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Effect of a Terminated Cover Crop and Aldicarb on Cotton Yield and *Meloidogyne incognita* Population Density

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Abstract: Terminated small grain cover crops are valuable in light textured soils to reduce wind and rain erosion and for protection of young cotton seedlings. A three-year study was conducted to determine the impact of terminated small grain winter cover crops, which are hosts for *Meloidogyne incognita*, on cotton yield, root galling and nematode midseason population density. The small plot test consisted of the cover treatment as the main plots (winter fallow, oats, rye and wheat) and rate of aldicarb applied in-furrow at-plant (0, 0.59 and 0.84 kg a.i./ha) as subplots in a split-plot design with eight replications, arranged in a randomized complete block design. Roots of 10 cotton plants per plot were examined at approximately 35 days after planting. Root galling was affected by aldicarb rate (9.1, 3.8 and 3.4 galls/root system for 0, 0.59 and 0.84 kg aldicarb/ha), but not by cover crop. Soil samples were collected in mid-July and assayed for nematodes. The winter fallow plots had a lower density of *M. incognita* second-stage juveniles (J2) (transformed to Log_{10} (J2 + 1)/500 cm^3 soil) than any of the cover crops (0.88, 1.58, 1.67 and 1.75 Log_{10}(J2 + 1)/500 cm^3 soil for winter fallow, oats, rye and wheat, respectively). There were also fewer *M. incognita* eggs at midseason in the winter fallow (3,512, 7,953, 8,262 and 11,392 eggs/500 cm^3 soil for winter fallow, oats, rye and wheat, respectively). Yield (kg lint per ha) was increased by application of aldicarb (1,544, 1,710 and 1,697 for 0, 0.59 and 0.84 kg aldicarb/ha), but not by any cover crop treatments. These results were consistent over three years. The soil temperature at 15 cm depth, from when soils reached 18°C to termination of the grass cover crop, averaged 9,588, 7,274 and 1,639 centigrade hours (with a minimum threshold of 10°C), in 2005, 2006 and 2007, respectively. Under these conditions, potential reproduction of *M. incognita* on the cover crop did not result in a yield penalty.

Key words: Aldicarb, conservation tillage, cotton, *Gossypium hirsutum*, *Meloidogyne incognita*, root-knot nematode.

Concerns about soil erosion, surface water quality and declining soil productivity have stimulated interest in alternative tillage systems (Hutchinson, 1993). Maintenance of plants and plant residue on the soil surface is one of the most effective means of reducing soil erosion (Hutchinson, 1993). Conservation tillage includes any tillage or planting system that maintains at least 30% coverage of the soil surface by residue after planting. Because cotton produces very little plant residue, cover crops are an essential part of conservation-tillage systems when rotation with high-residue crops are not utilized (Keeling, 1993). Cover crops can reduce erosion during spring months and protect young cotton from wind and sand damage (Keeling, 1993). Small grains, such as wheat, rye or oats, are used effectively as winter cover crops in many parts of the Texas High Plains and southwestern Oklahoma (Keeling, 1993).

In a terminated cover crop system, the cover crops are terminated prior to planting of cotton. Wheat or rye is terminated, typically with glyphosate, in the joint or early-boot stage to ensure adequate standing stubble. Winter and annual legumes have also been tested in this production area, but did not provide effective cover in drier years, which are typical of the winter months in this region (Keeling, 1993). Grass species, however, are good hosts for the southern root-knot nematode, *Meloidogyne incognita* (Potter et al., 1969; Roberts et al., 1981; Johnson and Motsinger, 1990).

The ability of *M. incognita* to penetrate roots and complete its life cycle is dependent on temperature. The minimum temperature at which *M. incognita* can develop is around 10°C (Vrain et al., 1978; Ploeg and Maris, 1999; Tzortzakakis and Trudgill, 2005). However, there is disagreement about the minimum temperature that is necessary for infection of plant roots. Roberts et al. (1981) indicated that 18°C was the minimum threshold for infection by *M. incognita,* though Vrain et al. (1978) indicated that infection could occur at 16 and 12°C. Prot and Van Gundy (1981) found that at 14, 18 and 20°C, approximately 2, 6 to 8, and 30% of *M. incognita* J2 were able to move at least 20 cm and infect roots. The time required for *M. incognita* to complete a life cycle also is dependent on temperature, and some reports indicate that 9,000 to 10,000 centigrade hours (with a base of 10°C) were necessary (Vrain et al., 1978; Ploeg and Maris, 1999). Soil temperature fluctuations do not change the basic thermal relationship between heat units and life cycle development (Milne and Du Plessis, 1964). The rate of development, however, can be affected by host status, so termination of the cover crop with a herbicide may affect development time, and this effect may depend on the developmental stage of the nematode (Milne and Du Plessis, 1964).

The primary objective of this work was to compare effects of a winter fallow with terminated grass cover crops on early season root galling of cotton, midseason nematode population density, and yield of cotton. A second objective was to determine if chemical management of root-knot nematode would be affected by the winter fallow or terminated grass cover crops.

Materials and Methods

The study was conducted near Lamesa, TX, in a field where the soil series is an Amarillo sandy loam (fine-loamy, mixed, superactive, thermic, Aridic Paleustalf;

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81% sand, 8% silt, 11% clay; 0.4% organic matter; pH 8.0). Main plots were winter fallow and three small grain cover crops (oats, rye or wheat), 12-m long and six rows wide (1-m centers) arranged in a randomized complete block design with eight replications. The plots remained in the same location (i.e., were not re-randomized) during the three-year test. The small grain cover crops were planted on 23, 22 and 17 November in 2004, 2005 and 2006, respectively. The wheat cultivar was 'Tam110', rye cultivar was 'Elbon', and oats were not cultivar specific (race horse oats, Economy Mills, Ltd., Lubbock, TX). Irrigation was applied as necessary to establish an adequate stand with 5.2, 4.6 and 0.0 ha-cm/ha of water applied in 2005, 2006 and 2007, respectively. Cover crops were terminated on 30 April, 8 April and 22 March in 2005, 2006 and 2007, respectively.

The subplots were aldicarb rates (0, 0.59 and 0.84 kg a.i./ha), which were applied to two-row plots at planting. The three aldicarb treatments were randomized within a cover plot each year. Plots were planted on 9, 2 and 15 May in 2005, 2006 and 2007, respectively at 13.3 seeds/m with the cotton cultivar 'Fibermax 989BR'. Weed control was achieved with the herbicide pendimethalin applied preplant at 1.4 kg/ha and glyphosate glycine, in the form of isopropylamine salt, applied post-emergence topically at 0.87 kg/ha before the 5th leaf stage and glyphosate post-emergence directed. Fertilizer (10–15–0 as ammonium polyphosphate) was banded in the soil at 17 kg/ha. Additional nitrogen was applied via irrigation as urea-ammonium nitrate at 146 kg/ha N. The test area was under a center pivot system with curved rows. Irrigation was applied during the season through low-energy precision application irrigation by drop hoses to every other furrow. Total seasonal irrigation was 25, 32 and 10 ha-cm/ha for 2005, 2006 and 2007, respectively. Irrigation timing and amounts during the season were based on recommendations from J. Bordovsky (agricultural engineer with Texas AgriLife Research, who monitored the site). Thrips (juveniles and adults) were monitored weekly on 10 plants/plot.

The three measurements of interest in this study were cotton root galling caused by the first generation of *M. incognita*, nematode population density in mid-July, and cotton yield. Ten plants per plot were removed (including roots) on 2, 15 and 18 June in 2005, 2006 and 2007, respectively. The roots were gently washed to remove soil, and all the galls present on the recovered roots were counted.

Soil samples for nematode assays were taken on 18, 18 and 9 July for 2005, 2006 and 2007, respectively. Samples were taken to a depth of 20 cm with a narrow-bladed shovel and consisted of five subsamples (approximately 200 cm^3 soil/subsample) that were composited. Soil and roots were removed from around the root system, on the side of the wet furrow from each two-row plot. Second-stage juveniles of root-knot nematodes were extracted from 200 cm^3 of soil (Thistlethwayte, 1970). The process of extracting root-knot nematode eggs consisted of two steps, removing organic matter from soil and then extracting the eggs from the organic matter. Organic matter from soil was extracted by adding 2 liters of water to 500 cm^3 of soil + root fragments, stirring for 15 sec and allowing 15 sec for settling before pouring the water + organic matter over a sieve with a 0.23-mm-pore opening. The eggs were extracted with NaOCl (0.5%) for 5 min from the residue collected on the sieve (Hussey and Barker, 1973). The plots were harvested with a cotton stripper which had been modified to catch the cotton from a plot in a small basket attached to load cells. Plots were harvested on 17 October, 1 November and 6 November in 2005, 2006 and 2007, respectively. A sample of the harvested cotton from half of the replications was ginned to determine the percentage lint.

A weather station was maintained at this site to measure environmental parameters. Measurements were recorded, and the database is available at http://txhighplainset.tamu.edu/. Average and maximum daily soil temperature at a 15 cm depth were examined for the winter/spring months. The soil temperature was <18°C in the fall/winter after planting the cover crops. In most years, the maximum daily soil temperature would exceed 18°C for only a few hours and for only one or two consecutive days. The starting time to calculate heat units for nematode development was arbitrarily determined to be when the maximum soil temperature at 15 cm depth reached 18°C for five consecutive days. This was earlier than when the average soil temperature at 15 cm reached 18°C. The ([average daily soil temperature – 10°C] × 24) was summed for each day, after the threshold was reached, until the cover crop was terminated. This term is referred to as centigrade hours.

The data were analyzed using PROC MIXED in SAS (Cary, NC, version 9.1). The fixed factors were aldicarb rate (A), cover crop treatment (CT), and their interaction, and the model was tested with Satterthwaite's option (Satterthwaite, 1946). The random statement included year, replication (REP) nested within year (REP(year)), year × CT, REP × CT(year), year × A, and year × A × CT. If the interaction between CT and A was not significant at $P < 0.10$, then it was moved to the random statement and the analysis was run again. The LSMEANS statement was used to estimate means of the main effects, and the PDIFF option was used to determine significant treatment differences at $P \leq 0.05$. The variables for J2 and eggs were analyzed as raw data and with a Log_{10} (J2 + 1) or Log_{10} (Egg + 1) transformation.

Results

Average soil temperatures during the spring were below 18°C until 4 April, 1 March and 19 March in 2005,

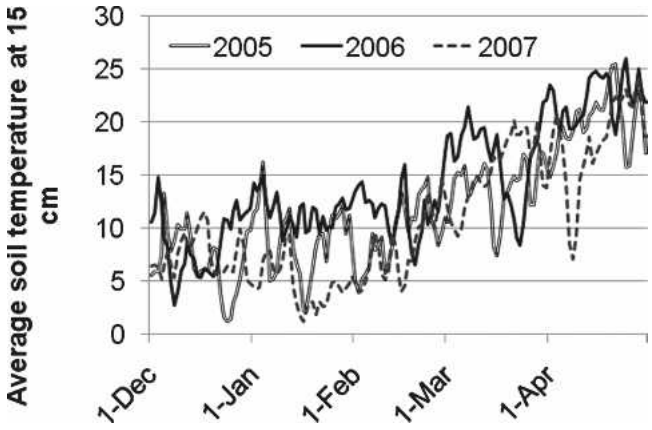

FIG. 1. Average soil temperature at a 15 cm depth prior to the 2005, 2006, and 2007 growing season.

2006 and 2007, respectively (Fig. 1). However, the maximum soil temperature reached 18°C for at least five consecutive days starting on 8 March, 27 February and 14 March in 2005, 2006 and 2007, respectively. The centigrade hours from this date until the cover crop was terminated were calculated at 9,588, 7,274 and 1,639 in 2005, 2006 and 2007, respectively.

There was no indication of a CT × year or A × year interaction, so all years were combined in the analyses. The early season galling on roots was significantly affected by aldicarb ($P = 0.05$) (Table 1). Root galling was similar at both the low and high rate of aldicarb and lower than root galling at the 0.0 rate (Table 1). Root-knot nematode J2 and eggs at midseason were not affected by aldicarb rate. Yield (kg lint/ha) was higher when aldicarb was present than in its absence (Table 1), but did not differ between the 0.59 and 0.84 kg a.i./ha rates of aldicarb. Thrip populations did not exceed the threshold of an average of one thrips for each true leaf during the first month after planting, so any aldicarb effect was not a function of thrips damage. Root galling was not affected differently by winter fallow or terminated cover crops (Table 2). Midseason root-knot nematode J2 (transformed) were lower in the winter fallow than with any of the terminated small grain cover crops (Table 2). Midseason root-knot nematode eggs (not transformed) were lower in the winter fallow than the wheat cover plots (Table 2). Yield was not affected differently by winter fallow or terminated cover crops (Table 2).

DISCUSSION

A small percentage of a root-knot nematode population can infect plants under cool conditions; however, the percentage increases as temperature increases to the 18 to 20°C range. Similarly, nematode development follows a probability distribution, with a proportion of the population developing faster than others (Triantaphyllou and Hirschmann, 1960; Vrain et al., 1978). Roberts et al. (1981) determined that infection of a cover crop would not occur until the soil temperature was at least 18°C. Root-knot nematodes could develop at much lower temperatures, but could not move and infect at temperatures below 18°C, so development would not initiate until temperatures had reached 18°C. During the three years of this study, *M. incognita* had approximately 9,588, 7,274 and 1,639 centigrade hours (with a minimum threshold of 10°C) to develop, based on when soil temperatures reached 18°C and through termination of the cover crop.

Triantaphyllou and Hirschmann (1960) found that at the equivalent of the development time during the spring of 2007 (i.e., 1,639 centigrade hours), the population of *M. incognita* would still be in the J2 stage. Thus, it is unlikely that any of the population of *M. incognita* in 2007 that infected the small grain cover crops were able to complete their life cycle before the cover was killed. However, there was no indication that the cover crop acted as a trap crop, because galling at approximately 35 days after planting was similar for cotton planted in winter fallow and in cover crops.

Similarly, at 7,274 centigrade hours (the predicted development time during the spring of 2006), between 8% and 51% of the nematodes would be expected to have matured to the adult stage, though no eggs were likely produced (Triantaphyllou and Hirschmann, 1960). At 9,588 centigrade hours (the predicted development time during the spring of 2005), about 75% of the population would be expected to have matured to the adult stage with only a small proportion (3%) producing eggs (Triantaphyllou and Hirschmann, 1960). Based on these assumptions, it is possible in 2006, and probable in 2005, that the small grain cover crops contributed additional nematodes to the population infecting cotton, but not in 2007. However, no impact was seen on the early season cotton root galling. If there had been more nematode eggs and J2 present, then

TABLE 1. Effect of rate of aldicarb on root galling, midseason second-stage juveniles (J2) and eggs of *Meloidogyne incognita*, and cotton yield.

Rate of aldicarb (kg/ha)	Galls/plant	Log_{10} (J2 + 1)/500 cm^3 soil	J2/500 cm^3 soil	Log_{10} (Eggs + 1)/500 cm^3 soil	Eggs/500 cm^3 soil	Kg of lint per ha
0	9.1 a[a]	1.57	958	3.4	10,537	1,527 a
0.59	3.8 b	1.54	389	3.0	6,029	1,694 b
0.84	3.4 b	1.30	365	3.2	6,772	1,678 b

[a] Different letters indicate that means are significantly different ($P \leq 0.05$), based of the PDIFF option of the LSMEANS statement in PROC MIXED, SAS version 9.1.

TABLE 2. Effect of small grain cover crops and winter fallow on root galling, midseason second-stage juveniles (J2) and eggs of *Meloidogyne incognita*, and cotton yield.

Cover crop	Galls/plant	Log_{10} (J2 + 1)/500 cm^3 soil	J2/500 cm^3 soil	Eggs/500 cm^3 soil	Kg of lint per ha
Winter fallow	4.3	0.88 b[a]	348	3,512 b	1,630
Oats	5.1	1.58 a	461	7,953 ab	1,639
Rye	6.6	1.67 a	715	8,262 ab	1,628
Wheat	5.7	1.75 a	761	11,392 a	1,635

[a] Different letters indicate that means are significantly different ($P \leq 0.05$), based of the PDIFF option of the LSMEANS statement in PROC MIXED, SAS version 9.1.

there should have been more root galling associated with the small grain cover crops than the winter fallow. Instead, they had similar numbers of galls (i.e., there was no significant year × CT interaction). Timper et al. (2006) also compared a winter fallow to rye cover crop in a *M. incognita*-infested field that was subsequently planted to cotton. The winter and spring temperatures were sufficiently warm that the nematode should have completed at least one life cycle, and possibly two, but they were unable to detect higher root galling associated with the rye cover crop. Rye, depending on the cultivar, can be as good a host for *M. incognita* as wheat (Zasada et al., 2007).

The difference in cover crop treatments from our work, however, was seen in the midseason nematode population density. There were more J2 and eggs in the presence of the terminated cover crops than in the winter fallow. This suggests that the bulk of the population that developed on the winter cover crops was not a factor in the first few weeks after cotton was planted, but did affect the nematode population density at a later time. Since yield was not affected by the presence or absence of a terminated cover crop, the cotton was able to compensate for the higher nematode load without further yield loss. These data differ from that of Timper et al. (2006), who found similar *M. incognita* J2 densities in both the winter fallow and rye cover crops during mid-July. So, the work in Georgia and Texas differed in terms of the midseason nematode population density. The Texas data suggest that at least a small proportion of *M. incognita* J2 did infect the cover crop, but that development was slowed to a point where they did not significantly impact the early season root galling of cotton. They did contribute to the midseason root-knot population density. The Georgia data do not suggest any impact of the cover crop on the nematode population dynamics. If there was infection and population increase occurring on the cover crop in Georgia, it did not result in any measurable increase during the cotton growing season from *M. incognita*. The minimal affect of root-knot nematode on cotton, even in years where there were sufficient heat units to have a nematode generation produced on the cover crop, may have been due to a combination of soil temperatures too cool for infection (Roberts et al., 1981) and dry soil. Dry soil inhibits egg hatch (Goodell and Ferris, 1989) and J2 movement (Wallace, 1958). During the days when soil temperature was sufficiently warm for *M. incognita* infection of the cover crop, soil moisture may have limited hatch or J2 movement.

Winter small grain cover crops can be used to reduce soil erosion in the Southern High Plains of Texas, without negatively impacting the yield of irrigated cotton. However, there should be an expectation of higher root-knot nematode densities in a terminated cover crop system by midseason. Management of root-knot nematodes in cotton was improved with the addition of aldicarb, and nematode management recommendations need not be changed by the presence or absence of a terminated small grain cover crop.

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