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Potential for Site-specific Management of *Meloidogyne incognita* in Cotton Using Soil Textural Zones

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Abstract: The effect of various edaphic factors on *Meloidogyne incognita* population densities and cotton yield were evaluated from 2001 to 2003 in a commercial cotton field in southeastern Arkansas. The 6.07-ha field was subdivided into 512 plots (30.5 m × 3.9 m), and each plot was sampled for *M. incognita* prior to fumigation (Ppre), at planting (Pi), at peak bloom (Pm) and at harvest (Pf) each year. Soil texture (percent sand fraction) and the pre-plant soil fertility levels each year were determined from each plot. To ensure that a range of nematode population densities was available for study, 1,3-dichloropropene was applied in strips (3.9-m wide) at rates of 14.1, 29.2 and 42.2 liter/ha (128 plots each) each year 2 wk prior to planting. Data were evaluated using both stepwise and multiple regression analyses to determine relationships among edaphic factors, nematode population densities and yield. Although Pi and the percent sand fraction of the soil were the most important factors in explaining the variation in cotton yield, regression models only accounted for <26% of the variation in yield. When the same data were evaluated on a more homogeneous large-scale platform based on similar geographic locations, soil types and nematicide treatments, regression models that included both Pi and sand content explained 65%, 86% and 83% of the variability in yield for 2001, 2002 and 2003, respectively. Prediction profiles of the combined effects also demonstrated that damage potential for *M. incognita* on cotton in this study varied by soil texture.

Key words: site-specific management, root-knot nematode, *Meloidogyne incognita*, cotton, soil texture, 1,3-dichloropropene, fumigation, yield monitor

Various edaphic factors affect the population density, dynamics and distribution of nematodes (McSorley, 1998). Soil bulk density and moisture content, various nutrients and elements and soil texture all can impact nematode communities (Mashela et al., 1992; Francl, 1993; Koenning et al., 1996; Gorres et al., 1998). Soil texture can influence nematode density and distribution both horizontally and vertically and has been suggested as a useful predictor of nematode densities and distributions that may be of value in predicting economic damage potential (Georgis and Poinar, 1983; Ferris, 1984; Noe and Barker, 1985; Queneherve, 1988). The population density of *Meloidogyne incognita* is negatively correlated with the clay or silt content of soil (Windham and Barker, 1986; Queneherve, 1988; Koenning et al., 1996). Damage to cotton was greater in coarse than in fine-textured soils, likely because nematode reproduction was suppressed at higher silt or clay contents (Koenning et al., 1996).

Meloidogyne incognita Kofoid and White (Chitwood) is widespread across the Cotton Belt and is the only *Meloidogyne* species in the U.S. that can reproduce on cotton (Koenning et al., 2004). Although crop rotation and other cultural practices are used to some extent to manage this nematode in cotton, nematode control is primarily dependent on the application of nematicides (Koenning et al., 2004). Because of the time and expense of characterizing the spatial distribution of nematodes in commercial fields, considerable research effort has focused on determining the spatial dependence of several nematode species with varying results (Burrough, 1991; Webster and Boag, 1992; Wallace and Hawkins, 1994; Robertson and Freckman, 1995; Boag et al., 1996; Rossi et al., 1996; Gorres et al., 1998; Marshall et al., 1998; Evans et al., 1999). Unfortunately, application of this concept in commercial fields has been characterized for only a select number nematode species (Wyse-Pester et al., 2002).

Identification of specific areas within individual fields for nematicide application may allow producers to reduce the amount of nematicide applied for nematode control and lower production costs (Evans et al., 1999). Precision farming technology now makes site-specific application of nematicides, as well as other inputs, possible, but the success of this approach to nematode management depends on the development of affordable nematode distribution maps (Wyse-Pester et al., 2002). Grid sampling of fields to develop site-specific nematicide application maps likely will be too labor intensive and costly for a relatively low value per hectare crop (Evans et al., 2002; Wrather et al., 2002). The objectives of this study were to evaluate the influence of

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certain edaphic factors including soil texture (percent sand fraction) on the spatial distribution and damage potential of *M. incognita* on cotton under commercial production conditions in Arkansas.

Materials and Methods

Tests were conducted from 2001 to 2003 in a 6.07 ha production field in southeastern Arkansas. The general soil series for the research site is a Rilla silt loam soil (fine-silty, mixed, thermic Typic Hapludalfs) (Anonymous, 1979). The field had been planted continuously in cotton for the past 10 yr and was considered by the producer to be a "problem field" based on declining yields and the presence of severe root galling on plants collected arbitrarily from the field. The field was subdivided into 512 plots (32 plots wide × 16 plots long) to facilitate sequential sampling over the 3-yr period. Each plot was approximately 0.012 ha consisting of four 30.5-m long rows (30.5 × 3.9 m). The geographic location of each plot was determined with a differential global position system (GPS) receiver (Trimble, Sunnyvale, CA) and Site-Mate, a GPS mapping software (Farmworks, Hamilton, IN). The cotton cultivar Stoneville 4892 BR (Emergent Genetics, Inc., Memphis, TN) was planted each year. To ensure that there were differences in nematode population densities across the field, the nematicide 1,3-dichloropropene (Telone II, Dow Agrosciences, Indianapolis, IN) was applied 2 wk prior to planting at rates of 0, 14.1, 29.2 or 42.2 liter/ha in 2001 and 2002; and at rates of 0 and 29.2 liter/ha in 488 m × 3.7 m (16 plots long × 1 plot wide) strips in a randomized complete block design across the entire research plot area. Nematicide treatments were replicated 8 times in 2001 and 2002 and 16 times in 2003. The nematicide was applied with a roller-squeeze pump injection system (Chemical Containers, Inc., Lakes Wales, FL) mounted on a 6-row ripper-bedder tillage implement on 96.2 cm centers with material being injected into the soil just behind the ripper foot at an approximate soil depth of 30.5 cm deep. The soil was then sealed directly behind the ripper shank in each row by a two-disc bedder system on each row. In strips where no nematicide was applied, the device was pulled through the field, but no 1,3-dichloropropene was injected.

All plots were sampled each year prior to nematicide application (Ppre), at the time of planting and representing the initial population after fumigation (Pi), approximately 70 d after planting (Pm) peak bloom and at harvest (Pf). Plot samples consisted of 16 soil cores collected from the bed or root zone with a soil sampling tube (2.5-cm deep) to a depth of approximately 25 cm from the center two rows of each plot. Cores were bulked and processed from a 500 cm^3 sub-sample using a semi-automatic elutriator (Byrd et al., 1976) followed by centrifugal flotation (Jenkins, 1964). Another sub-sample of the composite soil samples that were collected at planting each year was analyzed by the University of Arkansas, Soils Testing and Research Laboratory in Marianna, AR, for fertility. Soil texture (percent sand fraction) was also assessed for each grid plot utilizing hydrometer particle-size analysis (Gee and Bauder, 1979). Yield was recorded each year at crop maturity using a four-row John Deere cotton picker equipped with an AgLeader PF3000 cotton yield monitor (Ag Leader Technology, Ames, IA) equipped with a GPS receiver. The yield was determined for each plot utilizing a spatial overlay tool for averaging point data by polygon or plot within the geographic information system SSToolbox (SST Development Group, Inc., Stillwater, OK). Lint yield was calculated based on a 35% gin turnout of seed cotton.

Both *M. incognita* population density and yield data were spatially interpolated by kriging using the SSToolbox software for visual correlations among the parameters. The individual plot data collected each year was transferred to a statistical discovery software (JMP; SAS Institute Inc., Cary, NC) to attempt to develop regression models to help explain the influence of *M. incognita* population densities on cotton yield. Initially, *M. incognita* densities for all sampling dates except the Ppre for each year were subjected to stepwise statistical procedures to determine if specific sampling dates or nematode population densities influenced yield variations within each year. The Ppre sampling date was not included in the models because these were collected prior to the application of the nematicide and were not indicative of the nematode population densities that were directly related to crop performance in that year across all plots. The resulting nematode density and sample date parameter from the stepwise procedure were subjected to regression analysis to determine the significance of the relationship of *M. incognita* alone to cotton yield for each year.

The significance of the resulting model was further examined by including selected edaphic parameters (soil texture, and phosphorus, potassium, calcium and magnesium levels) into the regression model. The edaphic parameters along with the nematode sampling date parameter were subjected to stepwise procedures to determine their relationship to yield. Regression models were then used to describe the significance of the selected parameters from the stepwise procedures along with nematode sampling date and population density in explaining yield variability.

Based on the initial results from all 512 plots, the data were re-examined on a more homogeneous scale based on their geographic location within the field. Since soil texture was the most useful edaphic factor for explaining variation in yield alone, plots with similar soil texture were identified and assigned to four arbitrary texture categories as follows: i) 0 to 30% sand, ii) 30 to 45% sand, iii) 45 to 65% sand, and iv) 65 to 100%

sand. Applying these four categories to the plots partitioned the field into 10 geographically distinct regions (Fig. 1). The individual plot data were accumulated and averaged within each of the 10 soil texture regions. Because yield responses in cotton have typically been observed with the application of 1,3-dichloropropene, the data within each soil texture region were also averaged separately for each rate of nematicide applied (Kinloch and Rich, 1998; Baird, 2001). The data were then subjected to regression analysis to describe the effects of the parameters on yield. The resulting models were further examined using the graphic statistical tools in JMP (SAS Institute Inc., Cary, NC), a prediction profiler for examining individual effects and a contour profiler for examining combined effects, to enhance the visual interpretation of the results for the models constructed for all three years (Alexander, 2000; Obermiller, 2000; Hendriks et al., 1992).

Results

The soil texture in individual plots ranged from 21% to 81% sand and 18% to 68% silt (Fig. 1). *Meloidogyne incognita* juveniles were widespread throughout the research site across all sampling dates (Fig. 2), with mean nematode numbers ranging from 59 to 1,999 juveniles/500 cm^3 soil each year among the sampling dates (Table 1). The lowest populations densities were at planting (Pi), with densities increasing as the season progressed each year (Table 1). Mean lint yields were 915, 1,276 and 1,132 kg/ha for 2001, 2002 and 2003, respectively (Table 1). In addition to *M. incognita*, the reniform nematode (*Rotylenchulus reniformis*) was detected in a few of the plots, and several nematode species that are not considered to be of economic significance in cotton (Koenning et al., 2004) including *Helicotylenchus* spp., *Tylenchorhynchus* spp., *Paratrichodorus minor* and *Hoplolaimus magnistylus* were occasionally

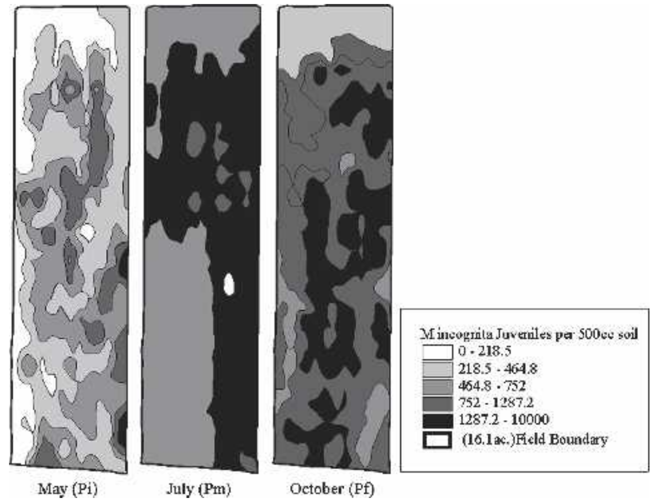

FIG. 2. Spatial interpolation (Kriging) maps showing the spatial distribution of *Meloidogyne incognita* in May (Pi), July (Pm) and October (Pf), 2002, in a 6.07 ha cotton field in southeastern Arkansas. Geographic location of the NW corner of the field is: Latitude = 33.26587012, Longitude = -91.47651691.

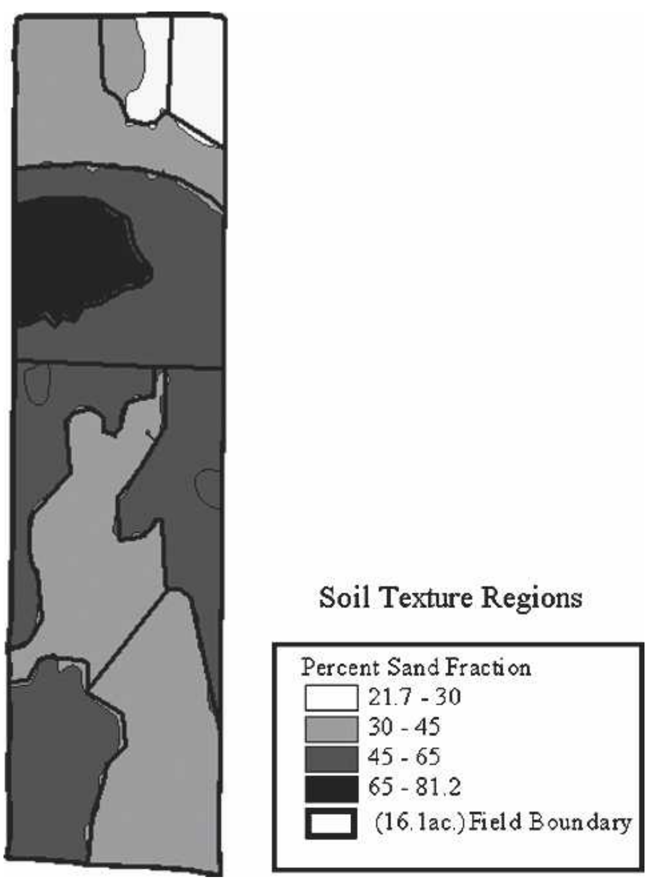

FIG. 1. Spatial interpolation (Kriging) maps showing the different soil type regions used for analysis of the relationship between *M. incognita* population density and yield in a 6.07 ha cotton field in southeastern Arkansas. Geographic location of the NW corner of the field is: Latitude = 33.26587012, Longitude = -91.47651691.

TABLE 1. Individual plot distribution of initial (Pi), mid-season (Pm) and harvest (Pf) population densities of *M. incognita* and cotton yield in a southeastern Arkansas field from 2001.

Year	Parameter	Range	Mean	Std error[a]
2001	Pi[b]	0–5,000	593	34.7
	Pm[c]	0–8,636	610	53.3
	Pf[d]	0–12,500	1,692	64.8
	Lint yield[e]	263–2,060	917	9.7
2002	Pi	0–3,409	474	24.9
	Pm	0–22,045	1,999	122.4
	Pf	0–8,409	1,181	41.9
	Lint yield	607–2,447	1,276	12.5
2003	Pi	0–10,273	59	8.9
	Pm	0–10,227	933	70.6
	Pf	0–10,227	928	71.1
	Lint yield	165–1,965	1,132	11.7

[a] Std error = standard deviation of the response mean.
[b] Pi = nematode population density (juveniles/500 cm^3 of soil) at planting and after fumigation of each year.
[c] Pm = nematode population density (juveniles/500 cm^3 of soil) approximately 70 d after planting of each year.
[d] Pf = nematode population density (juveniles/500 cm^3 of soil) at harvest of each year.
[e] Lint yield = average lint yield in kg/ha.

TABLE 2. Significance[a] of initial (Pi), mid-season (Pm) and harvest (Pf) population densities of *M. incognita* sampling dates on cotton lint yield in a southeastern Arkansas field.

Year	Sampling date	F ratio	Prob > F[b]
2001	Pi	4.02	0.046
	Pm	1.19	0.275
	Pf	0.37	0.543
2002	Pi	29.29	<0.0001
	Pm	10.67	0.0012
	Pf	2.26	0.134
2003	Pi	12.74	0.004
	Pm	10.80	0.001
	Pf	19.47	<0.0001

[a] Determined by stepwise regression procedures.
[b] Significance based on $\alpha = 0.05$.

found in the site (data not shown). Population densities of *Rotylenchulus reniformis* in plots were not correlated with cotton yield in any of the three years.

The results of the initial stepwise procedures suggested that initial population density (Pi) was more useful in describing the variability in yield ($\alpha = 0.05$) than mid-season or final population densities over the 3-yr period (Table 2). Regression models all three years indicated a significant effect of Pi on yield, but the utility of the models as predictors was minimal with coefficient of determination (R^2) values for 2001, 2002 and 2003 of ≤6% (Table 3). To aid in describing the effects of *M. incognita* on yield each year, soil nutrient levels in the plots and the percent sand, silt and clay of the soil were analyzed with Pi each year using stepwise procedures to determine the parameters that were most important. Inclusion of the percent sand fraction parameter in the model increased the precision of the regression models, explaining 21%, 26% and 23% of the variation in yield for 2001, 2002 and 2003, respectively (Table 4). The relationship between percent sand fraction and yield was visible in the spatial distribution maps as well (Fig. 3). None of the other edaphic factors studied were significant in describing yield variability in the presence of *M. incognita*.

Although the models using all individual grid plots were improved by including the sand component, they were still inadequate in describing the variability in yield. However, when the two most significant parameters, Pi and percent sand, were evaluated with lint yield on a more homogenous large-scale platform using the four arbitrarily determined soil textural groups (Fig. 1), the final model was much more effective in explaining the variability in the yield for all three years. The interaction parameter between percent sand and Pi was found to be significant in only one of the three years and therefore was not included in the final model

TABLE 3. Effects of initial (Pi) *M. incognita* population densities on lint yield in a southeastern Arkansas cotton field based on regression analysis of indiviual plots.

Year	Parameters[a]	Estimate	Std error[b]	t ratio	Prob > [t][c]	R[2d]
2001	intercept	932.25	12.12	76.89	<0.0001	0.01
	Pi	−0.02	0.01	−1.99	0.0473	
2002	intercept	1,332.99	16.19	82.35	<0.0001	0.06
	Pi	−0.12	0.02	−5.44	<0.0001	
2003	intercept	1,147.16	12.11	94.75	<0.0001	0.03
	Pi	−0.22	0.06	−3.75	0.0002	

[a] Pi = nematode population density in May (at planting) of each year.
[b] Std error = standard deviation of the response mean.
[c] Significance based on $P = 0.05$.
[d] Sample coefficient of determination (R^2) indicates the percentage of the variation in yield explained by the select parameters entered in the model.

TABLE 4. Effects of initial (Pi) *M. incognita* population densities and soil texture (% sand) on lint yield in a southeastern Arkansas cotton field based on multiple regression analysis of indiviual plots.

Year	Parameters[a]	Estimate	Std error[b]	t ratio	Prob > [t][c]	R[2d]
2001	intercept	1,345.42	39.94	33.68	<0.0001	0.21
	% sand	−8.67	0.81	−10.75	<0.0001	
	Pi	−0.05	0.01	−4.34	<0.0001	
2002	intercept	1,874.70	47.99	39.06	<0.0001	0.26
	% sand	−11.66	0.99	−11.82	<0.0001	
	Pi	−0.12	0.02	−6.18	<0.0001	
2003	intercept	1,591.96	44.13	36.07	<0.0001	0.23
	% sand	−9.68	0.93	−10.40	<0.0001	
	Pi	−0.21	0.05	−3.98	<0.0001	

[a] Pi = nematode population density in May (at planting) of each year; % sand = percent sand fraction of the soil texture determined by the hydrometer method.
[b] Std error = standard deviation of the response mean.
[c] Significance based on $P = 0.05$.
[d] Sample coefficient of determination (R^2) indicates the percentage of the variation in yield explained by the select parameters entered in the model.

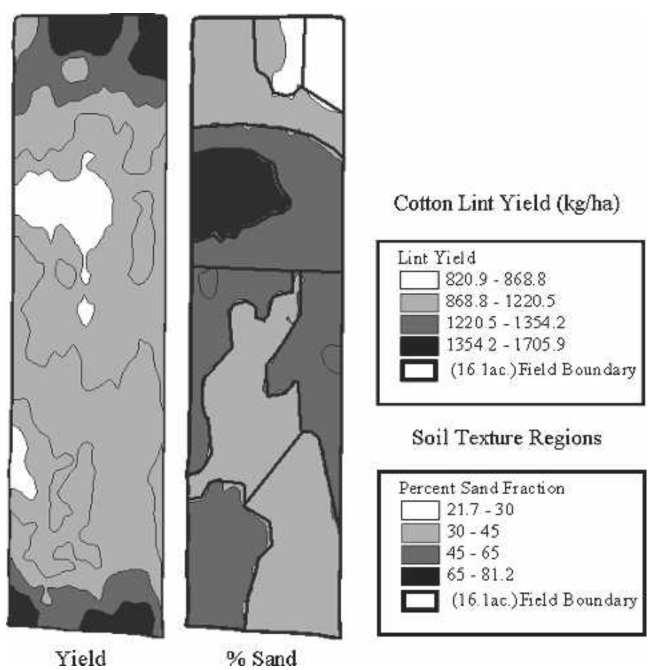

FIG. 3. Spatial interpolation (Kriging) maps showing the spatial distribution of lint cotton yield and percent sand fraction (% sand) levels of the soil in a 6.07 ha cotton field in southeastern Arkansas. Geographic location of the NW corner of the field is: Latitude = 33.26587012, Longitude = -91.47651691.

TABLE 5. Analysis of variance for the effects of initial (Pi) *M. incognita* population densities, soil texture (% sand), and their interaction on lint yield in a southeastern Arkansas cotton field based on multiple regression analysis across similar soil types.

Year	Source	Degrees of freedom	Sum of squares	F ratio	Prob > F	R^2 with interaction	R^2 without interaction
2001	C. total	37	586,215.8	36.06	0.0001	76%	65%
	Model	3	446,043.7				
	% sand[a]	1	415,815.5	100.86	0.0001		
	Pi[b]	1	160,800.1	39.00	0.0001		
	% sand × Pi	1	62,168.4	15.08	0.0005		
	Error	34	140,172.1				
2002	C. total	38	966,557.3	73.70	0.0001	86%	86%
	Model	3	834,464.6				
	% sand[a]	1	495,268.4	131.23	0.0001		
	Pi[b]	1	100,918.9	26.74	0.0001		
	% sand × Pi	1	7,714.9	2.04	0.1617		
	Error	35	132,092.7				
2003	C. total	18	587,715.8	32.07	0.0001	87%	83%
	Model	3	508,441.9				
	% sand[a]	1	292,564.6	55.36	0.0001		
	Pi[b]	1	185,456.3	35.09	0.0001		
	% sand × Pi	1	19,479.5	3.69	0.0741		
	Error	15	79,273.9				

[a] % sand = percent sand fraction of the soil texture determined by the hydrometer method.
[b] Pi = nematode population density (juveniles/500 cm^3 of soil) at planting and after fumigation of each year.

(Table 5). In this case, these parameters accounted for 65%, 86% and 83% of the variability in yield in 2001, 2002 and 2003, respectively (Table 6). The resulting models indicated that, when sand content was held constant, yield was suppressed by 0.11, 0.13 and 1.64 kg/ha in 2001, 2002 and 2003, respectively, for every additional *M. incognita* second-stage juvenile (per 500 cm^3 soil) that was present at planting (Table 6). Similarly, when Pi remained constant, the models indicate that there would be a 9.85, 12.81 and 8.74 kg/ha decrease in lint yield for every percentage increase in soil sand content in 2001, 2002 and 2003, respectively (Table 6).

The regression models were further examined using the profiler tools in JMP that illustrate the effects of both parameters alone and simultaneously on yield each year using target yields of 1,120 kg/ha and 841 kg/ha (Fig. 4). The prediction profiler showed that percent sand fraction had a greater impact on yield than *M. incognita*, which indicates that soil texture needs to be considered in determining the economic impact of *M. incognita* on cotton. The contour profiler of the above regression models indicated that yield suppression by individual *M. incognita* (Pi) juveniles increased as the percentage of sand in the soil increased in this field (Fig. 4). Although the magnitude of the individual effects of *M. incognita* varied each year, the relationship between *M. incognita* and the sand fraction of the soil was similar all years.

DISCUSSION

Management of *M. incognita* in cotton is crucial for sustained profitability in production. For many producers in the southern U.S., the most feasible nematode management strategy involves the application of a nematicide (Koenning et al., 2004). Effective root-knot nematode management depends on an accurate estimate of the initial population density of the nematode

TABLE 6. Effects of initial (Pi) *M. incognita* population densities and soil texture (% sand) on lint yield in a southeastern Arkansas cotton field based on multiple regression analysis across similar soil types.

Year	Parameters[a]	Estimate	Std error[b]	t ratio	Prob > [t][c]	R[2d]
2001	intercept	1,430.01	65.25	21.92	<0.0001	0.65
	% sand	−9.85	1.23	−8.04	<0.0001	
	Pi	−0.11	0.03	−4.21	<0.0002	
2002	intercept	1,941.31	47.99	41.73	<0.0001	0.86
	% sand	−12.81	0.99	−13.73	<0.0001	
	Pi	−0.13	0.03	−5.07	<0.0001	
2003	intercept	1,616.99	80.19	20.16	<0.0001	0.83
	% sand	−8.74	1.68	−5.19	<0.0001	
	Pi	−1.64	0.25	−6.68	<0.0001	

[a] Pi = nematode population density in May (at planting) of each year; % sand = percent sand fraction of the soil texture determined by the hydrometer method.
[b] Std error = standard deviation of the response mean.
[c] Significance based on $P = 0.05$.
[d] Sample coefficient of determination (R^2) indicates the percentage of the variation in yield explained by the select parameters entered in the model.

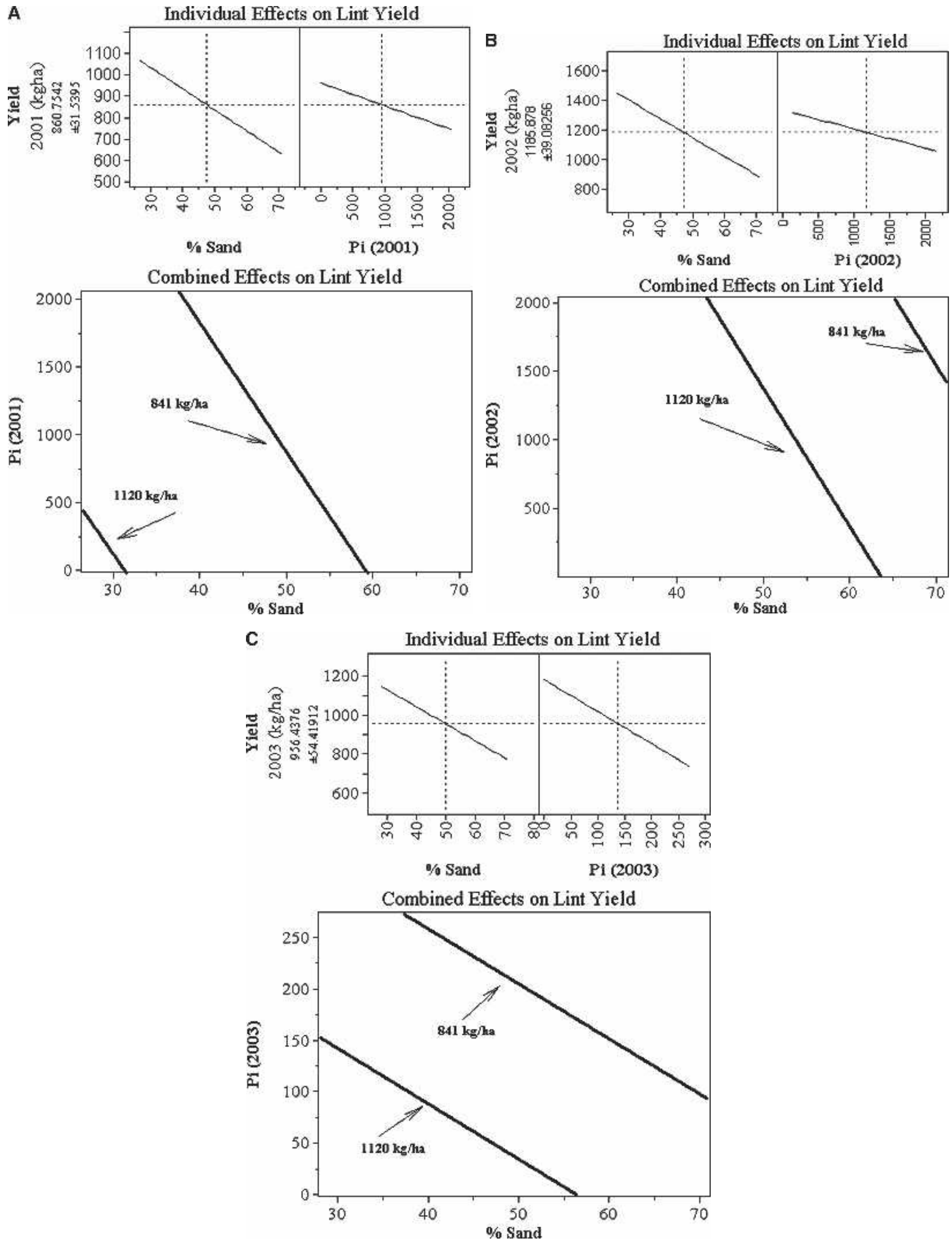

FIG. 4. A. Prediction and contour profiler illustrations of the individual and combined effects of May's (Pi) *M. incognita* population densities and percent sand fraction (% Sand) on lint yield in a cotton field in southeastern Arkansas in 2001. *Meloidogyne incognita* population densities are based on the number of juveniles per 500 cm^3 soil. Reference line for lint yield potential in combined effects graph at 841 kg (1.5 bales) and 1,120 kg (2 bales) of cotton/ha were used to show the change in damage resulting from the infection of *M. incognita* as % Sand changes. The multiple regression models for the above figure are: Lint Yield (Y) = 1430.01 – 9.85*(% Sand) – 0.11*(Pi). B. Prediction and contour profiler illustrations of the combined effects of May's (Pi) *M. incognita* population densities and percent sand fraction (% Sand) on lint yield in a cotton field in southeastern Arkansas in 2002. *Meloidogyne incognita* population densities are based on the number of juveniles per 500 cm^3 soil. Reference line for lint yield potential in combined effects graph at 841 kg (1.5 bales) and 1,120 kg (2 bales) of cotton/ha were used to show the change in damage resulting from the infection of *M. incognita* as % Sand changes. The multiple regression models for the above figure are: Lint Yield (Y) = 1941.31 – 12.81*(% Sand) – 0.13*(Pi). C. Prediction and contour profiler illustrations of the combined effects of May's (Pi) *M. incognita* population densities and percent sand fraction (% Sand) on lint yield in a cotton field in southeastern Arkansas in 2003. *Meloidogyne incognita* population densities are based on the number of juveniles per 500 cm^3 soil. Reference line for lint yield potential in combined effects graph at 841 kg (1.5 bales) and 1,120 kg (2 bales) of cotton/ha were used to show the change in damage resulting from the infection of *M. incognita* as % Sand changes. The multiple regression model for the above figure is: Lint Yield (Y) = 1616.99 – 8.74*(% Sand) – 1.64*(Pi).

(Barker, 1985). Unfortunately, due to logistical and time constraints, field sampling is rarely thorough enough to characterize spatial distributions of nematodes in individual fields; therefore, results from previous site-specific nematicide applications in cotton have been mixed (Baird et al., 2001; Wrather et al., 2002; Wheeler and Kaufman, 2003). Our research shows that both soil texture and nematode population density are important in predicting the economic impact of root-knot nematode in cotton. Although nematode detection and quantification are labor intensive and vary over time, soil textural variability within fields can be estimated relatively rapidly and easily using mobile soil electrical conductivity meters (Williams and Hoey, 1987; Johnson et al., 2001; Khalilian et al., 2001). Wyse-Pester et al. (2002) did not find evidence to support the use of soil data to target nematode sampling in two irrigated corn fields in Colorado, and only limited spatial dependence was detected for *Helicotylenchus* spp., *Tylenchorhynchus capitatus* and *Pratylenchus neglectus*. However, the soil texture in these fields ranged from a sand to a loamy sand with limited variation in sand content (75%–92%). In addition, the distribution (or aggregation) of *M. incognita* in a field may differ considerably from that of the plant-parasitic nematodes in their study. Soil texture was significant in describing densities of root-knot nematode in North Carolina fields (Noe and Barker, 1985).

Crop damage increased with increases in root-knot nematode population density, and the damage potential changed in relation to soil textural differences. In general, fewer nematodes were required to suppress cotton yield in areas of the field with a higher sand content than where soil texture was characterized by less sand and more silt. The availability of mobile soil electrical conductivity meters and other precision technology provides the opportunity for research in situ rather than in microplots on the relationship between nematodes and soil texture across a range of crops. Cotton yield was lowest in 2001, a year that was uncharacteristically hot and dry during much of the growing season. Weather patterns in the second and third years of the study followed more consistent seasonal patterns. Environmental effects also impacted the population dynamics of *M. incognita* and its damage potential across the three-year study. For example, while Pi was extremely low in 2003, effects on yield were greater than in either 2001 or 2002 when densities were greater. Regardless of the year, however, the relationship between *M. incognita* population densities and soil texture remained similar, with greatest yield suppression occurring each year where nematodes were present in areas with the highest sand content in the soil. The relative consistency of this relationship across years and different environments implies that it may be possible to develop root-knot nematode control strategies on a field-by-field basis that include site-specific nematicide application. From economic and environmental standpoints, lowering the quantity of nematicide used to maintain profitable yields would seem prudent.

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