Journal of Nematology 32(3):258–264. 2000.

Variability in Time and Space of *Meloidogyne incognita* Fall Population Density in Cotton Fields

Terry A. Wheeler,[1] Brant Baugh,[2] Harold Kaufman,[3] Greta Schuster,[4] and Kerry Siders[5]

Abstract: Three cotton fields infested with *Meloidogyne incognita* were intensively sampled in the fall for 3 years (1996 to 1998) to determine if intensive sampling for *M. incognita,* for which spatial location is important, was necessary every year in a continuous cotton system. Two composite soil samples (20 cores each), taken over an area covering one-third of the field length and two rows wide, were averaged to represent that area (row-location combination). Each field (except one) had 24 areas assayed for changes in *M. incognita* population density (Pf) over a 3-year period. At all three sites, Pf was higher during fall 1998 than fall 1996. There were no differences in Pf between rows within a year or between years (no. row × year interaction) at any of the sites. At all three sites, there was a consistent difference each year in Pf among locations in a field (no. year × location interaction). At each area, *M. incognita*/500 cm^3 was labeled for one of four Pf classes: <250, 250 to 999, 1,000 to 2,499, and ≥2,500. Management of root-knot nematode would likely be altered as classification changed. The areas that were reclassified by two classes or more after 1 and 2 years ranged from 0 to 29% and 25 to 54%, respectively. The risk of underestimating Pf of *M. incognita* was higher in one site 2 years after the initial intensive sampling procedure, whereas in another site there was little change in Pf 2 years after initial sampling. Sampling frequency will need to be decided on a field-by-field basis.

Key words: cotton, *Meloidogyne incognita,* nematode, population dynamics, root-knot nematode, sampling, spatial variability, temporal variability.

Precision agriculture is a system in which management of crops and animal production is organized by attributes, and rates or types of inputs are changed depending on the spatial and (or) temporal variation of the attributes. For example, if a field is divided into subunits based on nitrogen concentration, subunits with high levels of nitrogen will receive a different rate or type of fertilizer than subunits with low levels of nitrogen. Such management requires extensive information at the subunit level and ability to deliver variable rates of inputs.

Variable-rate application of nematicides may offer opportunities for more profitable cotton production through the application of nematicides, only where they are appropriate. Variable-rate application of nematicides will be most effective if population densities of damaging nematode species are aggregated, and range from zero to economically damaging levels.

Horizontal distribution of root-knot nematodes is highly aggregated (Goodell and Ferris, 1980; Noe and Barker, 1985; Wheeler et al., 1994). Current recommendations for use of nematicides to manage nematodes in cotton are based on nematode population densities estimated from soil samples collected in late summer or fall (Wrona et al., 1996). Collection and assay of soil samples may be an expensive proposition, with costs of assays as much as $25/sample. The greatest limitation in using variable-rate application of nematicides for nematode control is determining the precise location of damaging nematode densities. The expense of intensively sampling fields for nematode distribution would be more affordable if results were applicable for more than one growing season. Cotton is grown continuously in many fields in the High Plains of Texas. The purpose of this study was to determine if intensive sampling for *M. incognita,* for which spatial location of changes in the fall population densities was important, was nec-

Received for publication 28 April 1999.
Supported in part by the Texas A&M University System, and with grants from the Texas Pest Management Association and Texas Department of Agriculture.
[1] Texas Agricultural Experiment Station, Rt. 3, Box 219, Lubbock, TX 79403.
[2] Texas Agricultural Extension Service, 1418 Ave. G, Lubbock, TX 79401.
[3] Texas Agricultural Extension Service, Rt. 3, Box 213AA, Lubbock, TX 79403.
[4] West Texas A&M University, IPM, Division of Agriculture, Box 60998, Canyon, TX 79016-0001.
[5] Texas Agricultural Extension Service, 1212 Houston St., Suite 2, Levelland, TX 79336.
Email: ta-wheeler@tamu.edu
This paper was edited by T. L. Niblack.

essary every year in a continuous cotton system.

Materials and Methods

The three study sites were located in Hockley, Lamb, and Lubbock counties in west Texas. All sites were irrigated with center pivot systems, had row widths of 1.01 m, and were in continuous cotton production from 1995 to 1998. The Hockley County site consisted of a half-circle, in which the curved row length varied from 387 m to 575 m. The variety Paymaster (PM) 'HS-26′ was planted in 1995 to 1997, and PM '2326RR' (the recurrent parent was PM HS-26) was planted in 1998. The Lamb County site contained straight rows, 812 m in length. The variety All-Tex 'Atlas', which is equally susceptible to *M. incognita* as PM HS-26 (Wheeler and Gannaway, 1998), was planted at this site. The site in Lubbock County consisted of almost a full circle, with curved row lengths of 304 m to 716 m. The variety PM HS-26 was planted in 1995 and 1996, and PM 2326RR was planted in 1997 and 1998. All farming operations except harvest were carried out on 8-row patterns. Harvest was done on 4-row patterns.

Soil samples were taken at each site in October or early November 1996 to 1998. Composite soil samples consisted of 20 cores (50 cm^3/core), taken to a depth of 10 to 20 cm near the taproots of the plants. The distance between soil cores varied with site and row length. The sampling area consisted of 64 rows; a composite soil sample was taken from the center two rows in each 4-row interval and over a distance representing one-third the length of the row, for 48 samples per site. The only exception was at the Hockley County site in 1997, where each sample was taken from a 16-row width rather than a 4-row width, with a total of 12 samples collected from the test area. All samples were assayed for plant-parasitic nematodes within 1 week of sampling. Second-stage juveniles (J2) of *Meloidogyne* were extracted from 200 cm^3 soil with a pie-pan method (Thistlethwayte, 1970). Eggs were extracted from 500 cm^3 soil and roots mixed in 3 liters water for 15 seconds and allowed to settle for 15 seconds. The water and organic matter were then poured through a sieve with a pore size of 230 µm. Eggs were extracted from the organic matter caught on the sieve by the NaOCl extraction method (Hussey and Barker, 1973). The fall population density (Pf) of *M. incognita* was defined as the sum of the J2 and eggs. Soil texture was determined for each site (Gee and Bauder, 1986).

Individual estimates of Pf were divided into management classes of <250, 250, to 999, 1,000 to 2,499, and ≥2,500 *M. incognita*/500 cm^3 soil (Wheeler et al., 1999). Frequency distributions of Pf classes for each year and site were compared between years within sites with a chi-square test (Daniel, 1978). Pf values for each of the two 4-row areas were averaged (i.e., values for rows 2–3 and 6–7 in the 8-row unit were averaged) to obtain an estimate of Pf for each 8-row planting unit. In Hockley County for 1997, one sample was taken every 16 rows, for comparison with each set of 8-row data from 1996 and 1998. Analysis of variance was performed to determine the effects of year, row, location within a field, year × row, year × location, and row × location on Pf. Effects were considered significant at $P \leq 0.05$ unless otherwise noted. A 2-class change in management class over time was considered sufficient to cause a change in management recommendations.

Results

There was a shift in the frequency distributions of classes at all three sites between 1996 and 1998, and 1997 and 1998 (Fig. 1). The two lowest classes tended to decrease in frequency over time, whereas the two highest increased over time. The only year where a shift did not occur was at the Lamb County field between 1996 and 1997 (Fig. 1).

Effects of site, year, row, and location variables on Pf were compared. In the Hockley County and Lubbock County sites, there was an increase in Pf each year over the previous year (Fig. 2). At the Lamb County site there was an increase in Pf from 1996 and 1997 to

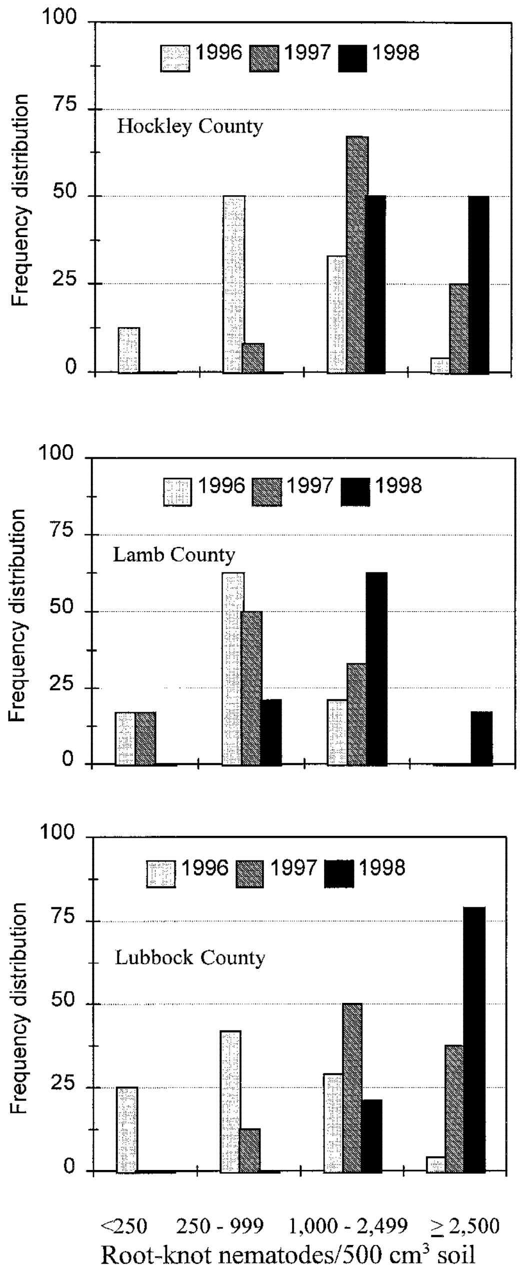

FIG. 1. Frequency distribution of *Meloidogyne incognita* fall density (Pf) from three cotton fields, taken in the fall 1996, 1997, and 1998. There were 24 locations in each site except for the Hockley County site in 1997, where there were only 12 locations. There was a significant ($P = 0.05$) shift in frequency distribution of Pf from 1996 to 1997 in the Hockley and Lubbock County sites, and at all three sites from 1997 to 1998 and 1996 to 1998.

1998 (Fig. 2). There was no difference in *M. incognita* Pf across rows within a site, but Pf differed among the three locations within a

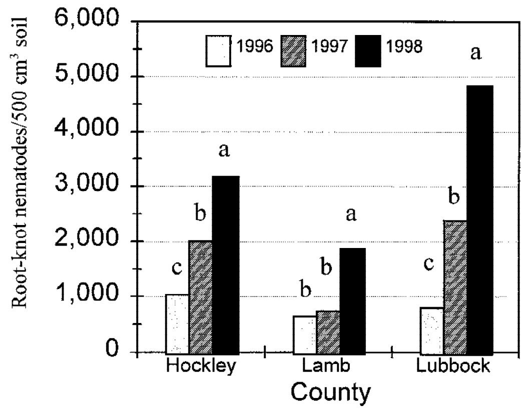

FIG. 2. The change in average fall density of *Meloidogyne incognita* (Pf) at three cotton fields from 1996 to 1998. Mean density followed by a different letter indicates a significant ($P = 0.05$) difference between Pf within a field, based on the Waller Duncan k-ratio *t* test. There were 24 samples used to estimate average Pf in a field each year, except for the Hockley County field in 1997, where there were only 12 samples.

site (Fig. 3). There were no significant location × year, or location × row interactions. Sand, silt, or clay content did not influence *M. incognita* Pf.

There were many examples of changes in *M. incognita* Pf classes over time at specific locations within the three sites (Tables 1–3).

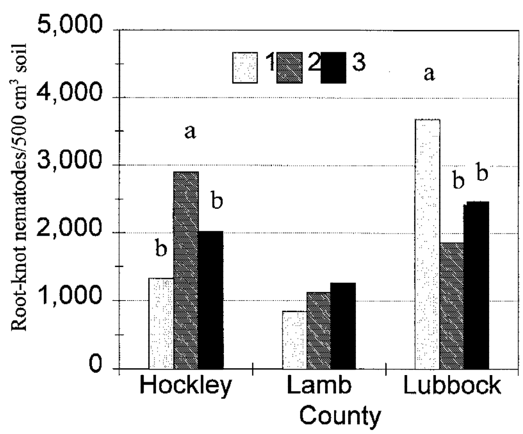

FIG. 3. The change in average fall density of *Meloidogyne incognita* (Pf) at three cotton fields, from areas within the fields. Each field was divided into thirds (1, 2, or 3), and significant ($P = 0.05$) differences between thirds of a field were identified by a different letter, based on the Waller Duncan k-ratio *t* test. There were eight samples used to estimate Pf in a third of a field (24 for the entire field) for each year, except for the Hockley County field in 1997, where there were only four samples used to estimate Pf in a third of the field.

TABLE 1. Comparison of the change in density classes[a] based on *Meloidogyne incognita* population densities from 24 locations (over a 64-row area and divided into west, east, and northern areas) in a Hockley County field between fall 1996 (96), 1997 (97), and 1998 (98).

	West			North			East		
Row	96–97	97–98	96–98	96–97	97–98	96–98	96–97	97–98	96–98
4	+3	−1	+2	+1	−1	0	+2	0	+2
12	+3	−1	+2	+1	0	+1	+1	+1	+2
20	−1	+1	0	0	0	0	+1	0	+1
28	−1	+1	0	+1	+1	+2	+1	+1	+2
36	+1	0	+1	0	+1	+1	0	0	0
44	+1	0	+1	+1	+1	+2	+1	+1	+2
52	+2	0	+2	+1	+1	+2	0	+1	+1
60	+2	−1	+1	−1	+1	0	0	+1	+1

[a] Density classes for *M. incognita* were as follows: <250, 250 to 999, 1,000 to 2,499, and ≥2,500. The table values are the difference when subtracting the density class of the earlier year from the class of the later year. A positive value indicates that an increase in root-knot nematode density was seen over time.

Changes of two or more Pf classes were fewest from 1997 to 1998, and ranged from 0 of 24 (Hockley County site) to 4 of 24 (Lamb County). Similar changes from 1996 to 1997 at each site ranged from 2 of 24 (Lamb County site) to 7 of 24 (Lubbock County site). However, 2-class shifts occurred in over 25% (Lamb County site) to 54% (Lubbock County site) of the locations within a site over a 2-year period.

DISCUSSION

Meloidogyne incognita densities changed substantially in the Lubbock County site over the 3 years of sampling. If management recommendations were based on our sampling scheme, management of *M. incognita* would have changed in 0 to 29% of the areas with yearly sampling, and in 25 to 54% of the areas over a 2-year period. The value of intensive sampling needs to be evaluated on a field-by-field basis.

Spatial correlations for *M. incognita* densities were greater within plant rows than across plant rows in a tobacco field (Noe and Campbell, 1985). In our study, estimates of *M. incognita* density varied more over the length of the field than the width, but sampling was at a much larger scale, par-

TABLE 2. Comparison of the change in density classes[a] based on *Meloidogyne incognita* population densities from 24 locations (over a 64-row area and divided into west, east, and middle areas) in a Lamb County field between fall 1996 (96), 1997 (97), and 1998 (98).

	West			Middle			East		
Row	96–97	97–98	96–98	96–97	97–98	96–98	96–97	97–98	96–98
4	+1	0	+1	+1	+1	+2	0	+1	+1
12	+1	−1	0	0	+2	+2	0	+1	+1
20	−1	+1	0	0	+1	+1	0	+1	+1
28	+1	0	+1	0	0	0	+1	+1	+2
36	−2	+2	0	0	+1	+1	+1	+1	+2
44	−1	+1	0	0	−1	−1	+1	0	+1
52	−2	+2	0	0	+1	+1	+1	0	+1
60	0	+2	+2	+1	+1	+2	0	+1	+1

[a] Density classes for *M. incognita* were as follows: <250, 250 to 999, 1,000 to 2,499, and ≥2,500. The table values are the difference when subtracting the density class of the earlier year from the class of the later year. A positive value indicates that an increase in root-knot nematode density was seen over time.

TABLE 3. Comparison of the change in density classes[a] based on *Meloidogyne incognita* population densities from 24 locations (over a 64-row area and divided into southwest, southeast, and northern areas) in a Lubbock County field between fall 1996 (96), 1997 (97), and 1998 (98).

	Southwest			North			Southeast		
Row	96–97	97–98	96–98	96–97	97–98	96–98	96–97	97–98	96–98
4	+1	0	+1	+2	0	+2	0	+1	+1
12	+1	0	+1	+1	+2	+3	+3	0	+3
20	+2	0	+2	+3	−1	+2	+1	+1	+2
28	+2	0	+2	0	+1	+1	+1	+1	+2
36	0	+1	+1	+2	+1	+3	+1	+1	+2
44	+1	+1	+2	+1	0	+1	+1	+2	+3
52	+1	0	+1	+2	+1	+3	+1	0	+1
60	0	+1	+1	−1	0	−1	+1	0	+1

[a] Density classes for *M. incognita* were as follows: <250, 250 to 999, 1,000 to 2,499, and ≥2,500. The table values are the difference when subtracting the density class of the earlier year from the class of the later year. A positive value indicates that an increase in root-knot nematode density was seen over time.

ticularly with respect to row length. Studies on spatial patterns of *Meloidogyne* spp. in potato (Wheeler et al., 1994), tobacco (Noe and Campbell, 1985), and cotton (T. Wheeler, unpubl.) fields have demonstrated that population densities change erratically (unpredictably) in plots with row lengths of more than 10 m. This means that samples for nematodes taken at smaller distances than 10 m have density values that can be adequately predicted with geostatistics (Warrick et al., 1986), but as the distance between samples increases to more than 10 m, then density values may no longer be accurately predicted. However, at the scale of commercial cotton production fields, sampling every 10 m or less would be cost-prohibitive.

Schmitt et al. (1990) found that assays of two composite samples increased the reliability of nematode population density estimates compared with a single composite sample. As a result, we decided to combine two composite samples for each representative area. Combining the results from two samples reduces the probability of a sample assay indicating an absence of root-knot nematode when damaging levels of the nematode are actually present. It is more costly to omit nematicide application in the presence of damaging levels of nematodes than to treat areas with a nematicide in the absence of damaging levels of nematodes.

The growing season for cotton is often restricted by water stress and by cool temperatures in the High Plains of Texas. There was less rainfall measured during the growing season in 1998 (<14 cm) than during 1996 (27 cm) or 1997 (28 cm). Higher mid- and late-season *M. incognita* population densities have been associated with increased soil moisture in soybean (Windham and Barker, 1993). However, in our study, *M. incognita* fall density was higher in 1998 than 1997 or 1996, and in two of the fields Pf was higher in 1997 than 1996. Very cool temperatures (3 °C) occurred on 28 and 29 September 1996, which may have caused cotton to cease vegetative growth earlier than in 1997, when the first cool temperatures (<0 °C) occurred on 18 October, or in 1998, when the first hard freeze was in December. Root-knot nematode reproduction is a function of both temperature and host growth (Seinhorst, 1967; Thomason and Lear, 1961). Understanding the factors that result in higher-than-normal increase of root-knot nematodes could reduce the need to sample every year.

Variable-rate application of nematicides may reduce the total amount of nematicides used in a field (Wheeler et al., 1999). However, variable-rate application will be limited unless cost-effective and accurate methods to determine Pf or preplant density for nematodes in specific field locations are developed. Developing soil texture maps of fields is one method that may reduce the necessary sampling area. Increase of *M. incognita* at midseason was higher in Fuquay sand and Norfolk sandy loam than in Cecil sandy clay and Cecil sandy clay loam (Koenning et al., 1996). However, in the three sites in this study, there was a greater change in *M. incognita* density among years than among areas of different soil textures in the field. In the Lubbock County field, the southeastern section was the highest in sand content and had the higher density of *M. incognita* in all 3 years (area 1 in Table 3); however, the northern section of the field (area 2 in Table 3), which averaged only 2% less sand content than the southeastern section, had a significantly lower density of *M. incognita*. The northern section of the field also had perennial weed problems (primarily *Helianthus ciliaris*), which stunted cotton growth and may have resulted in reduced root-knot nematode Pf. Factors other than soil texture, which affect plant growth like weeds, can impact nematode increase.

Intensive sampling for 1 year may provide acceptable accuracy for nematode management the following 2 years in some sites. Site-specific management of nematodes requires information on nematode Pf and management threshold categories or nematode damage categories (Ferris, 1986; Wheeler et al., 1999). In this study, it was determined that areas of a field that were highest for *M. incognita* Pf continued to be highest for Pf throughout the study (which should minimize the need for intensive yearly sampling) and that some fields will require more frequent sampling than others to determine changes in Pf that would result in new management recommendations.

Literature Cited

Daniel, W. W. 1978. Applied nonparametric statistics. Boston: Houghton Mifflin.

Ferris, H. 1986. Nematode population dynamics and management. Pp. 180–204 *in* K. J. Leonard and W. E. Fry, eds. Plant disease epidemiology population dynamics and management, vol. I. New York, NY: Macmillan Publishing Co.

Gee, G. W., and J. W. Bauder. 1986. Particle-size analysis. Pp. 383–411 *in* A. Klute, ed. Methods of soil analysis I. Physical and mineralogical methods. Madison, WI: American Society of Agronomy, Inc., Soil Science Society of America.

Goodell, P., and H. Ferris. 1980. Plant-parasitic nematode distributions in an alfalfa field. Journal of Nematology 12:136–141.

Hussey, R. S., and K. R. Barker. 1973. A comparison of methods of collecting inocula of *Meloidogyne* spp., including a new technique. Plant Disease Reporter 57: 1025–1028.

Koenning, S. R., S. A. Walters, and K. R. Barker. 1996. Impact of soil texture on the reproductive and damage potentials of *Rotylenchulus reniformis* and *Meloidogyne incognita* on cotton. Journal of Nematology 28:527–536.

Noe, J. P., and K. R. Barker. 1985. Overestimation of yield loss of tobacco caused by the aggregated spatial pattern of *Meloidogyne incognita*. Journal of Nematology 17:245–251.

Noe, J. P., and C. L. Campbell. 1985. Spatial pattern analysis of plant-parasitic nematodes. Journal of Nematology 17:86–93.

Schmitt, D. P., K. R. Barker, J. P. Noe, and S. R. Koenning. 1990. Repeated sampling to determine the precision of estimating nematode population densities. Journal of Nematology 22:552–559.

Seinhorst, J. W. 1967. The relationships between population increase and population density in plant-parasitic nematodes. III. Definition of terms host, host status, and resistance. IV. The influence of external conditions on the regulation of population densities. Nematologica 13:429–442.

Thislethwayte, B. 1970. Reproduction of *Pratylenchus penetrans* (Nematoda: Tylenchida). Journal of Nematology 2:101–105.

Thomason, I. J., and B. Lear. 1961. Rate of reproduction of *Meloidogyne* spp. as influenced by soil temperature. Phytopathology 51:220–224.

Warrick, A. W., D. E. Myers, and D. R. Nielsen. 1986. Geostatistical methods applied to soil science. Pp. 53–82 *in* A. Klute, ed. Methods of soil analysis I. Physical and mineralogical methods. Madison, WI: American Society of Agronomy, Inc., Soil Science Society of America.

Wheeler, T. A., and J. R. Gannaway. 1998. Effect of cotton pathogens on disease symptoms and yield of cotton varieties in large plot field trials. Pp. 165–168 *in* P. Dugger and D. Richter, eds. Proceedings of the 1998 Beltwide Cotton Conference. Memphis, TN: National Cotton Council of America.

Wheeler, T. A., H. W. Kaufman, B. Baugh, P. Kidd, G. Schuster, and K. Siders. 1999. Comparison of variable-and single-rate applications of aldicarb on cotton yield in fields infested with *Meloidogyne incognita*. Annals of Applied Nematology 31:700–708.

Wheeler, T. A., L. V. Madden, R. M. Riedel, and R. C. Rowe. 1994. Distribution and yield-loss relations of *Verticillium dahliae, Pratylenchus penetrans, P. scribneri, P. crenatus,* and *Meloidogyne hapla* in commercial potato fields. Phytopathology 84:843–852.

Windham, G. L., and K. R. Barker. 1993. Spatial and temporal interactions of *Meloidogyne incognita* and soybean. Journal of Nematology 25:738–745.

Wrona, A. F., D. Blasingame, P. Goodell, W. S. Gazaway, J. Mueller, C. Overstreet, and T. Wheeler. 1996. Timely soil sampling—a nematode's nemesis. Cotton Physiology Today 7:21–24.