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Effects of a Resistant Corn Hybrid and Fenamiphos on *Meloidogyne incognita* in a Corn-Squash Rotation[1]

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Abstract: The efficacy of a double-cross corn (*Zea mays*) hybrid (Old Raccoon selection X T216) X (Tebeau selection X Mp 307) resistant to *Meloidogyne incognita* as a rotational crop, and fenamiphos treatment for management of root-knot nematode (*M. incognita* race 1) in squash (*Cucurbita pepo* var. melopepo) was evaluated in field tests during 1996 and 1997. Numbers of *M. incognita* in the soil and root-gall indices were lower on the resistant hybrid than on a commercial cultivar DeKalb DK-683. Treatment means across both corn entries had lower root-gall indices following fenamiphos treatment. In soil collected 2 September 1997, there were more colony-forming units (cfu) per gram of oven-dried soil of *Pythium* spp. from plots planted to DK-683 treated with fenamiphos than in untreated plots (88 vs. 59 cfu). Some corn plots had individual plants with 10% to 15% of the crown and brace roots decayed, but no differences due to fenamiphos treatment. Lodging of stalks was 40% to 50% more in the double-cross hybrid than in DK-683. Yield was greater from DK-683 than the double-cross hybrid. Based on cultivar means across fenamiphos treatments and fenamiphos treatment means across cultivars, root-gall indices and yield of squash were significantly lower following the double cross hybrid than DK-683 and in fenamiphos-treated plots than in untreated plots of squash. Yield of squash was not affected by at-planting treatment with fenamiphos on the preceding crops of corn. Nematode resistance must be transferred into the elite materials of commercial seed companies to reach its full potential as a nematode management strategy.

Key words: corn, crop rotation, *Cucurbita pepo,* fenamiphos, maize, management, *Meloidogyne incognita,* nematicide, nematode, *Pythium,* resistance, *Rhizoctonia solani,* root-knot nematode, squash, stalk rot, *Zea mays.*

Numerous strategies can be beneficial for reducing population densities of plant-parasitic nematodes. Two alternatives that can be particularly applicable in the southeastern United States are crop rotation (Johnson, 1985; McSorley and Gallaher, 1992) and resistant cultivars (Noling and Becker, 1994; Young, 1998). Crop rotation has been particularly important in minimizing nematode populations and increasing yields in some cropping systems (Johnson, 1982, 1985). The use of nematode-resistant crop cultivars is often viewed as the foundation of a successful integrated nematode-management program on many high-value crops (Noling and Becker, 1994). The availability of resistant cultivars is often the only economic resource for nematode management available to the grower of low-value crops (Rodríguez-Kábana, 1992).

Corn (*Zea mays*) is a host for several species of root-knot nematodes (*Meloidogyne* spp.) (Baldwin and Barker, 1970). Corn is an important crop rotated in the southeastern United States. Host plant resistance in corn cultivars is needed in rotations or double-cropping systems to manage root-knot nematode populations effectively. Variability in root-knot nematode resistance exists within corn cultivars, hybrids, genotypes, and inbreds (Aung et al., 1990; Baldwin and Barker, 1970; Windham and Williams, 1987, 1988a, 1988b, 1994). Progress has been made in recent years in developing corn germplasm with resistance to root-knot nematodes (McSorley and Gallaher, 1997; Williams and Windham, 1998; Windham, 1998). Corn hybrids developed from root-knot nematode-resistant germplasm were successfully used in Florida to suppress population densities of *M. incognita* (Kofoid & White) Chitwood (McSorley and Dickson, 1995). The authors suggested that such hybrids may be effective in maintaining low

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nematode population densities. There is no information available on the effects of resistant corn hybrids on population densities of *M. incognita* or soilborne fungi in cropping systems. The objective of this study was to determine the effects of resistant corn and fenamiphos treatment on *M. incognita* race 1, soilborne fungal pathogens, and crop response in a corn-squash (*Cucurbita pepo* var. *melopepo*) rotation.

Materials and Methods

The 2-year study was initiated in 1996 on the Blackshank Farm at the Coastal Plain Experiment Station, Tifton, Georgia. The experimental area was planted to soybean (*Glycine max* (L.) Merr.) cv. Coker 6738 in 1995 followed by hairy vetch (*Vicia villosa* Roth) as a winter cover crop. The soil was a Dothan series (fine-loamy, siliceous, thermic Plinthic Paleudult; 87% sand, 7% silt, and 6% clay; < 1% organic matter; pH 6.1 to 6.3) infested with *M. incognita* race 1, *Pythium* spp., and *Rhizoctonia solani* (Kühn). The soil in all plots was disk-harrowed twice, plowed 25 to 30 cm deep with a moldboard plow, and shaped into beds 1.8 m wide and 10 to 15 cm high. Plots of corn were single beds 1.8 m wide × 15.2 m long with two rows 91 cm apart on each bed. Fallow alleys 3.1 m wide separated blocks.

The experiment was a randomized complete block in a split-plot design with five replicates. Whole-plot treatments were corn cultivars DeKalb DK-683 (susceptible) and an *M. incognita*-resistant double-cross (DC) hybrid (Old Raccoon selection × T216) × (Tebeau selection × Mp 307) developed by W. P. Williams and G. L. Windham at Mississippi State University, Mississippi. The Old Raccoon and Tebeau selections × Mp 307 are resistant to *M. incognita* (McSorley and Dickson, 1995; Windham and Williams, 1994). Subplots were two beds treated with fenamiphos (formulated as Nemacur 15G) at 2.2 kg a.i./ha in a 30-cm band at planting and two untreated beds. Squash sub-plots were two beds (one treated with fenamiphos as described for corn and one bed untreated) following both treated and untreated corn. This design allowed all possible treatment combinations for squash following each cultivar of corn. Squash was used because the crop is highly susceptible to root-knot nematodes (Johnson, 1998). Fertilizers were applied to corn and squash according to the recommendations of the University of Georgia Cooperative Extension Service based on soil tests (Plank, 1989).

Butylate + safener at 3.8 kg a.i./ha was incorporated 25 cm deep with a tractor-powered rototiller for weed control. Corn was planted in two rows spaced 91 cm apart in different beds on 16 April 1996 and 12 March 1997. Atrazine was applied as a post-emergence spray broadcast at 1.5 kg a.i./ha in 234 liters of water for weed control.

Squash cv. Goldie Hybrid was planted on 5 September 1996 and Dixie Hybrid on 25 August 1997. Ethalfluralin was applied at 0.8 kg a.i./ha broadcast in 187 liters of water immediately after seeding squash for weed control. Chlorothalonil was applied at 2.5 kg a.i./ha in 374 liters of water on 7 to 10-day intervals for control of foliar fungal pathogens. Imidacloprid and esfenvalerate were applied at 0.3 and 0.5 kg a.i./ha, respectively, in 374 liters of water as needed for insect control.

Ten soil cores (2.5-cm diam. × 15 cm deep) for nematode assay were collected from corn plots in May, June, July, and August and from squash plots in September and October each year. Soil samples from each plot were mixed thoroughly, and a 150-cm^3 subsample was processed by a centrifugal flotation method (Jenkins, 1964). Soil samples, collected on 1 November 1996 and 3 April and 2 September 1997, were assayed for *Rhizoctonia solani* and *Rhizoctonia* spp. on a modified tannic-acid benomyl (TAB) (Sumner and Bell, 1982) medium with a multiple-pellet soil sampler (Henis et al., 1978), and for *Pythium* spp. on P5ARP medium (Jeffers and Martin, 1986). Selected colonies from P5ARP medium were transferred to other media and identified. On 2 May 1997, four corn plants in each plot in the 6 to 8-leaf stage were dug, the root systems washed with tap water, and the percentage root discoloration and decay estimated. The number of crown and brace roots with reddish-brown lesions or terminal decay induced by *R. solani* anastomosis group (AG) 2-2 were counted on each plant (Sumner and Bell, 1982). Root sections (1 to 2 cm) with lesions on crown and brace roots were excised, rewashed 5 to 10 minutes in running tap water, blotted dry on sterile filter paper, and incubated at 26 °C on petri plates of TAB. Cultures of *R. solani* growing from the roots were identified to AG by morphological comparison with known tester isolates of *R. solani* from corn (Sumner and Bell, 1982).

Roots of 10 randomly selected corn plants from each plot were dug and rated for percentage galled by *M. incognita* on a 1-to-5 scale: 1 = no galling, 2 = 1% to 25%, 3 = 26% to 50%, 4 = 51% to 75%, and 5 = 76% to 100% (Barker et al., 1986). Immediately before harvest, the number of lodged corn plants was counted and recorded. When the moisture content of grain declined to approximately 16%, corn was harvested with a combine and weighed.

Roots of two randomly selected squash plants from each plot were dug in October and rated for galling as described for corn. Four plants from each plot were assayed in November. Squash was harvested three times each week from 18 October through 5 November 1996 and from 1 through 27 October 1997. Fruits were separated into marketable and cull categories, then counted and weighed. All data were analyzed with ANOVA followed by mean separation with Duncan's multiple range test (SAS Institute, Cary, NC).

Results

At the beginning of the experiment (April 1996), numbers of *M. incognita* J2 in the soil were >300/150 cm^3 soil and not different among plots assigned to various treatments (Table 1). No significant ($P = 0.05$) variety-by-year or treatment-by-year interactions occurred; therefore, J2 data were pooled over years. Numbers of J2 were consistently lower in plots of the DC hybrid than in plots of DK-638 in June, July, and August each year. During July, peak population densities of *M. incognita* J2 on DK-683 were 13 times greater than those on the DC hybrid. Population densities of J2 in fenamiphos-treated and untreated plots of corn did not differ. Root-gall indices were generally lower on the DC hybrid than on DK-683. Root-gall indices on corn from fenamiphos-treated plots tended to be lower than those in untreated plots, but differences were significant only on DK-

TABLE 1. Effects of cultivars and fenamiphos treatment on *Meloidogyne incognita* second-stage juveniles (J2) in soil, root-gall indices, lodging, and yield of corn during a 2-year experiment at Tifton, Georgia.

Cultivar[a]	Nematicide treatment	J2/150 cm^3 soil					Root-gall index[c]		Lodging index[d]		Yield (kg/ha)	
		April 1996	May	June	July	August	1996	1997	1996	1997	1996	1997
DK-683	−	708	11	84 a	166 a	97 a	1.55 a	2.08 a	1.00 b	1.00 b	6,939 b	8,054 a
DK-683	+	548	36	55 a	154 a	128 a	1.40 ab	1.65 b	1.00 b	1.00 b	7,253 a	8,334 a
DC	−	306	14	25 b	15 b	57 b	1.20 bc	1.00 c	2.80 a	3.90 a	4,301 c	4,188 b
DC	+	368	25	17 b	9 b	64 b	1.13 c	1.00 c	2.90 a	3.60 a	4,427 c	4,584 b
				Cultivar means across treatments								
DK-683			24	70 a	160 a	113 a	1.48 a	1.87 a	1.00 b	1.00 b	7,096 a	8,194 a
DC			20	21 b	12 b	61 b	1.17 b	1.00 b	2.85 a	3.75 a	4,364 b	4,386 b
				Treatment means across cultivars								
	−		13	55	91	77	1.38 a	1.54 a	1.90	2.45	5,620 b	6,121 b
	+		31	36	82	96	1.27 b	1.32 b	1.95	2.30	5,840 a	6,459 a

Data are means of five replications. J2 data were pooled over years. Within each table subdivision, means in columns followed by the same lowercase letter or no letters are not different ($P \leq 0.05$) according to Duncan's multiple range test.

[a]DK-683 = DeKalb DK-683; DC is the double cross (old Raccoon selection X T216) X (Tebeau selection X Mp 307).

[b]Granular fenamiphos applied at 2.2 kg a.i./ha in a 30.5-cm band at planting (+) and untreated (−).

[c]1-to-5 scale: 1 = no galls, 2 = 1% to 25%, 3 = 26% to 50%, 4 = 51% to 75%, and 5 = 76% to 100% of roots galled.

[d]1-to-5 scale: 1 = no lodging, 2 = 1% to 25%, 3 = 26% to 50%, 4 = 51% to 75%, and 5 = 76% to 100% of plants lodged.

683 in 1997. However, treatment means across cultivars had lower root-gall indices in the fenamiphos treatment than in untreated controls.

Lodging of stalks was more severe in the DC hybrid than in DK-683 but was not affected by fenamiphos treatment (Table 1). Population densities of *Pythium* spp. in soil did not differ ($P = 0.05$) between treatments on 1 November 1996 and 3 April 1997. In soil collected on 2 September 1997, there was a significant ($P = 0.05$) cultivar × fenamiphos interaction in populations of *Pythium* spp. More colony-forming units per gram of oven-dried soil (cfu) of *Pythium* spp. occurred in plots planted to DK-683 treated with fenamiphos than in untreated plots (88 and 59 cfu, respectively). No differences were found between nematicide-treated and untreated plots in population densities of *Pythium* spp. recovered from plots planted to the DC hybrid. Forty percent of the colonies identified from soil assays were *P. irregulare;* other colonies were not identified to species.

Rhizoctonia spp. were rarely detected in any assays. *Rhizoctonia solani* AG-4 was detected in soil infrequently in 1996 and was not detected in 1997. In some corn plots, individual plants had 10% to 25% of their crown and brace roots decayed. However, 88% of the plants in the experiment had no crown or brace root decay. No differences were found among the treatments ($P = 0.05$). *Rhizoctonia solani* AG2-2 was isolated frequently from roots with symptoms of crown and brace root rot. There was very little decay of fibrous primary and secondary roots and no isolation of *Rhizoctonia* spp. from lesions.

Corn yield was greater for DK-683 than the DC hybrid (Table 1). Fenamiphos-treated DK-683 plots had higher yields than untreated plots in 1996. Means across cultivars had an increase in yield from fenamiphos treatment.

Numbers of *M. incognita* J2 were lower in squash following the DC hybrid than DK-683 in September but not in October each year ($P = 0.10$) (Table 2). Population densities of

TABLE 2. Effects of corn cultivars and fenamiphos treatment on *Meloidogyne incognita* second-stage juveniles (J2) in soil, root-gall indices, and yield of squash during a 2-year corn-squash rotation at Tifton, Georgia.

					Root-gall indices[c]					
	Fenamiphos[b]		J2/150 cm^3 soil		1996		1997		Yield (kg/ha)	
Cultivar[a]	Corn	Squash	September	October	October	November	October	November	1996	1997
DK-683	–	+	80 a	27	3.92 b	4.38 a	3.70 a	4.38 a	4,919 a	12,201 b
	–	–	58 a	20	4.50 a	4.56 a	3.90 a	4.52 a	4,594 b	12,087 c
DK-683	+	+	50 a	26	4.04 b	4.22 b	2.90 b	4.38 a	4,777 a	13,067 a
	+	–	50 a	27	4.60 a	4.66 a	4.00 a	4.96 a	4,025 c	12,042 c
DC	–	+	2 b	14	3.50 b	3.92 b	2.20 b	3.08 b	4,208 c	11,599 d
	–	–	0 b	21	4.54 a	4.48 a	2.10 b	3.56 b	3,822 d	11,892 d
DC	+	+	20 b	23	3.14 b	3.64 b	2.80 b	3.32 b	4,574 b	11,441 d
	+	–	4 b	5	4.20 a	4.26 b	2.70 b	3.34 b	3,069 d	11,449 d
Cultivar means across treatments										
DK-683			60 a	25	4.27 a	4.46 a	3.63 a	4.56 a	4,579 a	12,349 a
DC			7 b	16	3.85 b	4.08 b	2.45 b	3.33 b	3,918 b	11,595 b
Treatment means across cultivars										
	–		35	21	4.12	4.34	2.98	3.89	4,386	11,945
	+		31	20	4.00	4.20	3.10	4.00	4,111	12,000
		+	38	23	3.65 b	4.04 b	2.90 b	3.79 b	4,620 a	12,077 a
		–	28	18	4.46 a	4.49 a	3.18 a	4.10 a	3,878 b	11,868 b

Data are means of five replications. J2 data were pooled over years. Within each table subdivision, means in columns followed by no letters or similar lowercase letters are not different ($P = 0.10$), or for yield means ($P = 0.05$), according to Duncan's multiple range test.

[a] DK-683 = DeKalb DK-683; DC is the double cross (old Raccoon selection X T216) X (Tebeau selection X Mp 307).

[b] Granular fenamiphos applied at 2.2 kg a.i./ha in a 30.5-cm band at planting (+) and untreated (–).

[c] 1-to-5 scale: 1 = no galls, 2 = 1% to 25%, 3 = 26% to 50%, 4 = 51% to 75%, and 5 = 76% to 100% of roots galled.

J2 in the soil were not affected by fenamiphos treatment. Corn cultivar means across all treatments had lower root-gall indices on squash following the DC hybrid than DK-683 ($P = 0.10$).

Root-gall indices were lower ($P = 0.10$) in fenamiphos-treated squash regardless of previous treatment or corn cultivar in October 1996 (Table 2). Root-gall indices in squash were also lower following treated DK-683 in November 1996 and October 1997, and following untreated DC hybrid in November 1996. Cultivar means across all treatments show that root-gall indices were lower following the DC hybrid than DK-683 on all sampling dates. Treatment means across cultivars indicate that an at-plant application of fenamiphos on corn did not have a residual effect on root-gall indices on subsequent squash. Also, treatment means across cultivars showed that root-gall indices of squash in fenamiphos-treated plots were lower than those in untreated plots ($P = 0.10$) on all sampling dates.

Yields of squash from fenamiphos-treated plots were greater ($P = 0.05$) than those from untreated plots on all harvest dates except following the DC hybrid in 1997 (Table 2). Cultivar means across treatments show that yields of squash following DK-683 were greater than those following the DC hybrid during both years. Yield of squash was not affected by at-planting fenamiphos treatments on the preceding crop of corn. However, yields of squash from at-plant fenamiphos treatments were consistently greater ($P = 0.05$) than those from untreated squash.

Discussion

In microplot experiments, McSorley and Dickson (1995) identified rotation crops that may be effective in maintaining low population densities of *M. incognita.* Among those crops were corn hybrids of Old Raccoon or Tebeau X Mp 307, which have shown a high degree of resistance to *M. incognita* race 4 from Mississippi (Windham and Williams, 1988b) and to *M. incognita* race 1 from Florida. Our field experiment showed that a double-cross corn hybrid can be used in rotation with a susceptible vegetable crop to suppress population densities of *M. incognita.* The few galls that occurred on roots indicate that the DC corn hybrid is resistant, but not immune, to *M. incognita.* Population densities of *M. incognita* were maintained in corn plots throughout the experiment. Numbers of *M. incognita* J2 in the soil from May through August were lower than those reported by McSorley and Dickson (1995) on resistant single-cross hybrids of corn.

The cause of the severe amount of lodging that occurred in the DC hybrid is not fully understood. Stalk rots are universally important and among the most destructive diseases of corn throughout the world (Shurtleff, 1980). Development of stalk rots is favored by an early environment that encourages kernel set and a late environment that is stressful to the plant. In most cases, stalk rots are caused by a complex of several species of fungi and bacteria that attack plants approaching maturity; thus, identification of a specific stalk rot is difficult. In southern Georgia, crown and brace root decay in corn is caused by *R. solani* AG2-2 and fibrous root decay is caused by *Pythium* spp. and *Fusarium* spp. (Sumner and Bell, 1982; Sumner et al., 1990). Corn stalk rot in Georgia is caused primarily by *F. moniliforme* and *Macrophomina phaseoli,* but numerous other fungi may be isolated from decayed corn stalks (Sumner and Hook, 1985).

The lower yield of the DC hybrid was caused by the genetic difference between the two corn entries. The inbreds included in the DC hybrid (except for T216) were selected for their resistance to *M. incognita.* There is no reason to believe that they should have superior agronomic traits, i.e. lodging resistance or high yields. For corn to be effective managing *M. incognita* population densities in crop rotations, the resistance recently released by Williams and Windham (1998) must be used by the commercial seed companies. Our data indicate no yield advantage from the use of fenamiphos on the *M. incognita*-resistant DC hybrid.

The low yield of squash during the first year of the experiment (1996) was attributed to cultivar Goldie Hybrid and an early infestation of whiteflies (*Bemisia argentifolii* Fellows and Perring). These pests adversely affected plant growth and fruit development and reduced the number of harvests to eight. The cause of the lower squash yields following the DC hybrid than DK-683 both years is not known.

The field experiment was useful in identifying the dangers of using rotation crops that are susceptible to *M. incognita* following resistant crops. *Meloidogyne incognita* survives as J2 and eggs in fallow plots for several weeks in the absence of a host in southern Georgia (Johnson et al., 1992, 1995, 1997). Fields infested with *M. incognita* in Georgia and planted to susceptible crops following 3 years of a resistant crop resulted in more effective *M. incognita* management than 1- or 2-year rotations (Johnson et al., 1995, 1997).

Because of the pathogenic variability of *Meloidogyne* spp. on corn (Baldwin and Barker, 1970), the DC hybrid used in this experiment may react differently to other host races or geographical isolates. This DC hybrid should be evaluated for host suitability for additional root-knot nematode species to determine the extent of the resistance. Sydenham et al. (1994) emphasized the need for testing candidate rotation crops against local nematode populations before they are widely planted.

Commercial corn hybrids currently available are not resistant to *M. incognita* (Windham, 1998). Nematode resistance must be transferred into the elite materials of commercial seed companies to reach its full potential as a nematode management strategy.

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