Journal of Nematology 46(2):101–107. 2014.


# Management of *Meloidogyne incognita* with Chemicals and Cultivars in Cotton in a Semi-Arid Environment

T. A. Wheeler,[1] K. T. Siders,[2] M. G. Anderson,[3] S. A. Russell,[4] J. E. Woodward,[5] B. G. Mullinix, Jr.[1]

*Abstract:* Management of *Meloidogyne incognita* (root-knot nematode) in cotton in the United States was substantially affected by the decision to stop production of aldicarb by its principle manufacturer in 2011. The remaining commercially available tools to manage *M. incognita* included soil fumigation, nematicide seed treatments, postemergence nematicide application, and cultivars partially resistant to *M. incognita*. Small plot field studies were conducted on a total of nine sites from 2011–2013 to examine the effects of each of these tools alone or in combinations, on early season galling, late-season nematode density in soil, yield, and value ($/ha = lint value minus chemical costs/ha). The use of a partially resistant cultivar resulted in fewer galls/root system at 35 d after planting in eight of nine tests, lower root-knot nematode density late in the growing season for all test sites, higher lint yield in eight of nine sites, and higher value/ha in six of nine sites. Galls per root were reduced by aldicarb in three of nine sites and by 1,3-dichloropropene (1,3-D) in two of eight sites, relative to the nontreated control (no insecticide or nematicide treatment). Soil fumigation reduced *M. incognita* density late in the season in three of nine sites. Value/ha was not affected by chemical treatment in four of nine sites, but there was a cultivar × chemical interaction in four of nine sites. When value/ha was affected by chemical treatment, the nontreated control had a similar value to the treatment with the highest value/ha in seven of eight cultivar-site combinations. The next "best" value/ha were associated with seed treatment insecticide (STI) + oxamyl and aldicarb (similar value to the highest value/ha in six of eight cultivar-site combinations). The lowest valued treatment was STI + 1,3-D. In a semi-arid region, where rainfall was low during the spring for all three years, cultivars with partial resistance to *M. incognita* was the most profitable method of managing root-knot nematode in cotton.

*Key words:* abamectin, aldicarb, oxamyl, resistance, root-knot nematode, 1,3-dichloropropene.

Root-knot nematode, *Meloidogyne incognita* (Kofoid & White) Chitwood, is an important parasite of cotton production in the United States. In the Southern High Plains of Texas, *M. incognita* infests at least 40% of the cotton acreage (Starr et al., 1993; Wheeler et al., 2000). Yield losses to *M. incognita* for susceptible cotton cultivars without any chemical control measures are estimated at 26% based on 80 fumigant trials conducted over 16 years (Orr and Robinson, 1984).

Management of *M. incognita* in cotton utilizes crop rotation, nematicides, and partially resistant cultivars (Koenning et al., 2004; Starr et al., 2007). Chemical tools available for management of cotton nematodes include preplant soil fumigants, seed treatment nematicides, and postemergence applications of oxamyl (Vydate® CLV, Dupont, Wilmington, DE). Aldicarb (Temik® 15G, Bayer CropSciences, Raleigh, NC), which was probably the most extensively utilized nematicide in the United States for cotton (Starr et al., 2007), is no longer manufactured commercially in the United States by its principle manufacturer. The remaining chemical tools all have their strengths and weaknesses.

1,3-dichloropropene (Telone® II, Dow AgroSciences, LLC, Indianapolis, IN) (1,3-D) is the predominant soil fumigant in cotton in the United States because of its relatively low cost compared with other fumigants, excellent nematicidal activity, and less stringent application requirements (anonymous www.epa.gov/pesticides/chem_search/ppls/062719-00032-20110607.pdf, verified 19 January 2014) compared with other soil fumigants that are labeled for cotton such as metam sodium (Vapam®HL, AMVAC Chemical Corp., (anonymous, www.epa.gov/pesticides/chem_search/ppls/005481-00468-20130814.pdf verified 19 January 2014)). However, application of any soil fumigant, including 1,3-D requires specialized equipment to place the product deep in the soil. Furthermore, soil conditions at the time of application need to meet critical moisture requirements for the product to be efficacious, as well as some method of sealing it in after application to reduce above-ground emissions (Thomas et al., 2003; Thomas et al., 2004; McDonald et al., 2009). Substantial cotton yield increases have been achieved with this product (Thomas and Smith, 1993).

Planting seed treatment nematicides (Aeris®, Bayer CropScience, Raleigh, NC; AVICTA®, Syngenta, Greensboro, NC) provides less risk than the use of either aldicarb or soil fumigants for the applicator. They are also less expensive than soil fumigants. However, the level of nematode control and yield response with seed treatment nematicides is generally lower than for aldicarb or soil fumigation (Kemerait et al., 2008; Wheeler et al., 2013).

Oxamyl has the unusual property of moving systemically from the leaves to the roots via the phloem (Rich and Bird, 1973), and is used as a postemergence nematicide. There are few phloem mobile insecticide/nematicides (Hsu and Kleier, 1996), though spirotetramat is a more recent insecticide/nematicide that has similar mobile properties on some crops (Smiley et al., 2011). Oxamyl is often combined with an at-plant application of aldicarb and/or seed treatment nematicide.

Received for publication January 27, 2014.
[1]Texas A&M AgriLife Research, Lubbock, TX 79403.
[2]Texas A&M AgriLife Extension Service, Levelland, TX 79336.
[3]Texas A&M AgriLife Extension Service, Seminole, TX 79360.
[4]Texas A&M AgriLife Extension Service, Brownfield, TX 79316.
[5]Texas A&M AgriLife Extension Service, Lubbock, TX 79403.
This research was supported by Texas Cotton State Support, Plains Cotton Improvement Program, Texas A&M AgriLife Research, and Texas A&M AgriLife Extension Service. We thank Bayer CropSciences, Dow AgroSciences, Dupont, and Syngenta for their assistance with cotton cultivars and chemical treatments used in this study.
E-mail: ta-wheeler@tamu.edu
This paper was edited by Richard F. Davis.

However, its performance with respect to yield increases above that of the at-plant nematicide or seed treatment nematicide have been sporadic (Lawrence and McLean, 2000, 2002; Koenning et al., 2007; Kemerait et al., 2008; Anderson et al., 2012; Siders, 2013; Wheeler et al., 2013).

Germplasm that is resistant to the southern root-knot nematode has been available for almost 40 years (Shepard, 1974), but utilization of commercial cultivars has been slow (Koenning et al., 2004; Starr et al., 2007). However, several commercial cotton cultivars with partial resistance to root-knot nematode are currently available. Integrating multiple tools of management for nematode control may be more effective than using a single tool, but the cost/benefit of these combinations has not been adequately demonstrated. The objective of this project was to determine the benefits of single and multiple tools for control of root-knot nematode in cotton, in a semi-arid region.

## Materials and Methods

Small plot trials were conducted in fields naturally infested with *M. incognita* in the Southern High Plains of Texas from 2011–2013. The chemical treatments were as follows: (i) a nontreated control; (ii) a seed treatment insecticide (STI) of thiamethoxam (Cruiser®, Syngenta, Greensboro, NC) applied at 0.34 mg a.i./seed; (iii) a seed treatment combination nematicide/insecticide/fungicides (STNIF) = abamectin (AVICTA) applied at 0.15 mg a.i./seed + thiamethoxam applied at 0.34 mg a.i./seed + Dynasty® CST (azoxystrobin + fludioxonil + mefenoxam, Syngenta, Greensboro, NC) applied at 0.03 mg a.i./seed; (iv) STI + oxamyl banded over the top at the 3–4 leaf stage at 0.56 kg a.i./ha; (v) STNIF + oxamyl banded over the top at the 3–4 leaf stage at 0.56 kg a.i./ha; (vi) aldicarb applied in furrow at-planting at 0.84 kg a.i./ha; and (vii) 1,3 D injected at a depth of 30 cm in the spring before planting (1 to 36 d before planting, varied with test) at 33 kg a.i./ha plus cotton seed was treated with STI at 0.34 mg a.i./seed.

The choice of cultivars to use in the study were based on small- and large-plot trials conducted previous to 2011 in the counties to be used in the tests. Factors included cultivar lint yield in those counties of interest (both in root-knot nematode infested and noninfested sites), maturity, and apparent resistance/tolerance or susceptibility to root-knot nematode. Cultivars were (i) the partially resistant/tolerant to southern root-knot nematode (www.dowagro.com/phytogen/varieties/phy_367.htm) Phytogen (PHY) 367WRF (W = Widestrike insect resistance, RF = Roundup Ready Flex Roundup resistance, Dow AgroSciences, LLC, Indianapolis, IN) (tested in county trials in 2009 to 2010) which had a base seed treatment package of fludioxonil + mefenoxam + myclobutanil + benzothiazole; (ii) partially resistant/tolerant to southern root-knot nematode (www.bayercropscience.us/learning-center/profiles-root-knot-nematode) Stoneville (ST) 5458B2F (B2 = Bollgard II insect resistance, F = Roundup Ready Flex resistance, Bayer CropScience, Lubbock, TX) (tested in county trials from 2007 to 2010) with a base seed treatment package of triadimenol + ipconzaole + metalaxyl + imidacloprid; and (iii) nematode susceptible cultivar Fibermax (FM) 9160B2F (Bayer CropScience, Lubbock, TX) (tested in county trials 2007 to 2010) with a base seed treatment package identical to the Stoneville cultivar. FM 9160B2F is no longer marketed in the United States by Bayer CropScience. ST5458B2F was used at sites 1, 3, 5, and 7; PHY 367WRF was used at sites 2, 4, 6, 8, and 9. The tests at sites 1 and 2 were conducted in 2011, sites 3 to 6 in 2012, and sites 7 to 9 in 2013. Sites 1, 3, and 7 were in Gaines Co., all located at different fields. Sites 2, 4, and 8 were in Cochran Co. with sites 2 and 4 being at the same field; sites 5 and 8 were at the same field in Dawson Co.; and site 6 was in Terry Co.

At each site, one of the partially resistant cultivars and FM 9160B2F were combined with the chemical treatments, in a randomized complete block design with a factorial arrangement of all cultivar/chemical treatment combinations. There was one exception, where the fumigation treatment (site 7) was not applied, because the previous wheat crop was harvested too late to allow time for proper fumigation. There were six replications of each treatment. Plot size was four rows wide, 11.0 m in length, with a row width of 76.2 to 101.6 cm.

Data collected included plant stand at 35 d after planting; the number of galls per root system were counted (10 plants/plot taken systematically across rows 1 and 4 at 35 d after planting); root-knot nematode density (second-stage juveniles [J2] and eggs), taken from soil in mid- to late August from rows 1 and 4; and yield. The middle two rows were harvested with a two-row plot cotton stripper, which harvests lint, seed, and some trash. The weight of the harvested plot was measured with load cells in the field, and a 1,000-g sample was collected from three replicates of the harvested plots. These samples were ginned to determine the percentage of the harvest weight that was lint, and the lint (50 g) was then sent to the Texas Tech Fiber and Biopolymer Center for high volume (HVI) analysis that was used to determine the Common Credit Corporation loan value for each year (anonymous www.cotton.org/econ/govprograms/cccloan/upload/2011Loan.pdf verified 19 January 2014; anonymous www.cotton.org/econ/govprograms/cccloan/upload/2012Loan.pdf verified 19 January 2014; anonymous www.cotton.org/econ/govprograms/cccloan/upload/2013Loan.pdf verified 19 January 2014).

Soil samples taken in August were used to determine *M. incognita* density. To obtain a composite sample, a narrow bladed spade was used at six locations per plot where approximately 200 $cm^3$ of roots and soil was removed from the sample hole from the 20- to 30-cm depth, in close proximity (< 10 cm) from the tap root. To obtain J2, a pie-pan assay (Thistlethwayte, 1970) was run with 200 $cm^3$ of soil for 48 hr. Eggs of *M. incognita* were extracted by adding 500-$cm^3$ soil + roots to 2 L water, stirring vigorously, then letting the soil settle out for 15 sec., and pouring the water + organic matter through a sieve with a pore size of 191 μm. The organic matter was washed into a beaker and stirred in a 10% solution of bleach (0.06% NaOCl) for 5 min. The eggs were then caught on a sieve with a 25-μm pore size, which was placed under a sieve with a pore size of 191 μm to catch the larger organic matter. Eggs were stained (Byrd et al., 1983). *M. incognita* density was calculated as the number of eggs or J2/500-$cm^3$ soil, whichever value was higher. They were not summed, since J2 obtained from a pie-pan extraction may have hatched from the existing eggs that are also counted (Vrain, 1977). Usually eggs have a much higher density than do J2; however, extraction of both stages was always conducted.

The value of cotton lint prices during this time period varied, but was roughly $0.49/kg lint higher than the loan value. So this amount was added to the loan value, and the lint weight/ha × (loan value + $0.49/kg) was used to determine the value of the crop/ha. The cost of the chemical treatment and seed was determined by calling agricultural businesses in the area to get prices on seed and chemical treatments. Costs for chemicals were STI = $20.02/ha; STNIF = $40.03/ha; oxamyl = $13.71/ha; aldicarb = $43.24/ha; and 1,3-D = $185.33/ha. PHY 367WRF = $181.84/ha in 2011 and 2012 and $182.41/ha in 2013. ST 5458B2F and FM 9160B2F = $183.72/ha in 2011 and 2012 and $190.46/ha in 2013. The value of each treatment combination was determined by the (kg lint/ha × (loan value + $0.49/kg) – the chemical and cultivar costs/ha).

Statistical analyses were conducted separately for each test using Proc Mixed, SAS version 9.3 (SAS Institute, Cary, NC). The dependent variables were galls/root, $\log_{10}$ (root-knot nematode density/500-$cm^3$ soil + 1), lint yield, and value/ha. The independent variables were cultivar, chemical treatment, and their interaction, with replication as the random term. The Satterthwaite option was used in all analyses to adjust denominator degrees of freedom to match adjustments in the sums of squares (Satterthwaite, 1946). Standard errors and differences between treatments were determined from the PDIFF option, where $P \leq 0.05$ was required to be significant. However, differences between treatments were only accepted if the overall model term (cultivar or chemical treatment or interaction) was significant at $P = 0.10$.

Regression analysis (Proc Reg, SAS version 9.3) was conducted with the average *M. incognita*/500-$cm^3$ soil of the susceptible cultivar at each site as the *x*-variable, and the ratio of the average lint yield for the partially resistant cultivar and the susceptible cultivar at each site (resistant/susceptible) as the *y*-variable.

## Results

There were no significant interaction between cultivar and chemical treatment with respect to galls per root system, so only significant main effects are presented. Galls per root system were higher for the susceptible cultivar than for the partially resistant cultivar in eight of nine sites (Table 1). Plots treated with aldicarb had fewer galls than the nontreated control in three of nine tests and 1,3-D treated soil had plants with fewer galls than the nontreated control in one of eight sites (Table 2). In no sites did STI, STNIF, or plots treated with oxamyl have fewer galls than the nontreated control (Table 2). Oxamyl applications were typically made 1 wk before rating galls and would not be expected to impact that measurement.

Root-knot nematode density was higher for the susceptible cultivar than the partially resistant cultivar in

Table 1. Effect of cultivar averaged across all chemical treatments[a] on root galls, *Meloidogyne incognita* (Mi) density in late August, lint yield, and value/ha[b].

| Site[c] | Galls/plant | | Mi/500-$cm^3$ soil | | kg lint/ha | | Value ($/ha) | |
|---|---|---|---|---|---|---|---|---|
| | Sus[d] | Res[d] | Sus | Res | Sus | Res | Sus | Res |
| 1 | 13.3 a[e] | 10.0 b | 23,777 a | 8,147 b | 900 b | 1,123 a | 1,220 b | 1,501 a |
| 2 | 5.2 a | 4.0 b | 9,517 a | 1,077 b | 1,248 b | 1,390 a | 1,867 b | 2,110 a |
| 3 | 1.2 a | 0.5 a | 10,690 a | 2,291 b | 1,227 a | 1,224 a | 1,645 a | 1,642 a |
| 4 | 1.4 a | 0.3 b | 4,418 a | 615 b | 784 b | 831 a | 1,047 a | 1,120 a |
| 5 | 1.7 a | 1.2 b | 9,447 a | 3,883 b | 1,414 b | 1,459 a | 2,145 a | 2,102 a |
| 6 | 7.0 a | 3.3 b | 14,295 a | 6,851 b | 623 b | 679 a | 737 b | 814 a |
| 7 | 31.9 a | 19.3 b | 18,773 a | 6,007 b | 805 b | 993 a | 1,150 b | 1,399 a |
| 8 | 14.6 a | 9.8 b | 7,543 a | 1,433 b | 835 b | 919 a | 1,147 b | 1,247 a |
| 9 | 12.7 a | 7.1 b | 10,886 a | 5,025 b | 1,602 b | 1,885 a | 2,452 b | 2,938 a |

[a] Chemical treatments included a nontreated check; seed treatment insecticide (STI); seed treatment combination of nematicide, insecticide, and fungicides (STNIF); STI + oxamyl (O) applied at the 3–4 leaf stage; STNIF + O; aldicarb; and 1,3-Dichloropropene + STI.

[b] Value/ha = (kg lint/ha × (loan value + $0.49/kg)) – (seed costs + chemical costs/ha).

[c] 1 = Gaines Co. in 2011; 2 = Cochran Co. in 2011; 3 = Gaines Co. in 2012; 4 = Cochran Co. in 2012; 5 = Dawson Co. in 2012; 6 = Terry Co. in 2012; 7 = Gaines Co. in 2013; 8 = Cochran Co., in 2013; 9 = Dawson Co. in 2013.

[d] Sus = susceptible cultivar Fibermax 9160B2F; Res = partially resistant cultivar (either Stoneville 5458B2F or Phytogen 367WRF).

[e] Letters that are the same between Sus and Res cultivars for an attribute are not significantly different at $P \leq 0.05$.

Table 2. Effect of chemical treatment[a] on galls/root system caused by *Meloidogyne incognita* at nine test sites, averaged across two cultivars.[b]

| | Site[c] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Chemical[a] | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| None | 16.1 a[d] | 5.5 a | 1.6 a | 0.7 a | 1.9 a | 5.5 a | 32.2 a | 14.7 ab | 7.9 a |
| STI | 13.0 a | 4.8 a | 0.3 a | 1.5 a | 0.9 a | 5.7 a | 30.4 a | 15.6 a | 13.1 a |
| STNIF | 13.0 a | 4.6 a | 1.1 a | 0.5 a | 1.4 a | 5.2 a | 32.1 a | 12.2 abc | 14.1 a |
| STI+O | 13.4 a | 4.2 a | 0.5 a | 1.2 a | 1.6 a | 3.8 a | 24.6 a | 15.1 a | 11.8 a |
| STNIF+O | 13.7 a | 7.1 a | 1.0 a | 0.6 a | 1.6 a | 4.4 a | 31.8 a | 10.1 abc | 8.8 a |
| Aldicarb | 6.5 b | 4.7 a | 0.2 a | 0.7 a | 1.6 a | 5.5 a | 2.8 b | 8.2 c | 4.9 a |
| 1,3-D+STI | 5.7 b | 1.2 a | 0.8 a | 0.6 a | 1.2 a | 5.4 a | – | 9.5 bc | 8.4 a |

[a] STI = seed treatment insecticide; STNIF = seed treatment combination of nematicide, insecticide, and fungicides; O = oxamyl applied at the 3–4 leaf stage; 1,3-D = 1,3-Dichloropropene.
[b] Each site contained two cultivars, Fibermax 9160B2F (susceptible to root-knot nematode), and either Stoneville 5458B2F or Phytogen 367WRF as the partially resistant cultivar to southern root-knot nematode.
[c] 1 = Gaines Co. in 2011; 2 = Cochran Co. in 2011; 3 = Gaines Co. in 2012; 4 = Cochran Co. in 2012; 5 = Dawson Co. in 2012; 6 = Terry Co. in 2012; 7 = Gaines Co. in 2013; 8 = Cochran Co., in 2013; 9 = Dawson Co. in 2013.
[d] Values that are within a column followed by the same letter are not significantly different for galls/root at $P \leq 0.05$.

all sites (Table 1). Chemical treatment either alone or as an interaction term significantly affected root-knot nematode density in five of nine sites (Table 3). Soil fumigation resulted in lower root-knot nematode densities at site 2, and site 8 for both cultivars, and site 4 for FM 9160B2F only. Soil fumigation did not affect the other five sites. Four of the sites where soil fumigation was ineffective late in the season were treated under very dry soil conditions (either subsurface drip irrigation under every other furrow, or where the producer declined to run the pivot before the application). The remaining site where soil fumigation was ineffective at reducing root-knot nematode density did have a significant reduction in root galling associated with the treatment (site 1, Table 2) and was also associated with the highest root-knot nematode buildup of any of the nine sites (Table 3). There were no significant rainfall events in March or April in any of the three years that wetted the soil sufficiently to make a 1,3-D application without supplementary irrigation (Table 4). The only other treatment effects that reduced root-knot nematode density below that of the nontreated control was aldicarb and STI + oxamyl at site 3 for the partially resistant cultivar (Table 3).

Lint yield was higher for the partially resistant cultivars compared with FM 9160B2F at eight of the nine sites. There was no difference between cultivar lint yields at site 3 (Table 1). Chemical treatment did not affect lint yields in six sites (sites 2 through 6 and 9, Table 5), and there was an interaction between cultivar and chemical treatment at three sites (sites 1, 7, 8, Table 5). At these sites, there were no differences between the nontreated control and any other chemical treatments for FM 9160B2F (Table 5). For the partially resistant cultivars, the two treatments with oxamyl (STI + oxamyl and STNIF + oxamyl) and soil fumigation had higher yields than the nontreated control at site 1 (Table 5). With sites 7 and 8, there were chemical treatment differences for PHY 367WRF, but no treatments differed from the nontreated control.

The value/ha was higher for the partially resistant cultivars than FM 9160B2F at six of the nine sites, and in

Table 3. Effect of chemical treatment on transformed[a] *Meloidogyne incognita* density sampled in late August at nine test sites, averaged across two cultivars[b] or presented separately by cultivar when a cultivar × chemical treatment interaction[c] occurred.

| | Site[e] | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Chemical[d] | 1 | 2 | 3FM[c] | 3ST[c] | 4FM[c] | 4PHY[c] | 5FM[c] | 5ST[c] | 6 | 7 | 8 | 9 |
| None | 4.08 a[f] | 2.60 a | 3.54 a | 3.18 a | 3.45 a | 1.45 bc | 2.97 b | 3.19 ab | 3.46 a | 3.75 a | 3.32 ab | 3.80 a |
| STI | 3.99 a | 2.38 a | 3.60 a | 3.01 a | 2.93 ab | 1.66 bc | 3.75 ab | 3.62 a | 3.88 a | 4.05 a | 3.30 a | 3.88 a |
| STNIF | 4.15 a | 3.08 a | 3.58 a | 3.16 a | 1.68 c | 2.96 a | 3.13 b | 3.27 ab | 3.57 a | 3.78 a | 2.88 ab | 3.52 a |
| STI+O | 4.13 a | 2.57 a | 4.03 a | 2.21 b | 3.22 a | 0.51 c | 3.56 ab | 2.52 b | 3.52 a | 3.85 a | 3.11 ab | 3.52 a |
| STNIF+O | 4.14 a | 2.90 a | 4.03 a | 3.33 a | 3.52 a | 2.16 ab | 4.13 a | 3.02 ab | 3.61 a | 3.83 a | 2.80 ab | 3.39 a |
| Aldicarb | 4.03 a | 3.12 a | 4.04 a | 2.02 b | 2.28 abc | 2.46 ab | 3.78 ab | 3.42 ab | 3.55 a | 3.85 a | 2.33 bc | 3.56 a |
| 1,3-D+STI | 3.91 a | 1.02 b | 3.66 a | 3.10 a | 1.96 bc | 0.89 c | 3.20 ab | 2.78 ab | 3.61 a | – | 1.67 c | 3.54 a |

[a] A $\log_{10}$(*M. incognita*/500-$cm^3$ soil + 1) transformation was used to analyze the data sets.
[b] Each site contained two cultivars, Fibermax 9160B2F ([FM] susceptible to root-knot nematode), and either Stoneville [ST] 5458B2F or Phytogen [PHY] 367WRF as the partially resistant cultivar to the southern root-knot nematode.
[c] Cultivar × chemical treatment interactions were significant at sites 3, 4, and 5.
[d] STI = seed treatment insecticide; STNIF = seed treatment combination of nematicide, insecticide, and fungicides; O = oxamyl applied at the 3–4 leaf stage; 1,3-D = 1,3-Dichloropropene.
[e] 1 = Gaines Co. in 2011; 2 = Cochran Co. in 2011; 3 = Gaines Co. in 2012; 4 = Cochran Co. in 2012; 5 = Dawson Co. in 2012; 6 = Terry Co. in 2012; 7 = Gaines Co. in 2013; 8 = Cochran Co., in 2013; 9 = Dawson Co. in 2013.
[f] Values within a column followed by the same letter are not significantly different for *M. incognita* density at $P \leq 0.05$.

TABLE 4. Monthly rainfall (cm) recorded at county weather stations[a] for each test site.

| | Sites | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Month | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| January | 0.0 | 0.0 | 1.2 | 0.0 | 2.0 | 0.3 | 2.2 | 1.8 | 3.1 |
| February | 0.5 | 0.4 | 0.9 | 0.9 | 1.4 | 1.4 | 1.5 | 1.4 | 1.3 |
| March | 0.0 | 0.2 | 2.2 | 1.6 | 0.8 | 1.5 | 0.0 | 0.0 | 0.0 |
| April | 0.0 | 0.0 | 0.0 | 0.2 | 1.5 | 1.7 | 0.0 | 0.0 | 0.0 |
| May | 0.0 | 1.1 | 6.5 | 5.2 | 7.7 | 5.0 | 0.5 | 0.5 | 1.1 |
| June | 0.0 | 0.0 | 2.6 | 4.6 | 0.3 | 4.3 | 4.3 | 8.6 | 6.1 |
| July | 0.0 | 4.3 | 2.7 | 1.6 | 1.3 | 4.0 | 6.2 | 9.8 | 8.0 |
| August | 0.0 | 0.1 | 1.5 | 8.2 | 3.9 | 2.7 | 2.6 | 2.5 | 2.6 |
| September | 4.1 | 3.3 | 8.4 | 3.6 | 10.7 | 4.0 | 1.8 | 1.6 | 9.0 |
| October | 0.9 | 2.0 | 0.0 | 1.0 | 0.6 | 0.2 | 5.7 | 1.4 | 5.1 |
| November | 0.1 | 0.3 | 0.4 | 0.0 | 0.3 | 0.3 | 1.5 | 2.4 | 1.4 |
| December | 3.4 | 3.7 | 0.9 | 1.4 | 0.4 | 1.4 | 2.4 | 0.9 | 4.7 |

[a] The weather data and sites are maintained by the West Texas mesonet at Texas Tech University, Lubbock (anonymous, www.mesonet.ttu.edu/mesone-precipitation.htm, verified 19 January 2014).

three sites the two cultivars were similar for value/ha (Table 1). Although lint yields were higher for the partially resistant cultivars in eight of nine fields, the fiber quality was typically not as good as FM 9160B2F, resulting in higher loan values for FM 9160B2F. This allowed FM 9160B2F to equal the value of the partially resistant cultivars in the two sites where its yields were lower.

Differences in value/ha were found between chemical treatments alone (main effect in site 3, Table 6) or with chemical treatment × cultivar interactions (sites 1, 6, 7, 8, Table 6). There were no chemical treatment differences for sites 2, 4, 5, and 9 (Table 6). There were eight situations where there were significant differences between the value/ha of chemical treatments for a main effect (site 3) or for one or both cultivars (site 1 FM 9160B2F, site 1 ST 5458B2F, site 6 FM 9160B2F, site 6 PHY 367WRF, site 7 ST 5458B2F, site 8 both cultivars) (Table 6). In seven of these eight situations, the nontreated control had either the highest value/ha or was not different from the most profitable treatment. In six of these eight situations, STI + oxamyl and aldicarb had either the highest value/ha or was not different than the most profitable treatment. In four of these eight situations, STNIF alone and with oxamyl had either the highest value/ha or was similar to the most profitable treatment. In three of these eight situations, STI had either the highest value/ha or was not different than the most profitable treatment. STI + 1,3-D did not differ from the most profitable treatment in one of these seven situations.

The ratio of the yield for the partially resistant cultivars divided by FM 9160B2F increased as the root-knot nematode density on FM 9160B2F increased (Fig. 1). The model (resistant/susceptible yield = 0.979 + $1.108 \times 10^{-5}$ (Root-knot nematodes/500-$cm^3$ soil of the susceptible cultivar)) predicted that the partially resistant and susceptible cultivars would yield the same (ratio of 1) at a root-knot nematode density of 1,944 *M. incognita* per 500-$cm^3$ soil in the susceptible cultivar, and the partially resistant cultivar would have a 10% increase in yield at a density of 11,204 *M. incognita* per 500-$cm^3$ soil.

TABLE 5. Effect of chemical treatment on cotton lint yield at nine test sites naturally infested with *Meloidogyne incognita* and averaged across two cultivars[a] or presented separately by cultivar when a cultivar × chemical treatment interaction[b] occurred.

| | Site[d] | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Chemical[c] | 1FM[b] | 1ST[b] | 2 | 3 | 4 | 5 | 6 | 7FM[b] | 7ST[b] | 8FM[b] | 8PHY[b] | 9 |
| None | 935 ab[e] | 985 c | 1,296 a | 1,261 a | 813 a | 1,376 a | 669 a | 778 a | 1,034 ab | 871 ab | 924 abc | 1,685 a |
| STI | 852 b | 1,137 abc | 1,272 a | 1,274 a | 802 a | 1,405 a | 609 a | 782 a | 936 bc | 782 b | 836 c | 1,696 a |
| STNIF | 876 ab | 1,028 bc | 1,345 a | 1,234 a | 824 a | 1,439 a | 648 a | 784 a | 991 bc | 885 a | 906 bc | 1,703 a |
| STI+O | 1,023 a | 1,174 ab | 1,360 a | 1,117 a | 823 a | 1,455 a | 625 a | 812 a | 1,127 a | 823 ab | 891 c | 1,764 a |
| STNIF+O | 831 b | 1,244 a | 1,267 a | 1,255 a | 806 a | 1,488 a | 677 a | 833 a | 892 c | 853 ab | 868 c | 1,684 a |
| Aldicarb | 847 b | 1,138 abc | 1,257 a | 1,207 a | 755 a | 1,418 a | 658 a | 840 a | 980 bc | 859 ab | 994 ab | 1,876 a |
| 1,3-D+STI | 940 ab | 1,152 ab | 1,439 a | 1,231 a | 830 a | 1,472 a | 663 a | – | – | 773 b | 1,015 a | 1,797 a |

[a] Each site contained two cultivars, Fibermax 9160B2F ([FM] susceptible to root-knot nematode), and either Stoneville [ST] 5458B2F or Phytogen [PHY] 367WRF as the partially resistant cultivar to the southern root-knot nematode.
[b] Cultivar × chemical treatment interactions were significant at sites 1,7, and 8.
[c] STI = seed treatment insecticide; STNIF = seed treatment combination of nematicide, insecticide, and fungicides; O = oxamyl applied at the 3–4 leaf stage; 1,3-D = 1,3-Dichloropropene.
[d] 1 = Gaines Co. in 2011; 2 = Cochran Co. in 2011; 3 = Gaines Co. in 2012; 4 = Cochran Co. in 2012; 5 = Dawson Co. in 2012; 6 = Terry Co. in 2012; 7 = Gaines Co. in 2013; 8 = Cochran Co., in 2013; 9 = Dawson Co. in 2013.
[e] Values within a column followed by the same letter are not significantly different for cotton lint yield at $P \leq 0.05$.

TABLE 6. Effect of chemical treatment (C) on value ($)/ha[a] at nine test sites naturally infested with *Meloidogyne incognita* and averaged across two cultivars[b] or presented separately by cultivar when a cultivar × chemical treatment interaction[c] occurred.

| | Site[e] | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C[d] | 1FM[c] | 1ST[c] | 2 | 3 | 4 | 5 | 6FM[c] | 6PHY[c] | 7FM[c] | 7ST[c] | 8FM[c] | 8PHY[c] | 9 |
| 1 | 1,349 ab | 1,296 b | 2,007 a | 1,755 a | 1,150 a | 2,080 a | 865 a | 897 a | 1,136 a | 1,497 ab | 1,263 a | 1,311 ab | 2,653 a |
| 2 | 1,208 b[f] | 1,637 a | 1,944 a | 1,754 a | 1,111 a | 2,107 a | 688 b | 830 abc | 1,122 a | 1,317 bc | 1,096 b | 1,149 b | 2,651 a |
| 3 | 1,186 b | 1,336 b | 2,048 a | 1,672 ab | 1,128 a | 2,145 a | 705 b | 826 abc | 1,107 a | 1,386 bc | 1,247 ab | 1,242 ab | 2,642 a |
| 4 | 1,480 a | 1,660 a | 2,080 a | 1,499 b | 1,133 a | 2,178 a | 780 ab | 710 bc | 1,161 a | 1,615 a | 1,150 ab | 1,224 ab | 2,752 a |
| 5 | 1,112 b | 1,683 a | 1,903 a | 1,691 ab | 1,084 a | 2,211 a | 681 b | 882 a | 1,176 a | 1,211 c | 1,180 ab | 1,167 b | 2,598 a |
| 6 | 1,108 b | 1,502 ab | 1,897 a | 1,629 ab | 1,011 a | 2,107 a | 770 ab | 858 ab | 1,198 a | 1,366 bc | 1,201 ab | 1,380 a | 2,931 a |
| 7 | 1,093 b | 1,395 b | 2,042 a | 1,504 b | 972 a | 2,035 a | 670 b | 699 c | – | – | 895 c | 1,254 ab | 2,637 a |

[a] Value ($)/ha was (kg lint/ha × (loan value + $0.49/kg)) – chemical costs/ha – seed cost/ha.
[b] Each site contained two cultivars, Fibermax 9160B2F ([FM] susceptible to root-knot nematode), and either Stoneville [ST] 5458B2F or Phytogen [PHY] 367WRF as the partially resistant cultivar to the southern root-knot nematode.
[c] Cultivar × chemical treatment interactions were significant at sites 1, 6, 7, and 8.
[d] C = Chemical treatments: 1 = none; 2 = seed treatment insecticide (STI); 3 = seed treatment combination of nematicide, insecticide, and fungicides (STNIF); 4 = STI + oxamyl applied at the 3–4 leaf stage; 5 = STNIF + oxamyl applied at the 3–4 leaf stage; 6 = aldicarb (0.84 kg a.i./ha); 7 = STI + 1,3-dichloropropene.
[e] 1 = Gaines Co. in 2011; 2 = Cochran Co. in 2011; 3 = Gaines Co. in 2012; 4 = Cochran Co. in 2012; 5 = Dawson Co. in 2012; 6 = Terry Co. in 2012; 7 = Gaines Co. in 2013; 8 = Cochran Co., in 2013; 9 = Dawson Co. in 2013.
[f] Values within a column followed by the same letter are not significantly different for value/ha at $P \leq 0.05$.

## DISCUSSION

Nematode management in cotton was substantially affected across the United States by the removal of aldicarb from the market. In the semi-arid conditions found in the Southern High Plains of Texas, soil moisture in the spring can be quite limited, even under irrigated conditions. Aldicarb required a certain amount of moisture to be effective at reducing root galls caused by *M. incognita* (Wheeler et al., 2013). However, nematicide seed treatments appear to require even more water to effectively move off the seed coat and distribute around the taproot (Faske and Starr, 2006, 2007; Wheeler et al., 2013). Soil fumigation also requires substantial water to wet the soil profile down to the depth of application (before application), and then since beds typically dry out some with the application, a second irrigation may be necessary before planting to avoid seeds drying out (personal observation). More than 50% of the irrigation applied before planting is typically lost from the profile (Bordovsky et al., 1992), so it is a difficult choice to apply extra water preplant to facilitate soil fumigation, when there may be insufficient irrigation water during the growing season.

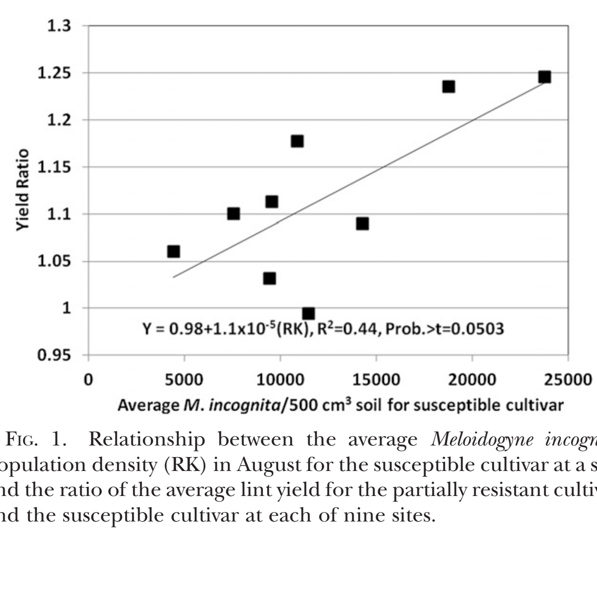


FIG. 1. Relationship between the average *Meloidogyne incognita* population density (RK) in August for the susceptible cultivar at a site and the ratio of the average lint yield for the partially resistant cultivar and the susceptible cultivar at each of nine sites.

None of the chemical options including aldicarb performed consistently under the relatively dry conditions that occurred during the three years of this project. However, the partially resistant cultivars did perform well in all three years of the study and at all sites. The partially resistant cultivars never performed worse than FM 9160B2F; yielding better in most sites; and had a higher value/ha in six of nine sites than FM 9160B2F. The yield response improved as nematode pressure increased, which is consistent with what has been found in other cultivars with root-knot nematode resistance (Davis and May, 2003, 2005). In conclusion, using cultivars with partial nematode resistance that are reasonably well adapted to the region can reduce the root-knot nematode population density substantially, and improve yield in root-knot nematode infested fields. Other chemical management tools may not perform adequately, particularly in years with relatively dry spring conditions.

## LITERATURE CITED

Anderson, M. G., Wheeler, T. A., and Woodward, J. E. 2012. Evaluation of variety tolerance and use of Vydate C-LV for management of southern root-knot nematodes. 2012 Beltwide Cotton Conferences, 3–6 January, Orlando, FL: 239–241.

Bordovsky, J. P., Lyle, W. M., Lascano, R. J., and Upchurch, D. R. 1992. Cotton irrigation management with LEPA systems. Transactions of the American Society of Agricultural Engineers 35:879–884.

Byrd, D. W., Jr., Kirkpatrick, T., and Barker, K. R. 1983. An improved technique for clearing and staining plant tissue for detection of nematodes. Journal of Nematology 15:142–143.

Davis, R. F., and May, O. L. 2003. Relationship between tolerance and resistance to *Meloidogyne incognita* in cotton. Journal of Nematology 35:411–416.

Davis, R. F., and May, O. L. 2005. Relationship between yield potential and percentage yield suppression caused by the southern root-knot nematode in cotton. Crop Science 45:2312–2317.

Faske, T. R., and Starr, J. L. 2006. Sensitivity of *Meloidogyne incognita* and *Rotylenchulus reniformis* to abamectin. Journal of Nematology 38:240–244.

Faske, T. R., and Starr, J. L. 2007. Cotton root protection from plant-parasitic nematodes by abamectin-treated seed. Journal of Nematology 39:27–30.

Hsu, F. C., and Kleier, D. A. 1996. Phloem mobility of xenobiotics VIII. A short review. Journal of Experimental Botany 47:1265–1271.

Kemerait, R. C., Shurley, W. D., Ziehl, A. R., Sanders, F. H., Davis, R. F., Brown, S. M., McGriff, D. E., Mickler, K. D., Spaid, D. G., Harrison, W. E., Mitchell, B. R., Beard, G. H., von Waldner, M. D., Duffie, W. D., Dollar, M., and Rucker, K. 2008. Assessment of efficacy and economic returns for nematicides applied in Georgia. 2008 Beltwide Cotton Conferences, 8–11 January, Nashville, TN: 245–257

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

Koenning, S. R., Morrison, D. E., and Edmisten, K. L. 2007. Relative efficacy of selected nematicides for management of *Rotylenchulus reniformis* in cotton. Nematropica 37:227–235.

Lawrence, G. W., and McLean, K. S. 2002. Foliar applications of oxamyl with aldicarb for the management of *Meloidogyne incognita* on cotton. Nematropica 32:103–112.

Lawrence, G. W., and McLean, K. S. 2000. Effect of foliar applications of oxamyl with aldicarb for the management of *Rotylenchulus reniformis* on cotton. Journal of Nematology 32(4S):542–549.

McDonald, J. A., Gao, S., Qin, R., Hanson, B. D., Trout, T. J., and Wang, D. 2009. Effect of water sealing on reducing 1,3-Dichloropropene emissions from different soil textures. Journal of Environmental Quality 38:712–718.

Orr, C. C., and Robinson, A. F. 1984. Assessment of losses in western Texas caused by *Meloidogyne incognita*. Plant Disease 68:284–285.

Rich, J. R., and Bird, G. W. 1973. Inhibition of *Rotylenchulus reniformis* penetration of tomato and cotton roots with foliar applications of oxamyl. Journal of Nematology 5:221–224.

Satterthwaite, F. E. 1946. An approximate distribution of estimates of variance components. Biometrics Bulletin 2:110–114.

Shepherd, R. L. 1974. Registration of Auburn 623 RNR germplasm (Reg no. GP20). Crop Science 14:911.

Siders, K. 2013. The use of Vydate on southern root-knot nematode tolerant cotton in the High Plains of Texas. 2013 Beltwide Cotton Conferences, 7–10 January, San Antonio, TX: 138–140.

Smiley, R. W., Marshall, J. M., and Yan, G. P. 2011. Effect of foliar applied spirotetramat on reproduction of *Heterodera avenae* on wheat roots. Plant Disease 95:983–989.

Starr, J. L., Heald, C. M., Robinson, A. F., Smith, R. G., and Krausz, J. P. 1993. *Meloidogyne incognita* and *Rotylenchulus reniformis* and associated soil textures from some cotton production areas of Texas. Journal of Nematology 24(4S):895–899.

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.

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

Thomas, J. E., Allen, L. H., Jr., McCormack, L. A., Vu, J. C., Dickson, D. W., and Ou, L. T. 2003. Diffusion and emission of 1,3-Dichloropropene in Florida sandy soil in microplots affected by soil moisture, organic matter, and plastic film. Pesticide Management Science 60:390–398.

Thomas, J. E., Ou, L. T., Allen, L. H., McCormack, L. A., Vu, J. C., and Dickson, D. W. 2004. Persistence, distribution, and emission of Telone C-35 injected into a Florida sandy soil as affected by moisture, organic matter, and plastic film-cover. Journal of Environmental Science and Health, Part B 39:505–516.

Thomas, S. H., and Smith, D. W. 1993. Effects of 1,3-dichloropropene for *Meloidogyne incognita* management on cotton produced under furrow irrigation. Journal of Nematology 25:752–757.

Vrain, T. C. 1977. A technique for the collection of larvae of *Meloidogyne* spp. and a comparison of eggs and larvae as inocula. Journal of Nematology 9:249–251.

Wheeler, T. A., Hake, K. D., and Dever, J. K. 2000. Survey of *Meloidogyne incognita* and *Thielaviopsis basicola*: Their impact on cotton fruiting and producers' management choices in infested fields. Journal of Nematology 32:576–583.

Wheeler, T. A., Lawrence, K. S., Porter, D. O., Keeling, W., and Mullinix, B. G., Jr. 2013. The relationship between environmental variables and response of cotton to nematicides. Journal of Nematology 45:8–16.