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Effect of Winter Cover Crops on Nematode Population Levels in North Florida[1]

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Abstract: Two experiments were conducted in north-central Florida to examine the effects of various winter cover crops on plant-parasitic nematode populations through time. In the first experiment, six winter cover crops were rotated with summer corn (*Zea mays*), arranged in a randomized complete block design. The cover crops evaluated were wheat (*Triticum aestivum*), rye (*Secale cereale*), oat (*Avena sativa*), lupine (*Lupinus angustifolius*), hairy vetch (*Vicia villosa*), and crimson clover (*Trifolium incarnatum*). At the end of the corn crop in year 1, population densities of *Meloidogyne incognita* were lowest on corn following rye or oat ($P \leq 0.05$), but no treatment differences were observed in year 2. Wheat was a good host to *Paratrichodorus minor,* whereas vetch was a poor host, but numbers of *P. minor* were not lower in vetch-planted plots after corn was grown. The second experiment used a split-plot design in which rye or lupine was planted into field plots with histories of five tropical cover crops: soybean (*Glycine max*), cowpea (*Vigna unguiculata*), sorghum-sudangrass (*Sorghum bicolor* × *S. sudanense*), sunn hemp (*Crotalaria juncea*), and corn. Population densities of *M. incognita* and *Helicotylenchus dihystera* were affected by previous tropical cover crops ($P \leq 0.05$) but not by the winter cover crops present at the time of sampling. Plots planted to sunn hemp in the fall maintained the lowest *M. incognita* and *H. dihystera* numbers. Results suggest that winter cover crops tested did not suppress plant-parasitic nematodes effectively. Planting tropical cover crops such as sunn hemp after corn in a triple-cropping system with winter cover crops may provide more versatile nematode management strategies in northern Florida.

Key words: crop rotation, cropping systems, *Helicotylenchus dihystera, Meloidogyne incognita, Mesocriconema ornata, M. sphaerocephala,* nematode management, *Paratrichodorus minor, Pratylenchulus brachyurus, P. scribneri,* root-knot nematode, sustainable agriculture, weeds.

Cover crops are crops planted between cycles of the main cash crop or intercropped with cash crops to improve soil fertility (Fortuna et al., 2003), soil structure, and water infiltration (Hartwig and Ammon, 2002) and to control soil erosion (Powers and McSorley, 2000), remove excess salt or scavenge soil nutrients that might be leached (Hall et al., 1984) or reduce pathogen (Davis et al., 1996), weed (Hartwig and Ammon, 2002), insect (Hooks and Johnson, 2003), and nematode pests (McSorley, 2001). There is an increasing interest in using cover crops to develop nematode management strategies in sustainable agricultural systems (Barker and Koenning, 1998; McSorley and Porazinska, 2001). Besides the host susceptibility of cover crops to key plant-parasitic nematodes, the choice of cover crop and planting times depend on regional climate. Winter cover crops are used where summer is the main economic cropping season, but tropical cover crops can be planted during summer or fall in temperate or subtropical climates, or planted year round in tropical climates. Many tropical cover crops have suppressed key nematode pests efficiently (Brodie et al., 1970; Good, 1968; McSorley et al., 1994; McSorley and Dickson, 1995; Rodríguez-Kábana et al., 1988, 1989; Sipes and Arakaki, 1997; Wang et al., 2002). Winter cover crops are important especially in warm temperate or subtropical climates, where the main cash crops are usually planted during the warm seasons of the year. Rye (*Secale cereale*) is a common winter cover crop in the southeastern United States and poor host to key nematode pests, e.g., *Meloidogyne* spp. (McSorley and Dickson, 1989; McSorley and Gallaher, 1992; Opperman et al., 1988). However, there is increasing interest in using leguminous cover crops because they can contribute nitrogen to subsequent crops and provide higher-quality forage in a silage production system because of greater protein content (Hartwig and Ammon, 2002).

The current study focuses on improving the winter cover cropping system for plant-parasitic nematode management in north and north-central Florida, which has a warm temperate climate. Six winter cover crops, consisting of grains and legumes, were selected for this research based on their beneficial properties as cover crops and economical value as grain or forage. While determining the susceptibility of cover crops to key plant-parasitic nematodes like *Meloidogyne incognita* is a critical research goal, the ability of the cover crops to compete with weeds was also evaluated. Many weeds are host to plant-parasitic nematodes (Belair and Benoit, 1996; Powers and Pitty, 1993) and, thus, reduce the nematode-suppressive effect of the cover crop.

A second approach to improving the cover cropping system for nematode management in northern Florida is to integrate tropical cover crops with winter cover crops in a triple-cropping system. This is based on the rationale that some tropical cover crops have multiple mechanisms for suppressing plant-parasitic nematodes besides being a poor host. For example, sunn hemp (*Crotalaria juncea*) and sorghum-sudangrass (*Soghum bicolor* x S. *sudanese*) produce allelopathic compounds

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that are toxic to many plant-parasitic nematodes (Mojtahedi et al., 1993; Wang et al., 2001). In addition, double cropping of a nematode-susceptible cash crop after a winter cover crop may result in an unmanageable nematode population (Wang et al., 2002). A triple-cropping system in northern Florida could be implemented by planting a tropical cover crop during late summer or fall after the spring cropping season and before the winter cover crop season (Tubbs et al., 2002). This practice may reduce soil erosion, improve soil fertility (especially when leguminous cover crops are planted), and improve the nematode-suppressive effect by the winter cover crops planted in the following season.

Therefore, the objectives of the current research were to determine the relative effectiveness of several leguminous and non-leguminous winter cover crops to suppress plant-parasitic nematodes and weeds, and to determine the nematode-suppressive effect of the winter cover crops when planted after tropical cover crops.

Materials and Methods

Two experiments were conducted during winter 2000 to fall 2002 at the University of Florida Plant Science Research Center, near Citra, Marion County, Florida. The first experiment was a winter cover crop experiment involving six winter cover crop species. The second experiment combined winter and summer cover crops in a triple-cropping system for nematode management, hereafter referred to as the triple crop experiment. Both of these experiments were repeated over two cropping cycles. The two field sites were planted previously to pasture dominated by bahiagrass (*Paspalum notatum*). The soil was an Arredondo fine sand (a loamy, siliceous, hyperthermic, Grossarenic Paleudults; Ultisol) consisting of 91.3% sand, 3.5% silt, and 5.2 % clay, with an organic matter content of 1.3%, and pH of 5.8. A mixture of *Helicotylenchus dihystera, M. incognita, Mesocriconema sphaerocephala, M. ornata, Paratrichodorus minor, Pratylenchus brachyurus,* and *P. scribneri* were present at this site.

Winter cover crop experiment: In this experiment, winter cover crops were rotated with the summer cash crop, corn (*Zea mays*). On 20 November 2000, six cover crops were planted in a field site of about 12,000 m^2 area. These cover crops were Foundation Fleming wheat (*Triticum aestivum*) seeded at 101 kg/ha, Wrens 96 rye seeded at 101 kg/ha, Chapman oat (*Avena sativa*) seeded at 101 kg/ha, Tifblue 78 lupine (*Lupinus angustifolius*) seeded at 45 kg/ha, hairy vetch (*Vicia villosa*) seeded at 22 kg/ha, and Dixie crimson clover seeded at 11 kg/ha. Lupine, vetch, and crimson clover seeds were treated with appropriate rhizobial inoculum. The experiment was arranged in a randomized complete block (RCB) design with six replications. Individual plots were 334 m^2 (12.2 m x 27.4 m). Aboveground biomass of winter cover crops was harvested for hay in April 2001. Winter cover crops did not receive pesticides but were fertilized with 136.64 kg N, 31.92 kg P_2O_5, 99.68 kg K_2O, 7.84 kg Mg, and 15.68 kg S/ha at planting. Crops were irrigated using an overhead irrigation system as needed.

On 29 May 2001, the experimental corn hybrid Florida IRR was planted in rows 25 cm apart (123,458 seeds/ha) in all plots. Prior to planting corn, winter cover crop residues were plowed down, field plots were sprayed with the pre-emergence herbicide atrazine at 2.46 kg a.i./ha, and carbofuran was applied at the insecticidal rate of 0.49 kg a.i./ha to control lesser cornstalk borer (*Elasmopalpus lignosellus*). Corn received a total per ha of 236.32 kg N, 58.24 kg P_2O_5, 216.16 kg K_2O, 13.44 kg Mg, and 28 kg S split among three applications for each crop. A foliar insecticide, methomyl, was applied several times during summer corn at 0.29 kg a.i./ha, and the field was irrigated using an overhead irrigation as needed. Corn was harvested on 18 September 2001.

This experiment was repeated again beginning in November 2001, when the winter cover crops were planted in the same field plots as in 2000. The hay of the winter cover crops was harvested in May 2002, and corn was planted in June 2002. Crops were maintained in the same manner as the previous year, and corn was harvested in September 2002.

Soil was sampled from each plot at the beginning and end of each crop, and at midseason of cover crops to estimate population densities of nematodes in both years. Six soil cores (2.54-cm-diam., 20-cm depth) from each plot were composited to form a sample. Nematodes were extracted from a subsample of 100 cm^3 of soil by the sieving and centrifugal flotation method (Jenkins, 1964). At harvest of each crop, aboveground plant biomass was removed, dried, and expressed as dry matter yield per ha.

Percentage coverage of cover crops and weeds from each plot was estimated using the 1-to-12 rating scale of Horsfall and Barratt (1945), where 1 = 0%, 2 = 0 to 3%, 3 = 4 to 6%, 4 = 7 to 12%, 5 = 13 to 25%, 6 = 26 to 50% of ground covered, whereas 7 = 26 to 50%, 8 = 13 to 25%, 9 = 7 to 12%, 10 = 4 to 6%, 11 = 0 to 3%, and 12 = 0% of ground not covered. Percentage coverage of total weeds, most commonly occurring weeds, and cover crops were estimated on 8 February and 1 May 2001, and on 14 March and 23 April 2002.

Triple crop experiment: In the triple-crop cropping system, a summer corn crop was grown between the winter and fall cover crop seasons using conservational tillage practices. This experiment was a continuation of a longer-term experiment (Tubbs et al., 2002). In November 2001, the winter cover crops were planted into plots previously planted with five types of tropical cover crops. Two winter cover crops were tested: Wrens 96 rye planted at 67.2 kg/ha and Tift Blue lupine planted at

33.6 kg/ha. The five tropical cover crops were Hinson Long Juvenile soybean (*Glycine max,* 1,040,000 seeds/ha), Iron Clay cowpea (1,040,000 seeds/ha), Cow Chow sorghum-sudangrass (*Sorghum bicolor x S. sudanense,* 1,040,000 seeds/ha), Tropic Sun sunn hemp (642,000 seeds/ha), and Florida IRR corn hybrid (123,000 seeds/ha). These tropical cover crops were planted in August 2001 and biomass was harvested on 3 October 2001 prior to winter cover crop planting. The experiment was arranged in a split-plot design, with two winter cover crops as main plots and five previous tropical cover crops as sub plots, and six replications. Individual main (winter cover crop) plots were 10.7 × 24.4 m^2 whereas each subplot (tropical cover crop) was 29.62 m^2 in size.

On 21 March 2002, the aboveground biomass of winter crops was harvested, leaving roots and stubble with height of about 5 cm. The field was prepared for the summer corn crop by killing weeds and crop residues with 0.92 kg a.i. glyphosate/ha. Florida IRR hybrid corn was no-till planted in rows 25 cm apart (123,000 seeds/ha). Corn was harvested on 28 June 2001, and the field was prepared for fall crops after the site was sprayed with glyphosate (0.92 kg a.i./ha) and then no-tilled with a Tye drill seed planter (Tye Farm Machinery, Ames, IA). Each main plot was split into five subplot tropical cover crop treatments as in August 2001. However, due to volunteer corn seedlings germinating in all the tropical cover crop subplots, the experiment was terminated at the end of the corn growing seasons. Winter cover crops and corn were fertilized as described in the winter cover crop experiment. Tropical cover crops were fertilized in the same manner as the corn crop. Pests were managed as described previously, and the field was irrigated with overhead irrigation as needed. Soil was sampled from each plot at the end of each crop to estimate population densities of nematodes.

Nematode counts were log-transformed ($\log_{10}[x+1]$) and analysis of variance performed on transformed values using the ANOVA procedure in Statistical Analysis System software (SAS Institute, Cary, NC); nontransformed means are presented in tables. In the winter cover crop experiment, nematode data collected after winter crop and summer corn, as well as weed data were subjected to ANOVA in RCB design at each sampling time. In the triple crop experiment, data collected after the winter crop were analyzed as a split-plot ANOVA with winter cover crop treatment as the main plot and the fall cover crop treatment as the subplot. Data collected from summer corn crop were subjected to one-way ANOVA. Weed or crop coverage data on the Horsfall-Barrett scale were transformed to midpoints of the percentage categories they represent prior to ANOVA (Campbell and Madden, 1990). Weed data with values less than 20% were square root ($\sqrt{x}$) transformed, whereas values with wide range of percentages were arcsin-square root ($\sin^{-1}\sqrt{x}$) transformed to fit normal distribution (Steel and Torrie, 1980) before ANOVA and means separations were performed. All means were separated by Waller-Duncan *k*-ratio ($k = 50$) *t*-test where appropriate; untransformed means are presented in tables.

Results

Effects of winter cover crops on weeds: Among the winter cover crops tested, the cereal cover crops (wheat, rye, and oat) outcompeted weeds much faster and more efficiently than the leguminous cover crops (lupine, hairy vetch, and crimson clover) ($P \leq 0.05$) early in the winter cover-cropping season in 2001 (Table 1). Although lupine and hairy vetch eventually out-competed weeds with total ground coverage not different from the cereals at the end of the winter cropping season on 1 May 2001, crimson clover still had poor establishment, with greater weed coverage and lower crop coverage than the other treatments ($P \leq 0.05$) (Table 1). The most common weeds occurring during this growing season were miscellaneous grasses, fumewort (*Corydalis sempervirens*), Carolina geranium (*Geranium caroliniarum*), henbit (*Lamium amplexicaule*), and swinecress (*Coronopus didymus*), but coverage by each of the last three weeds averaged less than 2% (data not shown). Similar results were observed in the second year when the cereal cover crops had greater ground coverage than the leguminous cover crops ($P \leq 0.05$) by mid season of the crop (14 March 2002) (Table 1). However, at the end of winter cover crop on 23 April 2002, wheat was infected with rust (*Puccinia* sp.), which resulted in the poorest crop coverage (Table 1). Unlike 2001, crimson clover became well established in 2002, and coverage did not differ ($P > 0.05$) from rye and oat at the end of the winter cropping season on 23 April 2002 (Table 1). More weed species occurred in 2002 than in 2001. Additional weeds present were cudweed (*Gnaphalium uliginosum*), sowthistle (*Sonchus* sp.), and Virginia pepperweed (*Lepidium virginicum*).

Effects of winter cover crops on plant-parasitic nematodes: Initial population densities of plant-parasitic nematodes were small prior to winter cover crop planting in 2000 (Table 2). Among the plant-parasitic nematodes present were root-knot (*M. incognita* race 1), stubby-root (*Paratrichodorus minor*), spiral (*Helicotylenchus dihystera*), and ring (*Mesocriconema* spp.) nematodes, with lesion (*Pratylenchus brachyurus*) occurring later. Population densities of *M. incognita* remained low throughout the winter cover-cropping season in 2000-2001. However the number increased drastically after a susceptible host, corn, was planted (Table 2). At the end of the corn season, numbers of *M. incognita* were greater in plots planted previously to lupine or vetch than in plots planted previously to rye and oat (Table 2). Rye and oat plots maintained the smallest numbers of *M.*

TABLE 1. Percentage ground coverage of crops and weeds during the winter cover crop growing season in Citra, Florida, 2001 and 2002.

Winter crop	Cudweed	Sowthistle	Pepperweed	Fumewort	Grasses	Total weeds	Crop
			8 Feb 2001				
Wheat	0 a	0 a	0 a	0.5 ab	0 a	1.5 c	94.8 a
Rye	0 a	0 a	0 a	0.2 b	0 a	0.2 c	99.8 a
Oat	0 a	0 a	0 a	2.0 ab	0 a	1.2 bc	95.7 a
Lupine	0 a	0 a	0 a	5.1 ab	0 a	17.9 ab	50.0 b
Vetch	0 a	0 a	0 a	6.1 a	0 a	20.5 a	49.3 b
Crimson clover	0 a	0 a	0 a	4.8 ab	0 a	12.1 a	32.4 b
			1 May 2001				
Wheat	0 b	0 a	0 a	0 a	0 b	0 b	100.0 a
Rye	0 b	0 a	0 a	0 a	0 b	0 b	100.0 a
Oat	0 b	0 a	0 a	0 a	0 b	0 b	100.0 a
Lupine	0 b	0 a	0 a	0 a	0 b	1.5 b	99.4 a
Vetch	0 b	0 a	0 a	0 a	0.8 b	1.0 b	99.5 a
Crimson clover	7.9 a	0 a	0 a	0 a	4.5 a	19.5 a	86.8 b
			14 March 2002				
Wheat	2.8 abc	0.2 b	1.0 bc	0.2 ab	0 a	—	98.0 ab
Rye	0.8 bc	0 b	0.2 c	0 b	0 a	—	100.0 a
Oat	0.2 c	0.2 ab	0.2 c	0.2 ab	0 a	—	99.5 a
Lupine	3.8 ab	1.2 ab	11.1 a	2.2 a	0 a	—	82.7 c
Vetch	4.8 a	1.5 a	4.0 ab	1.5 a	0 a	—	88.7 c
Crimson clover	2.5 ab	0.5 ab	5.3 ab	0.5 ab	0 a	—	93.4 bc
			23 April 2002				
Wheat	16.2 a	1.0 ab	1.5 a	2.2 a	0.2 a	—	92.8 d
Rye	1.8 c	0.2 b	0.2 bc	0 b	0 a	—	99.4 a
Oat	0.2 c	0.2 b	0 c	0 b	0 a	—	99.5 a
Lupine	2.0 bc	1.2 a	0.8 abc	0.2 b	0.2 a	—	98.2 bc
Vetch	4.2 b	1.2 a	1.8 a	1.2 a	0.2 a	—	96.8 c
Crimson clover	0.5 c	1.2 a	1.0 ab	0.8 ab	0.5 a	—	98.7 ab

Data are means of six replications. On each sampling date, means in a column followed by the same letters were not different according to Waller-Duncan *k*-ratio ($k = 100$) *t*-test at $P \leq 0.05$ based on square root transformation ($\sqrt{x}$) for cudweed, sowthistle, pepperweed, fumewort, and grasses, or $\sin^{-1}\sqrt{x}$ transformation (for crop and total weeds). Untransformed means are reported.

incognita at the end of winter in 2002 ($P \leq 0.05$). However, when corn was planted again in year 2002, numbers of *M. incognita* increased in all treatments and were similar ($P > 0.05$) (Table 2).

The stubby-root nematode *P. minor* was also affected by these winter cover crops treatments. Numbers of *P. minor* were greatest in wheat and fewest in hairy vetch during the winter cover-cropping seasons in both 2001 and 2002 ($P \leq 0.05$) (Table 2). However, this trend did not persist after corn was planted in both years (Table 2). These winter cover crops did not affect other plant-parasitic nematodes such as spiral, lesion, and ring nematodes except on 1 May 2001, when numbers of ring nematodes were greatest in wheat but fewest in crimson clover ($P \leq 0.05$) (Table 2).

Effects of winter cover crop on nematodes in triple-cropping system: The low temperatures in the winter kept populations of *M. incognita* low throughout the winter cover crop season. No differences in number of *M. incognita* were observed between rye and lupine plots ($P > 0.05$). However, nematode-suppressive effect of previous summer tropical cover crop treatments could still be differentiated at the end of winter cropping season. Plots planted previously to sunn hemp before rye or lupine had fewer numbers of *M. incognita* than those planted to soybean or corn ($P \leq 0.05$) (Table 3), although *M. incognita* abundances ($\leq 2/100$ cm^3) were generally small among all the treatments. No interaction ($P > 0.05$) between winter cover crop and tropical cover crop effects were observed on population densities of *M. incognita* at the end of winter cover cropping season. After corn was planted into these plots, no differences among winter cover crops were observed.

Rye was a relatively good host to *P. minor* compared to lupine ($P \leq 0.05$) (Table 3). However, this difference did not persist until the corn harvest. Conversely, previous tropical cover crop treatments in fall did not affect *P. minor* population densities in winter. Numbers of *H. dihystera* were unaffected by winter cover crop but were smaller in plots planted previously to sunn hemp and cowpea as compared to corn and soybean ($P \leq 0.05$) (Table 3). Other plant-parasitic nematodes were not affected by these cover crop treatments.

Discussion

Winter cover crops: Among the winter cover crops evaluated in the winter cover crop experiment, the cereal cover crops, except wheat, decreased numbers of *M. incognita* better than the leguminous cover crops during the winter season. Many commercial cultivars of wheat have been reported as hosts of *M. arenaria, M. incognita,* and *M. javanica* (Crittenden, 1961; Opperman et al., 1988; Sasser, 1954; Thomason, 1962), al-

TABLE 2. Population densities of plant-parasitic nematodes in 2 years of winter cover crop-corn rotation, Citra, Florida, 2000–2002.

Winter crop	Nematodes/100 cm^3 soil				
	Root-knot	Stubby root	Spiral	Lesion	Ring
12 November 2000 (Pi)					
Wheat	0 a	1 a	0 a	0	5
Rye	1 a	8 a	0 a	0	3
Oat	5 a	1 a	1 a	0	5
Lupine	0 a	0 a	3 a	0	21
Vetch	0 a	0 a	1 a	0	4
Crimson clover	0 a	0 a	2 a	0	12
8 March 2001 (mid season of winter crop)					
Wheat	2 a	41 a	0 a	0	27
Rye	0 a	3 bc	1 a	0	22
Oat	0 a	3 bc	0 a	0	7
Lupine	1 a	2 bc	6 a	0	12
Vetch	0 a	1 c	1 a	0	12
Crimson clover	0 a	8 b	1 a	0	7
1 May 2001 (Pf of winter crop)					
Wheat	2 a	16 a	0 a	0	29 a
Rye	0 a	5 abc	0 a	0	17 ab
Oat	0 a	3 bc	2 a	0	13 abc
Lupine	0 a	2 bc	0 a	0	8 bc
Vetch	3 a	1 c	0 a	0	12 abc
Crimson clover	4 a	8 ab	0 a	0	6 c
18 September 2001 (Pf of corn)					
Wheat	145 ab	42 a	5 a	3 a	46 a
Rye	41 bc	69 a	12 a	12 a	48 a
Oat	41 c	32 a	17 a	2 a	70 a
Lupine	267 a	48 a	8 a	5 a	86 a
Vetch	215 a	31 a	12 a	8 a	48 a
Crimson clover	225 ab	51 a	7 a	19 a	33 a
14 March 2002 (mid season of winter crop)					
Wheat	20 a	193 a	1 a	0 a	4 a
Rye	5 a	54 bcd	2 a	0 a	11 a
Oat	24 a	91 b	5 a	0 a	10 a
Lupine	26 a	48 cd	2 a	0 a	12 a
Vetch	12 a	33 d	10 a	0 a	11 a
Crimson clover	13 a	56 bc	1 a	1 a	11 a
16 April 2002 (Pf of winter crop)					
Wheat	15 ab	47 a	3 a	0 a	16 a
Rye	3 c	30 ab	1 a	1 a	8 a
Oat	8 c	30 ab	9 a	0 a	14 a
Lupine	12 abc	25 ab	5 a	2 a	24 a
Vetch	44 a	17 b	3 a	0 a	17 a
Crimson clover	8 abc	22 ab	0 a	0 a	14 a
1 October 2002 (Pf of corn)					
Wheat	187 a	5 ab	12 a	26 a	12 a
Rye	155 a	6 ab	2 a	19 a	4 a
Oat	202 a	2 b	2 a	4 a	2 a
Lupine	267 a	3 b	1 a	9 a	4 a
Vetch	264 a	10 a	2 a	14 a	3 a
Crimson clover	162 a	9 a	2 a	43 a	2 a

Data are means of six replications. On each sampling date, means in a column followed by the same letters were not different according to Waller-Duncan *k*-ratio (k = 100) *t*-test at $P \leq 0.05$ based on the log-transformed value.

TABLE 3. Population densities of plant-parasitic nematodes during winter of 2002 in a triple-cropping (winter cover crop-corn-summer cover crop) system, Citra, Florida.

Cover crop	nematodes/100 cm^3 soil				
	Root-knot	Stubby root	Spiral	Lesion	Ring
21 March 2002 (Pf of winter cover crop)					
Winter					
Rye	2[a]a	61 a	14 a	1 a	3 a
Lupine	2 a	28 b	10 a	1 a	4 a
Previous Summer					
Soybean	2 a[b]	50 a	27 a	0 a	5 a
Cowpea	2 ab	56 a	3 c	0 a	2 a
Sorghum	2 ab	42 a	11 bc	2 a	7 a
Sunn hemp	0 b	40 a	5 c	0 a	2 a
Corn	2 a	35 a	12 ab	1 a	3 a
8 Aug 2002 (Pf of corn)					
Winter					
Rye	310 a	4 a	31 a	36 a	23 b
Lupine	237 a	3 a	30 a	85 a	26 a

[a]Data are means of 30 replications for winter cover crop effect. Means in a column followed by different letters are different according to analysis of variance for a 2 × 5 (winter × summer) split-plot design at $P \leq 0.05$ based on the log-transformed value.

[b]Data are means of 12 replications for summer cover crop effect. Means in a column followed by different letters are different according to Waller-Duncan *k*-ratio (k = 100) *t*-test at $P \leq 0.05$ based on the log-transformed value.

though a number of cultivars had been reported previously as resistant to *M. incognita* (Barker, 1974). In addition, due to the poor establishment of wheat in the second winter, occurrence of weeds in wheat plots might have supported larger populations of *M. incognita*. Following the 2000-2001 winter season, population densities of *M. incognita* were too small (average 1/100 cm^3 soil) to differentiate host susceptibility among the winter cover crops. However, treatment effects against *M. incognita* were reflected after numbers were magnified following planting of corn in spring. Minimal development of *M. incognita* would be expected in winter. Roberts et al. (1981) demonstrated that population development of *M. incognita* on wheat varies according to temperature. Even though *M. incognita* can develop at lower temperature, 18 °C was the activity threshold for *M. incognita* for the nematode to migrate. Therefore, delaying planting of wheat until soil temperature is below 18 °C was suggested for *M. incognita* management (Roberts et al., 1981).

In the winter cover crop experiment, numbers of *M. incognita* from previously rye- and oat-planted corn plots were smaller than those from plots planted previously to lupine or vetch. Results with crimson clover were intermediate and variable, probably due to the poor establishment of this crop. In the second winter (2001-2002), numbers of *M. incognita* increased (average 15/100 cm^3 soil) above the previous winter, thus allowing differentiation of host susceptibility among the cover crops at the end of the winter cover crop season. These results are consistent with previous studies showing that related rye and Florida-developed oat cultivars are poor hosts to *M. incognita* (McSorley and Gallaher, 1991; McSorley et al., 1994; Opperman et al., 1988) and reduced *M. incognita* numbers below those in the fallow treatment (Minton, 1992; Minton and Parker, 1987). Crimson clover and hairy vetch were known previously to increase *M. incognita* over the winter (McSorley and Dickson, 1989; McSorley and Gallaher, 1991).

Johnson and Motsinger (1989) first suggested that reproduction of *Meloidogyne* spp. on rye in winter might be limited by low temperature. Later, McSorley (1994) studied the relationships between initial and final population densities of *Meloidogyne* spp. in plots planted to rye and concluded that rye was ineffective in decreasing population densities of *M. arenaria* but may maintain existing low densities. In this experiment, when corn was planted in spring 2002, warm temperatures and susceptible host allowed *M. incognita* populations to increase to an average number of 206/100 cm^3 of soil across the treatments. Therefore, by the end of summer, favorable effects from the rotation of rye and oat had disappeared.

Results from the triple crop experiment, together with our previous study (Wang et al., 2002), indicate that commonly used winter cover crops in Florida provide insufficient nematode suppression. Even when a poor host to *M. incognita,* such as rye, is used, the nematode population density will increase substantially when a suitable host, such as corn, is planted. Therefore, additional benefits of using legumes as winter cover crops should not be ignored based on their susceptibility to *M. incognita.* Timper et al. (2003) found that Cabaha White vetch (*V. sativa*) and Cherokee red clover (*Trifolium pratense*) were leguminous winter cover crops that produced less than 10% and 25% of the number of *M. incognita* eggs, respectively, as compared to hairy vetch in Georgia. Additional leguminous cover crops that are suitable to grow in northern Florida need to be evaluated for their susceptibility to *M. incognita.*

Although rye, in general, maintained smaller numbers of *M. incognita* than the leguminous cover crops, it allowed more reproduction of *P. minor* than on hairy vetch. However, this effect of winter cover crop on *P. minor* did not persist when corn was planted.

Although long-term plant-parasitic nematode suppression by the winter cover crops evaluated is not promising, the use of these winter cover crops may be encouraged due to their weed-suppressive properties. Rye and oat outcompeted weeds in both years consistently. Previously, rye and hairy vetch grown as winter cover crops followed by mulching also efficiently suppressed weeds in many crops (Mangan et al., 1995; Putnam et al., 1983).

Triple-cropping system: Results from the triple-cropping system lead us to reject our hypotheses that planting tropical cover crops during fall can improve the nematode-suppressive effect of the winter cover crop because no interactions were observed between winter and fall cover crop treatments on *M. incognita* numbers at the end of winter cover cropping season. However, planting Hinson Long Juvenile soybean, Iron Clay cowpea, Cow Chow sorghum-sudangrass, or Tropic Sun sunn hemp in fall suppressed *M. incognita* populations after the fall season as compared to planting corn continuously (Wang et al., 2002). Here, planting sunn hemp in fall maintained an undetectable level of *M. incognita* in the following winter cropping season. Further study is needed to examine the effect of tropical cover crops on corn planted in the following year, and the effect of tropical cover crops in suppressing *Meloidogyne* spp. after a second year of corn when the nematode pressure will be greater. The triple-cropping system might be better evaluated in a conventional tillage system to avoid volunteer cover crops or corn growing in the wrong season.

We conclude that commonly used winter cover crops in Florida did not suppress plant-parasitic nematodes, especially *Meloidogyne* spp., over time in cropping systems. However, weed suppression and green manure (for leguminous cover crops) properties of cover crops may encourage their planting during the winter. Using crop rotation for nematode management in this region could incorporate tropical cover crops that are more efficient for nematode suppression in a triple-cropping system to improve nematode-suppressive effects from cover cropping.

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