specific gravity 1.13) centrifugation and enumerated. Plant heights were evaluated at 60 DAP and harvest by measuring 3 random plants from each plot. At harvest, cotton plants were collected from 1 m of row for plant mapping. Total number of bolls produced per plant and respective fruiting positions of the bolls were recorded. Seed cotton was removed from each fruiting position, dried at 80°C for 48 hours, and weights were recorded. All plots were mechanically harvested at approximately 150 DAP.

Data were statistically analyzed by SAS (SAS Institute, Inc) using generalized linear models. Means were compared by Dunnett's Test, with the untreated with no nematicide control as the reference group with alpha = 0.10.

Results

Populations of *R. reniformis* were similar within each management zone at planting for all nematicide plots with the exception of the 1, 3-dichloropropene applied in management zones 1 and 2 (Table 6). The 1, 3-dichloropropene pre-plant treatments (28 and 42 L/ha) significantly lowered the at plant populations of *R. reniformis* compared to the untreated control. At 30 DAP, *R. reniformis* populations remained 50% lower than the untreated control in the plots that received the high rate of 1, 3-dichloropropene (42 L/ha) in management zone 1. All other nematicide treatments within zone 1 supported similar nematode numbers. In management zone 2, six of the nine nematicide applications reduced *R. reniformis* populations at 30 DAP. The mid and high rates (28 and 42 L/ha) of 1, 3-dichloropropene continued to suppress *R. reniformis* populations below the untreated control at 30 DAP. The at-plant applications of aldicarb at both rates (3.9 and 7.8 kg/ha) significantly lowered *R. reniformis* populations. The seed treatment Avicta Complete Pak with and without the low rate of aldicarb applied at plant also lowered the 30 DAP populations, however significantly so in only one out of two applications (pre-Oxamyl application). All nematicide treatments in management zone 3 reduced the first generation of *R. reniformis* populations. The plots that received the pre-plant treatments of 1, 3-dichloropropene at resulted in significantly lower *R. reniformis* population levels at 30 DAP. The Avicta Complete Pak seed treatment, as in management zone 2, produced significantly lower *R. reniformis* populations in 1 out of 2 applications (pre-Oxamyl application).

Rotylenchulus reniformis populations taken at 60 DAP and at harvest found no significant reduction in nematode populations for any nematicide treatment in any zone. Average populations within each zone, as at planting, were highest in management zone 2, followed by management zone 1 and management zone 3.

Cotton plant heights were significantly increased by 1, 3-dichloropropene application in management zones 1 and 2 (Table 7). At 60 DAP, all rates of 1, 3-dichloropropene significantly increased plant heights compared to the untreated control in management zone 1, and the high rate (42 L/ha) significantly increased cotton plant height in management zone 2. At harvest, cotton plant heights for the mid and high rate of 1, 3-dichloropropene (28 and 42 L/ha) remained significantly taller than the untreated control, as did the high rate treatment (42 L/ha) in management zone 2.

Cotton yield mapping data illustrates the plant yield potential as affected by nematicide. Boll weight and retention was significantly increased by the mid and high rates of 1, 3-dichloropropene as well as the high rate of aldicarb. A significant increase in 1st position boll weight was observed by the mid rate of 1, 3-dichloropropene (28 L/ha) in both management zones 2 and 3 (Table 8), while the number of 1st position bolls was similar. The weight of the first position bolls was increased but the retention of these bolls, or their numbers was not affected. The mid rate of 1, 3-dichloropropene (28 L/ha) produced significantly more 2nd position bolls in management zone 2 compared to the untreated control, though no significant increase in boll weight was observed. Thus the retention of the 2nd position bolls was increased by the nematicide application. The high rate of 1, 3-dichloropropene (42 L/ha) increased the number and weight of 3rd position bolls in management zone 1 compared to the untreated control; thus retention and boll weight were increased by nematicide. The mid rate of 1, 3-dichloropropene (28 L/ha) and the high rate of aldicarb (7.8 kg/ha) produced significantly heavier 3rd position bolls in comparison to the untreated control in management zone 3.

The application of 1, 3-dichloropropene increased seed cotton yields at all rates in all three management zones (Table 9). The mid rate (28 L/ha) was the highest yielding treatment across all management zones, and significantly greater than the untreated control in management zones 1 and 3. The low rate (14 L/ha) also produced higher seed cotton yields in management zone 3. The low rate of aldicarb (3.9 kg/ha), or the insecticide rate, did not increase seed cotton yields in comparison to the untreated control in management zones 1 and 2 which had the higher nematode numbers at planting; however, the high rate (7.8 kg/ha), or the nematicide rate, did increase yields in all management zones 1, 2, and 3 by 24, 2, and 6%, respectively. Avicta Complete Pak seed cotton yield was 17% greater in management zone 3 under minimal nematode pressure. The combination of Avicta Complete Pak and the low rate of aldicarb (3.9 kg/ha) at plant increased seed cotton yields by 18, 11, and 5%, respectively, in all management zones. The combination of Avicta Complete Pak and Oxamyl increased seed cotton yields by 12 and 8% in management zones 2 and 3, respectively. Average increase in seed cotton yields over the untreated control by all nematicides was 8.1, 7.0, and 7.1% in management zones 1, 2 and 3.

Discussion

The two factors utilized for zone delineation, apparent soil electrical conductivity and elevation, have proven extremely useful not only for nematode management (Khalilian *et al*., 2001, 2002, 2003; Monfort *et al*., 2007; Ortiz *et al*., 2007, 2008, Wolcott *et al*., 2004, 2005), but also for detecting areas with commonalities in soil productivity (Heermann *et al*., 1999; Jaynes, 1996; Kachanoski *et al*., 1988; McBride *et al*., 1990; Sudduth *et al*., 1995). Management zone 2 produced the highest average seed cotton yield despite having higher seasonal populations of *R. reniformis*. This observation is consistent with our previous findings (Moore *et al*., 2011) in which the effects of *R. reniformis* on cotton growth were related to soil productivity rather than population density. The nematicides applied within this trial did not exhibit any major differences in efficacy that could be attributed solely to the soil attributes utilized for management zone delineation, specifically EC and elevation. However when taking into consideration the zones with near or above threshold nematode populations (1,000/150cm^3), zones 1 and 2, the yield increases were numerically higher in the zone with a lower EC value, zone 1. This observation of increasing nematicides efficacy with decreasing EC values agrees with those reported by Overstreet *et al.*, 2012.

Differences in soil apparent electrical conductivity also can be used to predict spatial differences in soil water content (Kachanoski *et al*., 1988) which can influence the efficacy of certain nematicides (Koenning *et al.*, 2007).The addition of oxamyl to the seed treatment Avicta Complete Pak increased yields in management zones 2 and 3, but provided no benefit in management zone 1, which had the lowest seasonal VWC. This observation is consistent with the finding of Koenning *et al.* (2007) in which oxamyl was reported to be less effective in dry conditions.

Each of the other nematicides appeared to perform to their well documented standards. The 1, 3-dichloropropene treatments were able to effectively reduce nematode populations and increase yields as expected within each zone (Kinloch & Rich, 2001; Koenning *et al*., 2007; Lawrence *et al*., 1990; Rich and Kinloch, 2000). The high rate of aldicarb lowered nematode populations at 30 DAP and increased seed cotton yields within each zone, while the low rate provided a yield increase in management zone 3 under minimal nematode pressure. Similar nematode number reductions have been reported (Lawrence *et al*., 1990; Lawrence & McLean, 2000, Rich & Kinloch, 2000). The Avicta Complete Pak, much like the low rate of aldicarb, proved beneficial under lownematode populations in management zone 3 (Faske and Starr, 2006; Lawrence and Lawrence, 2007); however, when paired with a low rate of aldicarb, was able to reduce nematode numbers and increase seed cotton yields.

Management zone delineation by soil attributes provides cotton producers with valuable information that can be used to effectively manage *Rotylenchulus reniformis*. By creating management zones, the areas of the field with a potential for high productivity or specific in-season stress can be identified. When this knowledge is combined with nematode populations, management decisions can then be made to achieve maximized yields with minimal input.

Table 5. Attributes of each management zone.

Management Zone	Sand	Silt	Clay	OM	EC	Elevation	Average Seasonal VWC
	%	%	%	%	mS/m	meters	%
1	59	31	10	1.5	3.5	86.1	12.55
2	48	22	30	1.5	6.8	88.1	15.01
3	32	57	11	2.0	4.2	88.1	18.41

Table 6. *Rotylenchulus reniformis* populations per 150cm^3 of soil at each of the 4 sampling dates (planting, 30 and 60 DAP, and harvest) for each nematicide treatment in each of the three management zones as compared to the untreated control.

	R. reniformis /150cm^3 of soil at plant								
Treatment and Rate	Management zone 1			Management zone 2			Management zone 3		
	Mean	90% CL	Dunnett's *P* [z]	Mean	90% CL	Dunnett's *P*	Mean	90% CL	Dunnett's *P*
Untreated Control	734.8	(467.1, 1155.9)		1212.7	(770.5, 1908.7)		24.1	(9.0, 65.0)	
1, 3-dichloropropene 42.0 L/ha	323.7	(205.8, 509.2)	0.0359	256.2	(162.8, 403.3)	<0.0001	28.6	(10.6, 76.9)	0.8416
1, 3-dichloropropene 28.0 L/ha	385.1	(244.8, 605.8)	0.0972	525.6	(333.9, 827.3)	0.0326	26.1	(9.7, 70.2)	0.9268
1, 3-dichloropropene 14.0 L/ha	422.9	(268.9, 665.3)	0.1556	740.3	(470.4, 1165.3)	0.2049	20.8	(7.7, 56.1)	0.8626
Aldicarb 3.9 kg/ha	430.9	(273.9, 677.8)	0.1700	954.3	(606.3, 1502.1)	0.5373	22.0	(8.2, 59.2)	0.9128
Aldicarb 7.8 kg/ha	619.3	(393.7, 974.2)	0.6592	881.0	(559.8, 1386.7)	0.4109	22.1	(8.2, 59.6)	0.9191
Avicta Complete Pak	576.6	(366.6, 907.1)	0.5320	691.2	(439.1, 1087.9)	0.1490	20.8	(7.7, 56.1)	0.8626
Avicta Complete Pak + Aldicarb 3.9 kg/ha	453.5	(288.3, 713.4)	0.2144	1021.7	(649.1, 1608.1)	0.6589	19.9	(7.4, 53.6)	0.8204
Avicta Complete Pak + Oxamyl 1.26 L/ha	842.0	(535.3, 1324.5)	0.7252	856.5	(544.1, 1348.0)	0.3709	35.1	(13.0, 94.4)	0.6589
Avicta Complete Pak + Aldicarb 3.9 kg/ha + Oxamyl 1.26 L/ha	957.7	(599.2, 1530.6)	0.5022	643.8	(409.0, 1013.3)	0.1044	43.7	(16.2, 117.7)	0.4837

Table 6 (continued)

Treatment and Rate	*R. reniformis* /150cm^3 of soil 30 DAP								
	Management zone 1			Management zone 2			Management zone 3		
	Mean	90% CL	Dunnett's *P*	Mean	90% CL	Dunnett's *P*	Mean	90% CL	Dunnett's *P*
Untreated Control	711.9	(449.8, 1126.8)		2923.4	(2277.4, 3753.0)		105.4	(91.2, 121.8)	
1, 3-dichloropropene 42.0 L/ha	356.2	(225.1, 563.8)	0.0796	976.5	(760.7, 1253.6)	<0.0001	77.1	(66.7, 89.1)	0.0124
1, 3-dichloropropene 28.0 L/ha	438.3	(276.9, 693.5)	0.2180	1382.7	(1077.2, 1775.1)	0.0006	80.7	(69.9, 93.3)	0.0325
1, 3-dichloropropene 14.0 L/ha	570.3	(360.4, 902.6)	0.5725	2100.6	(1636.3, 2696.5)	0.1235	77.1	(66.7, 89.1)	0.0124
Aldicarb 3.9 kg/ha	379.4	(239.7, 600.4)	0.1106	1797.2	(1400.1, 2307.2)	0.0241	88.6	(76.7, 102.4)	0.1626
Aldicarb 7.8 kg/ha	483.1	(305.3, 764.6)	0.3244	1557.3	(1213.2, 1999.2)	0.0037	92.8	(80.3, 107.2)	0.3052
Avicta Complete Pak	768.3	(485.5, 1216.0)	0.8461	2213.2	(1724.0, 2841.0)	0.1941	97.3	(84.2, 112.4)	0.5182
Avicta Complete Pak + Aldicarb 3.9 kg/ha	545.7	(344.8, 863.6)	0.4988	1749.5	(1362.8, 2245.8)	0.0174	95.3	(82.5, 110.1)	0.4152
Avicta Complete Pak + Oxamyl 1.26 L/ha	712.5	(450.2, 1127.7)	0.9983	1955.3	(1523.1, 2509.9)	0.0614	129.5	(112.0, 149.6)	0.0977
Avicta Complete Pak + Aldicarb 3.9 kg/ha + Oxamyl 1.26 L/ha	584.9	(363.7, 940.7)	0.6231	2246.9	(1750.2, 2884.2)	0.2192	95.4	(82.5, 110.2)	0.4192

Treatment and Rate	*R. reniformis* /150cm^3 of soil 60 DAP								
	Management zone 1			Management zone 2			Management zone 3		
	Mean	90% CL	Dunnett's *P*	Mean	90% CL	Dunnett's *P*	Mean	90% CL	Dunnett's *P*
Untreated Control	801.5	(449.1, 1430.5)		674.2	(399.6, 1137.7)		40.2	(15.3, 105.6)	
1, 3-dichloropropene 42.0 L/ha	751.7	(421.2, 1341.7)	0.8971	486.7	(288.4, 821.2)	0.4669	56.8	(21.6, 149.2)	0.6755
1, 3-dichloropropene 28.0 L/ha	678.0	(379.9, 1210.2)	0.7358	607.1	(359.8, 1024.3)	0.8146	28.0	(10.7, 73.6)	0.6633
1, 3-dichloropropene 14.0 L/ha	854.7	(478.9, 1525.4)	0.8969	639.1	(378.8, 1078.5)	0.9048	29.9	(11.4, 78.7)	0.7224
Aldicarb 3.9 kg/ha	499.8	(280.1, 892.1)	0.3415	816.4	(483.8, 1377.5)	0.6693	33.3	(12.7, 87.6)	0.8211
Aldicarb 7.8 kg/ha	576.8	(316.7, 1050.6)	0.5145	785.6	(465.6, 1325.6)	0.7328	29.4	(11.2, 77.2)	0.7045
Avicta Complete Pak	769.2	(431.0, 1372.8)	0.9338	1054.7	(625.0, 1779.5)	0.3184	44.4	(16.9, 116.6)	0.9046
Avicta Complete Pak + Aldicarb 3.9 kg/ha	549.9	(308.1, 981.4)	0.4476	644.7	(382.1, 1087.9)	0.9203	31.2	(11.9, 82.0)	0.7605
Avicta Complete Pak + Oxamyl 1.26 L/ha	636.3	(356.4, 1135.6)	0.6414	1089.9	(634.2, 1873.0)	0.2928	69.8	(26.5, 183.4)	0.5046
Avicta Complete Pak + Aldicarb 3.9 kg/ha + Oxamyl 1.26 L/ha	911.6	(500.5, 1660.4)	0.7986	797.3	(472.5, 1345.2)	0.7082	32.8	(12.5, 86.3)	0.8071

Table 6 (continued)

Treatment and Rate	*R. reniformis* /150cm^3 of soil at harvest								
	Management zone 1			Management zone 2			Management zone 3		
	Mean	90% CL	Dunnett's *P*	Mean	90% CL	Dunnett's *P*	Mean	90% CL	Dunnett's *P*
Untreated Control	451.3	(253.2, 804.3)		1498.5	(828.3, 2710.8)		147.6	(98.0, 222.1)	
1, 3-dichloropropene 42.0 L/ha	607.8	(341.0, 1083.1)	0.5465	993.3	(549.1, 1796.9)	0.4171	123.2	(81.9, 185.5)	0.6057
1, 3-dichloropropene 28.0 L/ha	704.4	(395.2, 1255.4)	0.3676	940.5	(519.9, 1701.4)	0.3583	88.6	(58.8, 133.3)	0.1459
1, 3-dichloropropene 14.0 L/ha	479.4	(269.0, 854.4)	0.9026	1401.5	(774.7, 2535.4)	0.8948	97.0	(64.5, 146.1)	0.2315
Aldicarb 3.9 kg/ha	899.5	(504.7, 1603.1)	0.1642	794.5	(439.2, 1437.3)	0.2117	134.5	(89.4, 202.5)	0.7912
Aldicarb 7.8 kg/ha	768.5	(431.2, 1369.6)	0.2819	1094.9	(605.2, 1980.7)	0.5355	110.4	(73.3, 166.1)	0.4061
Avicta Complete Pak	583.1	(327.2, 1039.3)	0.6035	943.1	(521.3, 1706.2)	0.3612	127.4	(84.6, 191.8)	0.6742
Avicta Complete Pak + Aldicarb 3.9 kg/ha	688.0	(386.0, 1226.1)	0.3934	468.2	(424.7, 1389.8)	0.1287	130.7	(86.9, 196.8)	0.7288
Avicta Complete Pak + Oxamyl 1.26 L/ha	652.9	(366.3, 1163.6)	0.4546	775.0	(428.4, 1401.9)	0.1945	235.3	(156.3, 354.2)	0.1836
Avicta Complete Pak + Aldicarb 3.9 kg/ha + Oxamyl 1.26 L/ha	417.6	(227.1, 767.9)	0.8782	621.4	(343.5, 1124.2)	0.1844	172.9	(114.9, 260.3)	0.6501

[Z] Probability of being significantly different ($P \leq 0.10$) than the control (untreated control).

Table 7. Cotton plant heights (cm) at 60 DAP and harvest for each nematicide treatment in each of the three management zones.

Treatment and Rate	Plant height (cm) 60 DAP								
	Management zone 1			Management zone 2			Management zone 3		
	Mean	90% CL	Dunnett's P^z	Mean	90% CL	Dunnett's P	Mean	90% CL	Dunnett's P
Untreated Control	56.1	(45.9, 66.3)		58.4	(47.7, 69.0)		84.7	(69.3, 100.1)	
1, 3-dichloropropene 42.0 L/ha	82.1	(71.9, 92.4)	0.0034	77.9	(67.2, 88.6)	0.0341	94.0	(78.6, 109.4)	0.4821
1, 3-dichloropropene 28.0 L/ha	76.6	(66.4, 86.8)	0.0200	72.4	(61.7, 53.1)	0.1253	88.7	(73.3, 104.1)	0.7618
1, 3-dichloropropene 14.0 L/ha	72.5	(62.3, 82.8)	0.0614	70.9	(60.2, 81.5)	0.1731	86.0	(70.6, 101.5)	0.9189
Aldicarb 3.9 kg/ha	60.8	(50.5, 71.0)	0.5931	63.4	(52.7, 74.1)	0.5807	88.0	(72.6, 103.4)	0.8018
Aldicarb 7.8 kg/ha	63.0	(52.8, 73.2)	0.4295	67.7	(57.0, 78.4)	0.3092	83.3	(67.9, 98.7)	0.9151
Avicta Complete Pak	56.5	(46.3, 66.7)	0.9619	63.6	(52.9, 74.3)	0.5661	84.4	(69.0, 99.9)	0.9845
Avicta Complete Pak + Aldicarb 3.9 kg/ha	62.2	(51.9, 72.4)	0.4868	69.8	(59.1, 80.5)	0.2119	85.6	(70.2, 101.0)	0.9495
Avicta Complete Pak + Oxamyl 1.26 L/ha	56.3	(46.1, 66.5)	0.9788	57.7	(47.0, 68.4)	0.9439	74.0	(58.5, 89.4)	0.4150
Avicta Complete Pak + Aldicarb 3.9 kg/ha + Oxamyl 1.26 L/ha	63.5	(53.3, 73.7)	0.3972	63.3	(52.6, 74.0)	0.5870	80.3	(64.9, 95.7)	0.7366

Treatment and Rate	Plant height (cm) at harvest								
	Management zone 1			Management zone 2			Management zone 3		
	Mean	90% CL	Dunnett's P	Mean	90% CL	Dunnett's P	Mean	90% CL	Dunnett's P
Untreated Control	87.6	(75.9, 99.3)		93.8	(83.1, 104.5)		105.0	(95.0, 114.9)	
1, 3-dichloropropene 42.0 L/ha	114.0	(102.4, 125.7)	0.0093	109.5	(98.8, 120.2)	0.0872	112.8	(102.9, 122.7)	0.3569
1, 3-dichloropropene 28.0 L/ha	109.1	(97.4, 120.8)	0.0331	108.1	(97.4, 118.8)	0.1184	110.4	(100.4, 120.3)	0.5251
1, 3-dichloropropene 14.0 L/ha	101.9	(90.3, 113.6)	0.1522	105.2	(94.5, 115.9)	0.2104	110.3	(100.4, 120.3)	0.5287
Aldicarb 3.9 kg/ha	91.1	(79.5, 102.8)	0.7210	99.3	(88.6, 110.0)	0.5455	110.8	(100.9, 120.8)	0.4903
Aldicarb 7.8 kg/ha	97.3	(85.6, 109.0)	0.3298	106.1	(95.4, 116.8)	0.1779	109.1	(99.1, 119.0)	0.6298
Avicta Complete Pak	90.7	(79.1, 102.4)	0.7527	103.1	(92.4, 113.8)	0.3057	110.1	(100.2, 120.1)	0.5420
Avicta Complete Pak + Aldicarb 3.9 kg/ha	103.7	(92.0, 115.3)	0.1088	101.6	(90.9, 112.3)	0.3917	108.8	(98.9, 118.8)	0.6481
Avicta Complete Pak + Oxamyl 1.26 L/ha	96.5	(84.8, 108.2)	0.3723	96.2	(85.5, 106.9)	0.7912	105.8	(95.9, 115.8)	0.9198
Avicta Complete Pak + Aldicarb 3.9 kg/ha + Oxamyl 1.26 L/ha	101.0	(89.4, 112.7)	0.1788	99.5	(88.8, 110.2)	0.5316	105.6	(95.6, 115.5)	0.9448

[z] Probability of being significantly different ($P \leq 0.10$) than the control (untreated control).

Table 8. Cotton yield mapping parameters (number of bolls, weight, and corresponding position on the plant) for each nematicide treatment in each of the three management zones.

	1st Position Bolls								
	Management zone 1			Management zone 2			Management zone 3		
Treatment and Rate	Mean	90% CL	Dunnett's P [z]	Mean	90% CL	Dunnett's P	Mean	90% CL	Dunnett's P
Untreated Control	10.3	(8.4, 12.3)		10.6	(8.6, 12.5)		9.8	(8.6, 11.0)	
1, 3-dichloropropene 42.0 L/ha	10.4	(8.5, 12.4)	0.9467	12.0	(10.1, 14.0)	0.3844	8.8	(7.7, 10.0)	0.3159
1, 3-dichloropropene 28.0 L/ha	12.1	(10.1, 14.1)	0.2911	12.8	(10.8, 14.7)	0.1893	12.0	(10.8, 13.2)	0.0368
1, 3-dichloropropene 14.0 L/ha	10.7	(8.7, 12.7)	0.8254	11.5	(9.5, 13.4)	0.5919	10.2	(9.0, 11.4)	0.7205
Aldicarb 3.9 kg/ha	8.8	(6.8, 10.7)	0.3553	11.2	(9.2, 13.1)	0.7207	9.9	(8.7, 11.1)	0.9151
Aldicarb 7.8 kg/ha	11.2	(9.3, 13.2)	0.5967	11.1	(9.1, 13.0)	0.7709	9.8	(8.6, 11.0)	1.0000
Avicta Complete Pak	10.3	(8.3, 12.3)	0.9829	9.8	(7.9, 11.8)	0.6394	9.8	(8.6, 11.0)	1.0000
Avicta Complete Pak + Aldicarb 3.9 kg/ha	11	(9.1, 13.0)	0.6747	11.5	(9.6, 13.5)	0.5762	9.4	(8.2, 10.6)	0.6923
Avicta Complete Pak + Oxamyl 1.26 L/ha	10.7	(8.8, 12.7)	0.8082	12.0	(10.1, 14.0)	0.3844	10.9	(9.6, 12.1)	0.3169
Avicta Complete Pak + Aldicarb 3.9 kg/ha + Oxamyl 1.26 L/ha	9.8	(7.8, 11.7)	0.7412	9.1	(7.2, 11.1)	0.3848	10.0	(8.8, 11.2)	0.8295

	Weight of 1st Position Bolls (g)								
	Management zone 1			Management zone 2			Management zone 3		
Treatment and Rate	Mean	90% CL	Dunnett's P	Mean	90% CL	Dunnett's P	Mean	90% CL	Dunnett's P
Untreated Control	120.9	(93.1, 148.7)		116.5	(88.5, 144.5)		120.2	(102.0, 138.5)	
1, 3-dichloropropene 42.0 L/ha	123.1	(95.3, 150.9)	0.9252	143.4	(115.5, 171.4)	0.2605	121.0	(102.7, 139.2)	0.9637
1, 3-dichloropropene 28.0 L/ha	151.1	(123.4, 178.9)	0.2038	159.3	(131.3, 187.3)	0.0756	148.0	(129.8, 166.3)	0.0766
1, 3-dichloropropene 14.0 L/ha	128.0	(100.2, 155.8)	0.7645	139.4	(111.4, 167.4)	0.3387	134.5	(116.3, 152.7)	0.3609
Aldicarb 3.9 kg/ha	110.8	(83.0, 138.5)	0.6686	136.7	(108.7, 164.7)	0.3986	120.9	(102.7, 139.2)	0.9642
Aldicarb 7.8 kg/ha	137.7	(109.9, 165.5)	0.4781	132.7	(104.7, 160.6)	0.4990	124.6	(106.4, 142.9)	0.7771
Avicta Complete Pak	114.2	(86.4, 142.0)	0.7768	120.9	(92.9, 148.9)	0.8539	129.8	(111.6, 148.1)	0.5371
Avicta Complete Pak + Aldicarb 3.9 kg/ha	144.8	(117.0, 172.6)	0.3143	139.4	(111.5, 167.4)	0.3377	124.4	(106.2, 142.7)	0.7874
Avicta Complete Pak + Oxamyl 1.26 L/ha	122.4	(94.6, 150.2)	0.9494	148.3	(120.3, 176.3)	0.1850	137.9	(119.6, 156.1)	0.2588
Avicta Complete Pak + Aldicarb 3.9 kg/ha + Oxamyl 1.26 L/ha	114.6	(86.8, 142.4)	0.7897	122.4	(84.4, 150.3)	0.8062	129.7	(111.4, 147.9)	0.5449

Table 8 (continued)

Treatment and Rate	2nd Position Bolls								
	Management zone 1			Management zone 2			Management zone 3		
	Mean	90% CL	Dunnett's *P*	Mean	90% CL	Dunnett's *P*	Mean	90% CL	Dunnett's *P*
Untreated Control	3.7	(2.4, 5.0)		5.1	(3.5, 6.7)		4.7	(3.8, 5.5)	
1, 3-dichloropropene 42.0 L/ha	5.4	(4.1, 6.7)	0.1281	5.6	(4.1, 7.2)	0.7002	4.8	(4.0, 5.6)	0.8775
1, 3-dichloropropene 28.0 L/ha	5.7	(4.4, 7.0)	0.0697	5.4	(3.9, 7.0)	0.8038	4.6	(3.8, 5.4)	0.9153
1, 3-dichloropropene 14.0 L/ha	3.5	(2.2, 4.8)	0.8684	4.4	(2.8, 6.0)	0.6025	4.9	(4.1, 5.7)	0.7556
Aldicarb 3.9 kg/ha	3.4	(2.1, 4.8)	0.8155	4.2	(2.6, 5.7)	0.4766	4.8	(4.0, 5.6)	0.8775
Aldicarb 7.8 kg/ha	4.9	(3.6, 6.2)	0.2735	4.5	(2.9, 6.1)	0.6605	5.0	(4.1, 5.8)	0.6752
Avicta Complete Pak	3.5	(2.1, 4.8)	0.8163	4.4	(2.8, 6.0)	0.5841	4.9	(4.1, 5.8)	0.7150
Avicta Complete Pak + Aldicarb 3.9 kg/ha	4.1	(2.8, 5.4)	0.7147	4.6	(3.0, 6.2)	0.7008	4.7	(3.8, 5.5)	1.0000
Avicta Complete Pak + Oxamyl 1.26 L/ha	3.7	(2.4, 5.0)	0.9734	4.1	(2.5, 5.7)	0.4598	4.8	(4.0, 5.6)	0.8775
Avicta Complete Pak + Aldicarb 3.9 kg/ha + Oxamyl 1.26 L/ha	4.1	(2.8, 5.4)	0.7139	5.0	(3.5, 6.6)	0.9561	3.9	(3.1, 4.8)	0.2954

Treatment and Rate	Weight of 2nd Position Bolls (g)								
	Management zone 1			Management zone 2			Management zone 3		
	Mean	90% CL	Dunnett's *P*	Mean	90% CL	Dunnett's *P*	Mean	90% CL	Dunnett's *P*
Untreated Control	45.6	(28.8, 62.4)		58.1	(39.0, 77.2)		53.8	(42.8, 64.7)	
1, 3-dichloropropene 42.0 L/ha	58.6	(41.8, 75.4)	0.3663	62.9	(43.8, 82.0)	0.7687	62.6	(51.7, 73.5)	0.3441
1, 3-dichloropropene 28.0 L/ha	63.8	(47.0, 80.6)	0.2059	65.4	(46.3, 84.5)	0.6529	54.1	(43.1, 65.0)	0.9748
1, 3-dichloropropene 14.0 L/ha	39.2	(22.3, 56.0)	0.6520	45.0	(25.9, 64.1)	0.4237	62.2	(51.3, 73.1)	0.3660
Aldicarb 3.9 kg/ha	37.2	(20.4, 54.0)	0.5571	45.5	(26.4, 64.6)	0.4396	61.4	(50.5, 72.3)	0.4133
Aldicarb 7.8 kg/ha	61.0	(44.2, 77.8)	0.2842	46.2	(27.1, 65.3)	0.4677	61.9	(51.0, 72.8)	0.3827
Avicta Complete Pak	37.6	(20.8, 54.5)	0.5782	46.7	(27.6, 65.8)	0.4847	61.9	(51.0, 72.8)	0.3827
Avicta Complete Pak + Aldicarb 3.9 kg/ha	49.4	(32.6, 66.2)	0.7923	51.1	(31.9, 70.2)	0.6669	58.8	(47.9, 69.8)	0.5849
Avicta Complete Pak + Oxamyl 1.26 L/ha	37.8	(21.0, 54.6)	0.5854	46.1	(27.0, 65.2)	0.4638	56.3	(45.4, 67.3)	0.7818
Avicta Complete Pak + Aldicarb 3.9 kg/ha + Oxamyl 1.26 L/ha	39.8	(22.9, 56.6)	0.6829	54.5	(35.3, 73.6)	0.8242	45.1	(34.2, 56.1)	0.3555

Table 8 (continued)

Treatment and Rate	3rd Position Bolls								
	Management zone 1			Management zone 2			Management zone 3		
	Mean	90% CL	Dunnett's *P*	Mean	90% CL	Dunnett's *P*	Mean	90% CL	Dunnett's *P*
Untreated Control	0.1	(0.04, 0.6)		0.2	(0.04, 0.8)		0.2	(0.04, 0.5)	
1, 3-dichloropropene 42.0 L/ha	1.3	(0.3, 5.2)	0.0674	0.2	(0.04, 0.8)	1.0000	0.3	(0.1, 1.2)	0.4425
1, 3-dichloropropene 28.0 L/ha	0.3	(0.07, 1.2)	0.5494	0.3	(0.07, 1.3)	0.7478	0.8	(0.2, 2.8)	0.1262
1, 3-dichloropropene 14.0 L/ha	0.1	(0.04, 0.6)	1.0000	0.3	(0.07, 1.3)	0.7478	0.3	(0.1, 1.2)	0.5205
Aldicarb 3.9 kg/ha	0.1	(0.04, 0.6)	1.0000	0.3	(0.07, 1.3)	0.7478	0.3	(0.1, 1.2)	0.5516
Aldicarb 7.8 kg/ha	0.8	(0.2, 3.2)	0.1534	0.4	(0.09, 1.8)	0.5755	1.5	(0.4, 5.3)	0.0342
Avicta Complete Pak	0.1	(0.04, 0.6)	1.0000	0.9	(0.2, 3.8)	0.2445	0.2	(0.04, 0.5)	0.7885
Avicta Complete Pak + Aldicarb 3.9 kg/ha	0.4	(0.1, 1.6)	0.4039	0.5	(0.1, 2.3)	0.4396	0.6	(0.2, 2.1)	0.1983
Avicta Complete Pak + Oxamyl 1.26 L/ha	0.3	(0.07, 1.2)	0.6462	0.2	(0.04, 0.8)	1.0000	0.2	(0.04, 0.5)	0.8286
Avicta Complete Pak + Aldicarb 3.9 kg/ha + Oxamyl 1.26 L/ha	0.1	(0.04, 0.6)	1.0000	0.2	(0.04, 0.8)	1.0000	0.4	(0.1, 1.4)	0.3542

Treatment and Rate	Weight of 3rd Position Bolls (g)								
	Management zone 1			Management zone 2			Management zone 3		
	Mean	90% CL	Dunnett's *P*	Mean	90% CL	Dunnett's *P*	Mean	90% CL	Dunnett's *P*
Untreated Control	0.5	(0.06, 3.3)		0.7	(0.1, 5.4)		0.4	(0.1, 2.1)	
1, 3-dichloropropene 42.0 L/ha	13.1	(1.8, 93.4)	0.0475	0.7	(0.1, 5.4)	1.0000	3.0	(0.5, 17.8)	0.1605
1, 3-dichloropropene 28.0 L/ha	1.3	(0.2, 9.3)	0.5303	1.5	(0.2, 11.9)	0.6499	5.1	(0.9, 30.1)	0.0815
1, 3-dichloropropene 14.0 L/ha	0.2	(0.02, 1.1)	0.5300	1.3	(0.2, 10.4)	0.7028	1.6	(0.3, 9.4)	0.3220
Aldicarb 3.9 kg/ha	0.4	(0.06, 3.1)	0.9699	1.3	(0.2, 10.4)	0.7028	1.2	(0.2, 7.2)	0.4140
Aldicarb 7.8 kg/ha	7.0	(1.0, 49.7)	0.1062	2.3	(0.3, 18.4)	0.4858	12.7	(2.1, 74.9)	0.0204
Avicta Complete Pak	0.3	(0.05, 2.4)	0.8641	5.1	(0.6, 41.3)	0.2516	1.4	(0.2, 8.4)	0.3603
Avicta Complete Pak + Aldicarb 3.9 kg/ha	2.3	(0.3, 16.3)	0.3377	3.0	(0.4, 24.6)	0.3900	4.2	(0.7, 25.0)	0.1050
Avicta Complete Pak + Oxamyl 1.26 L/ha	1.0	(0.2, 7.4)	0.6214	0.9	(0.1, 7.2)	0.8653	0.8	(0.1, 4.7)	0.5948
Avicta Complete Pak + Aldicarb 3.9 kg/ha + Oxamyl 1.26 L/ha	0.3	(0.04, 1.9)	0.7372	0.7	(0.1, 5.4)	1.0000	2.6	(0.4, 15.1)	0.1944

[Z] Probability of being significantly different ($P \leq 0.10$) than the control (untreated control).

Table 9. Seed cotton yields (kg/ha) for each nematicide treatment in each of the three management zones.

Treatment and Rate	Seed Cotton Yields (kg/ha)								
	Management zone 1			Management zone 2			Management zone 3		
	Mean	90% CL	Dunnett's P^z	Mean	90% CL	Dunnett's P	Mean	90% CL	Dunnett's P
Untreated Control	2118.2	(1611.8, 2624.6)		2333.1	(1799.7, 2866.6)		2247.3	(1925.0, 2529.6)	
1, 3-dichloropropene 42.0 L/ha	2379.6	(1873.3, 2886.1)	0.5452	2673.8	(2140.4, 3207.3)	0.4546	2319.7	(2017.3, 2622.0)	0.2585
1, 3-dichloropropene 28.0 L/ha	2854.7	(2348.2, 3361.1)	0.0909	2933.0	(2399.5, 3466.4)	0.1896	2596.4	(2294.1, 2898.9)	0.0716
1, 3-dichloropropene 14.0 L/ha	2261.7	(1755.4, 2768.2)	0.9196	2437.8	(1904.3, 2971.2)	0.8181	2564.5	(2262.2, 2866.9)	0.0927
Aldicarb 3.9 kg/ha	1878.3	(1372.0, 2384.8)	0.5789	2300.2	(1766.8, 2833.6)	0.9422	2351.9	(2049.6, 2654.4)	0.3844
Aldicarb 7.8 kg/ha	2621.4	(2115.1, 3127.8)	0.2457	2380.1	(1846.6, 2913.4)	0.9179	2366.5	(2064.1, 2668.8)	0.1906
Avicta Complete Pak	2052.8	(1546.3, 2559.1)	0.7017	2258.9	(1725.5, 2792.4)	0.8704	2487.5	(2185.1, 2789.9)	0.1648
Avicta Complete Pak + Aldicarb 3.9 kg/ha	2508.1	(2001.7, 3014.6)	0.3676	2579.3	(2045.9, 3112.8)	0.5886	2341.6	(2039.3, 2644.0)	0.4066
Avicta Complete Pak + Oxamyl 1.26 L/ha	2084.0	(1577.7, 2590.4)	0.9369	2614.6	(2081.1, 3148.0)	0.5365	2398.9	(2096.6, 2701.2)	0.2936
Avicta Complete Pak + Aldicarb 3.9 kg/ha + Oxamyl 1.26 L/ha	1960.2	(1453.7, 2466.5)	0.7144	2393.3	(1759.8, 2826.8)	0.9302	2269.9	(1940.4, 2545.2)	0.6541

[Z] Probability of being significantly different ($P \leq 0.10$) than the control (untreated control).

Chapter 5

Evaluation of Nematicides for the Management of *Rotylenchulus reniformis* in a Field with Homogeneous Soil Characteristics

Abstract

The reniform nematode, *Rotylenchulus reniformis*, is currently the most damage cotton pathogen in Alabama. A trial to determine the efficacy of nematicides currently under consideration for use in site-specific management systems was conducted in a field with homogeneous soil characteristics from 2009 – 2011 to compare with observations from fields of highly variable soil characteristics. The nematicides aldicarb (2 rates), oxamyl, and the seed treatment Aeris® were evaluated alone and in combination against an untreated control for efficacy against *R. reniformis*. Although no significant increases were observed compared to the untreated control, all nematicides numerically increased seed cotton yield in at least one of three seasons with the exceptions of Aeris + oxamyl and aldicarb at the low rate. When compared to results of studies in variable soil types, these results suggest that variable rate nematicide programs in homogeneous soils is of much less importance for management of *R. reniformis*.

Introduction

The reniform nematode, *Rotylenchulus reniformis* Linford & Oliveira, is a major pathogen affecting U. S. cotton. Currently, *R. reniformis* can be found in 11 of the 17 cotton producing states and is estimated to have caused an annual loss of nearly 2% (Blasingame et al., 2002 – 2012).

Much research is currently focusing on developing site-specific management strategies for *R. reniformis* by constructing prescription application maps based on variability in soil characteristics. Results of these efforts have shown that nematicide efficacy and yield benefit increase with decreasing electrical conductivity values and accompanying soil productivity and moisture holding capabilities (Moore *et al.*, 2011; Overstreet *et al.*, 2012). The objective of this trial was to determine the efficacy of commonly used nematicides, alone and in combination, and use the resulting data for comparison against similar trials in fields with highly variable soils.

Materials and Methods

A trial to determine the efficacy of multiple rates of nematicides, alone and in combination, in a field with homogeneous soil characteristics was conducted in 2009-2011 at the Tennessee Valley Research and Extension Center near Belle Mina, Alabama. The soil was a Decatur silt loam, (fine, kaolinitic, thermic, Rhodic Paleudults: 23% sand, 49% silt, 28% clay; 1% organic matter; pH 6.2). Homogeneity was confirmed by collecting continuous apparent soil electrical conductivity (EC) and elevation data using a Veris 3100 sensor (Veris Technologies, Inc, Salina, KS) connected to a real-time kinematic (RTK) Trimble GPS receiver mounted to the tractor. The data collected was analyzed using the Mahalanobis distance technique within Management Zone Analyst software (USDA-ARS) resulting in one zone with an average EC and elevation of 9.82

mS/m and 186.5 m, respectively. *Rotylenchulus reniformis* populations initially averaged 696 per 150 cm^3 of soil across with a range of 425 to 850 across the 3.5 ha field in the spring of 2009.

Nematicide treatments in 2009 included the Aeris Seed Applied System® (thiodicarb + imidacloprid) (ASAS), ASAS + aldicarb (Temik 15G®) 3.9 kg/ha, ASAS + aldicarb 5.6 kg/ha, and ASAS + aldicarb 5.6 kg/ha + oxamyl (Vydate C-LV®) 1.26 L/ha. Nematicide treatments were expanded in 2010 and 2011 to include an untreated control, ASAS + oxamyl 1.26 L/ha, aldicarb 3.9 kg/ha, aldicarb 5.6 kg/ha, aldicarb 3.9 kg/ha + oxamyl 1.26 L/ha, and aldicarb 5.6 kg/ha + oxamyl 1.26 L/ha. All seeds received a base fungicide treatment of triadimenol, thiram, and metalaxyl and the insecticide imidacloprid was added to treatments not including ASAS. Aldicarb was applied at planting as an in-furrow granular while oxamyl was applied as a foliar spray at 45 days after planting (45 DAP). Plots were 8 rows with the nematicides applied to the center 4 rows. In 2009 plots were 55 m long, while in 2010 and 2011 plots were 27.5 m long.

Nematode population densities were evaluated at planting, 30 and 60 DAP, and at harvest by taking 10, 2.5 x 15 cm soil cores from the center two rows of each plot. The soil cores were homogenized and a 150cm^3 subsample was taken for analysis. Nematodes were extracted from the soil by combined gravity screening and sucrose (specific gravity 1.13) centrifugation and enumerated. At harvest, cotton plants were collected from 1 m of row for plant mapping and height evaluation. Total number of bolls produced per plant and respective fruiting positions of the bolls were recorded. Seed cotton was removed from each fruiting position, dried at 80°C for 48 hours, and weights were recorded. All plots were mechanically harvested at approximately 150 DAP.

Data were analyzed using analysis of variance (ANOVA) within the GLIMMIX procedure of SAS, version 9.2 (SAS Institute, Cary, NC). Means were compared by Dunnett's

Test, with the ASAS treatment as the reference group in 2009, and the untreated control as the reference group in 2010 and 2011.

Results

In 2011, the addition of oxamyl to the ASAS significantly lowered *R. reniformis* populations at 60 DAP (Table 10). All other nematicide treatments were comparable to either the ASAS in 2009 or the untreated control in 2010 and 2011. Similarly, plant heights and yield mapping parameters at harvest were not significantly affected by nematicide treatment (Tables 11 & 12) with one exception. The combination of ASAS + aldicarb 5.6 kg/ha + oxamyl 1.26 L/ha significantly increased number and weight of first position bolls in 2011 compared to the untreated control (Table 11). Seed cotton yield, although not significantly affected by nematicide treatment, was numerically higher compared to the respective controls in at least one year for all treatments with the exceptions of ASAS + oxamyl 1.26 L/ha and aldicarb 3.9 kg/ha (Table 13).

Discussion

The results of this study show that in a field with little variability of soil characteristics, the choice of which nematicide to use is of much less importance than in a field with high soil variability. All nematicides within this trial were comparable and performed as previously observed (Koenning, *et al.*, 2007; Lawrence *et al*., 1990; Lawrence & McLean, 2000; Lawrence & Lawrence, 2007; Rich & Kinloch, 2000). The populations of *R. reniformis* within this trial were very near current economic threshold levels for Alabama (1,000/150cm^3). Differences in efficacy may have been more pronounced had the populations been higher, especially for the low rate of aldicarb or the seed treatment alone. When compared to studies of fields with high variability, producers with fields of homogeneous soil characteristics can focus on *R. reniformis* levels alone rather than how that level will affect their cotton in a specific soil type.

Table 10. *Rotylenchulus reniformis* populations per 150cm^3 of soil at each of the 3 sampling dates (planting, 30 and 60 DAP) for each nematicide treatment in 2009, 2010, & 2011.

2009									
Treatment and Rate	Plant			30 DAP			60 DAP		
	Mean	95% CL	Dunnett's *P*	Mean	95% CL	Dunnett's *P*	Mean	95% CL	Dunnett's *P*
Aeris Seed Applied System	425.9	(86.4, 1128.3)		656.9	(317.4, 1359.3)		1112.3	(559.8, 2209.9)	
Aeris Seed Applied System + Aldicarb 3.9 kg/ha	840.6	(293.6, 2064.5)	0.3211	1116.6	(539.6, 2310.5)	0.3812	1439.6	(724.5, 2860.1)	0.6491
Aeris Seed Applied System + Aldicarb 5.6 kg/ha	845.5	(241.2, 2095.9)	0.3551	1169.5	(565.2, 2419.9)	0.3421	2268.1	(1141.5, 4506.6)	0.2184
Aeris Seed Applied System + Aldicarb 5.6 kg/ha + Oxamyl 1.26 L/ha	668.8	(205.9, 1626.6)	0.6572	895.8	(432.9, 1853.6)	0.6057	2248.9	(1131.8, 4468.5)	0.2237

2010									
Treatment and Rate	Plant			30 DAP			60 DAP		
	Mean	95% CL	Dunnett's *P*	Mean	95% CL	Dunnett's *P*	Mean	95% CL	Dunnett's *P*
Untreated Control	1030.8	(457.6, 2322.3)		143.8	(59.6, 346.7)		634.8	(240.6, 1675.2)	
Aeris Seed Applied System	729.2	(360.9, 1473.4)	0.5882	215.0	(89.2, 518.5)	0.5874	689.2	(261.2, 1818.7)	0.9197
Aeris Seed Applied System + Aldicarb 3.9 kg/ha	964.5	(477.3, 1948.9)	0.9170	200.1	(83.0, 482.5)	0.6556	659.2	(249.8, 1739.8)	0.9630
Aeris Seed Applied System + Aldicarb 5.6 kg/ha	1066.2	(527.7, 2154.3)	0.9578	125.6	(52.1, 303.0)	0.8555	547.4	(207.4, 1444.3)	0.8557
Aeris Seed Applied System + Aldicarb 5.6 kg/ha + Oxamyl 1.26 L/ha	355.8	(176.1, 718.9)	0.1033	233.9	(97.0, 564.0)	0.5122	1299.1	(492.3, 3428.2)	0.3828
Aeris Seed Applied System + Oxamyl 1.26 L/ha	408.7	(202.3, 825.9)	0.1543	361.6	(149.9, 872.0)	0.2183	681.9	(258.4, 1799.6)	0.9300
Aldicarb 3.9 kg/ha	1692.9	(837.8, 3420.7)	0.4391	115.5	(47.9, 278.6)	0.7675	987.7	(374.3, 2606.6)	0.5886
Aldicarb 5.6 kg/ha	980.9	(485.5, 1982.1)	0.9380	140.7	(58.3, 339.3)	0.9765	1083.4	(410.6, 2858.9)	0.5136
Aldicarb 3.9 kg/ha + Oxamyl 1.26 L/ha	741.7	(367.1, 1498.8)	0.6067	101.7	(42.2, 245.2)	0.6400	984.7	(373.2, 2598.5)	0.5912
Aldicarb 5.6 kg/ha + Oxamyl 1.26 L/ha	514	(254.4, 1038.6)	0.2802	246.7	(102.3, 594.9)	0.4674	361.6	(137.0, 954.2)	0.4917

Table 10 (continued)

2011									
Treatment and Rate	Plant			30 DAP			60 DAP		
	Mean	95% CL	Dunnett's *P*	Mean	95% CL	Dunnett's *P*	Mean	95% CL	Dunnett's *P*
Untreated Control	1648.5	(838.4, 3241.2)		759.8	(289.3, 1995.8)		531.4	(320.5, 881.1)	
Aeris Seed Applied System	686.5	(349.1, 1349.8)	0.1304	615.6	(234.3, 1617.0)	0.7954	406.7	(345.3, 674.2)	0.5301
Aeris Seed Applied System + Aldicarb 3.9 kg/ha	1078.6	(548.6, 2120.7)	0.4573	1174.6	(447.2, 3085.3)	0.5922	463.5	(279.6, 768.5)	0.7477
Aeris Seed Applied System + Aldicarb 5.6 kg/ha	1427.1	(725.8, 2806.0)	0.7997	676.5	(257.5, 1776.9)	0.8861	582.8	(351.5, 966.3)	0.8281
Aeris Seed Applied System + Aldicarb 5.6 kg/ha + Oxamyl 1.26 L/ha	1321.6	(672.2, 2598.5)	0.6977	698.6	(266.0, 1835.0)	0.9175	283.0	(170.7, 469.1)	0.1451
Aeris Seed Applied System + Oxamyl 1.26 L/ha	1090.9	(554.9, 2145.0)	0.4694	2328.5	(886.5, 6116.2)	0.1742	143.8	(86.7, 238.4)	0.0042
Aldicarb 3.9 kg/ha	1344.4	(683.8, 2643.3)	0.7199	645.4	(245.7, 1695.3)	0.8406	664.9	(401.0, 1102.4)	0.5988
Aldicarb 5.6 kg/ha	751.6	(382.3, 1477.8)	0.1735	759.8	(289.3, 1995.8)	1.0000	556.9	(335.9, 923.2)	0.9125
Aldicarb 3.9 kg/ha + Oxamyl 1.26 L/ha	1452.9	(738.9, 1856.6)	0.8241	1937.4	(737.5, 5088.8)	0.2539	865.4	(522.0, 1434.8)	0.2563
Aldicarb 5.6 kg/ha + Oxamyl 1.26 L/ha	988.3	(502.7, 1943.4)	0.3711	1255.5	(478.0, 3297.8)	0.5373	304.1	(183.4, 504.1)	0.1950

Table 11: Cotton yield mapping data (number of bolls, weight, and corresponding position on the plant) for each nematicide treatment in 2009, 2010, & 2011.

2009									
Treatment and Rate	Total 1st Position Bolls			Total 2nd Position Bolls			Total 3rd Position Bolls		
	Mean	95% CL	Dunnett's *P*	Mean	95% CL	Dunnett's *P*	Mean	95% CL	Dunnett's *P*
Aeris Seed Applied System	14.0	(11.9, 16.1)		7.3	(5.8, 8.8)		2.7	(1.3, 4.1)	
Aeris Seed Applied System + Aldicarb 3.9 kg/ha	15.1	(12.9, 17.2)	0.5475	7.9	(6.4, 9.4)	0.6272	5.0	(3.6, 6.4)	0.0639
Aeris Seed Applied System + Aldicarb 5.6 kg/ha	15.6	(13.5, 17.7)	0.3704	7.8	(6.3, 9.3)	0.6657	3.9	(2.5, 5.3)	0.3344
Aeris Seed Applied System + Aldicarb 5.6 kg/ha + Oxamyl 1.26 L/ha	16.1	(14.0, 18.3)	0.2369	8.9	(7.4, 10.4)	0.2052	4.4	(3.0, 5.8)	0.1627

2009									
Treatment and Rate	Total Weight 1st Position Bolls (g)			Total Weight 2nd Position Bolls (g)			Total Weight 3rd Position Bolls (g)		
	Mean	95% CL	Dunnett's *P*	Mean	95% CL	Dunnett's *P*	Mean	95% CL	Dunnett's *P*
Aeris Seed Applied System	197.6	(169.4, 230.5)		89.0	(69.1, 114.6)		35.5	(13.6, 57.4)	
Aeris Seed Applied System + Aldicarb 3.9 kg/ha	216.1	(185.2, 252.1)	0.4829	107.9	(83.8, 138.9)	0.3624	62.0	(40.1, 83.9)	0.1538
Aeris Seed Applied System + Aldicarb 5.6 kg/ha	216.2	(185.3, 252.2)	0.4801	105.9	(82.3, 136.4)	0.4083	63.7	(41.8, 85.6)	0.1313
Aeris Seed Applied System + Aldicarb 5.6 kg/ha + Oxamyl 1.26 L/ha	215.5	(184.7, 251.4)	0.4960	108.0	(83.9, 139.1)	0.3587	57.8	(35.9, 79.7)	0.2265

Table 11 (continued)

2010									
Treatment and Rate	Total 1st Position Bolls			Total 2nd Position Bolls			Total 3rd Position Bolls		
	Mean	95% CL	Dunnett's *P*	Mean	95% CL	Dunnett's *P*	Mean	95% CL	Dunnett's *P*
Untreated Control	27.25	(23.21, 31.29)		11.75	(9.10, 14.40)		3.30	(1.70, 4.80)	
Aeris Seed Applied System	29.75	(25.71, 33.79)	0.4634	11.00	(8.35, 13.65)	0.7360	3.00	(1.50, 4.50)	0.8436
Aeris Seed Applied System + Aldicarb 3.9 kg/ha	24.25	(20.21, 28.29)	0.3797	10.00	(7.35, 12.65)	0.4337	1.00	(-0.05, 2.50)	0.0835
Aeris Seed Applied System + Aldicarb 5.6 kg/ha	30.00	(25.96, 34.04)	0.4203	11.50	(8.85, 14.15)	0.9106	2.00	(0.50, 3.50)	0.3277
Aeris Seed Applied System + Aldicarb 5.6 kg/ha + Oxamyl 1.26 L/ha	25.75	(21.71, 29.79)	0.6589	9.75	(7.10, 12.40)	0.3716	1.80	(0.20, 3.30)	0.2418
Aeris Seed Applied System + Oxamyl 1.26 L/ha	32.25	(28.21, 36.29)	0.1478	10.25	(7.60, 12.90)	0.5016	3.80	(2.20, 5.30)	0.6936
Aldicarb 3.9 kg/ha	27.75	(23.71, 31.79)	0.8829	11.25	(8.60, 13.90)	0.8222	4.00	(2.50, 5.50)	0.5550
Aldicarb 5.6 kg/ha	27.00	(22.96, 31.04)	0.9412	10.25	(7.60, 12.90)	0.5016	4.30	(2.70, 5.80)	0.4325
Aldicarb 3.9 kg/ha + Oxamyl 1.26 L/ha	28.00	(23.96, 32.04)	0.8252	11.50	(8.85, 14.15)	0.9106	2.30	(0.70, 3.80)	0.4323
Aldicarb 5.6 kg/ha + Oxamyl 1.26 L/ha	24.50	(20.46, 28.54)	0.4202	9.00	(6.35, 11.65)	0.2220	1.50	(-0.10, 3.00)	0.1739

Table 11 (continued)

2010									
Treatment and Rate	Total Weight 1st Position Bolls (g)			Total Weight 2nd Position Bolls (g)			Total Weight 3rd Position Bolls (g)		
	Mean	95% CL	Dunnett's *P*	Mean	95% CL	Dunnett's *P*	Mean	95% CL	Dunnett's *P*
Untreated Control	123.83	(105.86, 141.80)		48.90	(38.26, 59.53)		11.30	(5.40, 17.30)	
Aeris Seed Applied System	127.50	(109.53, 145.47)	0.8080	45.62	(34.98, 56.25)	0.7139	11.40	(5.50, 17.30)	0.9968
Aeris Seed Applied System + Aldicarb 3.9 kg/ha	111.96	(93.99, 129.93)	0.4340	43.14	(35.51, 53.78)	0.5212	4.80	(-1.10, 10.70)	0.1921
Aeris Seed Applied System + Aldicarb 5.6 kg/ha	135.88	(117.91, 153.84)	0.4274	46.85	(36.22, 57.78)	0.8193	6.00	(0.10, 11.90)	0.2828
Aeris Seed Applied System + Aldicarb 5.6 kg/ha + Oxamyl 1.26 L/ha	119.40	(101.43, 137.36)	0.7692	42.15	(31.51, 52.78)	0.4522	5.70	(-0.20, 11.60)	0.2579
Aeris Seed Applied System + Oxamyl 1.26 L/ha	136.82	(118.85, 154.78)	0.3925	49.04	(38.41, 59.68)	0.9871	12.90	(7.00, 18.80)	0.7551
Aldicarb 3.9 kg/ha	123.65	(105.68, 141.62)	0.9905	47.13	(36.49, 57.76)	0.8430	15.40	(9.50, 21.30)	0.4167
Aldicarb 5.6 kg/ha	118.25	(100.28, 136.21)	0.7118	43.96	(33.32, 54.59)	0.5815	16.40	(10.40, 22.30)	0.3175
Aldicarb 3.9 kg/ha + Oxamyl 1.26 L/ha	121.06	(103.09, 139.03)	0.8544	43.85	(33.21, 54.48)	0.5732	8.20	(2.30, 14.10)	0.5229
Aldicarb 5.6 kg/ha + Oxamyl 1.26 L/ha	96.53	78.56, 114.49)	0.0782	35.44	(24.80, 46.07)	0.1393	4.40	(-1.50, 10.30)	0.1676

Table 11 (continued)

2011									
Treatment and Rate	Total 1st Position Bolls			Total 2nd Position Bolls			Total 3rd Position Bolls		
	Mean	95% CL	Dunnett's *P*	Mean	95% CL	Dunnett's *P*	Mean	95% CL	Dunnett's *P*
Untreated Control	24.50	(22.27, 26.73)		7.50	(5.36, 9.64)		3.50	(2.10, 4.90)	
Aeris Seed Applied System	24.75	(22.52, 26.98)	0.8937	10.00	(7.86, 12.14)	0.1706	4.00	(2.60, 5.40)	0.6783
Aeris Seed Applied System + Aldicarb 3.9 kg/ha	26.50	(24.27, 28.73)	0.2896	8.25	(6.11, 10.39)	0.6766	1.50	(0.10, 2.90)	0.1042
Aeris Seed Applied System + Aldicarb 5.6 kg/ha	25.50	(23.27, 27.73)	0.5938	12.00	(9.86, 14.14)	0.0170	4.00	(2.60, 5.40)	0.6783
Aeris Seed Applied System + Aldicarb 5.6 kg/ha + Oxamyl 1.26 L/ha	28.00	(25.77, 30.23)	0.0689	9.00	(6.86, 11.14)	0.4064	3.00	(1.60, 4.40)	0.6784
Aeris Seed Applied System + Oxamyl 1.26 L/ha	22.00	(19.77, 24.23)	0.1879	8.25	(6.11, 10.39)	0.6766	2.00	(0.60, 3.40)	0.2186
Aldicarb 3.9 kg/ha	23.50	(21.27, 25.73)	0.5938	6.50	(4.36, 8.64)	0.5786	1.00	(-0.40, 2.40)	0.0448
Aldicarb 5.6 kg/ha	27.25	(25.02, 29.48)	0.1487	8.00	(5.86, 10.14)	0.7808	1.00	(-0.40, 2.40)	0.0448
Aldicarb 3.9 kg/ha + Oxamyl 1.26 L/ha	26.50	(24.27, 28.73)	0.2896	10.00	(7.86, 12.14)	0.1706	3.30	(1.80, 4.70)	0.8355
Aldicarb 5.6 kg/ha + Oxamyl 1.26 L/ha	27.00	(24.77, 29.23)	0.1879	9.75	(7.61, 11.89)	0.2161	1.30	(-0.20, 2.70)	0.0692

Table 11 (continued)

2011									
Treatment and Rate	Total Weight 1st Position Bolls (g)			Total Weight 2nd Position Bolls (g)			Total Weight 3rd Position Bolls (g)		
	Mean	95% CL	Dunnett's *P*	Mean	95% CL	Dunnett's *P*	Mean	95% CL	Dunnett's *P*
Untreated Control	100.50	(88.87, 112.13)		26.50	(16.84, 36.16)		8.00	(3.60, 12.40)	
Aeris Seed Applied System	109.25	(97.62, 120.88)	0.3738	39.00	(29.34, 48.66)	0.1308	11.30	(6.90, 15.60)	0.3794
Aeris Seed Applied System + Aldicarb 3.9 kg/ha	108.75	(97.12, 120.38)	0.4014	30.50	(20.84, 40.16)	0.6227	4.00	(-0.40, 8.40)	0.2809
Aeris Seed Applied System + Aldicarb 5.6 kg/ha	104.50	(92.87, 116.13)	0.6828	36.50	(26.84, 46.16)	0.2236	8.80	(4.40, 13.10)	0.8383
Aeris Seed Applied System + Aldicarb 5.6 kg/ha + Oxamyl 1.26 L/ha	123.25	(111.62, 134.88)	0.0257	36.50	(26.84, 46.16)	0.2236	8.30	(3.90, 12.60)	0.9457
Aeris Seed Applied System + Oxamyl 1.26 L/ha	95.50	(83.87, 107.13)	0.6098	24.50	(14.84, 34.16)	0.8054	4.30	(-0.10, 8.60)	0.3115
Aldicarb 3.9 kg/ha	100.75	(89.12, 112.38)	0.9796	23.25	(13.59, 32.91)	0.6891	3.80	(-0.60, 8.10)	0.2526
Aldicarb 5.6 kg/ha	115.00	(103.37, 126.63)	0.1451	33.50	(23.84, 43.16)	0.3913	2.30	(-2.10, 6.60)	0.1250
Aldicarb 3.9 kg/ha + Oxamyl 1.26 L/ha	105.25	(93.62, 116.88)	0.6277	35.00	(25.34, 44.66)	0.2992	6.50	(2.10, 10.90)	0.6834
Aldicarb 5.6 kg/ha + Oxamyl 1.26 L/ha	110.00	(98.37, 121.63)	0.3349	33.00	(25.34, 44.66)	0.4256	1.80	(-2.60, 6.10)	0.0965

Table 12. Cotton plant heights (cm) at harvest for each nematicide treatment in 2009, 2010, & 2011.

Treatment and Rate	2009			2010			2011		
	Mean	95% CL	Dunnett's *P*	Mean	95% CL	Dunnett's *P*	Mean	95% CL	Dunnett's *P*
Untreated Control				94.3	(84.6, 99.6)		95.8	(86.0, 105.6)	
Aeris Seed Applied System	111.6	(106.7, 116.6)		92.1	(82.5, 97.6)	0.7253	106.4	(96.6, 116.2)	0.2051
Aeris Seed Applied System + Aldicarb 3.9 kg/ha	116.7	(111.8, 121.7)	0.2187	90.1	(84.6, 99.6)	0.5045	101.3	(91.5, 111.1)	0.5060
Aeris Seed Applied System + Aldicarb 5.6 kg/ha	111.5	(106.5, 116.4)	0.9739	92.1	(86.0, 101.1)	0.7253	101.7	(91.9, 111.5)	0.4808
Aeris Seed Applied System + Aldicarb 5.6 kg/ha + Oxamyl 1.26 L/ha	114.4	(109.5, 119.4)	0.4950	93.6	(83.1, 98.1)	0.9067	102.1	(92.3, 111.9)	0.4503
Aeris Seed Applied System + Oxamyl 1.26 L/ha	NA*	NA	NA	90.6	(86.8, 101.8)	0.5589	91.9	(82.1, 101.7)	0.6352
Aldicarb 3.9 kg/ha	NA	NA	NA	90.0	(82.4, 97.5)	0.4940	98.7	(88.9, 108.5)	0.7312
Aldicarb 5.6 kg/ha	NA	NA	NA	92.3	(84.8, 99.8)	0.7505	107.1	(97.3, 116.9)	0.1788
Aldicarb 3.9 kg/ha + Oxamyl 1.26 L/ha	NA	NA	NA	90.5	(83.0, 98.0)	0.5478	100.1	(90.7, 110.3)	0.5722
Aldicarb 5.6 kg/ha + Oxamyl 1.26 L/ha	NA	NA	NA	86.7	(79.2, 94.2)	0.2335	105.4	(95.6, 115.2)	0.2501

* Treatments were not applied in 2009.

Table 13: Seed cotton yields (kg/ha) for each nematicide treatment in 2009, 2010, & 2011.

Treatment and Rate	2009			2010			2011		
	Mean	95% CL	Dunnett's *P*	Mean	95% CL	Dunnett's *P*	Mean	95% CL	Dunnett's *P*
Untreated Control				2853.1	(2490.0, 3216.2)		2336.3	(1857.2, 2815.4)	
Aeris Seed Applied System	2510.4	(2306.1, 2714.8)		2959.8	(2959.8, 2596.7)	0.7268	2757.5	(2278.4, 3236.6)	0.2998
Aeris Seed Applied System + Aldicarb 3.9 kg/ha	2323.5	(2119.1, 2527.8)	0.2752	2921.4	(2558.3, 3284.5)	0.8231	2562.0	(2082.9, 3041.2)	0.5759
Aeris Seed Applied System + Aldicarb 5.6 kg/ha	2559.6	(2355.3, 2763.9)	0.7703	2922.1	(2559.0, 3285.2)	0.8213	2410.8	(1931.7, 2889.9)	0.8532
Aeris Seed Applied System + Aldicarb 5.6 kg/ha + Oxamyl 1.26 L/ha	2608.4	(2404.1, 2812.7)	0.5623	3181.7	(2818.6, 3544.8)	0.2861	2523.9	(2044.8, 3003.0)	0.6418
Aeris Seed Applied System + Oxamyl 1.26 L/ha				2775.1	(2412.0, 3138.2)	0.7983	2151.0	(1671.9, 2630.1)	0.6460
Aldicarb 3.9 kg/ha				2830.3	(2467.2, 3193.4)	0.9404	2013.9	(1534.8, 2493.0)	0.4257
Aldicarb 5.6 kg/ha				2743.9	(2380.8, 3107.0)	0.7206	2796.9	(2317.7, 3276.0)	0.2577
Aldicarb 3.9 kg/ha + Oxamyl 1.26 L/ha				2850.9	(2487.8, 3214.0)	0.9941	2553.0	(2073.9, 3032.1)	0.5912
Aldicarb 5.6 kg/ha + Oxamyl 1.26 L/ha				2869.5	(2506.4, 3232.6)	0.9572	2843.1	(2363.9, 3322.2)	0.2140

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