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Spatial Variability of Root Knot Nematodes in Relation to Within Field Variability of Soil Properties

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Abstract. *Site-specific management (SSM) of cotton (Gossypium hirsutum L.) fields under risk of southern root-knot nematode [M. incognita] (RKN) infection may offer producers better management of on-farm resources and optimization of profitability. However, it requires the study of RKN spatio-temporal variability and the identification of surrogate data spatially correlated with its occurrence. The objectives of this study were (i) determine the magnitude, extent, and changes through time on the spatial variability of RKN at the field scale, (ii) establish the relationship between RKN occurrence and the spatial variability of soil physical and chemical properties, and (iii) delineate areas at risk for RKN based on surrogate data. The spatial relations between soil physical properties (soil electrical conductivity - EC_a, slope, and elevation) and soil chemical properties (P, K, Ca, Mg, and soil pH) on RKN population density were studied in two cotton fields planted in southern Georgia, USA, in 2006. The spatio-temporal variability of the RKN was studied through semivariograms. The spatial correlation between RKN and soil properties was studied through canonical correlation and cross-correlograms. Soil properties highly correlated with RKN population density were entered into an* *ordinary logistic regression model to create a map of probability risk for RKN population density over a specific threshold value. The aggregated pattern of the RKN facilitated the segregation of RKN risk areas based on low values of* EC_a.

Keywords. Southern root knot nematodes, soil properties, spatial variability, semivariogram, cross-correlogram, logistic regression, cotton.

Introduction

Southern Root Knot Nematode (*Meloidogyne incognita*) is considered the major yield-limiting pest across the U.S. Cotton Belt. Yield losses attributed to southern root-knot nematode (RKN) account for 72 % of total losses caused by different species of nematodes. Because cotton fields reporting yield losses up to 15 % do not usually exhibit obvious above-ground symptoms of nematode damage, the identification of potential areas at risk for nematode infection should be the first step during implementation of site-specific management (SSM) of RKN intended to minimize losses.

The success of SSM for RKN could involve variable rate application of nematicides, fertilizers, or irrigation and a stratified sampling design for nematode population identification. The steps during implementation require: 1) characterization of the spatio-temporal variability of the nematodes, 2) identification of surrogate data related with the spatial distribution of nematodes, 3) delineation of homogeneous zones for variable rate application of nematicides.

Nematode populations are regulated by biotic and abiotic factors which control their reproduction, movement, and distribution within fields. Coarse-textured sandy soils have been associated with patches of high population density of RKN (Goodell and Ferris, 1980). Avendano et. al (2004) reported positive correlation between cyst nematode population density and percentage of sand contrasting with negative correlation values of percentage of clay and silt. Wyse-Pester et. al (2002) explained the spatial dependence of three different nematode species within two corn fields. Although nematode samples were correlated with distances of 115 to 649 m, these distances varied with direction. When they tried to associate nematode population density with soil texture and organic matter, the correlations were inconsistent. Noe and Barker (1985) evaluating 26 different edaphic properties with respect to the spatial distribution of RKN found high levels of clay, organic matter, low copper concentration, and small changes in percent soil moisture strongly related with their spatial variability. Other studies has correlated the abundance of RKN with soil pH (Melakeberhan et al., 2004), and soil moisture (Wheeler et al., 1991; Windham and Barker, 1993).

Although studies have shown that different species of nematodes follow a spatial structure and it is related with biotic and abiotic factors, more research is needed specifically on aspects of stability of spatial structure of RKN through time and assessment of the factors related with their spatial occurrence and reproduction.

The objectives of this study were to: (i) determine the magnitude, extent, and changes through time on the spatial variability of RKN at the field scale, (ii) establish the relationship between RKN occurrence and the spatial variability of soil physical and chemical properties, and (iii) delineate areas at risk for RKN based on surrogate data.

Materials and Methods

Study fields description and data collection

The two study sites were located in the Little River Watershed, Southern Coastal Plain of Georgia, USA. The CC field was 20 ha and the PG field was 25 ha in size. The fields were planted on May 2006 with the DP555 Boll-Guard®, Round-Up-Ready® cotton (*Gossypium hirsutum L.)* variety. Discrete data were collected on a square grid of 0.20 ha size in each field. Sample locations were georeferenced using a Trimble AgGPS 114 DGPS receiver. Around the center of each grid cell (1.5 m radius), five soil samples were collected and combined into a composite sample for phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and soil pH determination. These samples were collected one month after planting. Soil samples for RKN population density determination (second stage juveniles), RKN for subsequent references, were collected around the center of each grid cell three times during the growing season: late July (RKN S1), August-early September (RKN S2), and October-November (RKN S3). At each sample location, eight individual subsamples were collected from the root zone within a 1.5 m radius and combined into a composite sample. A total of 99 locations were sampled at the CC field and 105 locations at the PG field. Continuous apparent soil electrical conductivity (EC_a) (shallow - EC_s, deep - EC_d) data were collected prior to planting using the VERIS® 3100 implement. An AgGPS 214 real-time kinematic (RTK) Trimble GPS receiver mounted on the tractor pulling the VERIS® 3100 implement was used to collect topographic (elevation) data. This dense data set comprised approximately 7000 points of EC_a. The VERIS implement was run across every field in swaths approximately 9 m apart.

Data processing

Continuous surface maps of 1 m grid size for elevation and EC_a were created by ordinary punctual kriging using ArcVIEW 9.2 to match RKN and soil properties at sampling locations. Although the interpolation by kriging, the base for the generation of surface maps, tends to smooth the data set, the density of data points used suggests that the impact of estimation at unsampled locations was minimal. Slope maps were derived from elevation maps. Next, buffer areas of 1.5 m radius were created around each RKN sampling location. Pixel values from the surface maps (EC_a, elevation, slope) within the buffer were averaged and integrated into the analyses.

Statistical analyses

When RKN data departed from normality, data were log-transformed or square root-transformed. Descriptive statistics of soil physical and chemical properties and RKN at CC field (n = 99) and PG field (n = 105) were calculated to ascertain in-field variability as a first step. The relationship between RKN sampling events and the soil physical and chemical properties were evaluated through a canonical correlation analysis. This was done to study changes of the relationship between cotton RKN and soil properties through time and to identify surrogate data for future management zone (MZ) delineation for RKN. Sol physical properties included elevation, slope, and EC_a. Soil chemical properties included P, K, Ca, Mg, and soil pH.

Geostatistical analyses

Semivariograms and cross correlograms were used to study the spatio-temporal variability of RKN and relate their occurrence with the spatial variability of soil properties. A semivariogram, the core of geostatistics, defines the distance up to which a set of samples are correlated. If the semivariogram showed an indeterminate increment of the semivariance through the distance, it suggested the presence of a trend or nonstationarity. The presence of a trend on the data set was removed using the restricted maximum likelihood model in SAS (SASInstitute, 2000). The assessment of spatial structure or spatial dependence was evaluated through the ratio of the nugget (C_0) over the sill or total variance ($C+C_0$). This fraction varies between 0 and 1. Values greater than 0.6 indicate that 60% of the variability in the data set is inexplicable by the model and it is associated with a short distance random variability. Cross-correlograms were calculated to describe the join variability or spatial continuity between RKN and soil properties and to identify soil properties with potential as surrogate data for MZ delineation. The cross-correlograms presented in this paper correspond to the spatial correlation between RKN sampled in August – early September and the soil properties evaluated in the study.

Modeling the risk of RKN over threshold values

A map of predicted risk of RKN over a specific threshold value was produced through a logistic regression between RKN and RKN's surrogate data identified through the canonical correlation and geostatistical analyses. The ordinary logistic regression was used to determine the relationship between the prevalence of RKN population density over a threshold value and its soil properties predictors. The threshold value selected was 100 RKN second stage juveniles / 150 cm^3 of soil value which is used in Georgia to decide on the application of nematicides. The degree of spatial correlation of the residuals from the logistic regression was also used as additional criteria to model selection. The spatial dependence of the residuals from the logistic model was inspected by semivariograms. When the null hypothesis for errors none spatially correlated was rejected, the kriged residual predictions were added to the model. The model used for the logistic regression was $P = e^{[(\alpha+\beta*X)+\text{kriged residuals}]} / (1 + e^{[(\alpha+\beta*X)+\text{kriged residuals}]})$

Results and Discussion

Statistics and canonical correlation analysis

Descriptive statistics of the RKN assay results from the two studied fields are presented in the table 1. The mean values of RKN at the three sampling events evidenced an increase on population density through the growing season. The highest mean of RKN at the CC field was observed in September (S2). It contradicts the thesis of highest population density at harvest. This change may be related to drought conditions during the last month of the growing season. The coefficient of variation (CV) of RKN was fairly high, which could confirm the influence of biotic and abiotic factors on the changes in RKN spatio-temporal variability. The Moran's Index of spatial correlation indicated RKN aggregation with exception of the samples collected at harvest-S3 from the CC field (Table 1). High values of the Moran's Index for the CC field compared to the PG field indicated higher aggregation of RKN.

Table 1. Descriptive statistics of the cotton RKN assay results from the three sampling events.

	Field ID					
	CC			PG		
	Log_{10} RKN S1	Log_{10} RKN S2	Sqrt RKN S3**	Log_{10} RKN S1	Log_{10} RKN S2	Log_{10} RKN S3
Sample size	99	99	99	105	105	105
Mean (RKN/ 150 cm^3 soil)	2.0	3.7	8.8	0.1	0.8	1.2
Min.-max.	0-7.1	0-7.4	1-27	0-1.7	0-2.9	0-3.3
Std. deviation	1.9	1.9	6.3	0.4	1.0	0.94
Variance	3.6	3.6	39.2	0.1	0.9	0.9
CV (%)	93.1	51.4	71.2	400.0	112.5	75
Skewness	0.32	-0.5	0.72	2.93	0.65	0.11
Kurtosis	-1.05	-0.61	-0.1	10.72	1.97	1.78
Moran's I (Z)	0.32 (7.91)*	0.36 (8.80)*	0.06 (1.61)	0.27(2.89)*	0.19(5.32)*	0.15(3.09)*

*Significance at Z values equal or greater than 1.65. A Moran's Index value near +1.0 indicates clustering; an index value near -1.0 indicates dispersion.

** Square root transformation

The canonical correlation analysis indicated that 50 to 60 % of the variability in RKN was explained by a single canonical predictor composed of different soil physical and chemical properties (Table 2, 3). When the change in population density of RKN over time was related with the soil properties of CC field, the soil physical properties with the highest loading on the canonical predictor of RKN were elevation and EC_d and the soil chemical properties were Ca and K respectively.

An inverse relationship between RKN and EC_d for every sampling event and the mean RKN through the season (-0.32, -0.36, -0.32, and -0.30 respectively) was observed (Table 2). Because low EC_a (shallow - EC_s or deep - EC_d) values have been related with sandy or coarse texture soils, data re-emphasized the fact that nematodes prefer sandy areas (Khalilian et al., 2001; Perry et al., 2006). A direct relationship between elevation and RKN population density (r = 0. 47, 0.61, 0.41, and 0.59 for S1, S2, S3, and the mean of through the growing season respectively) was found. However, this field does not exhibit abrupt changes in topography (CV= 2.1 %) which makes this relationship less significant.

The relationship between soil chemical properties and RKN population density can be considered direct or indirect (plant mediated). Studies have shown that some mineral salts (NaCl, $NaNO_3$, KCl, KNO_3, $CaCl_2$, $Ca(NO_3)_2$, $MgCl_2$, $MgSO_4$, $FeCl_2$, and $FeSO_4$) exhibit some degree of repellency toward *M. javanica* and *M. incognita* (Cadet et al., 2004; Castro et al., 1990) . Therefore, the observed increase of RKN in areas with levels of K considered low for cotton growth and development (< 70 lbs/acre for the Coastal plain soils) could be related with lack of K in the soil to inhibit RKN reproduction and survival.

The influence of coarse texture, low EC_d, and K on the population density of RKN was also evidenced at the PG field (Table 3).

Geostatistical analysis

A weak spatial dependence, values of C_0/C_0+C greater than 0.60, characterized the RKN measured in August [residuals of Log_{10} (RKN S1+1)], and November [Sqrt(RKN S3+1)] (Figure 1, Table 4) at the CC field. In contrast, a moderated spatial dependence or structure, values of C_0/C_0+C equal to 0.40, was evidenced in the experimental semivariogram calculated for the samples taken in September [residuals of Log_{10} (RKN S2+1)].

In spite of the weak spatial dependence exhibited by the RKN sampled in August, the presence of small RKN clusters spatially distributed through the field was evidenced from a periodic pattern on the semivariogram (Figure 1a-2a). An increment on the clustering pattern of RKN sampled September, with a range of spatial correlation of 126 m, was reflected by its moderated spatial structure and periodicity (Figure 1b-2b). RKN samples related up to distances of 150 m were grouped on small clusters of RKN located on the central and north-eastern part of the field (Figure 2). A second range of spatial correlation (265 m) between the small clusters was observed on the semivariogram from September (Figure 1b). Although the size and the shape of the clusters changed from August to September, the locations of the high RKN population density areas remained stable until the end of the growing season (Figure 2). A smaller range of spatial variability, 74 m, observed for the RKN sampled in November indicated that the RKN samples from November were spatially independent at distances greater than 74 m (Table 4). This weak spatial structure, pairs of sample values aligned with the sample variance, observed in Figure 1c was related to small hot spots scattered up to distances of 265 m without a smooth continuity through space (Figure 1c, 2c).

The soil properties evaluated at the CC field showed moderated to strong spatial dependence (Table 4). The large range of spatial dependence for the soil chemical properties compared to the soil physical properties evidenced the presence of large clusters which favor their use for homogeneous zone delineation.

Table 2. Results from the canonical correlation analysis between the Log_{10} (cotton RKN/150 cm^3 of soil +1) sampled through the 2006 growing season and soil properties data for the CC field.

	Log_{10}RKN S1	Log_{10}RKN S2	Sqrt. RKN S3	Log_{10} RKN(ave)
Eigenvalue	0.43	0.67	0.35	0.61
Canonical correlation	0.55	0.63	0.51	0.61
Wilk's Lambda*	<.0001	<.0001	0.0002	<.0001
		Loadings		
Elevation	0.87	0.96	0.82	0.96
Slope	-0.56	-0.61	-0.46	-0.51
EC_d	-0.60	-0.57	-0.63	-0.48
soil pH	-0.27	-0.36	-0.37	-0.27
P	-0.06	-0.11	-0.03	-0.04
K	0.03	-0.43	-0.45	-0.44
Ca	-0.49	-0.68	-0.44	-0.51
		Correlation coefficients		
Elevation	0.47	0.61	0.41	0.59
Slope	-0.30	-0.39	-0.23	-0.31
EC_d	-0.32	-0.36	-0.32	-0.30
soil pH	-0.14	-0.23	-0.19	-0.17
P	-0.03	-0.06	-0.01	-0.02
K	0.01	-0.27	-0.23	-0.27
Ca	-0.26	-0.43	-0.22	-0.31
Mg	-0.20	-0.33	-0.18	-0.21

* Significant at P< 0.001

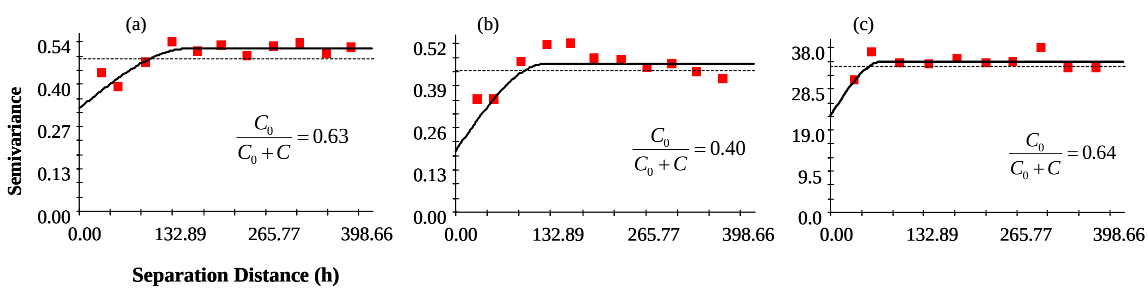

Figure 1. Semi-variograms of cotton RKN sampled in August [residuals of Log_{10} RKN S1] (a) , September [residuals of Log_{10}RKN S1] (b), and November [SqrtRKN S3] (c), CC field.

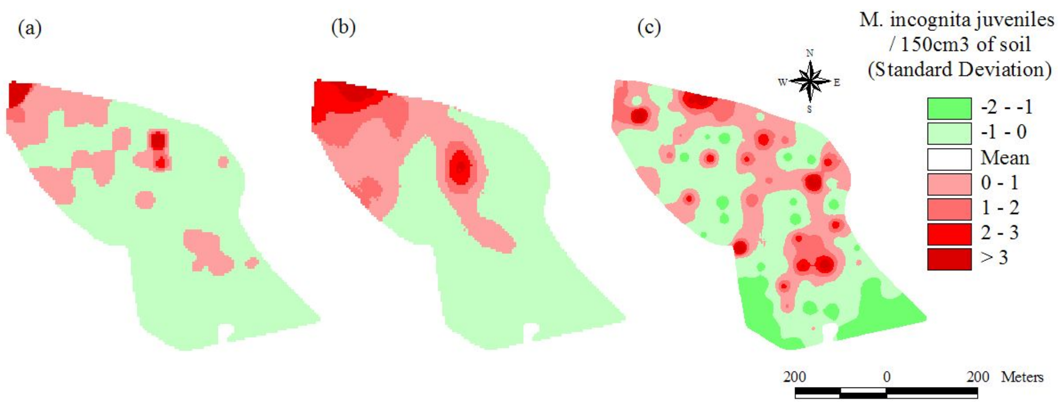

Figure 2. Cotton RKN spatio-temporal distribution evaluated in August-S1 (a), early September-S2 (b), and November-S3 (c) at the CC field in 2006.

Table 3. Results from the canonical correlation analysis between the Log_{10} (cotton RKN/150 cm^3 of soil +1) sampled through the 2006 growing season and soil properties data for the PG field.

	Log_{10}RKN S1	Log_{10}RKN S2	Log_{10}RKN S3	Log_{10} RKN(ave)
Eigenvalue	0.45	0.42	0.31	0.38
Canonical correlation	0.56	0.54	0.49	0.53
Wilk's Lambda*	<.0001	<.0001	0.0003	<.0001
		Loadings		
Elevation	-0.75	0.20	0.36	0.39
Slope	-0.08	-0.01	-0.18	-0.12
EC_d	-0.42	0.74	0.77	0.76
soil pH	0.23	0.34	0.52	0.42
P	0.71	-0.37	-0.28	-0.33
K	-0.37	0.86	0.75	0.82
Ca	0.03	0.73	0.75	0.71
		Correlation coefficients		
Elevation	-0.42	-0.11	-0.18	-0.21
Slope	0.04	0.06	0.09	0.06
EC_d	-0.24	-0.40	-0.38	-0.40
soil pH	-0.13	-0.18	-0.25	-0.23
P	0.40	0.20	0.13	0.18
K	-0.21	-0.46	-0.37	-0.44
Ca	-0.01	-0.39	-0.36	-0.38
Mg	-0.05	-0.39	-0.32	-0.36

* Significant at P< 0.001

Table 4. Semivariogram parameters, range of spatial correlation, and degree of spatial structure of cotton RKN population density and the soil properties from the two studied fields in 2006.

Variable	Model	C_0	C	C_0+C	Range (a)	C_0/C_0+C	Spatial structure
				Variogram parameters			
				CC field			
Log_{10}RKN S1	Spherical	0.33	0.19	0.52	159.00	0.63	Weak
Log_{10}RKN S2	Spherical	0.19	0.27	0.45	126.00	0.41	Moderated
Sqrt RKN S3	Spherical	22.00	12.47	34.47	74.39	0.64	Weak
Elevation *	Spherical	0.00	0.06	0.06	180.00	0.00	Strong
Slope	Spherical	0.21	0.10	0.31	162.80	0.69	Weak
EC_d *	Gaussian	0.12	1.79	1.91	103.94	0.06	Strong
soil pH	Exponential	0.08	0.14	0.22	139.21	0.37	Moderated
P	Spherical	279.37	121.08	400.45	169.67	0.70	Weak
K *	Gaussian	200.72	3237.00	3437.72	364.00	0.06	Strong
Ca *	Spherical	25893.00	55026.00	80919.00	213.00	0.32	Moderated
Mg	Spherical	1170.78	1713.16	2883.94	207.37	0.41	Moderated
				PG field			
Log_{10}RKN S1	Spherical	0.00	0.10	0.10	45.31	0.01	Strong
Log_{10}RKN S2	Exponential	0.66	0.28	0.94	181.36	0.70	Weak
Log_{10} RKN S3	Exponential	0.59	0.28	0.87	91.81	0.67	Weak
Elevation *	Gaussian	0.00	0.37	0.37	129.20	0.01	Strong
Slope	Exponential	1.06	0.76	1.82	93.02	0.58	Moderated
EC_d	Spherical	1.21	4.84	6.05	336.00	0.20	Strong
soil pH	Spherical	0.06	0.17	0.23	294.20	0.25	Strong
P*	Spherical	273.10	198116.00	198389.10	439.00	0.00	Strong
K	Exponential	0.06	0.06	0.12	159.54	0.47	Moderated
Ca	Gaussian	16996.00	26161.00	43157.00	103.72	0.39	Moderated
Mg	Gaussian	600.00	1425.89	2025.89	136.88	0.30	Moderated

* Quadratic trend was removed and residuals were use to calculate semivariogram parameters.

The semivariograms calculated for the RKN samples taken from the PG field in August [Log_{10} (RKN S2+1)], and October [Log_{10} (RKN S3+1)] showed a weak spatial structure with values of C_0/C_0+C greater than 0.60 (Figure 3, Table 4). In contrast, the spatial structure from the samples taken in late July [residuals of Log_{10} (RKN S1+1)] was strong, but the range of spatial autocorrelation was very small (45.31 m) and equal to the sampling distance. The maps of RKN spatial distribution show an increase in the size of the clusters from S2 to S3 as well as the stability of the clusters with high RKN population until the end of the growing season (Figure 4). The spatial structure of the soil properties at the PG field can be described as moderate to strong. Soil electrical conductivity (deep - EC_d) at the PG field was lower, highly structured and less variable than in the CC field, with a range of autocorrelation of 336 m (Table 4). This may indicate a high degree of uniformity in soil texture conditions compared with the CC field. Soil pH and P also had a higher range of autocorrelation in the PG field than in the CC field. In contrast, K, Ca and Mg in the PG field had lower range of autocorrelation than in the CC field. The low nugget in the empirical semivariogram of K indicated a moderated to strong spatial distribution of large clusters (159 m range).

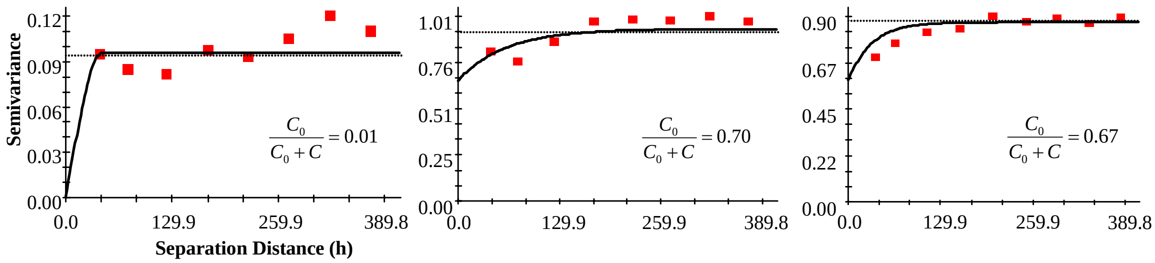

Figure 3. Semi-variograms of cotton RKN sampled in August [residuals of Log_{10} RKN S1] (a) , September [Log_{10}RKN S1] (b), and November [Log_{10}RKN S3] (c), PG field.

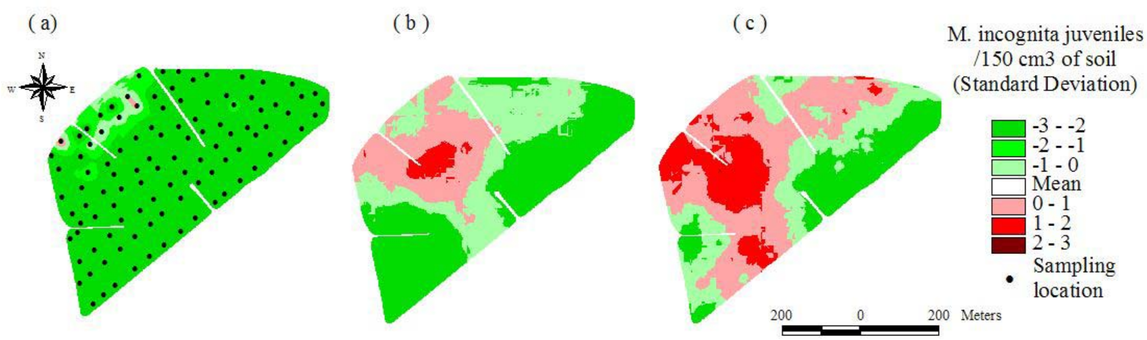

Figure 4. Cotton RKN spatio-temporal distribution evaluated in July-S1 (a), August-S2 (b), and October-S3 (c) at the PG in 2006.

The cross-correlograms from the CC field showed differences in spatial correlation of RKN with respect to different soil properties. All the soil properties had a negative spatial correlation with RKN except elevation (Figure 5a, 5b).

Although elevation showed a strong positive spatial cross-correlation, there were not significant differences in elevation (CV=2.1 %). A strong negative spatial correlation between RKN and EC_d was evidenced by the convex shape on the cross- correlogram and the range of the spatial correlation or spatial continuity (328 m). The symmetry in the cross-correlogram curves of elevation and EC_d indicated that the effect of elevation on the RKN was equal in magnitude to the effect of EC_d but with an opposite sign. Calcium had the strongest spatial correlation and largest range (370 m) between the group of soil chemical properties. The areas of high RKN agree with areas of Ca less than one standard deviation from the mean. Because some mineral salts including $CaCL_2$ and

$Ca(NO_3)_2$ have been described as having nematicidal effects on RKN (Cadet et al., 2004; Castro et al., 1990), the agreement between areas of high RKN and low soil levels of Ca support these findings. The similarities between the curve of Ca and Mg evidence covariance between these two variables. Although K showed higher contribution to the variability of RKN explained than soil pH on the canonical correlation analysis, the cross-correlation between RKN and soil pH was negative and stronger than K and had also a larger range of spatial correlation (Figure 5b).   The negative relationship between soil pH and RKN can be considered as indirect and related to the loss of nematicide activity by ammonia-releasing organic and inorganic fertilizers due to low levels of soil pH (Oka et al., 2006). Small changes in spatial correlation between RKN and P observed on the cross-correlogram (Figure 5b) evidenced the low impact of this variable on the population abundance of RKN.

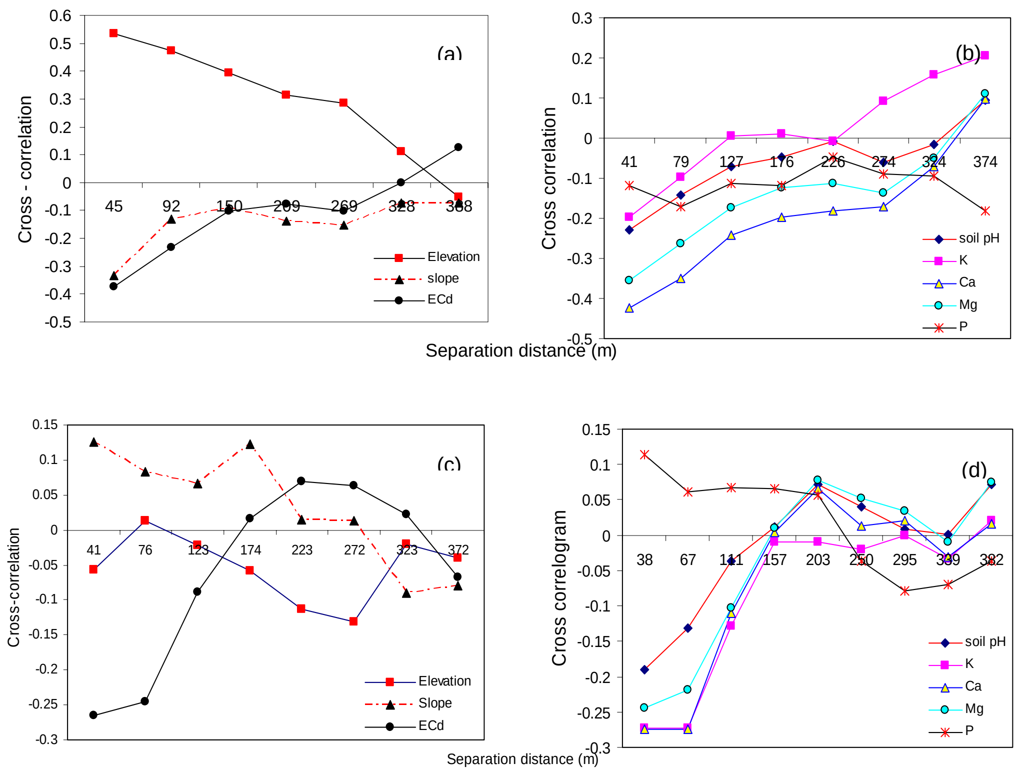

Figure 5. Cross-correlograms for cotton RKN [Log10 (RKN S2] vs. soil properties evaluated at the CC field (a,b) and PG field (c,d).

Significant differences between the cross-correlograms from PG field and CC field were observed (Figure 5). There were not significant spatial correlations between RKN and terrain properties, elevation and slope, at the PG field which may be related to the low variability of these properties across the field. The convex shape of the cross-correlogram between RKN and EC_d at the PG field indicated a moderated spatial correlation of samples separated up to 174 m (Figure 5c). The range of spatial correlation between RKN and the soil chemical properties from the PG field was smaller than the CC field. It may be related to the low range of spatial dependence exhibited by each one of these soil properties (Table 4). Between the soil chemical properties, K had the strongest spatial correlation with RKN which agrees with the results form the canonical correlation. The areas of high RKN agree with areas of low K levels (respect to the mean) up to a distance of 157 m. It could evidence a lack of K to maintain nematicidal activity on RKN in these areas.

A strong positive correlation between soil chemical properties and soil EC_a was observed (data not shown). Therefore, low levels of soil chemical properties can be related to low EC_d. Previous studies have shown that low EC_d has been associated with coarse texture soils at the Southern Coastal Plain of Georgia (Perry et al., 2007). As a result, soil amendments may be more easily leached on coarse texture soils, low ECa, resulting in areas with low soil fertility where nematicidal activity of some mineral salt in could be diminished.

Modeling the risk of RKN over threshold values

Because RKN sampled in September at the CC field had the highest spatial structure and best correlated with soil properties, these data were used for modeling the risk of RKN over the threshold of 100 RKN second stage juveniles / 150 cm^3 of soil. Table 5 shows the results from logistic regression modeling.

Table 5. Results of the logistic regression between RKN sampled in September and soil EC_d .

Regressor variables	Regressor coefficients	Standard Error	Chi-square	Pr>ChiSq
Constant	-0.7088	0.2554	7.70	0.005
Log ECa-deep	-0.33235	1.2766	13.76	0.0002

Deviance = 113.162, df= 97

Pearson Chi-Square = 106.943 , df=97

The spatial dependence of the residuals from the logistic model was inspected by semivariograms. The residuals were spatially correlated according to an exponential semivariogram with a range of spatial correlation of 99 m (Figure 6). The map of predicted RKN risk based on logistic regression between RKN and EC_d (Figure 7) indicated that the zone with the highest probability of having RKN population over the threshold value corresponded to the zone of lowest EC_d in the field. This indicates the ability of EC_d to predict the spatial variability of the RKN in this field and can also be used to identify potential areas for leaching of organic or inorganic amendments.

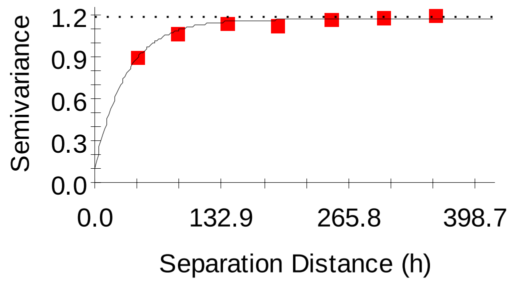

Figure 6. Residual variogram for ordinary logistic regression model. The squares represent the experimental semivariance calculated at different distances for 94 points.

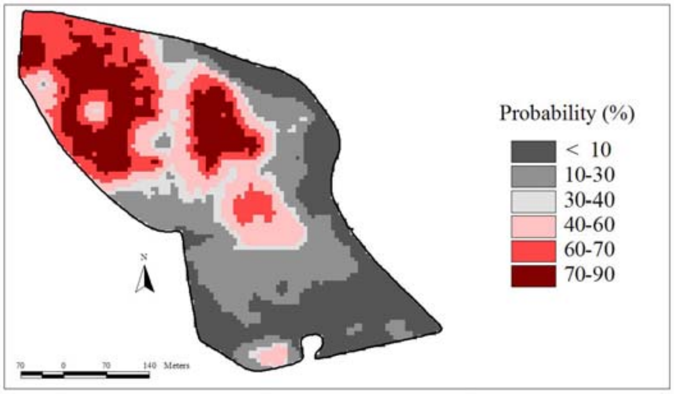

Figure 7. Map of predicted RKN risk over the threshold of 100 RKN second stage juveniles / 150 cm^3 of soil using logistic regression.

Conclusion

The aggregation pattern, spatial variability and temporal stability of RKN observed on the CC and PG fields meet some of the requirements for a SSM. Canonical correlation and cross-correlation allowed the identification of the most appropriate variables to use for delineation of management zones with RKN control purposes. The fact that RKN population density increases on areas of coarse textured soils, low EC_a, where leaching of nematicidal amendments is very likely to occur indicates the importance of having a probabilistic map of RKN risk over a specific threshold based on EC_d as the major contributing factor. The strong spatial correlation between the RKN and EC_d indicates that EC_d can be used to delineate management zones for RKN. Future research must be focused on the effect that soil chemical properties have on the reproduction and survival of nematodes.

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