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The Effect of Soil Texture and Irrigation on *Rotylenchulus reniformis* and Cotton

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Abstract: The reniform nematode, *Rotylenchulus reniformis*, is the most damaging nematode pathogen of cotton in Alabama. 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 were conducted in microplot and greenhouse settings during 2008 to 2010. Population density of *R. reniformis* was significantly influenced by soil texture and exhibited a general decrease with increasing median soil particle size (MSPS). As the MSPS of a soil increased from 0.04 mm in clay soil to > 0.30 mm in very fine sandy loam and sandy loam soils, *R. reniformis* numbers decreased. The *R. reniformis* population densities on all soil types were also greater with irrigation. Early season cotton development was significantly affected by increasing *R. reniformis* Pi, with plant shoot-weight-to-root-weight ratios increasing at low *R. reniformis* Pi and declining with increasing *R. reniformis* Pi. Plant height was increased by irrigation throughout the growing season. The results suggests that *R. reniformis* will reach higher population densities in soils with smaller MSPS; however, the reduction in yield or plant growth very well may be no greater than in a soil that is less preferential to the nematode.
Key words: Gossypium hirsutum, median soil particle size (MSPS), soil moisture, soil texture, site-specific management.

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 (*Hoplolaimus columbus*, Sher) nematodes by delineating management zones based on various soil edaphic factors and assigning a risk level to each zone (Monfort et al., 2007; Starr et al., 2007). However, the relationship of reniform nematode with soil characteristics is not clear, and therefore, risk levels are not well defined.

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 for soils with high sand content (Lewis and Smith, 1976; Koenning et al., 1996), making zone delineation using soil texture as a main factor highly useful (Monfort et al., 2007; Starr et al., 2007). A 1990 survey of 11 states found no consistent relationship between presence of reniform nematode 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); moderate clay + silt percentages (28%) (Koenning et al., 1996; Herring et al., 2010); and silt percentages ranging from 54% to 60% (Monfort et al., 2008). Herring et al. (2010) reported that irrigation did not increase *R. reniformis* population densities on five of the sandy soil classes examined. In their study, nonirrigated microplots had greater numbers of *R. reniformis* at midseason and harvest. Within Alabama, the reniform nematode is known to exist above currently defined economic thresholds in a wide variety of soils (Gazaway and McLean, 2003), and although population densities are generally observed to be higher in finer texture soils, the impact of these differing populations on cotton yield is difficult to compare because of environmental factors.

In order to further our understanding of the effects of soil texture on the reniform nematode/cotton relationship, either for management zone delineation or for making management recommendations based on nematode population density, a comparison of soils that is unbiased by environmental factors must be conducted. The objectives of our trials were to evaluate six soil types representative of the major agronomic regions of Alabama to determine (i) reproductive potential of *R. reniformis* under irrigated and nonirrigated conditions and subsequent effects on cotton yield; and (ii) the effects of increasing initial populations of *R. reniformis* on early season cotton growth.

Materials and Methods

Two trials were conducted during 2008 to 2010 in six different soil types from the major field crop cultivated regions of Alabama to evaluate the effect of soil particle size on (i) the reproductive potential of the reniform nematode on cotton over a 3-yr period from a standardized initial population under both irrigated and nonirrigated conditions; and (ii) 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

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Decatur silt loam (18% sand, 49% silt, 33% clay; 1.0% organic material; pH 5.5), Hartsells fine sandy loam (66% sand, 21% silt, 13% clay; 2.7% organic material; pH 5.4), Vaiden clay (9% sand, 53% silt, 38% clay; 3.8% organic material; pH 6.1), Lloyd loam (38% sand, 35% silt, 27% clay; 2.0% organic material; pH 5.5), Dothan sandy loam (82% sand, 11% silt, 7% clay; 0.6% organic material; pH 5.9), and Ruston very fine sandy loam (64% sand, 21% silt, 15% clay; 1.6% organic material; pH 5.8). Soils were collected from the plow layer (top 12 to 15 cm) of the soil in cultivated fields free of plant parasitic nematodes. Soils were determined to be free of plant parasitic nematodes by taking random subsamples of each soil collected and extracting the nematodes using combined gravity screening and sucrose centrifugal flotation (Jenkins, 1964). Four samples were collected from each of the soil types. Soils were analyzed for nutrient and pH levels and maintained according to standard recommendations set by the Alabama Cooperative Extension System. Both trials were conducted at the Auburn University Plant Science Research Center in Auburn, AL.

Inoculum preparation: The culture of *R. reniformis* was procured by collecting samples of soil from various infested field locations throughout Alabama. *Rotylenchulus reniformis* was propagated and increased on cotton 'DP161B2RF' (Monsanto, St. Louis, MO) in the greenhouse. After 60 d, cotton plants were removed and the nematodes were extracted from the soil by combined gravity screening and sucrose centrifugal flotation. *Rotylenchulus reniformis* numbers were standardized as the number of juveniles and vermiform adults per 1 ml of water for inoculation.

Microplot trial: The first trial was conducted for 3 yr from 2008 to 2010 in 4,400-cm^3 plastic tree microplots in an outdoor setting with hand-water irrigation. Microplots are 30.5-cm-diam. by 35.5-cm-deep spaced 30 cm apart in rows with 45 cm between blocks. Wood chip mulch is placed on the soil surface around all the microplots to reduce weeds. Treatments were arranged in a 6 × 2 split plot factorial design replicated five times with the first factor designated as soil type and the second factor designated as irrigation. Microplots were planted each season with five seed of 'DP161B2RF' cotton in a linear row simulating the production field planting system. Immediately after planting in 2008, 5,000 vermiform *R. reniformis* were pipetted into each microplot in 10 ml of water into the linear seed row. Irrigation was added by hand-watering up to a liter of water to the irrigated microplots twice a day throughout the growing season to maintain adequate moisture availability. All nonirrigated pots were rain fed (Fig. 1). Cotton plants were evaluated at 60 and 150 d after planting (DAP) for height, and the cotton was hand-picked as bolls matured (120 to 150 DAP) and weighed to determine yield. The population density of *R. reniformis* was evaluated at planting (Pi), 60 DAP (Pm), and 150 DAP (Pf) by taking four 2.5-cm-diam. × 12-cm-deep core samples from each microplot. 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 min in a 0.6% sodium hypochlorite (NaOCl) solution and collected on a 25-μm screen.

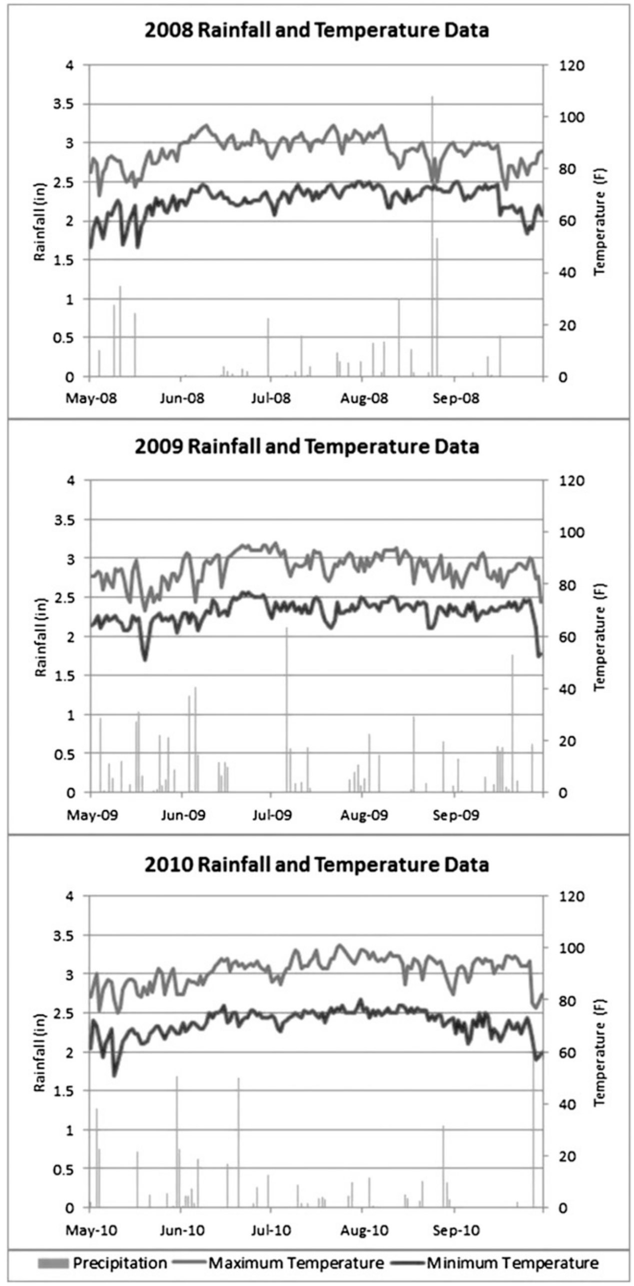

Fig. 1. Microplot trial air temperature daily maximums and minimums with precipitation for each growing season from 2008 to 2010.

Greenhouse trial: In order to determine the reproductive potential of *R. reniformis* with varying initial populations densities, greenhouse trials were conducted in 2010 using 500-cm^3 polystyrene pots for each of the six soil types. The tests were arranged in a randomized complete block design with four replicates and repeated twice for a total of three tests. At planting, six levels of reniform nematodes were added to the designated pots: 0, 500, 1,000, 2,000, 5,000, and 10,000 vermiform life stages were pipetted into each pot in 2 ml of water. Pots were planted with two germinated cotton 'DP161B2RF' seeds. Plant parameters measured included plant height at 30 and 60 DAP, and root and shoot fresh weight at 60 DAP. Shoot-weight-to-root-weight ratios indicating plant development were calculated by dividing the shoot fresh weight by the root fresh weight. Reniform nematodes 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- to 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 = $\sum$ [Percent particles of each category (coarse sand, medium sand, fine sand, very fine sand, coarse silt, fine silt, or clay) × median size of that category (1.25 mm, 0.75 mm, 0.175 mm, 0.075 mm, 0.035 mm, 0.011mm, or 0.001 mm)]/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 mean differences were separated using the PDIFF option in the LSMEANS statement, where $P \leq 0.05$ was required for significance. Interactions between the treatment factors of soil and irrigation were not significant for the microplot trials, and data were not analyzed separately. There were also no significant effects of year and thus the data for all three years were combined. Soil was a significant factor for the greenhouse trials; therefore, data for each soil type were analyzed separately. Mean Pf of *R. reniformis* and shoot-weight-to-root-weight ratios at 60 DAP were plotted against Pi of *R. reniformis.* Mean Pf of *R. reniformis* was plotted against median soil particle size, and graphics were generated using Microsoft Excel (Microsoft, Redmond, WA).

Results

Microplot trial: Drought was experienced during each growing season. Thus, water stress was observed annually throughout the duration of the microplot tests. Fig. 1 illustrates the air temperatures and precipitation through the growing season for each year. A soil type by irrigation interaction was not observed for nematode Pf, plant height, or seed cotton yield (Table 2). Irrigation increased mean population density of *R. reniformis* during the cotton growing season. Population density of *R. reniformis* was 45% higher in irrigated microplots than in nonirrigated microplots at 60 DAP, and 50% higher at 150 DAP. The overwintering nematode population densities were also influenced by irrigation. At cotton planting, the Pi in irrigated microplots were twice those in the nonirrigated microplots, even though the population numbers had declined by 48% from the previous Pf numbers.

Rotylenchulus reniformis population densities were less influenced by soil than by irrigation in this trial (Table 2). Among soil types, the silt loam soil averaged the highest *R. reniformis* population density at each sampling date in both irrigated and nonirrigated microplots, respectively, and population densities were higher ($P \leq 0.05$) in the irrigated pots at each sampling date. The silt loam soil supported a season total population density that was 54% greater than the average of all other soil types. The total *R. reniformis* population densities combined over the three seasons ranged from 13,108 per 150 cm^3 of soil in the silt loam, followed by 6,715 per 150 cm^3 of soil in the fine sandy loam, with the lowest numbers produced by the sandy loam at 5,063 per 150 cm^3 of soil. Irrigation affected *R. reniformis* population densities across soil type. Irrigation added to all soil types supported 36% higher *R. reniformis* population densities throughout the season ($P = 0.0642$) compared with the nonirrigated soils. The effect of irrigation was most prevalent on the silt loam soil with irrigation supporting 57% and 32% more *R. reniformis* at Pi ($P = 0.0051$) and Pm ($P = 0.0196$), respectively. Pi, Pm, and Pf were consistently lower in the clay, the very fine sandy loam, and sandy loam soils without irrigation.

Table 1. Particle size analysis and median soil particle size for each soil type used in greenhouse and microplot experiments.

	Particle size[a]							
Soil	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	MSPS (mm)[b]
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

[a] Values are percent of particle size present for each soil.
[b] Median soil particle size calculated as (MSPS) = $\sum$ [Percent particles of each category × median size of each category]/100.

TABLE 2. Mean *Rotylenchulus reniformis* populations at planting Pi, 60 d after planting (DAP) Pm and 150 DAP Pf, plant heights at 60 and 150 DAP, and seed cotton yields (grams/plot) for each soil type and irrigation regime from 2008 to 2010 in the greenhouse trial.

		Rotylenchulus reniformis/150 cm^3			Plant height (cm)		
Soil	Irrigation	Pi	Pm	Pf	60 DAP	150 DAP	Yield (g)[a]
Clay	Yes	865 b [y]	1,379 bc	1,978 bcd	29.3 abcde	47.3 abc	37.1 abc
	No	278 c	699 c	1,011 d	27.9 bcde	45.3 bcd	29.8 bcd
Silt loam	Yes	2,233 a	2,433 a	3,404 a	31.3 ab	45.2 bcd	43.7 a
	No	950 bc	1,661 b	2,427 ab	24.9 e	45.2 bcd	22.3 d
Loam	Yes	657 bc	1,058 bcd	2,092 bc	30.1 abcd	47.3 abc	33.8 abc
	No	355 bc	908 bcd	1,089 cd	25.3 e	42.4 cd	34.0 abc
Very fine sandy loam	Yes	935 bc	1,085 bcd	1,414 bcd	30.4 ab	46.4 bcd	36.0 abc
	No	595 bc	653 c	1,357 bcd	25.4 de	40.8 d	21.6 d
Fine sandy loam	Yes	1,151 b	1,321 bc	1,628 bcd	32.9 a	49.8 ab	31.5 bcd
	No	479 bc	1,020 bcd	1,116 cd	27.6 bcde	47.7 abc	29.0 cd
Sandy loam	Yes	579 bc	618 c	1,567 bcd	31.2 ab	52.8 a	41.1 ab
	No	471 bc	545 d	1,283 cd	25.9 cde	48.4 ab	29.0 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

[a] Means in the same column followed by the same letter do not differ significantly ($P \leq 0.05$) according to differences in least squares means.

Plant parameters were primarily affected by irrigation (Table 2) at 60 DAP. Plants were shorter ($P = 0.002$) in the nonirrigated pots within each soil type with the exception of the clay soil. The reduction of plant height between the irrigated and nonirrigated soils averaged 5.4 cm with a range of 4.8 to 6.4 cm in the silt loam through the sandy loam soil types. Plant height differences among soil types ($P = 0.0586$) were present at 150 DAP at cotton harvest. The fine sandy loam and sandy loam soils produced the tallest plants at harvest. Irrigation increased height ($P = 0.0260$) in the sandy loam, very find sandy loam, and loam soils from 4.5 to 5.6 cm. Only the silt loam, which displayed the most stunting at 60 DAP, supported plant growth equally at 150 DAP in the irrigated and nonirrigated systems. This soil also supported the greatest number of *R. reniformis.*

Irrigation had an effect ($P \leq 0.001$) on seed cotton yields (Table 2) in soils infested with reniform nematode. Seed cotton yields were 49%, 40%, and 30% greater in the irrigated pots containing the silt loam, the very fine sandy loam, and the sandy loam soils, respectively, compared with the nonirrigated pots ($P \leq 0.05$). Irrigation increased yields by an average of 39.6% in these soils. The irrigated silt loam soil produced the highest yield compared with all soil types. This soil also supported the highest nematode numbers throughout the season. The addition of adequate moisture through irrigation had a significant effect on seed cotton yield within this trial; more so than soil type or nematode population density.

Greenhouse trial: Cotton growth response to increasing Pi of *R. reniformis* was similar for all six soil types tested (Fig. 2). In each case, both shoot and root weight decreased at Pi = 500 compared with the Pi = 0; however, the decrease in root weight was double in magnitude compared with the decrease in shoot weight resulting in higher shoot-weight-to-root-weight ratios (Fig. 3). As *R. reniformis* population densities increased (Pi = 1,000 to 2,000), root weights steadily increased, and at Pi = 10,000 averaged 41% higher than the root weights in the Pi = 500 treatment. Inversely, after increasing back to levels at Pi = 2,000 that were similar to the Pi = 0 control, shoot weights decreased with increasing Pi, resulting in descending shoot-weight-to-root-weight ratios. These shoot-weight-to-root-weight ratios were significantly lower at Pi = 10,000 in the silt loam soil, Pi = 1,000 to 10,000 in the loam soil, and Pi = 5,000 to 10,000 in the sandy loam when compared with the Pi = 0 control. Pf in the soil increased significantly with increasing Pi. The clay soil supported the highest *R. reniformis* populations' densities, while the very fine sandy loam supported the lowest.

Regression analysis of *R. reniformis* population growth versus shoot-weight-to-root-weight ratios over the range of Pi's illustrates the differential effect of soils on the *R. reniformis*: cotton relationship (Fig. 2). The clay soil exhibited an increasing Pf with increasing Pi, described by the equation $Y = 8.0915x + 6061.9$ with an $r^2 = 0.957$, suggesting that the carrying capacity for this soil type was not achieved. The fine sandy loam soil also exhibited an increase, described by the equation $Y = 6.3727x + 1861.3$ with an $r^2 = 0.986$, similarly suggesting that the carrying capacity had not been achieved within the given range of Pi's. In comparison, the other four soil types (silt loam, loam, very fine sandy loam, and sandy loam) produced smaller r^2 values (0.524, 0.782, 0.433, and 0.8692, respectively) with distributions illustrating these soils to have reached or approached their carrying capacity for *R. reniformis.* Shoot-weight-to-root-weight ratios decreased with increasing Pi with the exception of the very fine sandy loam. However, as illustrated in Fig. 2, the decrease in shoot-weight-to-root-weight ratios by *R. reniformis* is very different between soils. For example, the population density of *R. reniformis* is very similar for the clay and loam soils at each Pi. However, the decrease in

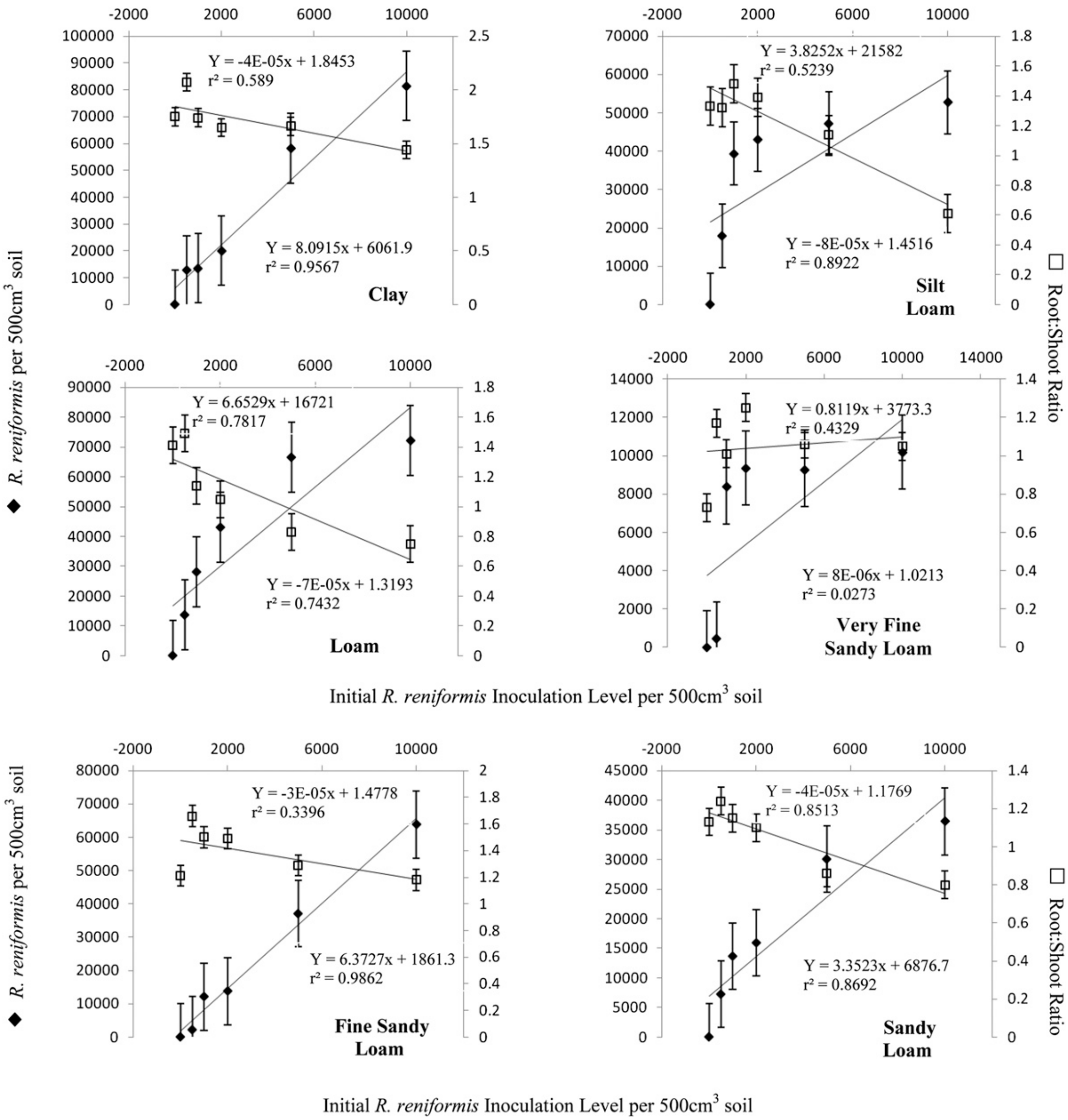

FIG. 2. Mean *Rotylenchulus reniformis* populations per 500 cm^3 of soil, and cotton plant shoot-weight-to-root-weight ratios at 60 d after planting for each initial population of *R. reniformis* within each of six soil types in the greenhouse trial.

shoot-weight-to-root-weight ratio is much more pronounced in the loam soil (slope = -4E-05× for the clay and -7E-05× for the loam).

Particle size analysis: The effect on soil particle size distribution on Pf for both the microplot and greenhouse trials is shown in Fig. 4. A quadratic relationship between Pf 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* numbers decreased. Although the initial classifications for the very fine sandy loam (64% sand, 21% silt, 15% clay) and fine sandy loam (66% sand, 21% silt, 13% clay) 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 five times 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

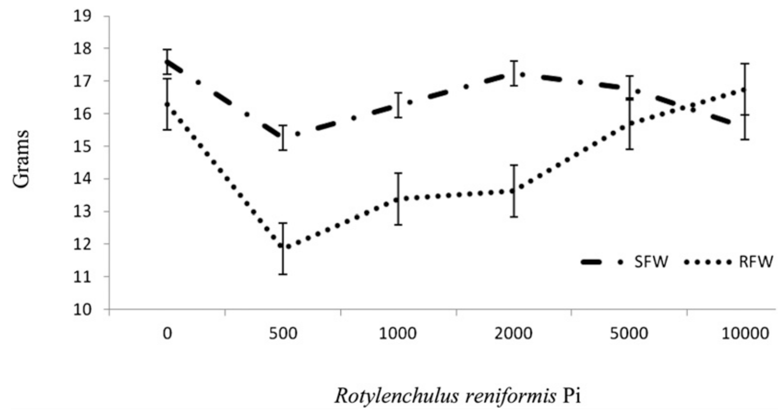

FIG. 3. Average shoot fresh weight (SFW) and root fresh weight (RFW) (g) at each initial inoculation level (Pi) of *Rotylenchulus reniformis*.

(Robinson et al., 1987; Heald and Robinson, 1990; Starr et al., 1993; Koenning et al., 1996; Herring et al., 2010) *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 elicit 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 and nutrient availability, may offer a beneficial growing environment to the cotton plant in a similar fashion as they provide benefit to the nematode. In the case of the silt loam soil, the irrigated microplots produced the highest yields even in the presence of the highest *R. reniformis* population density, similar to the results of Herring et al.

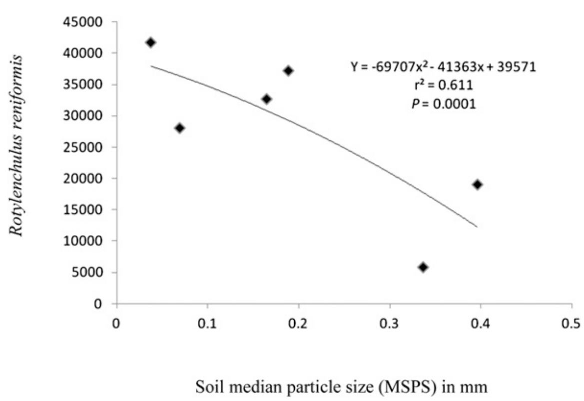

FIG. 4. Influence of soil median particle size (MSPS; MSPS = $\sum$ [Percent particles of a category (coarse sand, medium sand, fine sand, very fine sand, coarse silt, fine silt, or clay) $\times$ median size of that category (1.25 mm, 0.75 mm, 0.175 mm, 0.075 mm, 0.035 mm, 0.011 mm, or 0.001 mm)] /100) on Pf of *Rotylenchulus reniformis*/150 cm^3 of soil in six different soil types over a 3-yr period.

(2010). Contrastingly, Herring et al., (2010) found the population densities of *R. reniformis* were greater in nonirrigated microplots, while we observed the opposite in our microplots where all six of our soils types supported higher population densities of *R. reniformis* in the irrigated soils. However, in their studies Herring et al., evaluated various sand soils of North Carolina but did not include silty soils that are the cotton production soils of the mid South as found in Alabama.

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 low Pi of *R. reniformis* may accelerate plant maturity, while high 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. As nematode populations increased, the growth of roots was emphasized, ultimately to the detriment of shoot production. The reduced root mass with increasing Pi has been observed in our breeding work as well (Sikkens et al., 2011).

Current thresholds for economic damage are generally dictated on a state-to-state basis and are generally found on extension websites. In this article we suggest, as illustrated by the differential effects within soils from six different locations in one state, a more refined system could lead to significant economic benefits where current recommendations are either over- or under-estimating economic damage thresholds of a given soil type. For example, early season cotton growth in the fine sandy loam soil was no different between the nematode absent control and the Pi 10,000 treatment. The silt loam, in contradiction to the fine sandy loam, exhibited a large difference between the nematode absent control and the Pi 10,000 treatment although the Pf of both soils at the Pi 10,000 treatment was very close. The effects on season-long growth and cotton yield are needed to ultimately determine how soil type affects economic damage threshold for *R. reniformis* on cotton.

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* reproduction potential compared with previous methods. While our results are comparable with those previously mentioned (Starr et al., 1993; Koenning et al., 1996; Monfort et al., 2008; Herring et al., 2010), in that *R. reniformis* prefers or has an increased reproductive rate 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* population dynamics. 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, it is another tool that 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. 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 density must be considered and used to develop an economic threshold and management plan for each zone.

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