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Site Specific Nematode Management—Development and Success in Cotton Production in the United States

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Abstract: Variability in edaphic factors such as clay content, organic matter, and nutrient availability within individual fields is a major obstacle confronting cotton producers. Adaptation of geospatial technologies such global positioning systems (GPS), yield monitors, autosteering, and the automated on-and-off technology required for site-specific nematicide application has provided growers with additional tools for managing nematodes. Multiple trials in several states were conducted to evaluate this technology in cotton. In a field infested with *Meloidogyne* spp., both shallow (0 to 0.3 m) and deep (0 to 0.91 m) apparent electrical conductivity (EC_a) readings were highly correlated with sand content. Populations of *Meloidogyne* spp. were present when shallow and deep EC values were less than 30 and 90 mS/m, respectively. Across three years of trials in production fields in which verification strips (adjacent nematicide treated and untreated rows across all soil zones) were established to evaluate crop response to nematicide application, deep EC values from 27.4-m wide transects of verification strips were more predictive of yield response to application of 1,3-dichloropropene than were shallow EC values in one location and both EC_a values equally effective at predicting responses at the second location. In 2006, yields from entire verification strips across three soil zones in four production fields showed that nematicide response was greatest in areas with the lowest EC values indicating highest content of sand. In 2008 in Ashley and Mississippi Counties, AR, nematicide treatment by soil zone resulted in 36% and 42% reductions in the amount of nematicide applied relative to whole-field application. In 2007 in Bamberg County, SC, there was a strong positive correlation between increasing population densities of *Meloidogyne incognita* and increasing sand content. Trials conducted during 2007 and 2009 in South Carolina against *Hoplolaimus columbus* showed a stepwise response to increasing rates of aldicarb in zone 1 but not in zones 2 and 3. Site-specific application of nematicides has been shown to be a viable option for producers as a potential management tool against several nematode pathogens of cotton.
Key words: cotton, *Hoplolaimus columbus*, *Gossypium hirsutum*, management, *Meloidogyne incognita*, *Rotylenchulus reniformis*, site-specific, soil texture.

Plant-parasitic nematodes are major pests of cotton in the southern United States. The reniform nematode (*Rotylenchulus reniformis*), southern root-knot nematode (*Meloidogyne incognita*), and Columbia lance nematode (*Hoplolaimus columbus*) are the three species of greatest concern (Koenning et al., 2004). The incidence of these three nematodes is strongly influenced by soil type. The southern root-knot nematode is usually found in sandy or coarse-textured soils (Robinson et al., 1987; Koenning et al., 1996; Thomas and Kirkpatrick, 2001; Monfort et al., 2007). Reniform nematodes appear to be favored by soils that contain more silt or clay (Robinson et al., 1987; Starr et al., 1993; Koenning et al., 1996; Monfort et al., 2008; Herring et al., 2010). Columbia lance nematode, found primarily in the coastal plains soils of Georgia, North Carolina, and South Carolina, occurs only in soils with sand content >70% (Lewis and Smith, 1976; Martin et al., 1994; Khalilian et al., 2001).

A major obstacle confronting cotton growers is variability in edaphic factors such as clay content, organic matter, and nutrient availability within individual fields (Viscarra Rossel and McBratney, 1998). Conventional farming practices treat an entire field as a unit and ignore variability that occurs within the field (Corwin and Lesch, 2005). For example, if fertilizer is applied, it is applied at a single rate fieldwide, frequently resulting in areas that are over- or underfertilized. Nutrient variability and the cost of fertilizer application have prompted considerable research effort by soil scientists to explore how best to map a field for activities such as soil sampling and/or nutrient application. Across a number of approaches to this challenge, grid-sampling, which divides a field into sampling subunits based on an arbitrary grid, has been the most effective method (Mallarino and Wittry, 2004). Because nematodes are unevenly distributed both vertically and horizontally within a field, nematologists face a similar problem determining the best method to characterize nematode distribution (Barker and Campbell, 1981; Ferris, 1984). Although extensive soil sampling of fields using the grid sampling technique may be effective in defining nematode population densities, it is almost always cost-prohibitive (Wheeler et al., 2000; Wrather et al., 2002; Wheeler, 2006). This results from the labor

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and laboratory fees associated with extensive sampling in a relatively low-value crop such as cotton (Evans et al., 2002; Wrather et al., 2002; Wyse-Pester et al., 2002).

A second type of sampling protocol is referred to as zone sampling. This method arbitrarily subdivides a field into areas with similar characteristics such as cropping history, pH, nutritional status, or more commonly soil texture. Melakeberhan (2002) suggested that zone sampling might be an effective method to characterize the spatial distribution of nematode communities in a field. Zone sampling has also been shown to be an effective method to determine nutrient status in a field (Johnson et al., 2001).

Nematicides are used extensively in cotton production because of an absence of cotton cultivars with acceptable levels of nematode resistance (Koenning et al., 2004; Starr et al., 2007). Fumigant nematicides have historically provided the greatest and most consistent yield responses (Lawrence et al., 1990; Noe, 1990; Kinlock and Rich, 1998, 2001; Baird et al., 2000a, 2000b; Koenning et al., 2004). Major concerns, however, with continued reliance on nematicides include the cost of the products, difficulty in application, and the well-documented environmental consequences associated with existing fumigants.

Adaptation of geospatial technologies such as GPS, yield monitors, autosteering, and the automated on-and-off technology required for site-specific nematicide application has provided growers with additional tools for managing nematodes. Before site-specific nematicide application, the ability to reliably determine where in a field to apply nematicides for maximum efficacy and cost-effectiveness was an elusive goal. Apparent electrical conductivity (EC_a) has recently been investigated as a means of rapidly estimating the general soil texture in a particular site. This technique has previously been used to estimate many chemical and physical properties of nonsaline soils, including clay content (Williams and Hoey, 1987; King et al., 2005; Kitchen et al., 2005), depth to claypan (Doolittle et al., 1994), and soil texture (Williams and Hoey, 1987; Patzold et al., 2008). Devices such as the Veris® 3100 Soil EC Mapping System (Veris Technologies, Salina, KS) provide for rapid and economical measurement and mapping of EC_a across agricultural fields. This equipment utilizes a system of coulters that are in direct contact with the soil and measure the amount of current moved from the emitting to receiving coulters as the device travels through the field. Similarly, the EM 38® (Geonics, Ltd., Mississauga, Canada) induces a current into the soil and determines EC_a by measuring the resulting secondary current. Both of these devices yield similar results (Suddeth et al., 1999) and provide a means to classify fields with variable soil types into distinct zones (Johnson et al., 2001).

Since soil texture has been closely correlated with nematode incidence (Noe and Barker, 1985; Wyse-Pester et al., 2002; Avendaño et al., 2004a, 2004b; Monfort et al., 2007), the use of EC_a has been evaluated as a key component in site-specific nematode management. Khalilian et al. (2001) were one of the first researchers to look at the relationship among EC_a, nematode population densities and related cotton yield responses. They reported that percent clay or sand in the soil was strongly correlated with EC_a (R^2 values of 0.92 for clay and 0.91 for sand). When their field site was subdivided into four EC_a ranges that reflected increasing levels of sand, population densities of *H. columbus* at planting and at harvest was strongly correlated with the area having the greatest amount of sand.

The objectives of this research were to (i) determine if geographic information systems (GIS) technologies utilizing the Veris® 3100 Soil EC Mapping System can be utilized to define management zones across a range of soils; (ii) determine if GIS technology can be utilized to characterize and manage spatial and temporal variability of nematodes; and (iii) determine whether these technologies can be used to improve management strategies for nematode parasites of cotton.

Materials and Methods

General methodologies for all field experiments: A major aspect of this research was to evaluate the Veris® 3100 Soil EC Mapping System combined with a GPS unit and associated software as part of a site-specific nematode management project. The Veris® 3100 Soil EC Mapping System was used to collect soil EC_a at two soil depths. The unit consisted of six coulters, two of which introduce an electrical current into the soil. The remaining four coulters were spaced to receive the electrical current at soil depths of 0.3 and 0.91 m. These two measurements are referred to as EC-S ($EC_{a\text{-shallow}}$) and EC-D ($EC_{a\text{-deep}}$) and are expressed as millisiemens per meter (mS/m). Data were recorded at 1-sec intervals and georeferenced using a differentially corrected GPS receiver as the Veris equipment traveled across the field. The standard operating width spacing was 12.2 m producing more than 200 data points per ha. Electrical conductivity data was then exported into GIS software such as SSToolbox (SST Software, Stillwater, OK), which produced a map that divided the field into zones based on EC-S and EC-D that reflected differences in soil texture across the field.

Textural analysis of soil was conducted using the hydrometer method modified by Day (1965) and the American Society for Testing and Materials (1985). Soil for nematode analysis was collected either by grid sampling, along transects or along the length of a row to a depth of 20 cm with a 2.0-cm-d probe and processed by semi-automatic elutriation (Byrd et al., 1976) and centrifugal-flotation (Jenkins, 1964). Vermiform stages of nematodes were counted at a magnification of 40× using an inverted microscope.

Yield data was collected from all sites using yield monitors mounted on cotton pickers. Yield and nematode data from all trials was analyzed using Statistix 9 (Analytical Software, Tallahassee, FL) or SAS 9.3 (SAS Institute, Cary, NC) for analysis of variance (ANOVA) and Fisher's least significant difference test. Correlation coefficients were used for comparisons between EC_a and soil textural classes or population densities. Unless indicated otherwise, all differences mentioned were significant at the 5% level.

St. Joseph, LA: This study was conducted at the Northeast Research Station, St. Joseph, LA, during fall 2003 in a 31-ha field to determine if there was a correlation between EC_a and nematode distribution. The field was divided into 10 zones using EC-S and EC-D data (as described above) and overlaid with a 0.4-ha grid producing a total of 78 sites (Fig. 1). A sampling point was designated in the center of each site using a handheld Dell Axim X5 Pocket PC (Dell Computer Corp., Round Rock, TX) equipped with FarmWorks software (FarmWorks Information Management, Hamilton, IN). Sampling points were centered within each site to represent the dominant EC_a class and 10 soil cores were collected in fall 2003 for nematode and soil texture analysis as described above.

Tensas Parish, LA: Six trials, two per year between 2004 and 2006 were conducted in Tensas Parish, LA, in 9.6- and 28.2-ha fields containing the cotton cultivar Deltapine 555BGRR and designated respectively as Tensas 1 and Tensas 2. The purpose of these trials was to determine whether or not there was a relationship between EC_a and efficacy of 1,3-dichoropropene (1,3-D), Telone II® (Dow AgroSciences, Indianapolis, IN). In fall 2003, the Tensas 1 and Tensas 2 fields were divided into six and seven zones, respectively, using EC-D and overlaid with a 0.4-ha grid producing a total of 29 and 71 sites (Figs. 3A,B; 4A,B). Establishment of EC_a zones was as described above. A rate of 28.1 liter/ha of 1,3-D was applied each year 2 to 3 wk before planting. Areas treated in the two fields were a 3.2-ha portion of the Tensas 1 and a 5.0-ha portion of Tensas 2. There were five alternating treated and untreated strips, each 12 rows wide, established throughout the test area of each field. Nematicide treatments were applied using a two-row fumigant applicator equipped with 76.2-cm Yetter Avenger coulters (Yetter Manufacturing, Colchester, IL) set to a depth of 30 cm. To represent the predominant soil textural zones accurately within the test areas of each field, six transects within the treatment strips, each 27.4-m wide, were established in Tensas 1 and seven transects in the Tensas 2 to collect yield data. The test area of the Tensas 1 and Tensas 2 fields are illustrated as Figures 3C and 4C. Respectively, the blue and red lines indicate the 12-row strips that were treated with 1,3-D or left untreated. Black lines perpendicular to the red and blue lines illustrate the transects that were harvested to monitor yields associated with the treated and untreated rows. A John Deere

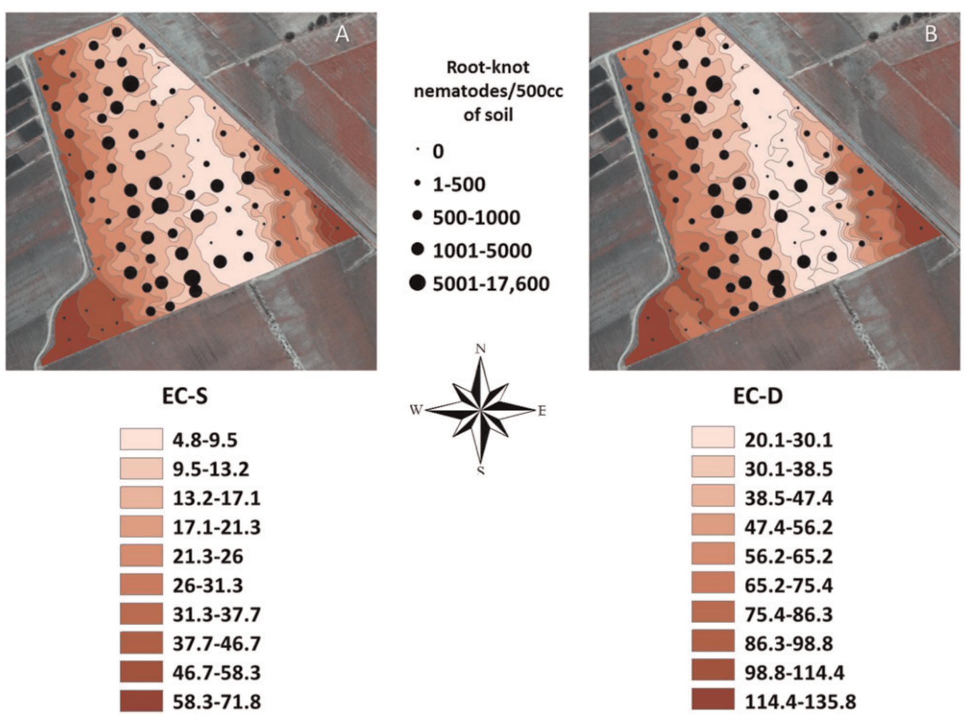

FIG. 1. Relationship between EC-S ($EC_{a\text{-shallow}}$) and EC-D ($EC_{a\text{-deep}}$) and population densities of *Meloidogyne incognita* at Northeast Research Station, St. Joseph, LA, in 2003. This 31-ha field was divided into 10 zones based on millisiemens per meter (mS/m) values obtained from the Veris® 3100 Soil EC Mapping System. Population densities of *Meloidogyne incognita* were determined after superimposing a grid sampling pattern that divided the field into 78 sites, each 0.4 ha in size.

(Goldman Equipment Co., Waterproof, LA) cotton picker equipped with a yield monitor was used for cotton harvest in late September-October of each year. Yield data was processed initially in Yield Editor (USDA Agricultural Research Service, Columbia, MO) and exported to SSToolBox for conversion to lint/ha.

Northeastern Louisiana: In 2006, areas representing 19.0, 35.3, 40.5, and 34.7 ha, respectively, in four cotton fields identified as Perry, Spyker, Railroad, and Faulk, in Morehouse Parish, LA, infested with *M. incognita* or both *M. incognita* and *R. reniformis* were mapped for EC-S. In each field, EC_a data was used to establish three soil texture zones. Eight alternating treated and untreated strips were established across these zones in each field. Strips treated with 1,3-D at 28 liter/ha were 64 rows wide and untreated strips were 16 rows wide. The purpose of these wider strips was to more accurately simulate a real-world environment and nematicide application. Nematode samples were collected from each of the untreated strips 2 wk after planting to establish nematode types and levels. Harvest data was collected by the producer using his equipment and yield monitor.

Arkansas: Trials were conducted in 2008 in a 6.4-ha field in Ashley County and a 65.0-ha field in Mississippi County, both in Arkansas. These fields had a history of cotton monoculture (10 + years) and were infested with *Meloidogyne* spp. A soil EC_a map that was developed in 2006 using the Veris equipment was used to define four soil textural zones and the zones were sampled for nematodes in fall 2007 immediately after harvest. A 1,3-D application map was developed based on the nematode population densities that were present above established threshold levels (Mueller et al., 2012). Treatments included four strips, each 12 rows wide, of 1,3-D at 28.1 liter/ha applied through the length of the field as the uniform application, 1,3-D at 28.1 liter/ha applied by prescription defined by nematode counts in zones (site-specific) or no fumigant. The fumigant was applied using a ripper-hipper equipped with a nitrogen-propelled applicator. Yield was recorded using a John Deere cotton picker equipped with a yield monitor.

South Carolina: In this study, the components of the site-specific nematicide placement (SNP) system (Khalilian et al., 2003a, 2003b) were installed on existing equipment of two producers. Three fields identified as Brubaker A and B (Bamberg County, SC) and Phillips (Orangeburg County, SC) were included in this study and ranged from 12 to 130 ha. The Brubaker A and Phillips trials were conducted in 2007 and the Brubaker B trial in 2009. Replicated tests were conducted on each of these sites to evaluate the performance and effectiveness of the SNP technology compared with current nematode management practices utilizing a uniform rate of nematicide across the entire field. Fields were mapped for soil EC_a, and three management zones were established based on variations in EC_a. In each zone, the following treatments were arranged as a randomized complete block design with three to six replications based on the field size: (i) uniform-application, (ii) site-specific, and (iii) untreated control. Either aldicarb or 1,3-D was used depending on each grower's standard practice. Georeferenced nematode samples were collected at planting and harvest from each management zone and cotton was harvested at crop maturity using a spindle picker equipped with an AgLeader (AgLeader Technology, Ames, IA) yield monitor and GPS unit to map changes in lint yield within and among treatments.

Result

St. Joseph, LA: Figure 1 illustrates the 10 electrical conductivity zones that were established and the nematode population densities associated with each zone. Population densities of *M. incognita* in the field ranged from zero to 17,600 J2/500-cm^3 soil. *Meloidogyne incognita* was not detected in zones 7 to 10 based on EC-S or zones 9 to 10 of EC-D. Both EC-S and EC-D values were positively correlated with sand (Fig. 2A,B). There was also a negative correlation with clay content (Fig. 2C,D). Populations of *M. incognita* were present when EC-S values were less than 30 mS/m (Fig. 2E) and when EC-D values were less than 90 mS/m (Fig. 2F).

Tensas Parish, LA: Electrical conductivity mapping of Tensas 1 field partitioned it into six zones (Fig. 3A). Subsequent grid sampling of the zones in this field showed that *M. incognita* population densities were present throughout the field in high populations except for the soil zone with the highest EC-DP values (Fig. 3B). Across all of the zones, the density of the root-knot population ranged from 0 to 34,880 nematodes per 500 cc of soil. Figure 3D indicates the areas of the field where there was a significant increase in yield of the treated rows over those of the untreated rows. Only in the zone representing the sandiest areas where EC-D values ranged from 24 to 49.9 mS/m of the field (shaded green) was the response to the fumigant positive.

Electrical conductivity mapping of Tensas 2 field partitioned it into seven zones (Fig. 4A). Subsequent grid sampling of the zones in this field showed that *M. incognita* distribution was relatively uniform across the field (Fig. 4B). However, population densities were variable ranging from 0 to 3,420 J2/500-cc soil. Figure 4D indicates the areas of the field where there was a significant increase in yield of the treated rows over those of the untreated rows. Positive responses were observed in five of the seven zones representing the sandiest areas where the EC-D values ranges from 4 to 39.6 (shaded green).

Overall, across all three years of these studies, EC-D values were more predictive of yield response to

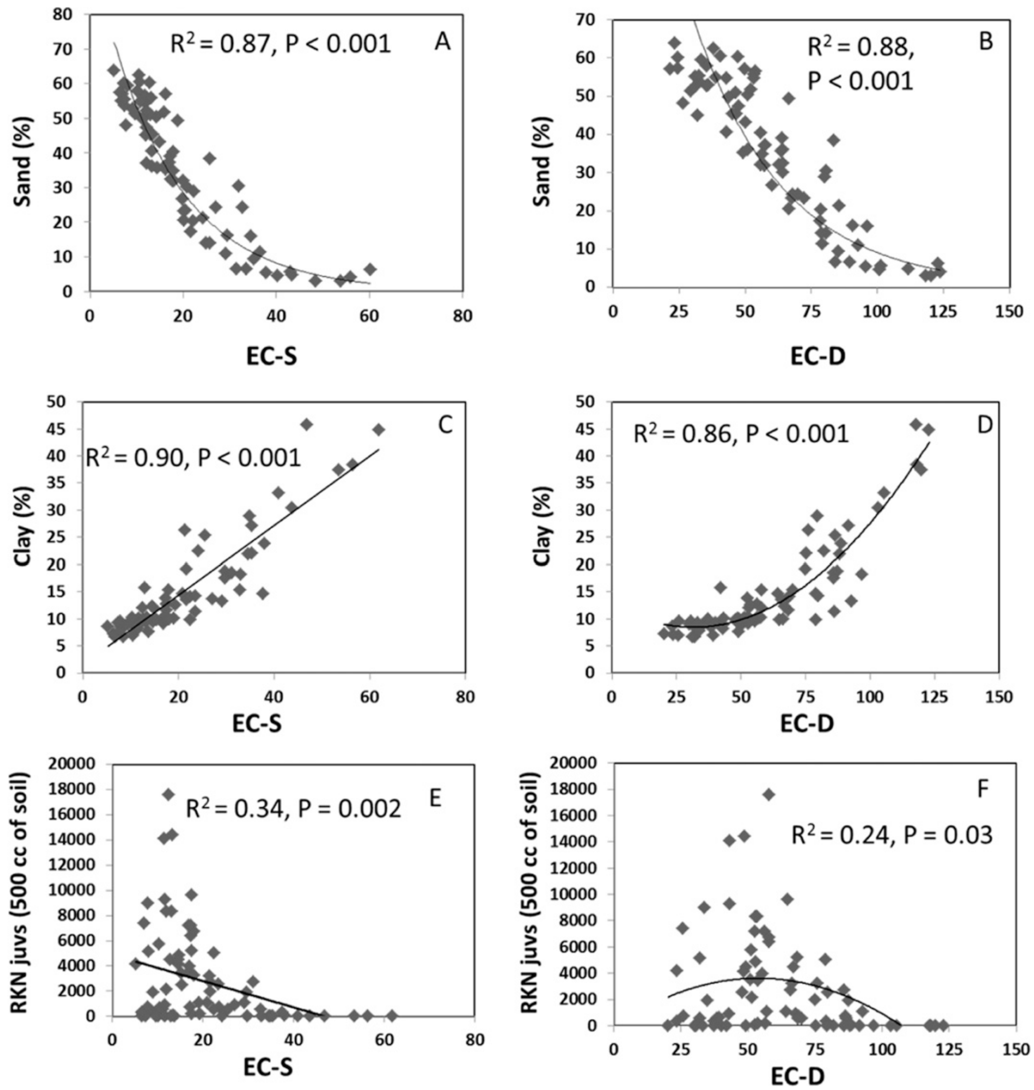

FIG. 2. Panels illustrate the relationship between the content of sand in the upper 20 cm of soil and (A) EC-S ($EC_{a\text{-shallow}}$) and (B) EC-D ($EC_{a\text{-deep}}$); the relationship between clay content in the upper 20 cm of soil and (C) EC-S and (D) EC-D; and the relationship between (E) EC-S and (F) EC-D and numbers of *Meloidogyne incognita* second-stage juveniles (RKN juvs/500 cc of soil). The experiment was conducted at Northeast Research Station, St. Joseph, LA, in 2003.

nematicide application than were EC-S values in Tensas 1 but both EC-D and EC-S could be used for Tensas 2 (Table 1). In both Tensas 1 and Tensas 2, transects with the highest EC-D values had the lowest response to 1,3-D each year. In Tensas 2, yields from transects treated with 1,3-D and having EC-D values between 8.3 and 21.5 mS/m had yields that were always numerically and usually significantly greater than those of the untreated controls in each of the three years. In each of the three years in the Tensas 1, the transect with an EC-D value of 35.0 mS/m and treated with 1,3-D had significantly greater yields than the untreated controls. Transects in Tensas 1, where the EC-D mean values ranged from 91.7 to 124.6 mS/m, never had significant yield response to treatment with 1,3-D.

Northeast Louisiana: Each of the four fields in this study were divided into three zones based on EC-S with zone 1 having the lowest EC_a values and zone 3 having the highest EC_a values. Levels of *M. incognita* and *R. reniformis* per 500 cc of soil at 2 wk after planting in the Railroad, Spyker, Perry Cutoff, and Faulk fields, respectively averaged 480 and 1,559; 4,948 and 0; 147 and 3,478; 1,600 and 7,550. Across all four fields, yields in zone 1 treated with 1,3-D were significantly greater than in zones left untreated (Table 2). Except for the Faulk field, yields from zone 2 in the Railroad, Spyker, and Perry Cutoff fields were also increased significantly by the application of 1,3-D. In zone 3, however, there was a significant increase in yield of treated over untreated areas only in the Railroad field.

Arkansas: Site-specific and uniform application with 1,3-D yielded similarly, and significantly better than the untreated strips. The application of 1,3-D in uniform application had lint averaging 1,090 and 1,205 kg/ha for the Ashley and Mississippi Counties fields compared with the untreated with 941 and 1,093 kg/ha,

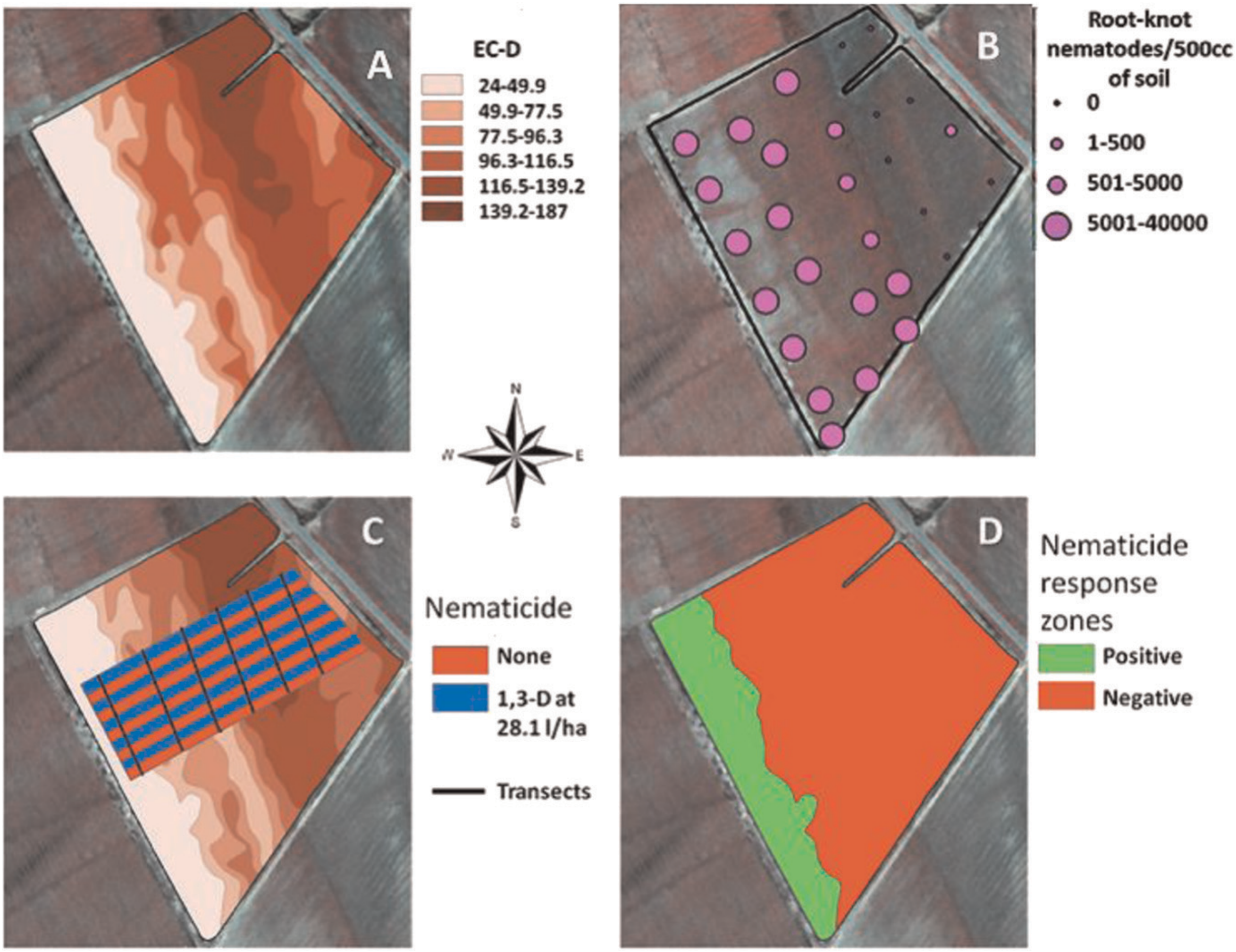

FIG. 3. The Tensas 1 field, Tensas Parish, LA, with (A) population densities of *Meloidogyne incognita* during fall 2003 based on 0.4-ha grid sampling, (B) six soil zones based on EC-D ($EC_{a\text{-deep}}$) values, (C) 12 row strips of 1,3-Dichloropropene at 28.1 liter/ha applied preplant or untreated in the spring across soil zones and transects, and (D) zones in the field that showed a significant yield response to the application of the fumigant during 2004 to 2006. Yield data from each plot was collected along a 27.4-m area centered on each transect.

respectively (Figs. 5,6). When 1,3-D was applied site-specific, yields were still significantly higher than the untreated and averaged 1,025 and 1,183 kg/ha lint for the Ashley and Mississippi Counties fields, respectively (Figs. 5,6). Treatment by site-specific resulted in a 36% reduction in fumigant applied relative to uniform application for the Ashley County field and 42% reduction for the Mississippi County field.

South Carolina: The effects of soil texture, as determined by soil EC_a, on population density of *M. incognita* in soil at the Brubaker farm A location is presented as Figure 7. At planting, there was a strong positive correlation between increasing population densities of *M. incognita* and increasing sand content. The average EC_a values for zones 1, 2, and 3 were 0.45, 2.32, and 5.64 mS/m, respectively. Population densities of *M. incognita* were three times greater in zone 1 than in zone 2 and 12 times greater in zone 2 than in zone 3. Figure 8 shows the effects of nematicide rate and management zones on cotton lint yield for a field at the Phillips farm during 2007. The average EC-S and EC-D values for zone 1 were 0.45 and 0.51 mS/m, zone 2 at 2.32 and 3.5 mS/m, and zone 3 at 5.6 and 8.8 mS/m, respectively. In zone 1, which had the highest population of *H. columbus*, application of 3.4, 5.6, or 7.9 kg/ha of aldicarb significantly increased cotton lint yield ($P <$ 0.05) compared with the untreated control. Application of 7.9 kg/ha aldicarb in zone 1 did not increase yields of lint above those of the 5.6 kg/ha treatment. In zone 2, there were no differences in yields of lint among the 3.4, 5.6, and 7.9 kg/ha rates of aldicarb. However, all rates of aldicarb significantly increased yields compared with those of the untreated control. There were no differences in yield of lint attributable to nematicide application in management zone 3. Results obtained from Brubaker B farm during 2009 followed a similar pattern against *H. columbus* (Fig. 9). That is, in zone 1 increasing nematicide rates produced increasing yields of lint; in zone 2 all nematicides produced similar yield responses; and in zone 3, where sand content of soil was

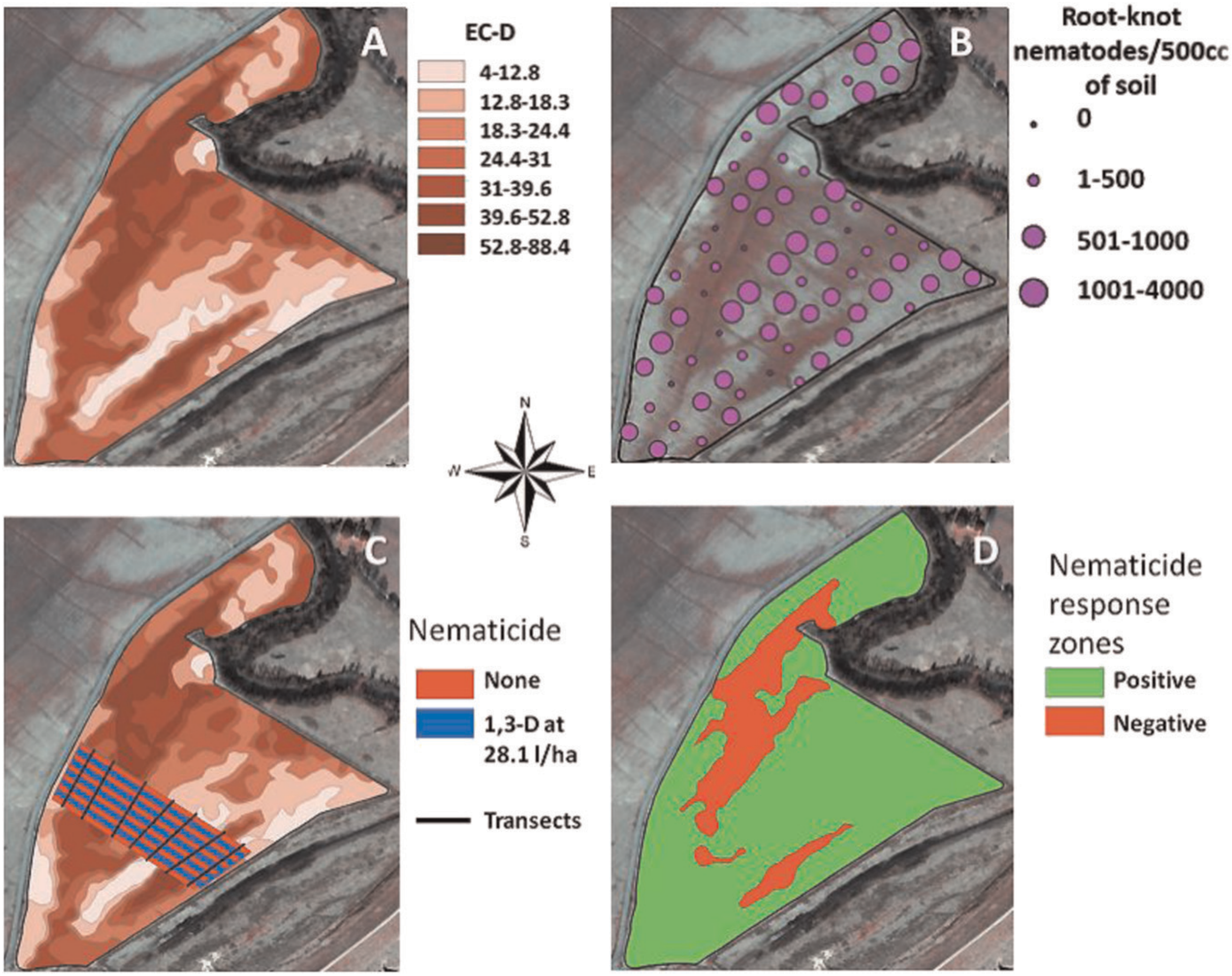

Fig. 4. The Tensas 2 field, Tensas Parish, LA, with (A) population densities of *Meloidogyne incognita* during fall 2003 based on 0.4-ha grid sampling, (B) seven soil zones based on EC-D ($EC_{a\text{-deep}}$)values, (C) 12 row strips of 1,3-Dichloropropene at 28.1 liter/ha applied preplant or untreated in the spring across soil zones and transects, and (D) zones in the field that showed a significant yield response to the application of the fumigant during 2004 to 2006. Yield data from each plot was collected along a 27.4-m area centered on each transect.

lowest, there was no significant response to nematicide application. The average EC-S and EC-D values for zone 1 were 1.4 and 1.8 mS/m, zone 2 at 2.2 and 3.3 mS/m, and zone 3 at 4.2 and 6.9 mS/m, respectively.

Discussion

This report describes some of the recent research to develop and refine site-specific nematicide placement as a management tool for cotton producers. In the mid-South and Southeast areas of the United States, remote sensing utilizing EC_a has been demonstrated to be an improvement over classical soil texture analysis methodologies. Using EC_a, a producer can generate a very detailed map showing the variation in the soil texture within a field to a depth of 1 m in a fraction of the time it would require to accomplish the same result to depth of only 15 to 20 cm using conventional soil sampling. These enhanced precision results from the collection of thousands of data points within a single field using Veris technology compared with a limited number of measurements that would be possible from classical soil-probe sampling activity and laboratory textural analysis.

In the alluvial soils found in many production areas of the U.S. Cotton Belt, there can be considerable variation in soil texture within a single field (Iqbal et al., 2005). Because nematode presence and damage potential of nematodes such as the *M. incognita* or *H. columbus* have been strongly linked to soil texture, this variability in texture can also be used as a general indicator of probable nematode occurrence within a field for targeted sampling.

In the initial study conducted at St. Joseph, LA, in 2003, the strong correlation between EC_a and sand and clay content of the soil made it obvious that this technology was applicable as a predictor of soil texture in this field. This correlation was in agreement with the

TABLE 1. Apparent electrical conductivity and yields of cotton from treated and untreated transects in Tensas 1 and Tensas 2 fields, Tensas Parish, LA, fields infested with *Meloidogyne incognita*, 2004 to 2006.

				Lint kg/ha					
				2004		2005		2006	
Field ID	Transect	EC-S[a,b] Mean	EC-D Mean	Untreated[c]	1,3-D[d]	Untreated	1,3-D	Untreated	1,3-D
Tensas 1	1	15.6	35.0	1,181.7 d-f	1,583.7 a	1,231.4 cd	1,467.1 b	1,334.6 c	1,560.4 b
	2	43.6	91.7	1,559.4 a	1,460.3 ab	1,244.1 cd	1,313.8 bc	1,391.7 c	1,420.2 bc
	3	24.0	87.1	1,559.4 a	1,580.9 a	1,142.6 d	1,244.8 cd	1,065.6 d	1,084.0 d
	4	49.0	131.2	1,241.5 c-e	1,354.9 bc	1,664.8 a	1,480.2 b	1,904.2 a	2,004.3 a
	5	83.7	145.4	1,078.4 ef	1,036.7 f	952.9 e	1,091.7 de	1,354.2 c	1,385.6 c
	6	80.7	124.6	1,312.0 b-d	1,107.7 ef	1,145.9 cd	1,187.2 cd	1,388.6 c	1,360.2 c
Tensas 2	1	10.2	15.8	1,399.4 g	1,720.9 c-e	863.2 c	1,474.5 ab	1,528.4 cd	1,816.9 ab
	2	20.8	41.7	1,848.3 a-d	1,882.2 a-d	1,650.8 a	1,675.7 a	2,043.4 a	1,910.0 a
	3	9.1	8.3	1,137.6 h	1,720.9 fg	317.6 d	428.1 d	764.5 g	862.1 fg
	4	13.8	12.3	1,619.2 ef	1,789.1 b-e	888.0 c	1,065.0 c	1,082.5 ef	1,519.4 c
	5	16.2	21.5	1,948.5 ab	2,006.3 a	1,352.4 b	1,558.5 ab	1,600.7 bc	1,959.4 a
	6	21.4	42.7	1,931.1 a-c	2,032.9 a	1,573.2 ab	1,560.2 ab	1,993.9 a	1,993.9 a
	7	18.6	19.6	1,680.6 de	1,890.4 a-d	897.5 c	900.7 c	1,018.2 e-g	1,219.5 de

[a] Data are the means of five replications.
[b] EC-S and EC-D correspond to $EC_{a\text{-shallow}}$ and $EC_{a\text{-deep}}$, respectively, and are expressed as millisiemens per meter (mS/m).
[c] For each location, values within individual years followed by the same letter are not significantly different according to Fisher's least significant difference test ($P \leq 0.05$).
[d] 1,3-D indicates 1,3-Dichloropropene used at the rate of 28.1 liter/ha.

data of Khalilian et al. (2001) in South Carolina who also indicated that electrical conductivity was a viable indicator of soil texture. Also in agreement with Khalilian et al. (2001) was the fact that this data could also be used as an indicator of potential *M. incognita* incidence in this field. Highest population densities of *M. incognita* at the St. Joseph field site occurred when EC_a data indicated soil with the greatest percentage of sand and lowest when the EC_a data indicated soil with the greatest amount of clay.

Data from Tensas 1 and Tensas 2 fields in LA showed that EC_a information can be employed as an indicator of where nematicide application will be most effective. Moreover, this trial highlighted the increased benefit of collecting EC_a data to a depth of 0.91 m, which more accurately reflects the total soil profile in which the cotton root system and nematode community coexist. Data from these trials may challenge some of the classical thoughts about the relationship between nematode population density and plant damage that indicates that the greater the nematode population, the more severe the plant damage (Seinhorst, 1965). In these trials, there were several locations in both Tensas 1 and Tensas 2 fields where nematode populations were very high and no yield reduction was observed. Other areas in both of these fields with similar population densities sustained significant yield reduction. Similarly, Monfort et al. (2007) found that *M. incognita* damage to cotton was more closely tied to soil texture than to population density. Electrical conductivity data provided the best explanation for these results in that yields in areas where there was a significant response to nematicide application had a soil texture that was sandy from the soil surface down to lowest EC_a reading at 0.91 m. Areas where the EC_a data showed that the soil profile was high in sand in the upper 0.3 m but high in clay in the lower 0.61 region had no significant response to nematicide application. In the Tensas 2 field, transect 3 had the lowest EC-S and EC-D values but yields did not show the respond to the fumigant in the

TABLE 2. Apparent electrical conductivity and yield of cotton from soil texture zones treated with 1,3-Dichloropropene or left untreated in four production fields infested with *Meloidogyne incognita* or *M. incognita* and *Rotylenchulus reniformis*, Northeast Louisiana, 2006.

Soil texture		Railroad Field		Spyker Field		Perry Cutoff Field		Faulk Field	
zone	1,3-D[a]	EC-S[b]	Lint kg/ha[c,d]	EC-S	Lint kg/ha	EC-S	Lint kg/ha	EC-S	Lint kg/ha
1	+	2.9-8.2	1,250.8 a	2.7-10.7	1,341.3 a	5.5-20.2	1,337.3 a	1.8-15.0	1,211.6 a
1	-		894.7 b		1,079.1 bc		1,087.6 b		1,017.0 b
2	+	8.2-13.3	1,261.8 a	10.7-21.4	1,293.1 a	20.2-40.3	1,350.8 a	15.0-35.3	900.6 bc
2	-		920.3 b		1,142.1 b		1,202.7 ab		818.7 c
3	+	13.3-41.9	1,281.8 a	21.4-57.5	1,047.8 c	40.3-77.3	1,180.0 ab	35.3-64	913.6 bc
3	-		1,001.6 b		1,046.8 c		1,033.1 b		863.3 c

[a] 1,3-D indicates 1,3-Dichloropropene at the rate of 28.1 liter/ha. Plus and minus signs indicate treated with 1,3-D or left untreated.
[b] EC-S corresponds to $EC_{a\text{-shallow}}$ and is expressed as millisiemens per meter (mS/m).
[c] Data are the means of eight replications.
[d] Values within columns followed by the same letter are not significantly different according to Fisher's least significant difference test ($P \leq 0.05$).

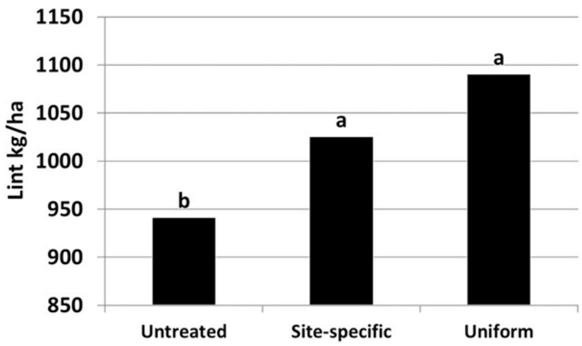

Fig. 5. Cotton yield in a field infested with *Meloidogyne incognita* in Ashley County, AR, during 2008. Areas within the field were treated with 1,3-Dichloropropene applied site-specifically or uniform application through the field; areas were also left untreated. Data in columns with common letters are not significantly different according to Fisher's least significant difference test ($P \leq 0.05$).

second and third year of the study. Additionally, transect 3 yielded considerable less than other transects in this field. This would indicate that some other factor was limiting plant growth in this area of the field such as pH or nutrient status.

Undoubtedly, other factors in addition to nematode population densities influenced yield. Most obvious among them are nutritional elements such as P, K, S, and Zn associated with soils having greater amounts of clay that are not available in soils containing sand through the profile (Wolcott et al., 2008). Also, soils with higher amounts of clay typically have a more buffered pH.

The data sets from Tensas 1 and Tensas 2 fields demonstrate that absolute numbers for EC_a are not acceptable predictors of where a significant response to fumigants will occur. In the Tensas 1 field, none of the transects resulted in positive response to 1,3-D when EC-D was greater than 35 mS/m. However, in the Tensas 2 field there were a number of transects/year combinations where the EC-D values were less than 35 mS/m and where there was no significant response to 1,3-D.

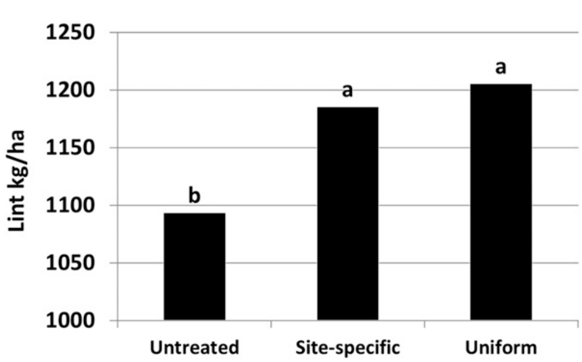

Fig. 6. Cotton yield in a 65.0-ha cotton field infested with *Meloidogyne incognita* in Mississippi County, AR, during 2008. Areas within the field were treated with 1,3-Dichloropropene site-specifically or uniform application through the field; areas were also left untreated. Data in columns with common letters are not significantly different according to Fisher's least significant difference test ($P \leq 0.05$).

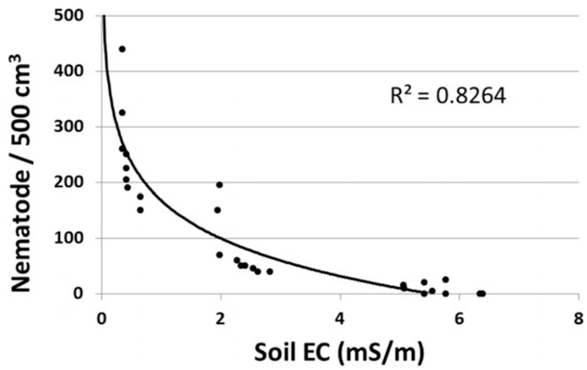

Fig. 7. Effects of soil texture as measured by EC_a on at planting levels of *Meloidogyne incognita* juveniles at Brubaker farm A, Bamberg County, SC, in 2007.

There was consistency in the lack of response to the fumigant in both of these locations when EC-D values were great than 41 mS/m.

From a practical standpoint, based on *M. incognita* incidence and population densities, most of Tensas 2 field would have required treatment with a nematicide, but only 49% of Tensas 1 field justified treatment based on the accepted nematode damage threshold (Mueller et al., 2012). In actuality, using EC_a data, only 74% of Tensas 2 field and only 22% of Tensas 1 field required a nematicide. Trials conducted in Northeast LA, Ashley and Mississippi Counties, AR, and Bamberg and Orangeburg Counties, SC, further supported the hypothesis that management zones and verification strips can be used to indicate areas of a field that should or should not be treated with a nematicide can be established using electrical conductivity data.

The lack of a stepwise response to nematicide application in zone 2 and the lack of a response in zone 3 at the Phillips site in South Carolina were probably

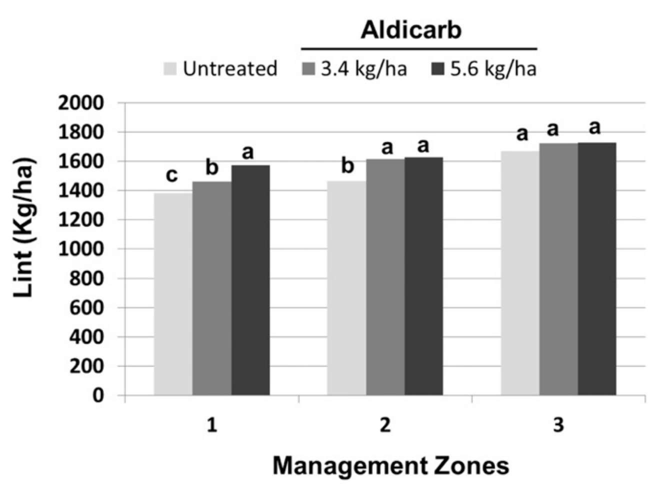

Fig. 8. Effects of aldicarb rates within management zones on cotton lint against *Hoplolaimus columbus* at Phillips farm, Orangeburg County, SC, during 2007. Within management zones, data with common letters are not significantly different according to Fisher's least significant difference test ($P \leq 0.05$).

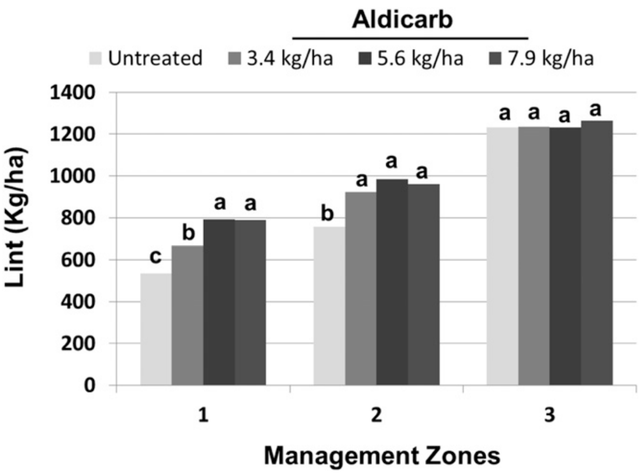

Fig. 9. Effects of aldicarb rates within management zones on cotton lint against *Hoplolaimus columbus* at Brubaker farm B, Bamberg County, SC, during 2009. Within management zones, data with common letters are not significantly different according to Fisher's least significant difference test ($P \leq 0.05$).

attributable to the absence of moisture stress known to exacerbate damage from nematodes. Zones 2 and 3 had slightly higher clay content and subsequently water retention was greater than in management zone 1. The uniform application required 50% more nematicide than the site-specific application system. However, there were no significantly different responses in yield between these two treatments. These results are similar to those obtained from the Brubaker farm B site and other trials in South Carolina (Mueller et al., 2010).

The utility of EC_a data without the use of verification strips to determine whether or not the use of a nematicide is justified is limited. Perry et al. (2006) attempted to use EC information from Veris sensors to identify "hotspots" of *M. incognita* in cotton fields in Georgia. This work indicated that EC_a data was correlated with soil texture but not with nematode population densities in the suspected "hotspots." Similarly, Ortiz et al. (2008) delineated *M. incognita* "risk zones" using parameters such as fuzzy clustering of elevation and the slope of the terrain, spectral reflectance of bare soil and both EC-S and EC-D. The fumigant 1,3-D worked best in high-risk zones and nonfumigants such as aldicarb provided acceptable levels of control in lower-risk zones.

Based on research conducted in 11 cotton fields in 2005 and 2006, Ortiz et al. (2011) reported that the areas likely to have high levels of *M. incognita* could be predicted using within-field changes in EC_a. They concluded that EC-S or EC-D could provide enough detail to define high- and low-risk areas for root-knot nematode. In their study, nematode population densities were stable in areas where populations were high initially and remained high throughout the growing season (Ortiz et al., 2010). Wheeler et al. (2000) found a similar pattern with high populations of *M. incognita* occurring in the same areas over a 3-yr period.

Site-specific application of nematicides in cotton has great potential for managing *M. incognita*, *H. columbus*, and likely other important nematodes in cotton in a more economical and ecologically sound way than whole-field application. The use of soil EC_a to predict soil texture and map textural variability within fields has been shown to be effective management tool for nematodes in the mid-South and southeastern United States. The use of apparent electrical conductivity to establish management zones does not eliminate the need for sampling of soil to verify the existence and estimate population densities of damaging species of nematodes. The use of verification strips is an essential component of this management tactic and should be used extensively by growers during each growing season to improve the efficiency of their nematicide program. Technology such as that afforded by the use of Veris and other equipment to determine electrical conductivity of soils combined with the development of more environmental compatible nematicides will allow producers to deal with nematodes and other pathogens in an era of escalating production costs.

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