COTTON YIELD RESPONSE TO VARIABLE RATE NEMATICIDES ACCORDING TO RISK ZONES

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Abstract

Cotton (*Gossypium hirsutum* L.) lint yield losses by southern root-knot nematode [*Meloidogyne incognita*] (RKN) have increased during the last 20 years. Site-specific management (SSM) of nematicides is a promising method to reduce yield losses, increase profitability and reduce adverse environmental impacts associated with excess allocations of agrochemicals. The impact of two nematicides applied at two rates on RKN population density and lint yield were compared across previously determined RKN risk zones in commercial fields during the 2007 growing season. Root knot nematode risk zones were delineated in 2006 using fuzzy clustering of elevation and slope of the terrain, normalized difference vegetation index (NDVI) calculated from a bare soil spectral reflectance, and apparent soil electrical conductivity [shallow ($EC_{a\text{-shallow}}$) and deep ($EC_{a\text{-deep}}$)]. Four different treatments of nematicides were randomly allocated among blocks that spanned the entire length of the fields. Test bare soil spectral reflectance plots (16 rows by 100 feet long) including the four treatments were also randomly selected within each zone to collect RKN population density, soil water content, and plant height, root galling, and final yield. In general, there were no benefits associated with a high rate of Telone (6 gal ac^{-1}) versus a lower rate of 3 gal ac^{-1}. Similarly, the higher Temik rate of 6 lbs ac^{-1} did not provide additional nematicide control compared to the low rate (3 lbs ac^{-1}). Comparing treatment results across management zones, Telone provided better RKN control compared to Temik in high risk zones, comprised of more coarse-textured, sandy soil. However, in low risk zones, which were comprised of relatively heavier textured soil compared to the high risk areas, the application of Temik would provide sufficient nematicide control. The results from this study clearly showed that RKN control and final yield varied with respect to the nematicide type and rate across management zones (MZ). These results are promising and support the idea of variable rate nematicide applications based on RKN risk zones.

Introduction

Across the U.S. Cotton Belt, southern root-knot nematode [*Meloidogyne incognita*] (RKN) causes considerable yield reduction. In Georgia, this nematode is considered one of the most critical pest problems facing producers today. A University of Georgia survey carried out between 2002 and 2003 by members of the University of Georgia's Cooperative Extension found RKN in all 67 cotton producing counties in Georgia. Seventy percent of the commercial cotton fields they surveyed were infested with some level of these pathogens.

In Georgia, management strategies such as crop rotation and planting moderately resistant cultivars are currently being implemented to reduce nematode related yield losses. In recent years, the control of nematodes through the application of soil fumigants such as Telone II (1,3 – dichloropropene) before planting and/or the use of a granular nematicide such as Aldicarb (Temik) has become a common practice for cotton growers. However, the high cost of nematicides suggests there may be an advantage to site-specific nematicide applications. Therefore, a management zone approach targeting areas at risk for high nematode populations could reduce the cost of nematicide applications, as well as improve placement and efficacy compared to uniform field application strategies.

Root knot nematodes exhibit an aggregated pattern of spatial variability, influenced primarily by variability in soil texture. This behavior suggests that site-specific management (SSM) of nematicides may be used to improve the efficacy of nematicide control and reduce costs. Studies conducted in Louisiana have shown differences in average nematode population and cotton yield with respect to the application of different nematicides treatments as a function of soil textures (Erwin et al., 2007; Wolcott, 2007). When evaluating the differences in yield between Telone and non-Telone treatments applied across two fields in Louisiana, coarsely textured areas in one of the fields showed a greater response to the application of Telone compared to areas having a relatively heavier soil texture (Erwin et al., 2007).

Although the fields planted with cotton in Georgia do not exhibit abrupt changes in soil texture, differences in soil texture are mainly due to variability in sand particle size. Variability in sand particle size has proven useful in conjunction with topographic information and bare soil reflectance to delineate areas with different levels of risk for high RKN population density (Ortiz et al., 2007b).

The main goal of this study was to compare the impact of rate and type of nematicide on RKN populations and cotton lint yield across management zones having different levels of risk for having a high population of RKN.

Methods

Three fields (20 – 49 ac) located in an intensely row-cropped region of southern Georgia, were selected for this study in 2007. The fields were planted on May 2007 with Delta & Pineland (DPL) 555 Boll-Guard®, Round-Up-Ready® cotton (*Gossypium hirsutum* L.) variety, using a 4 row Monosem vacuum planter. Planting occurred approximately 2 weeks after each field was strip-tilled. Because of space limitations, detailed results from one of the fields, CC field, are presented.

Management zones (MZ) for RKN were delineated based on fuzzy clustering of various surrogate data for soil texture. The methodology for the MZ delineation was developed using data collected in 2005 and 2006 from 11 cotton fields (Ortiz et al., 2007). The surrogate data for soil texture included in the MZ delineation were: terrain elevation and slope, normalized difference vegetation index (NDVI) calculated from bare soil spectral reflectance, and apparent soil electrical conductivity (EC_a). Although the fuzzy clustering of all these variables allowed the identification of three zones with different levels of risk for having high population of RKN at the CC field, the accuracy on the MZ delineation using EC_a alone, measured between 0-3 ft ($EC_{a\text{-deep}}$) with a VERIS® 3100 implement, was reduced only 30% (Figure 1).

The experiment was established in a randomized complete block design to evaluate the differences of two nematicides (Temik and Telone) applied at two different rates. A total of four treatments were randomly allocated in strips of 16 rows, spanning the length of the field. Within each treatment strip, plots (4 rows by

100 feet long) were randomly assigned and replicated six times within each of the three MZ. Treatments included: Temik – 3.0 lbs ac^{-1} (T1), Temik – 6.0 lbs ac^{-1} (T2), Telone – 3.0 gal ac^{-1} plus Temik 3.0 lb ac^{-1} (T3), and Telone – 6.0 gal ac^{-1} plus Temik 3.0 lb ac^{-1} (T4) (Figure 1a, 1b). Between each set of 16 rows of treatments a strip of four rows was left as a buffer which received 3.0 lbs ac^{-1} Temik. This rate was applied in the buffer as the cooperating farmers required, at a minimum, an insecticide rate of Temik in all rows.

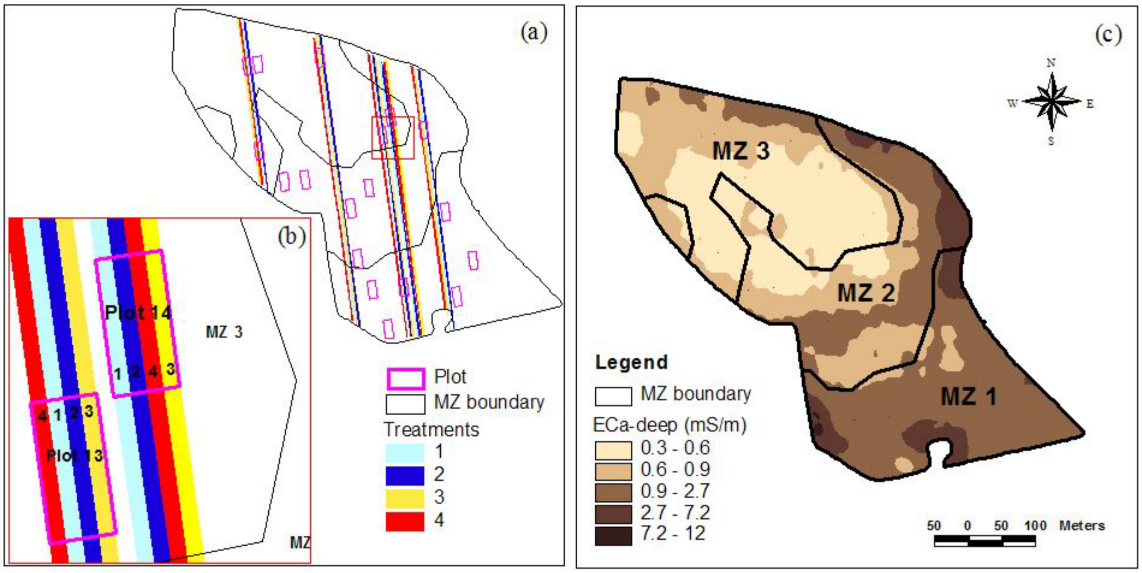

Figure 1. Spatial distribution of plots (a) and nematicide treatments (b) in relation to RKN management zones delineated using 2006 data (c), CC field.

Telone was applied approximately 2 weeks prior to planting using a 4-row KMC strip-till implement fitted with a nitrogen-based Telone application system. All T4 treatments were strip-tilled first, followed by the T3 treatments. Then the non-Telone treatments (T1 and T2) were strip-tilled. Temik was applied at planting from Microsem distributor boxes on the Monosem planter. The T2 treatments were planted first, followed by the T1, T4, and T3 treatments. A Trimble Autopilot auto-steer system made this operation very manageable. Both the Telone and Temik application systems were calibrated prior to field work.

Although each treatment was applied at random in four 16-row strips, sampling was conducted inside each experimental unit (4 rows by 100 feet long). Soil samples for RKN population density determination (second stage juveniles) were composed of soil cores collected at random within each experimental unit three times during the growing season: 76, 108, and 171 days after planting (DAP). Soil probes with a 1.2 in diameter opening and approximately 8 in long were used to extract the soil samples for nematode density analysis. The probes were inserted 6 - 12 in deep into the soil adjacent to the plant tap root. Root knot nematodes were extracted from 100 cm^3 of soil by centrifugal flotation (Jenkins, 1964).

The spatial variability of cotton yield (lint mass) was recorded using an Ag Leader cotton yield monitor system (Ag Leader Technology, Ames, IA) installed on a 9965 four-row John Deere picker. The system used an AgGPS 132 DGPS receiver with differential correction to calculate the position of the harvester at any time in the field.

Spatial analysis of yield monitor and RKN data were processed using the Spatial Analyst extension of ArcVIEW v. 9.0 (ESRI, 2004). Differences in yield due to nematode treatments within and between MZ were performed using PROC MIXED with a restricted maximum likelihood approach accounting for spatially correlated errors using the Statistical Analysis System (SAS Institute, 2000). Nematode treatment effects and the interaction between treatments and zones on RKN population density were computed through PROC MIXED in SAS.

Results

Field characteristics for each of the RKN management zones delineated for the CC field are shown in Table 1. The zone with the highest risk for high population of RKN, has the coarsest soil texture as demonstrated by the lowest values of $EC_{a\text{-deep}}$, slope and NDVI. In contrast, MZ 1 with the lowest risk for high population of RKN exhibited a heavier sand texture compared to MZ 3 (higher values of $EC_{a\text{-deep}}$, slope and NDVI).

Table 1. Characteristics of management zones delineated from fuzzy clustering of elevation, slope, NDVI and $EC_{a\text{-deep}}$. CC field

Zone	Log_{10} (RKN/ 100 cm^3+1)		Elevation (ft)		EC_a-deep (mS/m)		Slope (%)		NDVI		RKN/ 100 cm^3 soil	
	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1 - Low risk	1.1	73.5	250.0	1.1	1.5	38.8	1.4	19.6	0.09	19.7	41.3	179.8
2	1.6	55.2	256.9	1.7	2.5	87.0	2.1	30.2	0.09	23.4	170.3	191.7
3 - High risk	1.9	35.0	260.5	0.8	0.7	29.3	0.9	56.6	0.06	37.2	174.9	140.3

The RKN management zones delineated using 2006 data were validated prior to analysis of the 2007 data set to ensure differences within or among MZ were attributable to variability in RKN population and not an artifact of poorly delineated zones. The same 0.5 ac grid used in 2006 to collect RKN samples was used in 2007; however, soil samples were only collected from buffer strips. Figure 2 shows the spatial variability of the mid-season RKN population density in 2006 and late-season in 2007. The late-season (129 DAP) RKN population density sampled in 2007 followed the same pattern of RKN spatial variability segregated by the MZ delineated in 2006. The strength of the MZ delineation may be demonstrated by comparing RKN densities between zones, without regard to treatments. Regardless of any nematicide treatment, MZ 3, with the highest RKN risk, exhibited significantly ($P < 0.10$) higher RKN population densities compared to the other two zones.

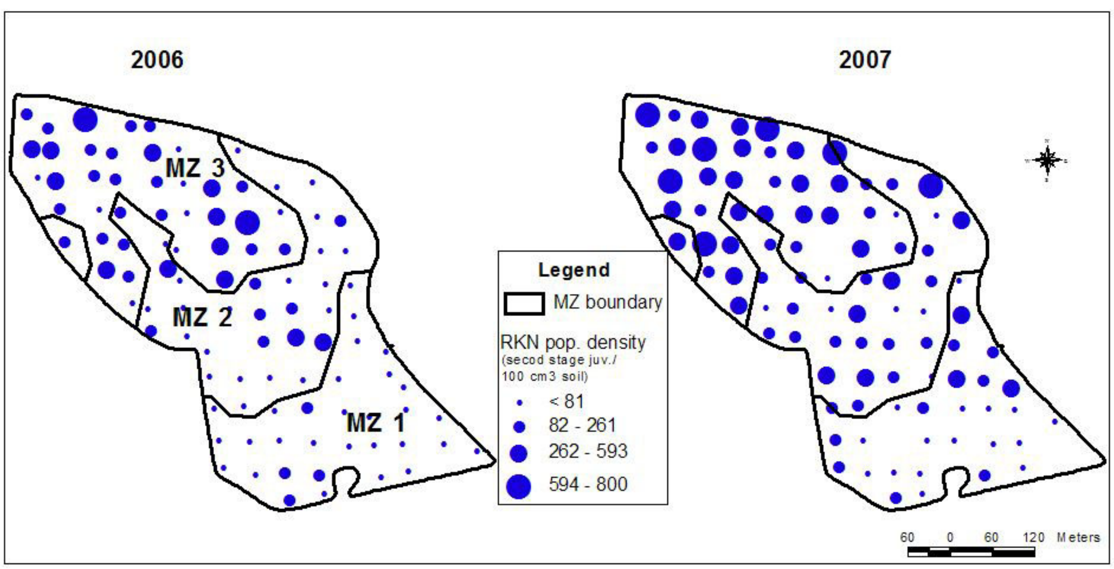

Figure 2. Spatial distribution of RKN population based on grid sampling in mid-season 2006 and late-season 2007 at the CC field.

An analysis of differences in average RKN population densities due to treatment by zone indicated significant treatment differences only in moderate (MZ2) and high (MZ3) RKN risk zones ($P < 0.05$).

In the low-risk zone (MZ1) a numerical difference in RKN population densities was observed between Temik at 6.0 lbs ac^{-1} (T2) and Telone at 6.0 gal ac^{-1} plus Temik at 3.0 lbs ac^{-1} (T4). Although the average reduction in RKN population between T4 and T2 was 57%, this difference was not statistically significant, Table 2, Figure 3. Considering the low risk for high population of RKN within MZ1 along with the lack of significant treatment differences, data suggest that any nematicide applied there had a low impact on RKN population; therefore a low rate of Temik may be sufficient nematicide control within this zone.

Table 2. Average RKN population density differences between nematicide treatments applied across three RKN management zones

Treament	**Zone number**		
	1 - Low risk	**2 - Moderate risk**	**3 - High risk**
	RKN population (second stage juveniles/100 cm^3 of soil)		
Temik 3 lb/ac (T1)	77.94	102.78	173.67
Temik 6 lb/ac (T2)	101.58	152.78	195.44
Telone 3 gal/ac + Temik 3 lb/ac (T3)	63.95	57.33	90.33
Telone 6 gal/ac + Temik 3 lb/ac (T4)	43.27	44.66	57.33

* Significant differences between nematicide treatments within a management zone, $P < 0.05$.

In MZ 2, there were significant differences between treatments ($P < 0.05$). On average, a reduction in RKN population density was observed between treatments: T4 vs. T1 (56% reduction), T3 vs. T2 (62% reduction), T4 vs. T2 (71% reduction), and between nematicide type - Telone vs. Temik (60 % reduction).

In MZ 3, there were also significant differences between treatments ($P < 0.05$). On average, a reduction in RKN population was observed between treatments: T4 vs. T1 (67% reduction), T3 vs. T2 (54% reduction), T4 vs. T2 (70% reduction), and between nematicide type – Telone vs. Temik (60% reduction).

A significant reduction in RKN population between Telone and Temik treatments (T3T4 vs. T1T2) when we moved across the management zones was observed. In MZ 1, the lowest reduction in average RKN population was observed in Telone treatments over Temik treatments, 36 second stage juveniles/100 cm^3 of soil which corresponded to 40% reduction. In contrast, MZ3 exhibited the highest reduction in average RKN population when using Telone compared to Temik. The reduction was 60% which was equivalent to 111 second stage juveniles/100 cm^3 less on average in the plots receiving any of the Telone treatments.
A consolidated analysis of the RKN population density by zone-treatment showed that not matter the zone there were no differences between Temik rates (T1 and T2 treatments) or Telone rates (T3 and T4 treatments).

When the RKN population density measured at different DAP was analyzed, there were no significant differences between nematicides and rates in MZ 1, however Telone – 6.0 gal ac^{-1} plus Temik 3 lbs ac^{-1} (T4) controlled RKN populations best throughout the growing season, Table 2. The differences between Telone and Temik treatments were statistically significant in MZ 2 and MZ 3. In MZ 2, although the highest rate of Telone (T4) significantly reduced the RKN population, the low rate of Telone (T3) produced similar results. MZ 3 had the highest RKN population throughout the growing season compared to MZ 2 and MZ 1, however Telone treatments (T3 and T4) resulted in the highest reductions in population density, Figure 3 and Table 3. When the RKN population was measured at 108 DAP, the high rate of Telone – 6.0 gallons per acre (T4) controlled RKN population better than the other three nematicide treatments within this zone (MZ3).

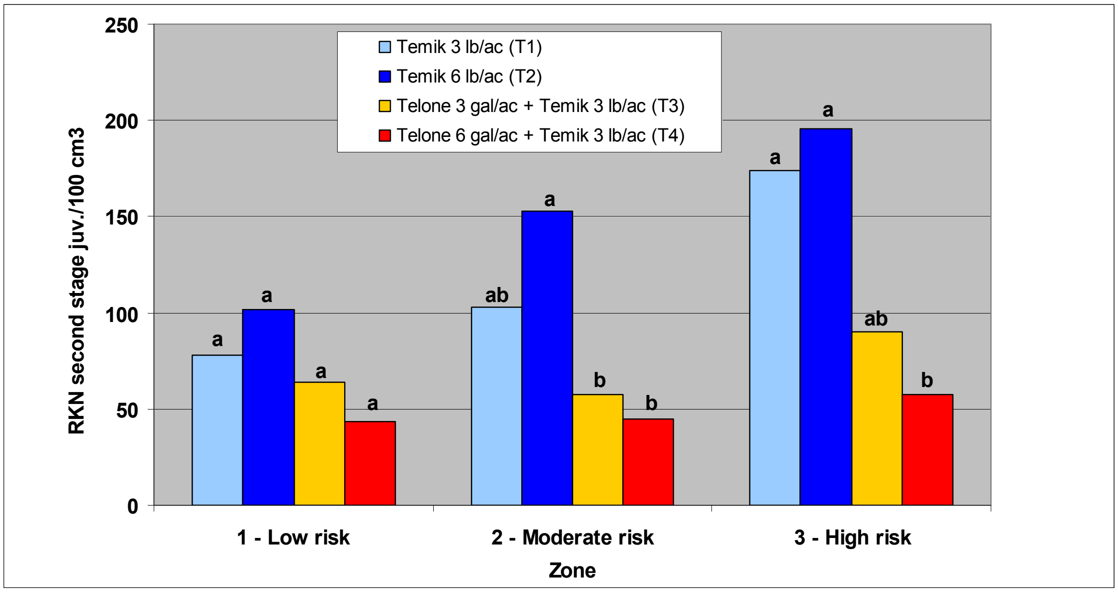

Figure 3. Average RKN population density differences between zones and treatments within zones. CC field.

Table 3. RKN population density differences at different DAP between nematicide treatments applied across three RKN management zones.

Treatment	Zone number 1			2*			3*		
	DAP 76	108	171	76	108	171	76	108	171
	RKN population density (second stage juveniles / 100 cm^3 of soil)								
1	0.7	154.4	78.3	20.7	218.3	69.3	40.7	323.0	157.3
2	24.0	132.0	148.0	10.7	324.0	123.7	38.0	360.3	188.0
3	4.7	151.2	34.0	9.0	97.0	66.0	24.0	135.3	111.7
4	12.7	61.6	54.7	18.0	85.3	30.7	14.0	68.7	89.3

* Significant differences between nematicide treatments within a management zone, $P < 0.05$.

The statistical analyses indicated significant yield differences between MZ, treatments and most important an interaction between MZ and treatments (Table 4, Figure 4). In MZ 1, the zone with the lowest risk for high RKN population, there was a significant difference ($P < 0.05$) in yield between treatments. When yield data coming from T4 plots within this zone was compared with yield data from T2 plots, the highest average yield increase was observed on T4 plots, 219 lb lint ac^{-1} (Table 5). However, the average difference in RKN population between these treatments was not significant, peaking at 58 second stage juveniles/100 cm^3 of soil. When the average yield from Temik (T1 and T2) and Telone (T3 and T4) treatments was compared, an increase of 122 lb lint/ac was observed, a 12% yield increase for Telone treatments. Recalling that RKN populations were numerically reduced with applications of Telone within this zone, slight increases in yield associated with T3 and T4 is not unexpected.

In MZ 2, the greatest yields were observed for plots receiving either T3 or T4, increasing yields by 28% (170 lbs ac^{-1}) in plots receiving Telone treatments compared to Temik treatments. The greatest yield increment was observed comparing treatments T4 and T2, 237 lb/ac. This yield response was expected due to the 71% reduction in RKN population caused by the application of high rate of Telone (T4) compared to high rate of Temik (T2).

In MZ 3, the zone with the highest risk for high RKN populations, there were significant yield effects ($P < 0.05$) between Temik and Telone treatments. However, there were no significant differences between Temik rates (T1 and T2 treatments) or Telone rates (T3 and T4 treatments), Table 4. When cotton yields from the two Telone treatments were averaged and compared to the average of the two Temik treatments, cotton yield increased by 71% (228 lbs ac^{-1}) in Telone treated plots. This result could be associated with the 60% reduction in RKN population due to Telone application compared with Temik within this zone.

The similarities in average RKN population between zones 2 and 3 and the contrasting yield between these two zones suggests that RKN population is not the only factor reducing and/or limiting cotton yield. The presence of high RKN population density in zones with low water availability, coarse-textured sandy areas with lowest $EC_{a\text{-deep}}$ values, may exacerbate yield losses. Ortiz et al. (2007a) evaluating the relationship between cotton yield, soil physical and chemical properties, and RKN in two cotton fields found the presence of aggregated high population densities of RKN in coarse textured areas exacerbate yield losses due to the conjunction of low uptake of water and K by RKN infected plants and the low availability of these resources in sandy areas. In this study, a good example of the integrated effects of RKN and landscape attributes is when treatments with similar population densities were compared across management zones (Figure 5). Even though the RKN population density between the three treatments were similar, yield losses increased when RKN were present in coarse-textured sandy areas like MZ3. Therefore, variable or precision application of the appropriate rate and type of nematicide may reduce cost, increase nematicide efficacy and improve economic returns on nematicide inputs.

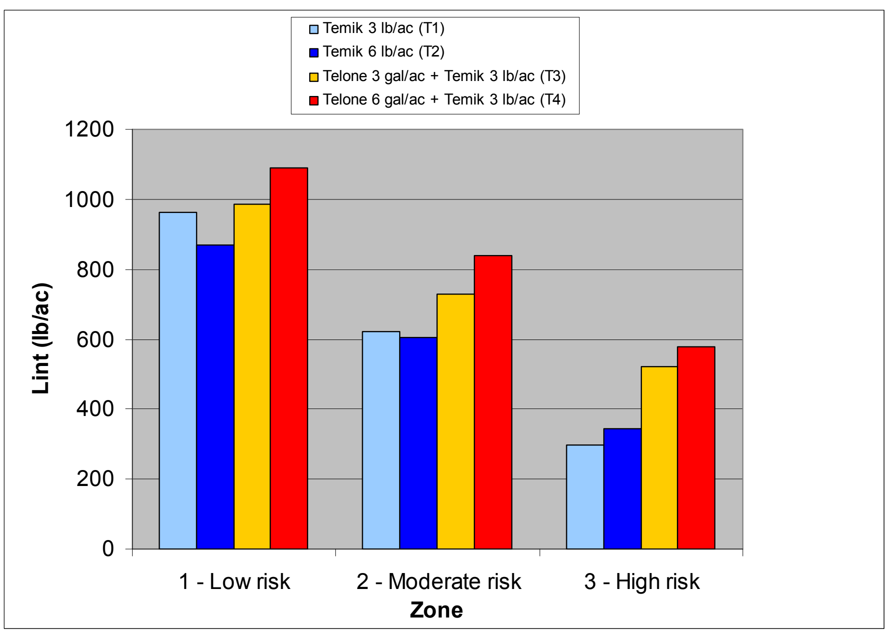

Figure 4. Cotton yield differences between zones and treatments within zones. CC field.

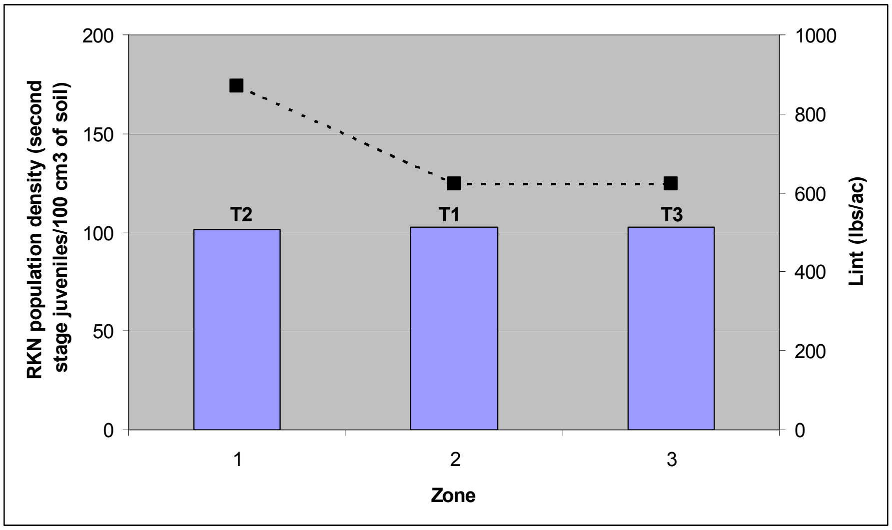

Figure 5. Changes in average RKN population density and cotton yield between zones and treatments within zones. CC field

Table 4. Cotton yield difference to nematicide treatments within a particular management zone, and P values for the CC field in 2007.

Zone								
1*			2*			3*		
Combination	LSD†	Pr > |t|	Combination	LSD†	Pr > |t|	Combination	LSD†	Pr > |t|
T2T1	-92.7	0.0335*	T2T1	-16.7	0.7083	T2T1	46.8	0.0847
T3T1	24.5	0.5689	T3T1	108.0	0.0303*	T3T1	224.2	<.0001*
T4T1	126.4	0.0007*	T4T1	216.9	0.0007*	T4T1	278.6	<.0001*
T3T2	117.2	0.0033*	T3T2	124.6	0.0200*	T3T2	177.3	0.0002*
T4T2	219.1	<.0001*	T4T2	233.6	0.0005*	T4T2	231.8	<.0001*
T4T3	101.9	0.0206*	T4T3	109.0	0.0369*	T4T3	54.4	0.0551
T3T4 vs. T1T2	121.8	<.0001*	T3T4 vs. T1T2	170.8	0.0004*	T3T4 vs. T1T2	228.0	<.0001*

* Significant differences between nematicide treatments within a management zone, P< 0.05.
† Least square yield difference between two nematicide treatments.

Studies conducted in the Mississippi Delta river area of Louisiana demostrated that a yield increase of 80-100 lbs lint ac^{-1} was necessary to cover the cost of nematicide treatments such as Telone. In our study, considering differences in RKN population and yield across zones, significant differences in average net return for the nematicide treatments occurred only within higher risk zones. Therefore, the application of Telone (at any rate) was economically prudent in zones MZ2 and MZ3 (Table 5). For example, in MZ 1 with the lowest RKN population, the cost of Telone or higher rate of Temik application would not be offset by yield. In the lower risk zone (MZ 1) the grower would have actually lost money ($553- $541) when using Telone, 3 gal/acre rather than the base Temik, 3 lb/acre, treatment. He would have realized a small gain ($561- $553) by increasing rate to 6 gal/acre.

Table 5. Average net returns by zone and treatment. CC field

Treatment	Zone					
	1		2		3	
	mean	std dev	mean	std dev	mean	std dev
Temik 3 lb/ac (T1)	$553.59	$ 37.44	$361.42	$118.67	$150.82	$ 58.91
Temik 6 lb/ac (T2)	$485.74	$ 59.44	$340.11	$124.07	$173.65	$ 32.05
Telone 3 gal/ac + Temik 3 lb/ac (T3)	$541.43	$ 45.80	$401.80	$114.62	$259.76	$ 31.65
Telone 6 gal/ac + Temik 3 lb/ac (T4)	$561.68	$ 81.18	$413.28	$126.96	$249.63	$ 44.52

Conclusions

The results from this study clearly showed that RKN control and final yield varied with respect to the nematicide type and rate across risk management zones based on fuzzy clustering of terrain elevation and slope, NDVI of bare soil reflectance and apparent soil electrical conductivity. Low RKN population was confirmed in the MZ with the lowest risk level for RKN. In this zone, there were no significant differences in RKN population between the application of Temik or Telone II at any rate. In contrast, the MZ with the highest risk level exhibited the highest RKN population, along with significant differences in nematicidal control between treatments. The highest reduction in average RKN population was observed with the use of Telone. A consolidated analysis of the RKN population density by zone-treatment showed that regardless of the zone there were no differences between Temik rates (T1 and T2 treatments) or Telone rates (T3 and T4 treatments).

Cotton yield increases were observed on plots receiving Telone treatments compared to Temik treatments and these differences increased when we moved from a MZ with a low risk level to high risk level. In general, nematicide control for Telone responded better than Temik on more coarse-textured sandy areas and especially when Telone was applied at a rate of 6 gal ac^{-1}. In contrast, no statistical difference between nematicide types and rates with respect to RKN population and the lowest yield increments was observed in less coarse-textured sandy areas. These results suggest that the application of Temik would be enough to control RKN present in the lower risk zones. Therefore, the application of Telone (at any rate) was economically prudent in moderate and high risk levels (MZ2 and MZ3). In contrast, in the lowest risk zone (MZ1), the cost of Telone or higher rate of Temik application would not be offset by yield.
In conclusion, the results presented here demonstrate the value of variable rate application of nematicide based on management zones depicting different levels of risk for high population of RKN.

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