Journal of Nematology 34(2):115–119. 2002.

Effects of Site-specific Application of Aldicarb on Cotton in a *Meloidogyne incognita*-infested Field[1]

J. A. Wrather,[2] W. E. Stevens,[2] T. L. Kirkpatrick,[3] and N. R. Kitchen[4]

Abstract: Cotton farmers in Missouri commonly apply a single rate of aldicarb throughout the field at planting to protect their crop from *Meloidogyne incognita*, even though these nematodes are spatially aggregated. Our purpose was to determine the effect of site-specific application of aldicarb on cotton production in a field infested with these nematodes in 1997 and 1998. Cotton yields were collected from sites not treated with aldicarb (control), sites receiving aldicarb at the standard recommended rate of 0.58 kg a.i./ha, and sites receiving specific aldicarb rates based on the soil population densities of second-stage infective juveniles of root-knot nematode. Yields for the standard rate and site-specific rate treatments were similar and greater ($P \le 0.05$) than the control treatment. Less aldicarb was used for the site-specific than the uniform-rate treatment each year—46% less in 1997 and 61% less in 1998. Costs associated with the site-specific treatment were very high compared with the uniform-rate treatment due to a greater number of soil samples analyzed for nematodes. Site-specific application of aldicarb for root-knot nematode management in cotton may pose fewer environmental risks than the uniform-rate application of aldicarb.

Key words: aldicarb, cotton, *Gossypium hirsutum*, *Meloidogyne incognita*, root-knot nematode, site-specific precision agriculture.

Farmers in Missouri harvest approximately 150,000 ha of cotton (*Gossypium hirsutum* L.) annually. The majority (98%) is grown in New Madrid, Pemiscot, and Dunklin Counties (Pauley and Oxenhandler, 1999) in southeast Missouri.

The presence and geographic distribution of nematode pests of cotton in Missouri have been described (Wrather et al., 1992). Root-knot nematodes, *Meloidogyne incognita* (Kofoid & White) Chitwood, were found in 30% of the cotton fields surveyed in Missouri, and nematode distribution was spatially aggregated within each field. The estimated cotton yield reduction in Missouri due to root-knot nematodes averaged 653.1 metric tons of lint each year from 1994 to 1997 (Wrather et al., 1997). The value of this loss was about $1.1 million per year. Reniform nematodes, *Rotylenchulus reniformis* (Linford & Oliveira), and lance nematodes, *Hoplolaimus galeatus* (Cobb) Thorne, also were found in this survey but were present in only 3% and 2% of the fields sampled, respectively. The population density of both nematodes was never ≥10 juveniles/100 cm^3 soil.

Very few Missouri farmers rotate cotton with root-knot-resistant soybean cultivars, and root-knot nematode-resistant cotton cultivars adapted for Missouri have not been developed. Therefore, the primary management option for the nematode is an at-planting application of the nematicide aldicarb. This nematicide is applied throughout a field at one rate depending on the nematode population density determined from a field-wide assay. The University of Missouri-recommended rates for infurrow application of aldicarb for management of *M. incognita* in cotton are 0 kg a.i./ha for 0 to 149 J2, 0.5 kg a.i./ha for 150 to 499 J2, 0.83 kg a.i./ha for 500 to 999 J2, and 1.17 kg a.i./ha for ≥1,000 J2/250 cm^3 soil from samples collected in September of the year before planting (Wrather et al., 1997). However, a single-rate treatment may be inefficient, considering the tendency for spatial aggregation of these nematodes in Missouri cotton fields (Wrather et al., 1992). Precision application of aldicarb only to nematode-infested areas of a field may be more economical and environmentally sound.

Precision farming, a current area of interest in agriculture, is usually defined as tailoring soil and crop management to fit the different conditions found within a field (Sawyer, 1994). Precision farming uses the global positioning system (GPS) and other technology to ensure precise application of agricultural amendments to identified locations within fields. The GPS is a network of satellites, controlled by the U.S. Department of Defense, designed to help ground-based units determine their real-time location using latitude and longitude coordinates (Strickland et al., 1998). For agricultural applications, GPS is being used for machine guidance and control (variable-rate-input applications), data collection during harvesting operations, soil sampling, and field scouting.

Recent advances in GPS technology may be useful for more precise application of nematicides for cotton root-knot nematode management. Fields may be grid-sampled using GPS to develop density maps of nematode populations, and a nematicide may then be applied to areas where the nematode population density is above the damage threshold. Furthermore, the rate of nematicide applied may be adjusted based on nematode population density. Advantages of this approach over uniform field-wide application may include improved efficiency in nematode control, lower nematicide input costs, and decreased environmental risks by applying less nematicide.

The objectives of this research project were to determine: (i) the effect of site-specific application of aldi-

Received for publication 20 February 2001.

[1] The research reported in this publication was supported by funding provided by Rhône-Poulenc Ag Company, Cotton Incorporated Project 98-545MO, and the University of Missouri Precision Agriculture Center. Contribution number 13,154 of the Missouri Agriculture Experiment Station.

[2] University of Missouri-Delta Center, PO Box 160, Portageville, MO 63873.

[3] University of Arkansas, Southwest Research Extension Center, 362 Hwy 174 N, Hope, AR 71801.

[4] USDA-Agriculture Research Service, 240 Agricultural Engineering, Columbia, MO 65211.

The authors thank Don and Bud Hart for use of their farm, and Joyce Elrod for technical assistance.

E-mail: wratherj@missouri.edu

This paper was edited by Patricia Timper.

carb on cotton yield in a field infested with *M. incognita*, (ii) if a distribution map of nematode densities could be used more than 1 year for guiding site-specific application of aldicarb, and (iii) if soil samples taken on a 0.1-ha grid were suitable to develop accurate nematode population maps. Applications of either aldicarb or the soil fumigant 1,3-dichloropropene (1,3-D) have been reported to improve cotton yield significantly in *M. incognita*-infested fields (Colyer et al., 1997; Kinloch and Rich, 1998; Wheeler et al., 1999). Although yield improvement appears to be greater in some situations with 1,3-D, aldicarb was selected for this study because it is less difficult to apply and is most commonly used by cotton growers in Missouri.

Materials and Methods

A 4.5-ha portion of a field near Hornersville, Missouri, was selected as the study site. The soil was a fine-silty, mixed, thermic, Aeric Ochraqualfs and was 67% sand, 13% silt, and 20% clay. The field was planted to cotton from 1994 through 1999.

We collected soil samples for nematode counts from the field during September 1996, 1997, 1999 and June 1997, using a strategy referred to as grid-point sampling (Wollenhaupt et al., 1994). We used the Northstar Integrated GPS/DGPS Position Sensor to establish the grid (Northstar Technologies, Acton, MA). The accuracy of the sensor with U.S. Coast Guard broadcast differential signals was ±1 m. The GPS sensor was attached to a laptop computer, and both were mounted on a backpack frame. We carried the equipment around the boundary of the site, and the computer generated an image of the site border on the screen. The software then overlaid a grid on the border image. The spacing between grid intersection points was 31.8 m, resulting in 45 grid intersection points in the 4.5-ha area. The cursor showed the position of the backpack-mounted sensor relative to the grid during movement through the field.

Fifteen soil cores (2.5 cm diam. × 20 cm deep) were arbitrarily collected from within rows of cotton from a 4-m^2 area centered over each grid node point (1 sample/0.10 ha). The soil cores were composited, and nematodes were extracted from a 250-cm^3 subsample by semiautomatic elutriator and centrifugation (Barker, 1978). Plant-parasitic nematodes were identified to genus. Second-stage juveniles (J2) of root-knot nematode were assumed to be *M. incognita* because of the history of cotton in the field and because other species of *Meloidogyne* have not been found in Missouri cotton fields.

To test whether sampling on a 31.8-m grid was at a spacing sufficiently close for creating interpolated maps of the nematode population, geostatistical analysis of J2 was performed for each September sampling date. For this analysis, a semivariagram figure was created that showed semi-variation (half the variation) between pairs of points (y axis) relative to the distance between those points (x axis). Typically, a number of pairs at the same distance are averaged. If the semi-variation for the various separation distances examined is approximately the same, then the interpretation is that information obtained at any grid point is independent of the information at any other grid point. If semi-variation increases with increasing separation distance, the interpretation is that the grid spacing is close enough to capture spatial dependence information between the points. Spatial dependence of nematode population levels in this site was evaluated using GS+ 5.1.1 software (Gamma Design Software, Plainwell, MI). Because only four samples were obtained along the north-south axis at this site due to the shape of the field, we assessed the spatial structure of the nematode population from samples collected along the east-west axis (i.e., anisotropic semivariagram), using a total of 9 to 13 samples per row. When spatial dependence between sample points was evident, linear, spherical, and exponential models were tested and the best-fitting model was identified using a least-squares procedure (i.e., greatest R^2). For all 3 years, maps showing nematode densities within each cell of the grid were drawn (Surfer 7.0, Golden Software, Golden, CO).

Four treatments were established at each of the 45 grid points in 1997 and 1998. The treatments were in-furrow applications of 0.58, 0.83, and 1.17 kg a.i./ha of aldicarb at cotton planting and a control that received no aldicarb. These rates were selected based on University of Missouri recommendations (Wrather et al., 1997). The treatments were randomized at each grid point. Treated plots were two rows wide (0.97-m row spacing) and 15 m long. The cotton cultivar Suregrow 125 was planted 1 May 1997 and 4 May 1998. The acid-delinted seeds were treated with imidacloprid (Gustafson, Inc., Dallas, TX) at 2.76 g a.i./kg seed prior to planting for early-season insect control. The crop was harvested when mature with a 2-row picker.

Differences in yield among treatments were determined with analysis of variance (SAS Institute, Cary, NC). A site-specific treatment was not included in the experimental design because the application equipment was not available. Instead, the yield for the site-specific treatment was selected from the treatments (0, 0.58, 0.83, and 1.17 kg a.i./ha aldicarb) at each grid point based on the nematode population that corresponded to the action threshold for that treatment. For example, the yield for the 1.17-kg a.i./ha aldicarb treatment was selected as the site-specific treatment when the *M. incognita* population density there was ≥1,000 J2/250 cm^3 soil at a grid point. The yield for the 0, 0.58, or 0.83-kg a.i./ha aldicarb treatments was selected as the site-specific treatment when the *M. incognita* population density was 0 to 149, 150 to 499, and 500 to 1,000 J2/250 cm^3 soil at a grid point, respectively. There were

45 replicate plots for each uniform aldicarb treatment and for the site-specific treatment.

Results

Pratylenchus spp., *Helicotylenchus* spp., *Trichodorus* spp., and *M. incognita* were detected in the soil samples collected at the field site in September 1996, 1997, 1999 and June 1997. Population densities of the first three genera never exceeded 100 individuals/250 cm^3 soil in September samples and 10 individuals/250 cm^3 soil in the samples collected in June. These nematodes are not considered damaging to cotton in Missouri (Wrather et al., 1992).

The average population density of *M. incognita* for the 4.5-ha site was 350 J2/250 cm^3 soil in September 1996 and 180 J2/250 cm^3 soil in September 1997. The population density of *M. incognita* at individual grid points ranged from 0 to 1,127 J2/250 cm^3 soil in September 1996, 0 to 281 J2/250 cm^3 soil in September 1997, and 0 to 852 J2/250 cm^3 soil in September 1999 (Fig. 1). The population density at grid points varied from 0 to 45 J2/250 cm^3 soil in June 1997. The root-knot nematode population density was above the action threshold at 47% of the grid points in 1996, 40% of the grid points in 1997, and 17% of the grid points in 1999. Soil population densities of *M. incognita* at many individual grid points varied among years. For example, the densities at one point were 1,127; 181; and 120 J2/250 cm^3 soil in September of 1996, 1997, and 1999, respectively. The J2 decline at individual grid points ranged

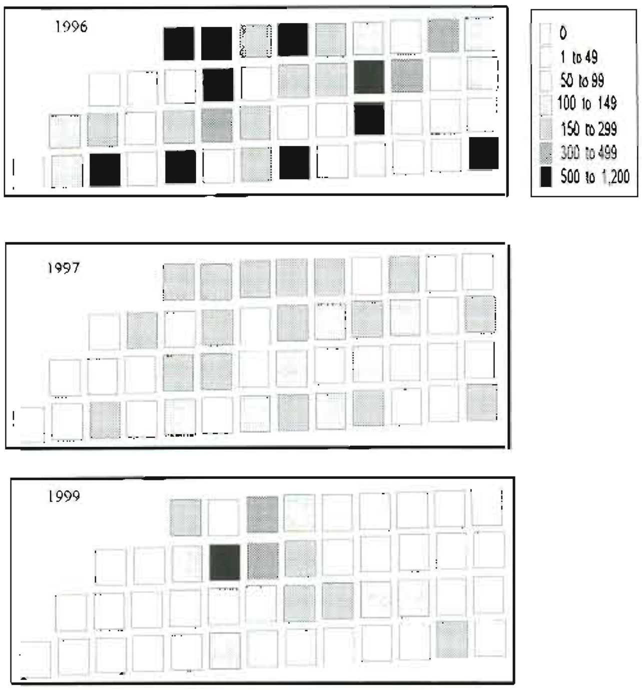

Fig. 1. Density-distribution maps of *Meloidogyne incognita* second-stage juveniles (J2) for September 1996, 1997, and 1999 from a 4.5-ha southeast Missouri cotton field. Each cell represents J2/250 cm^3 soil in a 0.1-ha area.

from 70% to 99% from September 1996 to June 1997. The change in overwinter population density was not determined for other years.

All three distribution maps provide evidence of strong spatial heterogeneity in densities of *M. incognita* (Fig. 1). Nematode densities were too variable between adjacent grid points to observe any patterns in density distribution using a 0.10-ha sampling grid in 1996 and 1997 (Fig. 2). However, spatial dependence of the root-knot nematode population was apparent in September 1999 ($R^2 = 0.30$) (Fig. 2). These data also indicate that the population-density patterns of the nematode from a 31.8-m grid sample spacing were not stable among years.

The cost for collecting and assaying one sample for every 0.10 ha was $220/ha (10 samples/ha @ $2/sample for collection and $20/sample for nematode analysis). Consultants currently charge Missouri cotton farmers $2/sample to collect soil. The University of Missouri Nematology Laboratory charges $20/sample to analyze soil for nematodes. The costs to develop density maps were not included because, to our knowledge, no private company in Missouri has developed fees for this. The costs of collecting and analyzing soil samples may be higher or lower in other states.

There were no differences in cotton yield among the three aldicarb treatments or between these treatments and the site-specific treatment in 1997 and 1998. The yields for all these treatments were greater than the control in both years (Table 1). Yields were lower for all treatments in 1998 than 1997 because of dry weather.

On a field-wise basis, less aldicarb was used for the site-specific treatment than for the 0.58-kg a.i./ha aldicarb treatment. The average population density for this field was 350 J2/250 cm^3 soil, and a Missouri farmer would apply 0.58 kg a.i./ha aldicarb field wide based on this action threshold. This rate of aldicarb was applied to plots at each of the 45 grid-intersection points in 1997 and 1998. The site-specific treatment in 1997 resulted in no aldicarb applied at 24 points, 0.58 kg a.i./ha applied at 14 points, 0.83 kg a.i./ha applied at 6 points, and 1.17 kg a.i./ha applied at 1 point. In 1998, the site-specific treatment resulted in no aldicarb applied at 27 points and 0.58 kg a.i./ha applied at the remaining 18 points. If the entire area were treated with the lowest uniform rate, the total amount of aldicarb used would be 2.63 kg a.i./4.5 ha in 1997 and 1998. If the field were treated using site-specific rates, the total amount of aldicarb used would be 1.44 kg a.i./4.5 ha in 1997 and 1.05 kg a.i./ha in 1998.

Discussion

Nematode density maps will be necessary before site-specific application of nematicides can be made. The tendency of *M. incognita* to aggregate in fields requires intensive sampling to develop accurate predictions of

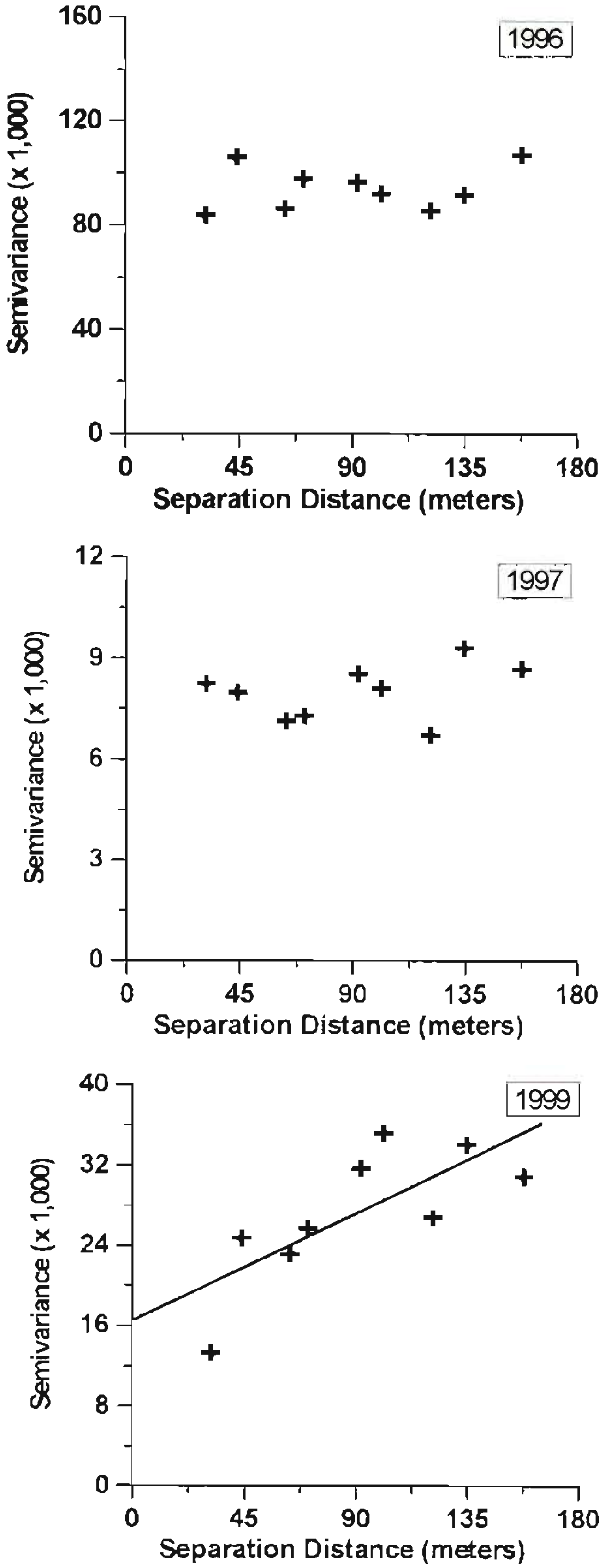

FIG. 2. Semivariagram of density of *Meloidogyne incognita* second-stage juveniles (J2) for September 1996, 1997, and 1999 from a 4.5-ha southeast Missouri cotton field. There was no evidence that the J2 density at one sampling point was related to the density at an adjacent point in 1996 and 1997, but there was spatial dependence in 1999, $R^2 = 0.30$.

TABLE 1. Effect of site-specific application of aldicarb on seed cotton yields (kg/ha) in a *Meloidogyne incognita*-infested field.

Treatment	1997 yield[a]	1998 yield[a]
Control (no aldicarb)	4,285 b	2,115 b
0.58 kg a.i./ha aldicarb	4,763 a	2,429 a
0.83 kg a.i./ha aldicarb	4,660 a	2,485 a
1.17 kg a.i./ha aldicarb	4,818 a	2,357 a
Site-specific treatment	4,720 a	2,326 a

[a] Data are means of 45 replicates. Means in a column followed by the same letter are not significantly different ($P \leq 0.05$) according to LSD.

nematode distribution (Barker and Campbell, 1981). Sampling soil on a 0.10-ha grid was not always sufficient for creating a predictive density map of *M. incognita* in our test location. The spacing between grid points in September 1996 and 1997 was generally not close enough to provide evidence of spatial dependence between points with any statistical confidence. However, the spacing between points in September 1999 could be used to estimate population density between grid points. Consequently, it appears that geostatistics may provide accurate maps of root-knot nematode population density, but grid spacing for collecting soil samples may need to be much closer together than is economically practical.

Variability in *M. incognita* population density at individual grid points and among years was likely due to edaphic, environmental, and host factors. The decline in population density at individual points from September 1996 to June 1997 (92% decline averaged over all grid points) was dramatic, but not unexpected. Eggs of *M. incognita* represent a major portion of the overwintering nematode population (Starr, 1993; Starr and Jeger, 1985), and accurate techniques for detection of eggs or egg masses free in soil have not been developed (Starr, 1993). Consequently, estimates of J2 density from soil samples collected in the spring or early summer may be much lower than the actual population density. The variation in population-density distribution among grid points at this site was similar to that reported by others for *M. incognita* (Barker, 1985). Although soil texture was not measured at each grid point in this study, differences in soil texture across the field were apparent. Soil texture can influence the ecology and distribution of *M. incognita* (Koenning et al., 1996; Prot and Van Gundy, 1981; Robinson et al., 1987).

There were few grid-intersection points where the rate of aldicarb applied for the site-specific treatment was greater than for the uniform-rate treatment. This may explain why site-specific application of aldicarb did not result in greater cotton yields than the uniform-rate treatment. Wheeler et al. (1999) also determined that site-specific application of aldicarb did not consistently result in greater cotton yields than a uniform application in *M. incognita*-infested fields.

Site-specific application of aldicarb in this study posed less environmental risk than the uniform-rate treatment because less aldicarb was applied on a per-hectare basis. In some situations, site-specific application of nematicide may also save producers money. However, a major impediment to this approach is the labor, expense, and equipment required to develop density distribution maps for plant-parasitic nematodes (Wheeler et al., 1999). The costs of sampling and nematode assay, which were based on current fees charged for these services in Missouri, were much greater than the savings that would result from decreased costs for site-specific application of nematicides relative to uniform-rate application. Additional costs also would be expected from purchase and maintenance of the equipment required to develop maps and apply site-specific nematicide rates.

The potential for minimizing the environmental impact of nematicide applications to cotton while maintaining grower profitability merits further investigation. Techniques such as aerial photography of growing crops (Brunoehler, 1997), use of precision yield monitors to detect problem zones, or predictions based on certain edaphic factors such as soil texture also should be investigated.

Literature Cited

Barker, K. R. 1978. Determining nematode population responses to control agents. Pp. 114–125 *in* E. I. Zehr et al., eds. Methods for evaluating plant fungicides, nematicides, and bactericides. American Phytopathological Society Press: St. Paul, MN.

Barker, K. R. 1985. Sampling nematode communities. Pp. 3–17 *in* K. R. Barker, C. C. Carter, and J. N. Sasser, eds. An advanced treatise on *Meloidogyne*, vol. 2: Methodology. Raleigh, NC: North Carolina State University Press.

Barker, K. R., and C. L. Campbell. 1981. Sampling nematode populations. Pp. 451–474 *in* B. M. Zuckerman and R. A. Rohde, eds. Plant-parasitic nematodes, vol. 3. New York: Academic Press.

Brunoehler, R. 1997. Remote sensing is ready to fly. Soybean Digest April 1997:18a–18c.

Colyer, P. D., T. L. Kirkpatrick, W. D. Caldwell, and P. R. Vernon. 1997. Influence of nematicide application on the severity of the root-knot nematode-fusarium wilt disease complex in cotton. Plant Disease 81:66–70.

Kinloch, R. A., and J. R. Rich. 1998. Responses of cotton yield and *Meloidogyne incognita* soil populations to soil applications of aldicarb and 1,3-D in Florida. Journal of Nematology 30:639–642.

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

Pauley, V., and S. Oxenhandler. 1999. Missouri farm facts 1999. Missouri Agriculture Statistics Service, Columbia, MO.

Prot, J. C., and S. D. Van Gundy. 1981. Effect of soil texture and the clay component on migration of *Meloidogyne incognita* second-stage juveniles. Journal of Nematology 13:213–217.

Robinson, A. F., C. M. Heald, S. L. Flanagan, W. H. Thames, and J. Amador. 1987. Geographical distributions of *Rotylenchulus reniformis*, *Meloidogyne incognita*, and *Tylenchulus semipenetrans* in the lower Rio Grande Valley as related to soil texture and land use. Annals of Applied Nematology 1:20–25.

Sawyer, J. E. 1994. Concepts of variable-rate technology with considerations for fertilizer application. Journal of Production Agriculture 7:195–201.

Starr, J. L. 1993. Recovery and longevity of egg masses of *Meloidogyne incognita* during simulated winter survival. Journal of Nematology 25:244–248.

Starr, J. L., and M. J. Jeger. 1985. Dynamics of winter survival of eggs and juveniles of *Meloidogyne incognita* and *M. arenaria*. Journal of Nematology 17:252–256.

Strickland, R. M., D. R. Ess, and S. D. Parsons. 1998. Precision farming and precision pest management: The power of new crop production technologies. Journal of Nematology 30:431–435.

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*. Supplement to the Journal of Nematology 31:700–708.

Wollenhaupt, N. C., R. P. Wolkwoki, and M. K. Clayton. 1994. Mapping soil test phosphorus and potassium for variable-rate fertilizer application. Journal of Production Agriculture 7:441–448.

Wrather, J. A., T. L. Niblack, and M. R. Milam. 1992. Survey of plant-parasitic nematodes in Missouri cotton fields. Supplement to the Journal of Nematology 24:779–782.

Wrather, A., B. Phipps, and M. Milam. 1997. Cotton nematodes in Missouri: Your hidden enemies. University of Missouri Extension Publication, G4259, Columbia, MO.