EVALUATION OF WINTER COVER CROPS IN COTTON CROPPING FOR MANAGEMENT OF *ROTYLENCHULUS RENIFORMIS*

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ABSTRACT

Jones, J. R., K. S. Lawrence, and G. W. Lawrence. 2006. Evaluation of Winter Cover Crops in Cotton Cropping for Management of *Rotylenchulus reniformis*. Nematropica 36:53-66.

Thirty-one winter cover crops and varieties were tested for host status to *Rotylenchulus reniformis* in greenhouse tests, and eight were selected for further microplot and field trials. Greenhouse trials indicated that crimson clover, subterranean clover, and hairy vetch serve as good hosts for *R. reniformis*. Reproduction factors (Rf) for those crops were 7.2, 2.2, and 3.7, respectively when grown in the greenhouse at an average temperature of 30°C. 'Licapo' rape, 'Tyfon' mustard spinach, 'Barnapoli' rape, PI2863 and PI4048 canola, produced Rf values of 1.3, 1.1, 1.0, 1.0, and 1.2 as compared to the Rf value of 4.2 on cotton when grown at an average temperature of 21°C. Varieties of radish, black mustard, white mustard, canola, lupin, ryegrass, wheat, oats, and rye produced Rf values of less than 1 indicating *R. reniformis* did not reproduce on these hosts. In microplot and field trials, *R. reniformis* population densities did not increase on crimson clover, subterranean clover, and hairy vetch over the winter months under natural conditions. Aldicarb applied in the seed furrow at cotton planting subsequent to cover crop termination, decreased *R. reniformis* population densities for 90 days after planting compared to the untreated control. Seed cotton yields were not affected by the cover crop but increased an average of 20% in all plots treated with aldicarb. Although crimson clover, subterranean clover, and hairy vetch were shown to be hosts of *R. reniformis* in greenhouse tests, the populations did not increase on these cover crops under the natural environmental conditions of the field and microplot tests.

Key words: Avena sativa, A. strigosa, black mustard, black oat, *Brassica campestris, B. napus, B. napus* ssp. *biennis, B. nigra, B. rapa*, canola, cotton, cover crops, crimson clover, *Gossypium hirsutum, Lolium multiflorum*, lupin, *Lupinus albus*, mustard spinach, oat, radish, rape, *Raphanus sativus*, reniform nematode, *Rotylenchulus reniformis*, rye, ryegrass, *Secale cereale, Sinapis alba*, subterranean clover, *Trifolium incarnatum, T. subterraneum, Triticum aestivum*, vetch, *Vicia villosa*, wheat, white mustard.

RESUMEN

Jones, J. R., K. S. Lawrence, and G. W. Lawrence. 2006. Evaluación de Cultivos de Cobertura de Invierno en el Cultivo de Algodón para el Manejo de *Rotylenchulus reniformis*. Nematropica 36:53-66.

Se evaluó la reproducción de *Rotylenchulus reniformis* en 31 cultivos de cobertura en invernadero, y se seleccionaron ocho de ellos para estudios en microparcelas y campo. Las pruebas de invernadero indicaron que el trébol encarnado, el trébol subterráneo y la vicia vellosa son buenos hospedantes de *R. reniformis*. Los factores reproductivos (Rf) para estos cultivos en invernadero a temperatura promedio de 30°C fueron 7.2, 2.2 y 3.7, respectivamente. En colza 'Licapo', nabo 'Tyfon', colza 'Barnapoli' y canola PI2863 y PI4048 los valores de Rf fueron 1.3, 1.1, 1.0, 1.0 y 1.2, comparados con un valor de Rf de 4.2 en algodón a temperatura promedio de 21° C. Las variedades evaluadas de rábano, mostaza negra, mostaza blanca, canola, altramuz, raigrás, trigo, avena y centeno produjeron valores de Rf por debajo de 1, indicando que *R. reniformis* no se reproduce en estos hospedantes. En pruebas de microparcelas y campo, las densidades de población de *R. reniformis* no aumentaron en trébol encarnado,

trébol subterráneo y vicia vellosa durante los meses de invierno en condiciones naturales. Aldicarb aplicado en el momento de la siembra del algodón después del cultivo de cobertura, disminuyó la densidad de población de *R. reniformis* durante 90 días después de la siembra comparado con el control sin tratamiento. Los cultivos de cobertura no afectaron la producción de semilla de algodón, pero la producción aumentó 20% en promedio en todos los lotes tratados con aldicarb. Aunque el trébol encarnado, trébol subterráneo y vicia vellosa resultaron ser hospedantes de *R. reniformis* en pruebas de invernadero, las poblaciones no aumentaron en estos cultivos de cobertura bajo condiciones naturales ambientales en el campo y en microparcelas.

Palabras clave: algodón, altramuz, avena, avena negra, *Avena sativa*, *A. strigosa*, *Brassica campestris*, *B. napus*, *B. napus* ssp. *biennis*, *B. nigra*, *B. rapa*, canola, centeno, colza, cultivos de cobertura, *Gossypium hirsutum*, *Lolium multiflorum*, *Lupinus albus*, mostaza blanca, mostaza negra, nabo, nematodo reniforme, rábano, raigrás, *Raphanus sativus*, *Rotylenchulus reniformis*, *Secale cereale*, *Sinapis alba*, trébol encarnado, trébol subterráneo, *Trifolium incarnatum*, *T. subterraneum*, trigo, *Triticum aestivum*, vicia vellosa, *Vicia villosa*.

INTRODUCTION

The reniform nematode, *Rotylenchulus reniformis* Linford and Oliveira, has become one of the most economically important pathogens on cotton. *Rotylenchulus reniformis* is the most economically damaging nematode pest on cotton in Alabama with an estimated yield loss of 8% in 2002 (Gazaway and McLean, 2003). This pathogen has spread rapidly when compared to other plant-parasitic nematodes that damage cotton. Since the first report on cotton in 1940, *R. reniformis* has been detected in every cotton producing state in the southeastern U.S.A., from North Carolina to Texas (Robinson *et al.*, 1997).

Currently, no commercially available cotton cultivars provide resistance to the reniform nematode (Starr, 1998; Usery *et al.* 2005). Therefore, most short-term management solutions for nematodes involve the use of nematicides. Nematode management throughout the Southeast relies heavily on the nematicides 1,3 dichloropropene, oxamyl, and aldicarb (Lawrence and McLean, 2001). Nematicides are considered to only be short term solutions with nematode population densities increasing by the end of the growing season; therefore, these products must be applied year after year. This extensive use of nematicides is a risk to sustainable agriculture. Furthermore, alternatives to nematicides are important as the Food Quality Protection Act of 1996 may drastically affect the availability and registration of nematicides (Huettel, 1997). The use of cover crops may offer one such alternative for managing plant-parasitic nematodes.

Targeted plant-parasitic nematodes can be suppressed by cover crops that are either poor hosts or produce allelopathic chemicals (Halbrendt, 1996; McSorley *et al.*, 1994; Rodriguez-Kabana *et al.*, 1998). The nematode suppressive effect is operative during the growing period of the cover crop, with plant-parasitic nematode populations likely to increase after the subsequent susceptible crop is planted (McSorley *et al.*, 1994). However, a cover crop can enhance nematode-antagonistic microorganisms by providing a more favorable environment for microbial activity (Kloepper *et al.*, 1991), by increasing the soil organic matter content that favors the development of a diverse microflora (Muller and Gooch, 1982).

The current study focuses on improving the winter cover cropping system for *R. reniformis* management on cotton in Alabama. Winter cover crops consisting of

small grains and legumes more common to southeastern United States cotton production systems were selected for this research based on beneficial properties as cover crops. The objectives of these studies were: 1) to determine whether winter cover crops suppressed or enhanced *R. reniformis* populations and 2) to determine the effects of winter cover crops on subsequent growth and yield of cotton in a field naturally infested with *R. reniformis.*

MATERIALS AND METHODS

Greenhouse

Greenhouse trials were conducted at the Plant Science Research Center on the campus of Auburn University, Alabama U.S.A. In the greenhouse, 31 winter cover crops were initially evaluated in comparison to cotton (Paymaster 1218 BR) for host suitability to *R. reniformis* in the winter season from October through February. Winter cover crops used in this greenhouse experiment were common varieties of: black oat (*Avena strigosa*), black mustard (*Brassica nigra*), canola (*Brassica campestris*), crimson clover (*Trifolium incarnatum*), lupin (*Lupinus albus*), mustard spinach (*Brassica rapa*), oats (*Avena sativa*), radish (*Raphanus sativus*), rape (*Brassica napus* and *B. napus* ssp. *biennis*), rye (*Secale cereale*), ryegrass (*Lolium multiflorum*), subterranean clover (*Trifolium subterraneum*), vetch (*Vicia villosa*), wheat (*Triticum aestivum*), and white mustard (*Sinapis alba*) (see Table 1 for variety names). In a second screening, eight selected cover crops, 'AU Robin' crimson clover (*Trifolium incarnatum*), 'Mt. Barker' subterranean clover (*Trifolium subterraneum*), 'Gulf' ryegrass (*Lolium multiflorum*), 'Wren's Abruzzi' rye (*Secale cereale*), 'Hairy' vetch (*Vicia villosa*), 'Soil saver' black oat (*Avena strigosa*), 'Homer' lupin (*Lupinus albus*), and 'Coker 9663' wheat (*Triticum aestivum*) were evaluated in the greenhouse during the summer months of May through September including both cotton and fallow treatment comparisons. In both greenhouse tests, the cover crops were planted in 500 cm^3 of soil in polystyrene pots. The soil was classified as a loamy sand (72.5%, 25%, 2.5%, S-S-C, pH 6.4) and was autoclaved twice at 121°C and 103.4 kPa for two hours on two consecutive days. Seeds were allowed to germinate and grow for seven days, at which time, each pot was inoculated with 2,000 *R. reniformis* juveniles and vermiform adults. Tests were arranged on a greenhouse bench in a randomized complete block design with five replications. Plants grew in the greenhouse for 60 days after inoculation. Pots were fertilized weekly using Peter's 20-10-20 water-soluble fertilizer. Nematodes were extracted from the soil by combined gravity screening and sucrose (specific gravity = 1.13) centrifugal flotation and enumerated with a stereo-microscope (Jenkins, 1964). In the second screening, in addition to extracting vermiform stages form the soil, *R. reniformis* eggs were extracted from the roots by shaking for 4 minutes in a 0.6% sodium hypochlorite (NaOCl) solution (Hussey and Barker, 1973). Eggs were then collected by washing through a 75-µm pore sieve nested on a 25-µm pore sieve. Eggs collected on the 25-µm pore sieve were rinsed with tap water, stained using a 20% solution of red food coloring, and enumerated. Following enumeration of *R. reniformis* populations, reproductive factors (Rf = final vermiform + egg populations/initial population) were determined. All greenhouse tests were conducted three times.

Microplots

Field microplot experiments were conducted on the North Plant Science Research Farm at Mississippi State Univer-

Table 1. Host suitability in greenhouse evaluations of winter cover crops to *Rotylenchulus reniformis*.

Cultivar	Scientific name	Common name	*R. reniformis*[y]	Rf[z]
Idaho	*Raphanus sativus*	Radish	221.5 i	0.11
Rufus	*Raphanus sativus*	Radish	377.7 g-i	0.18
Final	*Raphanus sativus* L.	Radish	386.3 g-i	0.19
Slobot	*Raphanus sativus*	Radish	310.7 hi	0.15
Liforum	*Brassica napus*	Rape	1697.8 c-i	0.85
Licapo	*Brassica napus*	Rape	2698.6 b-d	1.34
Nemfix	*Brassica nigra*	Black Mustard	755.3 e-i	0.28
Bnigra	*Brassica nigra*	Black Mustard	1450.6 d-i	0.73
Sirola	*Sinapis alba*	White Mustard	753.6 e-i	0.73
Salvo	*Sinapis alba*	White Mustard	1107.3 d-i	0.55
Civastro "R"	*Brassica rapa*	Mustard Spinach	1931.3 b-h	0.96
Samson Turnip	*Brassica rapa*	Mustard Spinach	1660.0 c-i	0.83
Samson	*Brassica rapa*	Mustard Spinach	727.9 e-i	0.36
Tyfon	*Brassica rapa*	Mustard Spinach	2185.3 b-e	1.09
PI2863	*Brassica campestris*	Canola	2041.1 b-g	1.02
PI4048	*Brassica campestris*	Canola	2085.8 b-f	1.04
Barnapoli	*Brassica napus* ssp. *biennis*	Rape	1598.2 c-i	0.80
Barnapoli	*Brassica napus* ssp. *biennis*	Rape	2322.7 b-e	1.16
AU Homer	*Lupinus albus*	Lupin	858.3 e-i	0.43
AU Alpha	*Lupinus albus*	Lupin	1038.6 d-i	0.52
Marshall	*Lolium multiflorum*	Ryegrass	386.3 g-i	0.19
Gulf	*Lolium multiflorum*	Ryegrass	434.3 f-i	0.22
Coker 9835	*Triticum aestivum*	Wheat	1012.8 e-i	0.51
Coker 9663	*Triticum aestivum*	Wheat	479.0 f-i	0.24
Pioneer 26R61	*Triticum aestivum*	Wheat	515.0 f-i	0.26
EK 102	*Triticum aestivum*	Wheat	660.9 e-i	0.33
Soil Saver	*Avena strigosa*	Black oats	290.1 hi	0.15
Coker 227	*Avena sativa*	Oats	491.0 f-i	0.25
Cahaba II	*Vicia villosa*	Vetch	3146.7 bc	1.57
Wren's Abruzzi	*Secale cereale*	Rye	314.2 hi	0.16
AU Robin	*Trifolium incarnatum*	Crimson Clover	3508.9 b	1.75
Paymaster 1218 BR	*Gossypium hirsutum*	Cotton	8478.6 a	4.24
LSD ($P \leq 0.05$)			1669.7	

[y]Populations of vermiform and eggs per 500 cm^3 of soil.
[z]Reproductive factor (Rf) = (final population/initial population).
Nematode populations reported as means from three tests with five replications in each test. Initial inoculum was 2000 vermiform stages and eggs per 500 cm^3 of soil.
Means within columns followed by different letters are significantly different according to Fisher's protected least significant difference test ($P \leq 0.05$).

sity. Microplots consisted of 76 cm dia. fiber-glass cylinders placed 45 cm deep in the soil. The soil was classified as a sandy loam (61.25%, 31.25%, 7.5%, S-S-C, pH 6.4). Each test was arranged in a randomized complete block design with five replications. The soil in the microplots was previously infested with *R. reniformis* cultured on cotton. Microplots were lightly cultivated with a hoe and planted in October with eight winter cover crops: 'AU Robin' crimson clover, 'Mt. Barker' Subterranean clover, 'Gulf' ryegrass were seeded at 0.4 g per microplot, 'Wren's Abruzzi' rye, 'Hairy' vetch, 'Soil Saver' black oat, 'Homer' lupin, and 'Coker 9663' wheat were seeded at 1.8 g per microplot. Two controls consisted of fallow treatments with and without weeds. Weeds were removed by hand hoeing. Cover crops were sown by broadcasting the seed inside the perimeter of the microplots. After sowing, seeds were lightly covered by hand hoeing. Nematode samples were collected at planting and then bi-monthly throughout the winter growing season. Samples consisted of six soil cores 2.5 cm in diameter and 20 cm in depth. A 150 cm^3 subsample was extracted and *R. reniformis* populations were enumerated using the methods previously described. The test was repeated in two consecutive years.

Field

Winter cover crops were planted near Prattville, Alabama in a cotton field naturally infested with *R. reniformis*. The soil was a sandy loam (63.75%, 31.25%, 5%, S-S-C, pH 6.7). Immediately following cotton harvest, the eight previously selected winter cover crops were planted along with the fallow treatment controls. Each cover crop was sown at seeding rates recommended by Alabama Extension System using a field plot grain drill with a row spacing of 19.1 cm. Field plots, 9.1 m in length and 3.0 m in width, were arranged in a randomized complete block design with five replications. Fallow treatments without weeds were sprayed with paraquat at 4.69 l/ha. Nematode samples were collected at planting and then monthly throughout the summer growing season. Twenty soil cores, 2.5 cm in diameter and 20 cm in depth, were collected using a systematic zig-zag sampling pattern. The soil was mixed thoroughly and a 150 cm^3 subsample was extracted and *R. reniformis* populations were enumerated using the methods previously described.

Three to four weeks before cotton planting, cover crops were terminated with glyphosate at 4.69 l/ha. Cotton cv. Delta and Pine Land 451 BR Cruiser treated seed was sowed at a seeding rate of 16 seed/m of row. Each previous winter cover crop plot was split and aldicarb was applied in the seed furrow with a granular applicator attached to the planter at 7.9 kg/ha to two rows. The remaining two rows were left untreated. All plots were maintained without tillage throughout the summer season with standard herbicide, insecticide, and fertility production practices as recommended for cotton production by the Alabama Cooperative Extension System. Nematodes were sampled monthly from each two row subplot by taking ten soil cores, 2.5 cm in diameter and 20 cm in depth. *Rotylenchulus reniformis* populations were extracted from a 150 cm^3 sub sample and enumerated using the methods previously described. At harvest, cotton plants were collected from 1 m of row for plant mapping. Plant height, total number of nodes, number of bolls produced per plant, and respective fruiting positions of the bolls were recorded. Seed cotton was removed from each fruiting position, dried at 80°C for 48 hours, and weights were recorded. All plots were

mechanically harvested approximately 150 days after planting. The field test was repeated in over two consecutive years.

Rotylenchulus reniformis numbers, cotton plant growth parameters and yield were analyzed according to analysis of variance via the mixed model procedure of statistical analysis software (SAS Institute, Inc., Cary, NC.) (Littell *et al.*, 1996). Repeats of the experiments, blocks and associated interactions with treatment factors were considered to be random effects. Least square means for treatments were separated using Fisher's protected least significance difference at ($P \leq 0.05$). When interactions were significant ($P \leq 0.05$), appropriate interaction least square means were examined and least square means separation was calculated (Fisher's protected LSD).

RESULTS

Greenhouse

All winter cover crops tested during the winter months supported lower ($P \leq 0.05$) numbers of *R. reniformis* compared to the susceptible cotton control (Table 1). Each crop with Rf values greater than one indicates *R. reniformis* was increasing in number using that specific cover crop as a food source. 'AU Robin' crimson clover, 'Cahaba II' vetch, 'Licapo' rape, 'Tyfon' mustard spinach, 'Barnapoli' rape, PI2863 and PI 4048 canola, produced Rf values of 1.7, 1.5 1.3, 1.1, 1.0, 1.0, and 1.2 as compared to the Rf value of 4.2 on cotton. Varieties of radish, black mustard, white mustard, canola, lupin, ryegrass, wheat, oats, and rye did not increase *R. reniformis* numbers. Temperatures in this greenhouse test ranged from 18 to 24°C with an averaged ambient air temperature of 21°C. These temperatures are well suited for the cover crops but lacking in heat units for cotton. When examined during the summer months, greenhouse ambient air temperatures increased to an average of 30°C with a range of 24 to 35°C. All selected winter cover crops again supported lower ($P \leq 0.05$) populations of *R. reniformis* compared to cotton even with the increased temperatures (Table 2). 'AU Robin' crimson clover produced the greatest Rf value of 7.2 for the cover crops; however, *R. reniformis* numbers were 54% lower than those on cotton. 'Hairy' vetch and 'Mt. Barker' subterranean clover produced Rf values of 3.7 and 2.2, respectively. Nematode numbers increased on 'AU Robin' crimson clover were 195% and 320% higher ($P \leq 0.05$) than those increased on 'Hairy' vetch and 'Mt. Barker' Subterranean clover, respectively. The number of eggs per root system was greater ($P \leq 0.05$) in pots planted with cotton compared to all cover crops. The number of eggs produced on 'AU Robin' crimson clover and 'Hairy' vetch were 45% and 60% less than that of cotton but averaged 98% higher ($P \leq 0.05$) when compared to the other cover crops. 'Paymaster 1218 B/RR' cotton, 'AU Robin' crimson clover, 'Hairy' vetch, and 'Mt. Barker' Subterranean clover had Rf values of 15.8, 7.2, 3.7, and 2.2, respectively. The Rf values for all other cover crops ranged from a high of 0.22 for 'Gulf' ryegrass to a low of 0.07 for the fallow treatment.

Microplots

At planting, *R. reniformis* populations ranged from a high of 13,596 to a low of 8,044 juveniles and vermiform adults per 150 cm^3 of soil with an average of 10,531 following summer increase on cotton. Sixty days after planting, no differences in *R. reniformis* numbers were observed among the winter cover crops; however, over all treatments numbers had decreased 28% since planting (Table 3). At cover crop ter-

Table 2. Host suitability of winter cover crops to *Rotylenchulus reniformis* as measured by number of eggs, vermiform life stages, and nematode reproductive factors in the greenhouse.

Cultivar	Scientific name	Common name	*Rotylenchulus reniformis*[a]		Rf value[c]
			Egg	Vermiform	
'AU Robin'	*Trifolium incarnatum*	Crimson clover	131897 b	14523 b	7.20
'Mt. Barker'	*Trifolium subterraneum*	Subterranean clover	11363 c	4532 c	2.20
'Gulf'	*Lolium multiflorum*	Ryegrass	373 c	445 d	0.22
'Wren's Abruzzi'	*Secale cereale*	Rye	152 c	183 d	0.09
'Hairy'	*Vicia villosa*	Vetch	97412 b	7416 c	3.70
'Soil Saver'	*Avena strigosa*	Black oat	306 c	201 d	0.10
'AU Homer'	*Lupinus albus*	Lupin	373 c	219 d	0.10
'Coker 9663'	*Triticum aestivum*	Wheat	255 c	296 d	0.14
'PM 1218 BRR'	*Gossypium hirsutum*	Cotton	241200 a	31698 a	15.80
		Fallow soil	—	147 d	0.07
LSD ($P \leq 0.05$)		51490	3634	—	—

[a]Populations of eggs or vermiform stages per 500 cm^3 of soil.
Nematode populations reported as means from three tests with five replications in each test. Initial inoculum was 2000 vermiform stages and eggs per 500 cm^3 of soil.
Means within columns followed by different letters are significantly different according to Fisher's protected least significant difference test ($P \leq 0.05$).
[c]Rf = final population/initial population.

mination 120 days after planting, nematode numbers ranged from 5,340 to 1,873 per 150 cm^3 of soil with an average overall reduction of 68%. 'Homer' lupin plots contained higher populations of *R. reniformis* than the 'Soil saver' oat, 'Gulf' ryegrass, and 'Coker 9663' wheat. *Rotylenchulus reniformis* populations in the fallow treatments with and without weeds were similar to all the cover crop treatments. The Rf values of *R. reniformis* on the winter cover crops ranged from 0.61 in the 'Homer' lupin plots to 0.17 in plots planted with 'Soil saver' black oat. All winter cover crops had nematode Rf values less than 1, thus *R. reniformis* populations did not increase over the December to April winter season. Averaged over both tests, soil temperatures from a 10 cm depth ranged from 8 to 21°C with a mean of 12°C and 36 cm of accumulated rainfall was measured.

Field Cover Crops

Fall populations of *R. reniformis* at cover crop planting ranged from a high of 2,441 to a low of 1,663 with an average population of 2,073 juveniles and vermiform adults per 150 cm^3 of soil (Table 4). Nematode populations varied spatially across the field. Thirty days after emergence (DAE), *R. reniformis* population densities decreased to an average of 913 juveniles and vermiform adults with no differences among the various cover crop treatments. *Rotylenchulus reniformis* decreased to an average of

Table 3. Evaluations of winter cover crops for suppression of *Rotylenchulus reniformis* in field microplot environments as measured by bi-monthly soil sampling and nematode reproductive factors.

	Planting[x]	60 DAP[y]	120 DAP	
Treatment	Dec	Feb	Apr	Rf value[z]
Fallow + weeds	12032	6943	3177 ab	0.26
Fallow no weeds	13596	10139	3911 ab	0.29
Black oat	10400	6325	2704 b	0.26
Ryegrass	11101	6083	1873 b	0.17
Wheat	8681	5620	2482 b	0.29
Rye	12672	9840	3293 ab	0.26
Crimson clover	8044	7995	2839 b	0.35
Subterranean clover	10187	9029	3920 ab	0.38
Lupin	8729	6103	5340 a	0.61
Vetch	9869	7937	3689 ab	0.37
LSD ($P \leq 0.05$)	8510	4787	2356	1.01

[x]Populations of vermiform stages per 150 cm^3 of soil.
[y]DAP is days after planting.
[z]Rf = final population/initial population.
Nematode populations reported as means from five replications. The test was repeated twice.
Means within columns followed by different letters are significantly different according to Fisher's protected least significant difference test ($P \leq 0.05$).

872, 811, and 681 juveniles and vermiform adults per 150 cm^3 of soil at 60, 90, and 120 DAE, respectively. Cover crop treatments did not affect nematode numbers on any sample date. A 67% reduction in *R. reniformis* population densities over all treatments was observed by the end of the cover crop season. At winter cover crop termination, Rf values for each winter cover crop was less than 1, indicating there was no increase in *R. reniformis* populations over two consecutive cover cropping seasons under natural field conditions. Soil temperatures from a 10 cm depth averaged over both years, between Dec. and March, ranged from 9 to 20°C with a mean of 13°C and accompanied by 40 cm of rain fall.

Field Cotton

Due to the lack of an interaction between cover crop and nematicide application, these data were combined. The cover crops had a minimal effect on *R. reniformis* populations during the cotton production season. Thirty days after planting (DAP), population densities of *R. reniformis* were higher ($P \leq 0.05$) in plots following 'Homer' lupin when compared to 'Mt. Barker' subterranean clover, 'Coker 9663' wheat, and the fallow without weeds (Table 5). No differences ($P \leq 0.05$) in *R. reniformis* population densities were observed between cover crop treatments at 60 and 90 DAP when soil temperatures remained

Table 4. Evaluation of winter cover crops for suppression of *Rotylenchulus reniformis* in a naturally infested cotton field as measured by monthly soil sampling and nematode reproductive factors.

		30 DAE[2]	60 DAE	90 DAE	120 DAE	
Treatment	Planting[1]	Jan	Feb	Mar	Apr	Rf value[3]
Fallow + weeds	1929 ab	917	829	827	587	0.46
Fallow no weeds	2333 a	968	914	1015	791	0.49
Black oat	1931 ab	999	958	698	572	0.32
Ryegrass	1939 ab	870	814	670	572	0.35
Wheat	2441 a	775	979	739	837	0.43
Rye	2289 a	739	850	904	948	0.46
Crimson clover	1772 ab	739	685	641	585	0.46
Subterranean clover	2176 a	989	855	744	652	0.54
Lupin	1663 b	1053	953	1097	680	0.45
Vetch	2258 a	1084	886	780	597	0.33
LSD ($P \leq 0.05$)	677	NS	NS	NS	NS	0.25

[1]Populations of vermiform stages per 150 cm^3 if soil.
[2]DAE is days after emergence.
[3]Rf = final population/initial population.
Nematode populations reported as means from five replications. The test was repeated twice.
Means within columns followed by different letters are significantly different according to Fisher's protected least significant difference test ($P \leq 0.05$). NS = non significant.

near 31°C. At 120 DAP, *R. reniformis* numbers were higher ($P \leq 0.05$) following 'Homer' lupin compared to 'Gulf' ryegrass. Populations of *R. reniformis* were lower in the aldicarb treated plots as compared to the non treated plots at 30, 60 and 90 DAP. However, populations rebounded in the aldicarb plots by 120 DAP. The 10 cm soil temperatures for both years of the cotton production season averaged 27.2°C, 30.3°C, 31.5°C, 31.0°C, and 29.4°C for May, June, July, August, and Sept. respectively. These temperatures were combined with an average of 53.8 cm of rainfall producing an ideal soil environment for this tropical nematode.

Seed cotton yields varied from 1,840 to 1,461 kg/ha for cover crop treatments (Table 5). Seed cotton yields were increased ($P \leq 0.05$) in the 'AU Robin' crimson clover, 'Mt. Barker' subterranean clover, 'Homer' lupin, 'Hairy' vetch, 'Soil saver' oat, and fallow with weeds cover crop treatments as compared to 'Wren's Abruzzi' rye.

Nematicide application reduced *R. reniformis* numbers regardless of the winter cover crop at all sample dates except for 90 DAP during the cotton production season. *Rotylenchulus reniformis* populations in the nematicide treated plots were reduced 22%, 8%, and 37% at 30, 60, and 90 DAP, as compared to the untreated control plots, respectively. However, in the aldicarb treated plots, *R. reniformis* populations were 32% higher ($P \leq 0.05$) than in the untreated

Table 5. Residual effects of winter cover crops on *Rotylenchulus reniformis* populations during the cotton growing season and seed cotton yields of 'DPL 451 BR' cotton.

Treatment	Planting[y] May	30 DAP[z] Jun	60 DAP Jul	90 DAP Aug	120 DAP Sep	Seed cotton kg/ha
Fallow w/weeds	698	1868 ab	996	1232	1377 ab	1740 a
Fallow wo/weeds	742	1418 b	816	1099	1434 ab	1677 ab
Black oat	764	1906 ab	735	1130	1404 ab	1721 a
Ryegrass	605	1837 ab	889	833	1216 b	1641 ab
Wheat	744	1520 b	876	995	1735 ab	1602 ab
Rye	754	1881 ab	719	987	1447 ab	1461 b
Crimson clover	610	1692 ab	683	1062	1369 ab	1830 a
Subterranean clover	790	1616 b	884	933	1592 ab	1840 a
Lupin	692	2652 a	816	1247	1945 a	1767 a
Vetch	757	1904 ab	909	1077	1497 ab	1777 a
LSD ($P \leq 0.05$)	NS	944	NS	NS	636	224
Nematicide						
Aldicarb	1084 b	614 b	749	1085 b	2080 a	1715 a
No Aldicarb	2081 a	797 a	815	1736 a	1577 b	1447 b
LSD ($P \leq 0.05$)	381	177	NS	272	327	101

[y]Populations of vermiform stages per 150 cm^3 if soil.
[z]DAP is days after planting.
Nematode populations reported as means from five replications. The test was repeated over two years.
Means within columns followed by different letters are significantly different according to Fisher's protected least significant difference test ($P \leq 0.05$). NS = non significant.

plots at harvest. All plots treated with the nematicide aldicarb produced an 18% increase in ($P \leq 0.05$) seed cotton yield compared to the untreated plots.

Cover crop treatments had little effect on cotton plant growth and development. No interaction was observed between the cover crop and nematicide treatments from plant mapping data. Cotton plant height was greater ($P \leq 0.05$) in plots following a 'Homer' lupin cover crop as compared to plots following 'Hairy' vetch, 'Coker 9663' wheat, 'Wren's Abruzzi' rye, and fallow without weeds (Table 6). Plants in plots following 'AU Robin' crimson clover, averaged 23.6 nodes or 2 nodes greater ($P \leq 0.05$) than all other treatments except for fallow with weeds. The number of first position bolls ranged from 6.7 to 5.3 and were ($P \leq 0.05$) greater following 'Hairy' vetch and 'Gulf' ryegrass compared to 'Mt. Barker' subterranean clover. The number of second and third position bolls was not affected by cover crop treatment. Cotton following 'Hairy' vetch, 'Homer' lupin, and 'Coker 9663'

Table 6. Residual effects of winter cover crops on cotton 'DPL 451 BR' plant height, nodes per plant, number and weight of 1st, 2nd, and 3rd position bolls and node of first fruiting branch in a field naturally infested with *Rotylenchulus reniformis*.

Treatment	Height (cm)	Total nodes	1st position bolls	2nd position bolls	3rd position bolls	Lowest fruiting node	1st position wt. (g)	2nd position wt. (g)	3rd position wt. (g)
Fallow + weeds	100.9 ab	21.2 ab	6.4 ab	3.9	5.0	7.0 ab	12.8 a	13.5 a	14.7 ab
Fallow no weeds	91.3 c	20.4 b	5.6 ab	3.4	5.8	7.2 a	11.3 ab	12.4 abc	12.6 abc
Black oat	100.5 abc	20.1 b	6.2 ab	3.4	7.3	7.2 a	10.7 b	12.0 abc	13.2 abc
Ryegrass	98.8 abc	20.6 b	6.5 a	3.8	6.7	6.2 bc	12.0 ab	12.0 abc	13.0 abc
Wheat	91.7 bc	19.9 b	5.9 ab	2.9	4.0	5.9 c	11.8 ab	11.1 c	12.8 abc
Rye	80.0 d	20.1 b	6.1 ab	2.8	6.6	7.2 a	12.9 a	11.7 abc	11.4 bc
Crimson clover	98.3 abc	23.6 a	6.1 ab	3.9	7.9	6.9 ab	12.9 a	13.3 ab	13.0 abc
Subterranean clover	98.3 abc	20.1 b	5.3 b	3.5	4.6	6.4 abc	11.6 ab	11.5 bc	11.0 c
Lupin	102.4 a	20.2 b	6.3 ab	3.9	4.4	5.9 c	12.3 ab	13.4 ab	14.0 abc
Vetch	93.0 bc	20.0 b	6.7 a	3.6	7.7	5.8 c	12.4 ab	13.3 ab	15.4 a
LSD ($P \leq 0.05$)	3.67	2.99	1.20	NS	NS	0.87	2.06	1.87	3.44
Nematicide									
Aldicarb	96.3	20.9	6.1	3.8 a	6.5	6.7	12.5	12.2	13.3
No Aldicarb	94.2	20.3	6.1	3.2 b	5.5	6.5	11.7	12.6	13.0
LSD ($P \leq 0.05$)	NS	NS	NS	0.56	NS	NS	NS	NS	NS

Means within columns followed by different letters are significantly different according to Fisher's protected least significant difference test ($P \leq 0.05$). NS = non significant.
Cotton plant parameters reported as means from five replications. The test was repeated over two years.

wheat retained the first open boll at a lower main stem node ($P \leq 0.05$) compared to all other cover crop treatments except 'Gulf' ryegrass and 'Mt. Barker' subterranean clover. First, second, and third position cotton boll weights varied 2.2, 2.4, and 4.4 g, respectively. Heavier or lighter boll weights across positions were not consistent with any cover crop treatment. There were no differences measured for the plant mapping parameters due to the nematicide application as compared to the control.

DISCUSSION

Among the winter cover crops evaluated, 'AU Robin' crimson clover, 'Hairy' vetch, and 'Mt. Barker' subterranean clover all served as good hosts for *R. reniformis*. 'Cahaba II' vetch, 'Licapo' rape, 'Tyfon' mustard spinach, 'Barnapoli' rape, PI2863 and PI4048 canola, technically by Rf values, were also hosts but could be considered as poor hosts. The small grain, grass, brassica, and lupin crops would be preferred cover crops in a cotton production

system over the clovers and vetch because; in general, they supported lower populations of *R. reniformis* in the greenhouse studies. Reduction of *R. reniformis* populations by 'Gulf' ryegrass, 'Wren's Abruzzi' rye, 'Soil saver' oat, 'Homer' lupin, and 'Coker 9663' wheat in our greenhouse experiments is in agreement with reports that these plants are non hosts (Jones and McLean, 2004; Robinson *et al.*, 1997). However, the reduction of *R. reniformis* was similar to that attained by the fallow soil treatment both in the microplots and field. Thus, suppression of *R. reniformis* by these cover crops was not observed in this study.

Cover crops that served as hosts for *R. reniformis* in the greenhouse trials did not produce the same results in the microplots even in the presence of high populations of *R. reniformis*. This could be due to unfavorable natural environmental temperatures (Gaur and Perry, 1991). Cover crops were terminated to allow the plant biomass to dry before planting the cotton crop. Thus when soil temperatures began to ascend into the favorable ranges each spring, the cover crops were treated with herbicides. The timing required for cover crop termination and cotton planting did not allow the cover crop to grow long enough during warmer temperatures to increase the *R. reniformis* populations.

A reduction in *R. reniformis* was observed in all cover crop treatments in the field experiments. The host suitability of the cover crops for *R. reniformis*, does not appear to be the limiting factor controlling population levels. In 2002-2003, from the time of planting until 60 DAP average soil temperatures were less than 15°C which is unfavorable for *R. reniformis* development (Gaur and Perry, 1991). However, soil temperatures 90 DAP until cover crop terminations were greater than 15°C with a high of 23°C. Previous research has shown that seasonal population changes, life stage development, and survival are greatly influenced by temperature. Optimum soil temperatures for development of *R. reniformis* range between 25 and 36°C (Heald and Thames, 1982). Life cycle completion has been shown to occur in as little as 14 days at 24°C or as long as 26 days at 21.5°C (Bird, 1983; Gaur and Perry, 1991).

In 2003-2004, cover crops were sowed in October when soil temperatures were favorable for development of *R. reniformis*. Due to an insufficient amount of rainfall, the cover crops did not germinate until December of 2003. As in 2002-2003, no increase in *R. reniformis* populations was observed based on cover crop treatment. Although 'AU Robin' crimson clover, 'Mt. Barker' subterranean clover, and 'Hairy' vetch may be suitable hosts for *R. reniformis* at optimum soil temperatures, they did not increase at marginal soil temperatures during two consecutive winters. Previous research with *Meloidogyne javanica* has indicated that barley and rye were suitable hosts, however, an increase in nematode numbers was not observed over the winter months (Thomason, 1962).

The use of the nematicide aldicarb reduced *R. reniformis* numbers for the majority of the season and increased seed cotton yields following a winter cover crop sequence. The highest seed cotton yields were observed in the leguminous cover crops, oat, and fallow without weeds; however, the application of aldicarb increased yield in all cover crop plots. Since *R. reniformis* numbers were not reduced or increased by the clover and vetch cover crops, the residual nitrogen that was fixed by these crops is potentially responsible for the yield increase. However, the fallow and oat treatments also sustained a similar yield increase. Cotton following rye produced a substantially lower seed cotton yield in both the nematicide treated and

untreated plots. The low seed cotton yields following rye are believed to be attributed to a nitrogen deficiency because the rye produced the greatest biomass of the cover crops tested. All plots were fertilized with the same rate of nitrogen, thus additional fertilizer applied with cotton planting following a rye cover crop could eliminate the yield reduction observed in this study. Recent studies suggest that cotton following a cereal cover crop may need additional nitrogen to eliminate the effect of immobilization of nitrogen by the decomposing residue (Bauer and Reeves, 1999).

Cotton plant growth and development was not affected by cover crop or nematicide in these tests. Previous research has shown cotton boll position and weight were affected by nematicide application in *R. reniformis* infested fields (Lawrence and McLean, 2000). The number of heavier lower position bolls is often increased with nematicide application. However, in our study boll numbers and weights were not affected by nematicide or cover crop.

The host status of the winter cover crop (non host, poor host, or a good host) for *R. reniformis*, did not affect the *R. reniformis* population density the following season. In the cropping rotation, *R. reniformis* population density increases substantially when the summer host such as cotton is planted. Therefore, the additional benefits of using leguminous winter cover crops such as crimson clover, subterranean clover, and vetch suggests that these crops should not be dismissed based solely on their susceptibility to *R. reniformis*.

A good plant cover during the winter months following a cotton crop has many advantages over fallow soil in the Southeast (Ko and Schmitt, 1996). Winter cover crops compete with weeds, decrease soil erosion, enhance soil health, and provide a niche for nematode antagonistic microflora. Some cover crops may promote indigenous mycorrhizae or produce chemical compounds that are allelopathic to *R. reniformis* (Wang *et al.*, 2004). It would be beneficial to discover a winter cover crop that would suppress *R. reniformis* in infested cotton fields and promote nematode antagonists to sustain suppression. However, results from this study indicate that commonly used winter cover crops in Alabama do not provide sufficient suppression of *R. reniformis*. In this study, leguminous cover crops such as clover and vetch did not increase *R. reniformis* population densities under natural field conditions. Therefore, in the presence of *R. reniformis*, their use as a winter cover crop should be based solely on their agronomic benefits. No cover crop tested reduced *R. reniformis* population densities more than the fallow treatments.

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