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Alternate row placement is ineffective for cultural control of *Meloidogyne incognita* in cotton

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Abstract: The objective of this study was to determine if planting cotton into the space between the previous year's rows reduces crop loss due to *Meloidogyne incognita* compared to planting in the same row every year. Row placement had a significant ($P \leq 0.05$) effect on nematode population levels only on 8 July 2005. Plots receiving 1,3-dichloropropene plus aldicarb had lower nematode population levels than non-fumigated plots on 24 May and 8 July in 2005, but not in 2004. The effect of nematicide treatment on nematode populations was not affected by row placement. Row placement did not have a significant effect on root galling or yield in 2004 or 2005. Nematicide treatment decreased root galling in all years, and the decrease was not influenced by row placement. Yield was increased by nematicide application in 2004 and 2005, and the increase was not affected by row placement. Percentage yield loss was not affected by row placement. Changing the placement of rows reduced nematode population levels only on one sampling date in one year, but end-of-season root galling and lint yield were not affected by changing the placement of rows, nor was the effect of fumigation on yield influenced by row placement. Therefore, row placement is unlikely to contribute to *M. incognita* management in cotton.
Key words: cotton, cultural control, *Gossypium hirsutum*, nematode management, *Meloidogyne incognita*, root-knot nematode, row placement.

Plant-parasitic nematodes, especially the southern root-knot nematode (*Meloidogyne incognita*), are the primary pathogens of cotton (*Gossypium hirsutum*) in the US (Blasingame, 2006). Cotton in the US is often grown in the same field for several consecutive years (Starr et al., 2007) because monocropping can be a profitable cropping sequence (Davis et al., 2003; Starr et al., 2007) even though nematode population levels may increase. Nematicides can reduce the damage caused by plant-parasitic nematodes, but losses can still occur when the damage potential is high, and nematode population densities can increase regardless of nematicide use (Lawrence et al., 1990; Koenning et al., 2000, 2004).

Unfortunately, even when cotton is rotated with another crop, the rotation crop may allow reproduction of nematodes. For example, corn is rotated with cotton, but corn allows significant reproduction of *M. incognita* and does not contribute to management of this nematode (Davis and Timper, 2000). It is possible to select soybean cultivars resistant to *M. incognita*, *Rotylenchulus reniformis* or both (Robbins et al., 1999, 2001; Davis et al., 2003); however, most cultivars are not resistant to these nematodes.

Other tactics that can be combined with chemical control or host-plant resistance could contribute to nematode management. A simple cultural control practice that does not add to the cost of production was shown to be effective in minimizing damage from *R. reniformis* in continuous cotton (Rich and Wright, 2002). By moving the row placement such that the current year's rows are not planted in the same place as they were the previous year, cotton plants suffered less parasitism early in the growing season which resulted in reduced crop loss. The objective of this study was to determine if moving the placement of rows between years during continuous cotton production affects either the crop loss caused by the southern root-knot nematode, *M. incognita*, or the nematode population levels.

Materials and Methods

A three-year-long study was initiated in 2003 by planting cotton into a root-knot nematode-infested field to establish the initial row placement. Treatments were arranged in a split-plot experimental design. Within each of the six replications in the study, three whole plots were established: One whole plot was planted with the same row placement in 2003, 2004 and 2005 (designated O-O-O for original rows in 2003 - original rows in 2004 - original rows in 2005); one whole plot was planted into the original (2003) row middles in 2004 and 2005 (designated O-A-A for original rows in 2003 - alternate rows in 2004 - alternate rows in 2005); and one whole plot was planted into the original rows in 2004 and the original row middles in 2005 (designated O-O-A for original rows in 2003- original rows in 2004 - alternate rows in 2005). This allowed two replications in time of the effect of moving row placement in the same field over a three-year period: O-A-A plots showed the effect of moving rows in 2004 and O-O-A plots showed the effect in 2005. Each whole plot was divided into two sub-plots: fumigation with 1,3-dichloropropene (28 liters formulation/ha; formulation = 97.5% a.i. by weight) plus aldicarb (1.01 kg a.i./ha) to duplicate the nematicide regime a farmer might use or a low rate of aldicarb (0.33 kg a.i./ha) for thrips control with no 1,3-dichloropropene fumigation. The nematicide treatments were used to provide a measure of nematode-induced yield loss in the whole-plots.

This study was conducted at the University of Georgia Gibbs Farm in Tifton, GA. The soil type was a Tifton

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loamy sand (fine, loamy, siliceous, thermic Plinthic Kandiudults; 85% sand, 11% silt, 4% clay; <1% organic matter). The field was naturally infested with *M. incognita* and planted to cotton for several years prior to initiation of this study. A winter cover crop of hairy vetch (*Vicia villosa*) had been planted in November 2002. All plots were strip-tilled during the study, but had been conventionally tilled in prior years. Strip-tillage consisted of a single sub-soil chisel per row with shallow (approximately 10 cm) disking and rollers which left a smooth seed-bed 20-cm wide; the remaining space between rows was undisturbed. Cotton (Delta and Pine Land DP458BR) was planted (14.3 seeds/m) into strip-tilled beds on 30 May 2003, 5 May 2004 and 12 May 2005. All cotton plots received 672 kg/ha 3-9-18 (N-P-K) fertilizer on 30 May 2003, 392 kg/ha on 20 May 2004 and 392 kg/ha on 10 May 2005. Plots also received ammonium nitrate (34% nitrogen) on 17 July 2003 (308 kg/ha), 17 July 2004 (308 kg/ha) and 1 July 2005 (101 kg/ha). Applications of insecticides and herbicides followed University of Georgia Extension Service recommendations and were the same for all plots (Brown et al., 2001). The fumigant 1,3-dichloropropene was applied each year when the field was strip-tilled, approximately 2 wk prior to planting. Aldicarb was applied in the furrow at planting each year. After cotton emergence, all plots were sprayed one to two times with acephate at 0.20 kg a.i./ha for thrips control. Irrigation was applied as needed through overhead sprinklers.

All plots were four rows wide (91-cm apart and 15-m long), but data was collected from only the middle two rows to avoid edge effects. The data collected included nematode population levels at planting, midseason and harvest; yields; and root galling at harvest. Soil samples were collected on 12 June, 15 July and 13 November 2003; 13 May, 24 June, 4 August and 15 October in 2004; and 24 May, 8 July, 31 August and 31 October 2005. Soil samples used for nematode extraction were collected from the current year's plant rows regardless of original row placement. Soil samples consisted of a composite of 8 to 10 cores/plot (2.5-cm-diam. and approximately 20-cm deep) collected from the root zone. Nematodes were extracted from 150 cm^3 soil by centrifugal flotation (Jenkins, 1964). Root galling was evaluated each year on a 0 to 10 scale within a few days of harvest by digging and rating 10 root systems per plot. The scale used was as follows: 0 = no galling, 1 = 1-10% of the root system galled, 2 = 11-20% of the roots system galled, etc., with 10 = 91-100% of the root system galled. Cotton was harvested on 10 November 2003, 7 October 2004 and 20 October 2005 from the two center rows of each plot. The weight of seed cotton (cotton lint plus seed) from each subplot was determined, and lint yield was estimated as 40% of the seed cotton weight. Percentage yield loss within each row-placement treatment was calculated as (([yield in fumigated plots] − [yield in nonfumigated plots])/[yield in fumigated plots]) × 100.

Data from each year were analyzed separately. Initially, data were analyzed with a split-plot analysis of variance to determine if the factors (row placement and fumigation) had a significant effect on nematode counts, yield or root gall ratings, and whether there was an interaction between factors. Statistical differences, unless otherwise specified, were with an α of 0.05. Nematode counts were subjected to square-root transformation prior to analysis. Then, a subset of the data from nonfumigated plots only was analyzed with a randomized complete block analysis of variance with means separation by Fisher's protected $LSD_{(0.05)}$ to determine whether the dependent variables, including percentage yield loss, differed among the row placement treatments.

Results

Split-plot analysis of variance confirmed that plots receiving 1,3-dichloropropene plus aldicarb had lower nematode counts on 12 June and 15 July in 2003 and 24 May and 8 July in 2005. There was no interaction between row placement and nematicide treatment affecting nematode counts. The nematicide treatment did not result in statistically lower nematode counts in 2004. Nematicide treatment decreased root galling in all years, and there was no interaction between nematicide treatment and row placement on galling. Yield was increased by nematicide application in 2004 and 2005, but not in 2003 ($P = 0.125$), though there was a numerical increase in 2003 of 10%. There was no interaction of nematicide treatment and row placement on yield.

Split-plot analysis of variance showed that row placement had a significant effect on nematode counts only on 8 July 2005. Analysis of variance using only plots that did not receive 1,3-dichloropropene plus aldicarb nematicide treatment also showed differences in nematode counts among the row placement treatments only on 8 July 2005 (Table 1); moving the row placement in 2005 resulted in lower nematode counts than maintaining the original row placement. Split-plot analysis of variance also showed that row placement did not have a significant effect on root galling or yield in 2004 or 2005. Analysis of variance using only plots that did not receive 1,3-dichloropropene plus aldicarb nematicide treatment also did not show an effect of row placement on root galling or yield in 2004 or 2005 (Table 2). Percentage yield loss was not affected by row placement in any year of this study (Table 2).

Discussion

The underlying assumption of moving the row placement to reduce damage from nematodes is that, at

TABLE 1. Soil counts of *Meloidogyne incognita* from cotton rows that either are planted in the same place each year or are planted between the rows from the previous year.

Year	Treatment Number[1]	Row Placement[2]	*Meloidogyne* soil counts (juveniles/150 cm^3 soil)			
2004			13 May	24 June	4 August	15 October
	1	O-O-	7 a[3]	70 a	483 a	643 a
	2	O-A-	47 a	87 a	937 a	803 a
	3	O-O-	12 a	132 a	498 a	738 a
2005			24 May	8 July	31 August	31 October
	1	O-O-O	58 a	115 a	720 a	532 a
	2	O-A-A	40 a	123 a	627 a	602 a
	3	O-O-A	3 a	35 b	1298 a	787 a

[1]Plots with a given treatment number remained in the same location in the field throughout all years of the study.
[2]O = original row placement; A = alternate row placement. Original (initial) row placement was established for all plots in 2003. Alternate row placement means rows were planted between the original row locations. Letter designations for row placement in this column are sequential for the years 2003 through the year that data was collected (2004 or 2005).
[3]Means separation based on Fisher's protected $LSD_{(0.05)}$.

least early in the season, there should be fewer nematodes between rows than in the rows from the previous year. That expectation is because nematodes should be at greater concentrations where there had been greater root concentrations, and root densities are greater in the rows than between the rows (Grimes et al., 1975).

Row placement was initially established in 2003, the first year of the study, and that placement was designated as the original rows. But the field was disked in November 2002, and a winter cover crop of hairy vetch, a good host for *M. incognita* (Timper et al., 2006), was planted, thereby reducing or eliminating any residual row-placement effect from previous years. Additionally, to accommodate movement of the rows in some plots in future years, some of the 2003 rows in the O-A-A and O-O-A plots were in the same place as 2002 rows, but others were not, whereas all O-O-O plots were planted in the same place as the 2002 rows. Therefore, it is inappropriate to draw conclusions about the effects of row placement based on 2003 data.

The six combinations of row placement and nematicide use allow us to evaluate the benefit of changing the row placement and to determine if the effect of nematicides is consistent when row placement is changed. Two analyses were performed on the data: a split-plot analysis of variance, which included plots fumigated with 1,3-dichloropropene, and an analysis of variance on a subset of the data which omitted the fumigated plots. Fumigated plots were included in the study to minimize damage from nematodes and thereby provide a means of estimating yield suppression. Therefore, the split-plot analysis of variance, which analyzes the effect of the row-placement factor across all levels of the fumigation factor, was less appropriate than analysis of a subset of data for evaluating the effect of row placement. However, the results of the two analyses were consistent.

Moving the placement of rows was effective in suppressing early-season densities of *Rotylenchulus reniformis* and increasing yields in cotton by 30% one year and 40% another year (Rich and Wright, 2002). In contrast, changing row placement did not lead to an increase in yield in either year of our study. A reduction in levels of *M. incognita* was observed eight weeks after planting where row placement had been moved for the first time in 2005, but at no other time during this study. Therefore, we conclude that moving row placement had little or no effect on nematode population levels. The difference between the current results and the previous study (Rich and Wright, 2002) could be due in part to unknown differences in environmental conditions and how those differing conditions affected the nematode population levels and crop yield.

Though not significant, there was a small numerical decrease in galling where row placement was moved for the first time in both 2004 and 2005. Consistent with that, there also was a small, though statistically insignificant, numerical increase in yield in those plots in both years. The average nematode pressure across all plots, as measured by nematode counts and root

TABLE 2. Root galling, yield and percentage loss from cotton rows that either are planted in the same place each year or are planted between the rows from the previous year.

Year	Treatment Number[1]	Row Placement[2]	RGI[3]		Yield (kg lint/ha)		% loss[4]	
2004	1	O-O	1.6	a[5]	1032	a	8.3	a
	2	O-A	2.2	a	1143	a	7.4	a
	3	O-O	2.2	a	1032	a	11.3	a
2005								
	1	O-O-O	1.9	a	1246	a	11.2	a
	2	O-A-A	2.2	a	1209	a	12.8	a
	3	O-O-A	2.0	a	1274	a	7.9	a

[1]Plots with a given treatment number remained in the same location in the field throughout all years of the study.
[2]O = original row placement; A = alternate row placement. Original (initial) row placement was established for all plots in 2003. Alternate row placement means rows were planted between the original row locations. Letter designations for row placement in this column are sequential for the years 2003 through the year that data was collected (2004 or 2005).
[3]RGI = root gall index on a 0 to 10 scale: 0 = no galling, 1 = 1-10% of the root system galled, 2 = 11-20% of the roots system galled, etc., with 10 = 91-100% of the root system galled.
[4]$(([\text{yield in fumigated plots}] - [\text{yield in nonfumigated plots}])/[\text{yield in fumigated plots}]) \times 100$.
[5]Means separation based on Fisher's protected $LSD_{(0.05)}$.

galling, was moderate in 2004 and 2005. The effect of row placement might have been greater if nematode pressure had been greater in those years.

The planting date of a cotton crop may influence the effect of moving row placement as a cultural control method. Parasitism of cotton by *R. reniformis* or *Hoplolaimus columbus* (Columbia lance nematode) can delay maturity of the crop (Bond and Mueller, 2007; Robinson, 2007). A cotton boll typically takes about 50 days after flowering to reach maturity, but that can increase substantially late in the season (Oosterhuis and Bourland, 2001), and bolls produced too late in the season will not mature in time to be harvested. Cotton in the study in which using alternate row placement suppressed *R. reniformis* (Rich and Wright, 2002) was planted much later than the cotton in our study: 22 and 26 June compared to 5 and 12 May. A combination of late planting and delayed maturity from nematode parasitism may have contributed greatly to the 30% or more yield suppression in the study with *R. reniformis*. If the crop had been planted earlier, thereby allowing bolls more time to reach maturity, the benefit of moving the row placement may not have been as great. Perhaps movement of row placement is a more beneficial method of nematode management in cotton fields that are planted late, such as when cotton is double cropped with wheat.

Literature Cited

Blasingame, D. 2006. 2005 cotton disease loss estimate. Pp. 155–157 *in* Proceedings of the 2006 Beltwide Cotton Conferences, San Antonio, TX, 3-6 January 2006.

Bond, C. R., and Mueller, J. D. 2007. Delayed maturity and associated yield loss in cotton infected by the Columbia lance (*Hoplolaimus columbus* Sher) nematode. Journal of Cotton Science 11:275–287.

Brown, S. M., Bader, M., Culpepper, S., Harris, G., Jost, P., Kemerait, B., Roberts, P., and Shurley, D. 2001. 2002 Georgia cotton production guide. Cooperative Extension Service publication CSS-02-01, Athens: University of Georgia.

Davis, R. F., Koenning, S. R., Kemerait, R. C., Cummings, T. D., and Shirley, W. D. 2003. *Rotylenchulus reniformis* management in cotton with crop rotation. Journal of Nematology 35:58–64.

Davis, R. F., and Timper, P. 2000. Resistance in selected corn hybrids to *Meloidogyne arenaria* and *M. incognita*. Supplement to the Journal of Nematology 32:633–640.

Grimes, D. W., Miller, R. J., and Wiley, P. L. 1975. Cotton and corn root development in two field soils of different strength characteristics. Agronomy Journal 67:519–523.

Jenkins, W. R. 1964. A rapid centrifugal flotation technique for separating nematodes from soil. Plant Disease Reporter 48:692.

Koenning, S. R., Barker, K. R., and Bowman, D. T. 2000. Tolerance of selected cotton lines to *Rotylenchulus reniformis*. Journal of Nematology 32:519–523.

Koenning, S. R., Kirkpatrick, T. L., Starr, J. L., Wrather, J. A., Walker, N. R., and Mueller, J. D. 2004. Plant-parasitic nematodes attacking cotton in the United States: Old and emerging production challenges. Plant Disease 88:100–113.

Lawrence, G. W., McLean, K. S., Batson, W. E., Miller, D., and Borbon, J. C. 1990. Response of *Rotylenchulus reniformis* to nematicide applications on cotton. Journal of Nematology 22:707–711.

Oosterhuis, D. M., and Bourland, F. M. 2001. Development of the cotton plant. Pp. 3–7 *in* T.L. Kirkpatrick and C.S. Rothrock, eds. Compendium of Cotton Diseases, second edition. St. Paul, Minnesota: The American Phytopathological Society.

Rich, J., R., and Wright, D. L. 2002. Alternating cotton row patterns to reduce damage from reniform nematodes. Nematropica 32:229–232.

Robbins, R. T., Rakes, L., Jackson, L. E., and Dombeck, D. G. 1999. Reniform nematode resistance in selected soybean cultivars. Supplement to the Journal of Nematology 31 667–677.

Robbins, R. T., Rakes, L., Jackson, L. E., Gbur, E. E., and Dombeck, D. G. 2001. Host suitability in soybean cultivars for the reniform nematode, 2000 tests. Supplement to the Journal of Nematology 33:314–317.

Robinson, A. F. 2007. Reniform in U.S. cotton: When, where, why, and some remedies. Annual Review of Phytopathology 45:263–288.

Starr, J. L., Koenning, S. R., Kirkpatrick, T. L., Robinson, A. F., Roberts, P. A., and Nichols, R. L. 2007. The future of nematode management in cotton. Journal of Nematology 39:283–294.

Timper, P., Davis, R. F., and Tillman, P. G. 2006. Reproduction of *Meloidogyne incognita* on winter cover crops used in cotton production. Journal of Nematology 38:83–89.