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Peanut-Cotton-Rye Rotations and Soil Chemical Treatment for Managing Nematodes and Thrips[1]

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Abstract: In the southeastern United States, a cotton-peanut rotation is attractive because of the high value and extensive planting of both crops in the region. The objective of this experiment was to determine the effects of cotton-peanut rotations, rye, and soil chemical treatments on management of plant-parasitic nematodes, thrips, and soilborne fungal diseases and on crop yield. Peanut-cotton-rye rotations were conducted from 1988 to 1994 on Tifton loamy sand (Plinthic Kandiudult) infested primarily with *Meloidogyne incognita* race 3, *Belonolaimus longicaudatus, Sclerotium rolfsii, Rhizoctonia solani,* and *Fusarium oxysporum.* Continuous peanut, continuous cotton, cotton-peanut rotation, or peanut-cotton rotation were used as main plots; winter rye or fallow as sub-plots; and cotton with and without aldicarb (3.36 kg a.i./ha), or peanut with and without aldicarb (3.36 kg a.i./ha) plus flutolanil (1.12 kg a.i./ha), as sub-sub-plots. Population densities of *M. incognita* and *B. longicaudatus* declined rapidly after the first crop in continuous peanut and remained low thereafter. Neither rye nor soil chemical treatment affected *M. incognita* or *B. longicaudatus* population density on peanut or cotton. Cotton and peanut yields from the cotton-peanut rotation were 26% and 10% greater, respectively, than those from monoculture over the 7-year study. Cotton and peanut yields were improved 9% and 4%, respectively, following rye vs. fallow. Soil chemical treatments increased yields of cotton 23% and peanut 32% over those of untreated plots. Our data demonstrate the sustainable benefits of using cotton-peanut rotations, winter rye, and soil chemical treatments to manage plant-parasitic nematodes and other pests and pathogens and improve yield of both cotton and peanut.

Key words: Arachis hypogaea, Belonolaimus longicaudatus, cotton, *Criconemella ornata,* crop rotation, fallow, *Frankliniella* spp., *Gossypium hirsutum,* management, *Meloidogyne incognita,* monocrop, nematicide, nematode, peanut, population dynamics, ring nematode, root-knot nematode, rye, *Secale cereale,* sting nematode, thrips.

In the southeastern United States, cotton (*Gossypium hirsutum* L.) and peanut (*Arachis hypogaea* L.) are damaged by many nematode species (Minton, 1984; Minton and Baujard, 1990; Minton and Bell, 1969; Motsinger et al., 1976; Riggs and Niblack, 1993; Starr and Page, 1990). In most areas, the most serious nematode pathogens for both crops are *Meloidogyne* spp. *Meloidogyne incognita* (Kofoid & White) Chitwood race 3 often is the most severe nematode pathogen on cotton, whereas *Meloidogyne arenaria* (Neal) Chitwood race 1 is the most severe nematode pathogen on peanut (Hirunsalee et al., 1995a, 1995b, 1995c). Cotton is a nonhost of *M. arenaria,* and peanut is a nonhost of *M. incognita.*

The sting nematode, *Belonolaimus longicaudatus* Rau, is a virulent pathogen of cotton and other crops in coastal plain sandy soils (Norton et al., 1985; Starr and Page, 1990). Peanut is a nonhost of the Georgia population of *B. longicaudatus* (Good, 1968; Minton, 1984; Minton and Baujard, 1990).

In addition to crop damage directly attributable to nematode pathogenesis, *M. incognita* and *B. longicaudatus* frequently are involved in disease complexes involving *Pythium, Rhizoctonia, Fusarium,* and *Thielaviopsis* spp. on cotton (Starr and Page, 1990). Traditionally, nematodes in cotton and peanut are managed by nematicides and crop rotations (Heald and Orr, 1984; Johnson, 1982; Johnson et al., 1975; Minton, 1984; Minton and Baujard, 1990; Rodríguez-Kábana et al., 1987; Starr and Page, 1990).

Winter cover crops differ in their impact on nematode management. Mixed results have been reported in previous studies of peanut and cotton produced following winter cover (Good, 1968, 1972; Johnson, 1982;

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McSorley and Dickson, 1989). Rye (*Secale cereale* L.) is important as a winter crop for forage (Johnson and Motsinger, 1989; Pfahler et al., 1985). Fall and winter cover crops of rye increase soil organic matter, improve soil tilth, decrease soil erosion, increase water penetration and retention, and provide grazing for cattle (Benoit et al., 1962; Blevins et al., 1971). Rye is a poor host of *M. incognita* (Johnson and Motsinger, 1989, 1990; Opperman et al., 1988) and has been used to successfully manage this nematode. A rye winter cover crop preceding snapbean had little effect on *M. incognita* population densities or root galling on snapbean in the presence or absence of fenamiphos (Smittle and Johnson, 1982). Rye did not affect peanut yield when included as a winter cover crop with continuously planted peanut (R. A. Flowers, unpubl.). *Meloidogyne incognita* population densities increased more slowly (or declined more quickly) than *M. arenaria* on rye (McSorley, 1994). In other studies (McSorley and Dickson, 1989; Opperman et al., 1988), population densities of *M. incognita* on rye declined to less than preplant levels. Johnson and Motsinger (1989, 1990) suggested that reproduction of *M. incognita* on rye may be limited by low winter temperatures. Although rye supports relatively low levels of reproduction by *M. incognita* and *B. longicaudatus* (McSorley and Dickson, 1989), the effects of rye on nematodes, diseases, and yields are not well defined in peanut and cotton monocultures or in peanut-cotton rotations.

Cotton and peanut have been suggested for use in rotation to reduce population densities of *M. incognita* and other nematodes on cotton (Johnson et al., 1974, 1975; Sasser, 1979) and *M. arenaria* on peanut (McSorley et al., 1994a, 1994b; Rodríguez-Kábana et al., 1987, 1989). Cotton grown for 1 year preceding peanut decreased population densities of *M. arenaria* on peanut by 43% and increased peanut yields 19% without the use of nematicides (Rodríguez-Kábana et al., 1987, 1991). There is little information on the relative efficacy of peanut for control of *M. incognita* and other nematodes on cotton (Johnson et al., 1975; Kirkpatrick and Sasser, 1984). A cotton-peanut rotation is attractive because of the high value and extensive planting of both crops in the southeastern coastal plain region.

This study was part of a large field experiment designed to determine the effects of cotton-peanut rotations, rye, and soil chemical treatments on management of plant-parasitic nematodes, thrips, and soilborne fungal diseases, and on crop yield. The data on soilborne fungal diseases will be published elsewhere.

Materials and Methods

The study was initiated in 1988 on the Gibbs Farm at the Coastal Plain Experiment Station, Tifton, Georgia. The experimental area was planted to soybean in 1987. The soil was a Tifton loamy sand (fine-loamy, siliceous, thermic Plinthic Kandiudult; pH 6.1–6.3) infested with *M. incognita* race 3, *B. longicaudatus, Criconemella ornata* (Raski) Luc & Raski, *Pratylenchus brachyurus* (Godfrey) Filipjev & Schuurmans Stekhoven, and *Paratrichodorus minor* (Colbran) Siddiqi. To prepare for planting of peanut and cotton, the soil in all plots was disc-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 in early April. Plots were 7.6 × 5.5 m and consisted of three beds with two rows 0.91 m apart on each bed. Nematode population densities, plant stand counts, yield, and other data were recorded from the center bed. Fallow alleys 4.3 m wide separated plot blocks.

The experimental design was a split-split plot with four replicates. Whole-plot treatments were crop rotations as follows: peanut in monoculture, cotton in monoculture, peanut-cotton, and cotton-peanut. Sub-plots were rye and no rye, and sub-sub-plots were soil chemical treatments (peanut with and without aldicarb 15 G at 3.36 kg a.i./ha plus flutolanil 50 WP at 1.12 kg a.i./ha; cotton with and without aldicarb 15 G at 3.36 kg a.i./ha). Aldicarb was applied to both crops in a 30.5-cm band at planting and incorporated 3 to 5 cm deep. Flutolanil was applied to peanut in 124 liters of water/ha in split applications of 0.56 kg a.i./ha each. The first application was 70 days after planting in a 31-cm band, and the second was broadcast 3 weeks later.

Cotton (11 to 12 kg/ha) and peanut (100 to 112 kg/ha) were seeded in rows. The cotton genotypes Tifcot 56 (planted from 1988 to 1992) and Georgia King (planted in 1993) were moderately resistant to *M. incognita.* The breeding line M-240 (planted in 1994) was highly resistant to *M. incognita.* Florunner peanut was planted each year. Wrens Abruzzi rye (49 kg/ha) was seeded with a grain drill in November or December each year. Rye was clipped to about 15 to 20 cm high each year to simulate grazing, and clippings were left on the ground. Fallow plots were disc-harrowed after harvest and received no other treatment until spring planting. Cultural practices and control of insects and weeds for cotton and peanut were according to recommendations for the area (Delaplane, 1988–1993). The field plots were irrigated as needed.

Ten soil cores (2.5-cm-diam. × 15 cm deep) for nematode assay were collected from cotton and peanut plots at planting and at harvest 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). The remaining samples were air-dried and analyzed for pH, P, K, Ca, and Mg (Balaguravaiah et al., 1996). Fertilizers were applied to all crops according to the recommendations of the University of Georgia Cooperative Extension Service (Plank, 1989).

Thrips (*Frankliniella* spp.) damage to peanut was based on percentage of leaflets damaged by thrips. Forty leaflets per plot were evaluated in June each year except 1988. The peanut plants were dug and inverted in September each year. Roots, pods, and pegs of 10 randomly selected plants from each plot were examined and rated immediately after digging for percentage galled by *Meloidogyne* spp. 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). When the moisture content declined to approximately 12 to 16%, the pods were harvested with a combine, dried to ca. 8% moisture, weighed, and graded according to official Federal-State Inspection Service methods (U.S. Department of Agriculture, 1974).

Cotton stand counts were recorded at various times each year. Cotton was harvested mechanically in October each year, and yields were calculated as kilograms of seed cotton per hectare. Twenty-five cotton bolls were collected from each plot at harvest and weighed. Seeds were separated from lint, and the percent lint was determined. Twenty cotton plants were dug from each plot and rated for percentage of root system galled by *M. incognita* as described for peanut.

Data collected within each experimental year were analyzed separately. The statistical model included effects due to rotation (ROT), replicate (REP) within rotation or Error-a, presence or absence of rye (RYE), ROT × RYE interaction, RYE × REP(ROT) or Error-b, pesticide application (PEST), ROT × PEST, RYE × PEST, and ROT × RYE × PEST interactions. Error-a was used to determine the significance of the rotation effect, but effects of RYE and rotation by rye interaction were tested with Error-b. All remaining effects were tested with the residual error. Also, data from all years were pooled and analyzed to determine differences among experimental years. Interactions of year and all other effects also were included in the model. Data were subjected to analysis of variance using the general linear model procedure of the Statistical Analysis System (SAS Institute, Cary, NC). Differences were reported to be significant at $P < 0.05$.

Results

At the initiation of the experiment, *M. incognita* second-stage juveniles (J2) were found in all field plots (149 to 330 J2/150 cm^3 soil) (Table 1). Numbers of *M. incognita* J2 in continuous cotton plots in 1988, 1993, and 1994 were similar at planting to those at harvest, but in 1989–1992 numbers were higher at harvest than at planting. Popula-

TABLE 1. Effects of cropping sequences, cover crops, and soil chemical treatments on population densities of *Meloidogyne incognita* race 3 at planting and at harvest during a 7-year rotation experiment at Tifton, Georgia.

		M. incognita second-stage juveniles per 150 cm^3 of soil									
		Cropping sequence						Cover crop		Soil chemical treatment[b]	
Year	Date[a]	Cotton-cotton	Peanut-peanut	Cotton-peanut		Peanut-cotton		Rye	Fallow	Control	Aldicarb + flutolanil
1988	AP	243	149 A	157	—	330 A	—	155	284	164	276
	AH	132 a	3 bB	214 a	—	1 bB	—	127	88	127	88
1989	AP	31 aB	1 b	—	42 a	—	0 b	13	25	20	18
	AH	319 aA	8 b	—	3 b	—	75 b	123	81	72	132
1990	AP	13 B	0	0	—	11	—	7	5	7	5
	AH	502 aA	2 b	128 b	—	8 b	—	168	302	265	205
1991	AP	40 aB	1 b	—	4 b	—	1 b	9	13	7	16
	AH	509 aA	3 b	—	16 b	—	88 b	96	212	93	215
1992	AP	29 B	4	3	—	11	—	6	18	6	18
	AH	296 aA	1 b	107 b	—	1 b	—	110	92	68	133
1993	AP	13	0	—	10	—	3	8	12	9	11
	AH	68 b	0 c	—	1 c	—	107 a	41	46	54	33
1994	AP	2	1	1	—	0	—	1	1	1	1
	AH	50	1	47	—	5	—	25	25	41	9

Data are means of four replications. Means in rows followed by different small letters are different ($P \leq 0.05$). Means in columns followed by different capital letters comparing AP vs. AH for each year are different ($P \leq 0.05$). Means followed by no letters are not different ($P \leq 0.05$).

[a] AP = at planting, AH = at harvest.

[b] Chemical treatments were aldicarb 15 G at 3.36 kg a.i./ha for cotton, aldicarb 15 G at 3.36 kg a.i./ha plus flutolanil 50 WP at 1.12 kg a.i./ha for peanut, and untreated control. Aldicarb was applied to both crops in a 31-cm-wide band at planting and incorporated 3 to 5 cm deep. Flutolanil was applied at 0.56 kg a.i./ha to peanut 70 days after planting in a 31-cm-wide band and 3 weeks later in 124 liters of water/ha.

TABLE 2. Effects of cropping sequences, cover crops, and soil chemical treatments on population densities of *Belonolaimus longicaudatus* at planting and at harvest during a 7-year rotation experiment at Tifton, Georgia.

		B. longicaudatus per 150 cm^3 of soil									
		Cropping sequence						Cover crop		Soil chemical treatment[b]	
Year	Date[a]	Cotton-cotton	Peanut-peanut	Cotton-peanut		Peanut-cotton		Rye	Fallow	Control	Aldicarb + flutolanil
1988	AP	228 A	278 A	232 A	—	263 A	—	223	276	256	244
	AH	42 aB	2 bB	41 aB	—	2 bB	—	20	23	26	17
1989	AP	26	3	—	2	—	18	13	12	16	9
	AH	20	1	—	19	—	3	12	9	14	7
1990	AP	22 a	0 b	1 b	—	3 b	—	3	9	7	6
	AH	23 a	0 b	2 b	—	1 b	—	6	7	8	6
1991	AP	21 a	0 b	—	4 b	—	1 b	8	5	11 a	3 b
	AH	8 ab	0 b	—	0 b	—	12 a	1 b	9 a	9 a	1 b
1992	AP	17 a	0 b	0 b	—	4 b	—	2 b	9 a	8	3
	AH	11 a	0 b	3 b	—	0 b	—	4	2	4	2
1993	AP	20 a	0 b	—	0 b	—	0 b	3	1	2	2
	AH	14 a	0 b	—	0 b	—	0 b	3	5	4	3
1994	AP	23 a	0 b	1 b	—	1 b	—	6	7	8	4
	AH	25 a	1 b	7 b	—	0 b	—	8	9	10	6

Data are means of four replications. Means in rows followed by different small letters are different ($P \leq 0.05$). Means in columns followed by different capital letters comparing AP vs. AH for each year are different ($P \leq 0.05$). Means followed by no letters are not different ($P \leq 0.05$).

[a] AP = at planting, AH = at harvest.

[b] Chemical treatments were aldicarb 15 G at 3.36 kg a.i./ha for cotton, aldicarb 15 G at 3.36 kg a.i./ha plus flutolanil 50 WP at 1.12 kg a.i./ha for peanut, and untreated control. Aldicarb was applied to both crops in a 31-cm-wide band at planting and incorporated 3 to 5 cm deep. Flutolanil was applied at 0.56 kg a.i./ha to peanut 70 days after planting in a 31-cm-wide band and 3 weeks later in 124 liters of water/ha.

TABLE 3. Effects of cropping sequences, cover crops, and soil chemical treatments on population densities of *Criconemella ornata* at planting and at harvest during a 7-year rotation experiment at Tifton, Georgia.

		C. ornata per 150 cm^3 of soil									
		Cropping sequence						Cover crop		Soil chemical treatment[b]	
Year	Date[a]	Cotton-cotton	Peanut-peanut	Cotton-peanut		Peanut-cotton		Rye	Fallow	Control	Aldicarb + flutolanil
1988	AP	0	0 B	0	—	0 B	—	0	0	0	0
	AH	1 b	514 aA	3 b	—	206 aA	—	154	208	194	168
1989	AP	4 b	247 aB	—	8 abB	—	33 ab	52	95	58	88
	AH	15 b	1,582 aA	—	344 aA	—	5 b	444	553	556	416
1990	AP	3 b	373 a	202 abA	—	13 b	—	75	220	170	125
	AH	5 c	366 a	12 cB	—	145 b	—	135	129	132	132
1991	AP	3 b	170 aB	—	27 bB	—	68 b	39 b	96 a	73	61
	AH	8 b	601 aA	—	529 aA	—	82 b	181 b	428 a	268	341
1992	AP	4 c	235 ab	374 aA	—	26 bc	—	83 b	237 a	118	201
	AH	55 b	337 a	70 bB	—	311 a	—	215	171	160	225
1993	AP	17 c	218 b	—	24 cB	—	350 aA	103	166	156	113
	AH	82 b	350 a	—	378 aA	—	45 bB	177	249	227 a	199 b
1994	AP	21 b	86 abB	136 a	—	20 b	—	30 b	102 a	60	72
	AH	109 bc	349 abA	80 c	—	465 a	—	233	268	218	283

Data are means of four replications. Means in rows followed by different small letters are different ($P \leq 0.05$). Means in columns followed by different capital letters are different ($P \leq 0.05$). Means followed by no letters are not different ($P \leq 0.05$).

[a] AP = at planting, AH = at harvest.

[b] Chemical treatments were aldicarb 15 G at 3.36 kg a.i./ha for cotton, aldicarb 15 G at 3.36 kg a.i./ha plus flutolanil 50 WP at 1.12 kg a.i./ha for peanut, and untreated control. Aldicarb was applied to both crops in a 31-cm-wide band at planting and incorporated 3 to 5 cm deep. Flutolanil was applied at 0.56 kg a.i./ha to peanut 70 days after planting in a 31-cm-wide band and 3 weeks later in 124 liters of water/ha.

tion densities of J2 declined rapidly after the first crop in the peanut monoculture and remained low thereafter. Generally, plots of cotton in rotation with peanut had fewer J2 than those under continuous cotton. Neither the winter cover crop of rye nor applications of aldicarb + flutolanil on peanut and aldicarb on cotton had an effect on J2 population densities on these crops late in the season.

Population densities of *B. longicaudatus* ranged from 228 to 278/150 cm^3 soil among treatments at planting in 1988 and were below 43/cm^3 soil for the remainder of the study (Table 2). Numbers of *B. longicaudatus* were fewer in peanut plots on most sampling dates than in continuous cotton plots. After 1 year of peanut in all cropping sequences, *B. longicaudatus* was almost undetectable. The numbers of *B. longicaudatus* were not affected by a winter cover crop of rye except at harvest in 1991 and at planting in 1992 when numbers were fewer in rye plots than in fallow plots. Applications of aldicarb to cotton and aldicarb + flutolanil to peanut had no effect on *B. longicaudatus* population densities except in 1991, when numbers were fewer in treated than untreated plots.

Numbers of *C. ornata* were undetectable at planting in 1988 but increased to greater densities on peanut than cotton on most sampling dates (Table 3). In continuous peanut, numbers of *C. ornata* were higher at harvest than at planting on most sampling dates. Population densities of *C. ornata* in the cotton-peanut and peanut-cotton sequences consistently declined on cotton and increased on peanut between planting and harvest. The large numbers of *C. ornata* in cotton plots at planting in the cotton-peanut sequence were carryover from the previous crop of peanut. The winter cover crop of rye and the application of soil chemical treatments to cotton and peanut had no effect on *C. ornata* population densities on most sampling dates.

Population densities of *P. minor* ranged from 0 to 30/150 cm^3 of soil and were slightly greater in plots of cotton than pea-

TABLE 4. Effect of cropping sequences, cover crops, and soil chemical treatments on stand counts of cotton during a 7-year rotation experiment at Tifton, Georgia.

		Plants per 15.2-m row					
		Cropping sequence		Cover crop		Soil chemical treatments[a]	
Year	Date	Cotton-cotton	Cotton-peanut	Rye	Fallow	Control	Aldicarb
1988	23 May	105	108	106	107	102	110
	7 June	86	87	86	87	81	93
	16 June	82	82	82	82	74	87
	13 July	76	76	76	75	62	89
	10 October	39	42	40	41	31	50
1989	25 May	59	53	55	58	55	57
	28 July	58	51	54	56	51	57
	11 October	58	51	54	57	54	56
1990	8 June	75	72	74	73	73	74
	23 October	56 b	64 a	63	58	56 b	65 a
1991	14 June	62	69	66	66	62	70
1992	3 June	113	137	131 a	118 b	122	128
	18 November	77 b	126 a	111	93	93 b	111 a
1993	26 May	119	118	118	119	108 b	129 a
	14 October	105	104	104	104	95 b	113 a
1994	25 May	150	143	152	141	143	150
	31 October	105 b	143 a	137	112	106 b	142 a

Data are means of four replications. Means in rows followed by different letters are different ($P \leq 0.05$). Means in rows followed by no letters are not different ($P \leq 0.05$).

[a] Treatments were aldicarb 15 G at 3.36 kg a.i./ha for cotton and untreated control. Aldicarb was applied in a 31-cm-wide band at planting and incorporated 3 to 5 cm deep.

nut, but differences were not significant on most sampling dates (data not included). Neither a winter crop of rye nor applications of soil chemical treatments to cotton and peanut had an effect on *P. minor* population densities on most sampling dates. Numbers of *P. brachyurus* ranged from 0 to 28/150 cm^3 soil in all plots and were not affected by cropping sequence, winter cover crop, or soil chemical treatment (data not included).

Cotton stand counts were not affected by cropping sequence or cover crop on most sampling dates (Table 4). Approximately 20% of the stand loss in all plots during 1988 occurred between 23 May and 7 June. In the same year, approximately 45% of the remaining stand died between 13 July and 10 October. Only in 1993 were the initial stand counts of cotton greater in aldicarb-treated than untreated plots. However, the final stands were greater in aldicarb-treated than in untreated plots in 1990, 1992, 1993, and 1994. The greatest stand loss between planting and harvest (50% to 70%) occurred during the first year of the study, primarily from seedling damping-off caused by the interaction of soilborne fungi and large population densities of *M. incognita* and *B. longicaudatus*.

Root-gall indices were greater in continuous cotton in 1990 and 1992 than in the cotton-peanut sequence (Table 5). In 1990 and 1993, root-gall indices of cotton following fallow were lower than those following rye. Aldicarb suppressed root-gall indices on cotton the first year of the study (1988), but not thereafter.

Percentage of peanut leaflets damaged by thrips was not affected by cropping sequence or cover crop but was consistently greater in untreated plots than in plots treated with aldicarb + flutolanil (Table 6). Means across years show that 42% of peanut foliage on aldicarb + flutolanil-treated plants was damaged by thrips vs. 71% on untreated plants.

Cotton yields were generally lower in 1988 than other years (Table 7). For 3 years (1989, 1990, and 1994) cotton yields following peanut were greater than those for monoculture. Cotton-yield increase in the cotton-peanut sequence varied from 7% to 81% (mean 26%) more than continuous cotton. Following rye, cotton yield increases varied from 0% to 23% (mean 9%) more than fallow. Except for one year (1989), there were no differences ($P \leq 0.05$) in yield of cotton following rye vs. fallow. Yields from aldicarb-treated cotton were consistently greater than those from untreated plots. The average yield increases in cotton over the entire study were 19% for the cotton-peanut vs. cotton-cotton sequence, 8% for rye vs. fallow, and 19% for aldicarb- vs. untreated plots. Percentage lint of cotton (a yield quality parameter) varied from 41% to 45% and was not affected ($P \leq 0.05$) by

TABLE 5. Effects of cropping sequences, cover crops, and soil chemical treatments on root gall indices of cotton during a 7-year rotation experiment at Tifton, Georgia.

	Root gall index[a]					
	Cropping sequence		Cover crop		Soil chemical treatment	
Year	Cotton-cotton	Cotton-peanut	Rye	Fallow	Control	Aldicarb[b]
1988	2.00	2.20	2.05	2.05	2.40 a	1.70 b
1989	1.01	1.10	1.05	1.10	1.15	1.00
1990	1.40 a	1.20 b	1.35 a	1.25 b	1.25	1.35
1991	1.10	1.10	1.10	1.10	1.10	1.15
1992	1.50 a	1.10 b	1.40	1.30	1.20	1.40
1993	1.66	1.47	1.70 a	1.43 b	1.47	1.66
1994	1.00	1.00	1.00	1.00	1.00	1.00

Data are means of four replications. The two means followed by different letters in rows under cropping sequence, cover crop, and soil chemical treatment are different ($P \leq 0.05$). No letters = no significant differences.

[a] 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.

[b] Aldicarb 15 G was applied at 3.36 kg a.i./ha in a 31-cm-wide band at planting and incorporated 3 to 5 cm deep.

TABLE 6. Thrips damage on peanut as affected by soil chemical treatment during a 7-year rotation experiment at Tifton, Georgia.

		Percentage of leaflets damaged					
		Untreated		Aldicarb + flutolanil[a]		Mean	
Year	Cropping sequence	Rye	Fallow	Rye	Fallow	Untreated	Aldicarb + flutolanil[a]
1989	Peanut-peanut	61	58	30	16		
	Peanut-cotton	62	63	27	23		
	Mean	61 a	60 a	29 b	19 b	61 z	24 y
1990	Peanut-peanut	74	68	26	38		
	Peanut-cotton	74	73	35	37		
	Mean	74 a	70 a	31 b	37 b	72 z	34 y
1991	Peanut-peanut	46	52	32	24		
	Peanut-cotton	54	43	31	23		
	Mean	50 a	48 a	32 b	24 b	49 z	28 y
1992	Peanut-peanut	89	91	69	72		
	Peanut-cotton	92	95	79	82		
	Mean	91 a	93 a	74 b	77 b	92 z	76 y
1993	Peanut-peanut	68	66	34	31		
	Peanut-cotton	73	67	38	36		
	Mean	70 a	67 a	36 b	34 b	69 z	35 y
1994	Peanut-peanut	81	79	48	63		
	Peanut-cotton	81	79	54	59		
	Mean	81 a	79 a	51 b	61 b	80 z	56 y

Data are means of four replications. Means in rows under cropping sequence comparing rye vs. fallow and untreated vs. aldicarb + flutolanil treated plots followed by the same letter are not different ($P \leq 0.05$).

[a] Treatments were aldicarb 15 G at 3.36 kg a.i./ha plus flutolanil 50 WP at 1.12 kg a.i./ha for peanut and untreated control. Aldicarb was applied in a 31-cm-wide band at planting and incorporated 3 to 5 cm deep. Flutolanil was applied at 0.56 kg a.i./ha to peanut 70 days after planting in a 31-cm-wide band and 3 weeks later in 124 liters of water/ha.

cropping sequence, cover crop, or soil chemical treatment (data not included).

Peanut yields fluctuated each year and declined in all plots from 1988 to 1990 (Table 7). Yields of peanut in 1989 and 1990 were greater following cotton than continuous peanut. In the cotton-peanut sequence, peanut yields increased 0% to 25% over continuous peanut during the study period. Following rye, peanut yields increased 0% to 12% more than fallow during the study period, but these differences were not significant ($P \leq 0.05$). Peanut yields from aldicarb + flutolanil-treated plots were consistently greater than those from untreated plots. The mean yield increase in peanut over the entire study period was 10% for peanut-cotton vs. peanut-peanut sequence, 4% for rye vs. fallow, and 32% for aldicarb + flutolanil vs. chemically untreated plots. There were no galls on roots, pegs, or pods of peanut.

The percentage of sound, mature kernels of peanut was not affected ($P \leq 0.05$) by cropping sequence, cover crop, or soil chemical treatment each year, except in 1988 and 1994 (Table 8). In 1988, the percentage of sound, mature peanut kernels was greater in flutolanil + aldicarb-treated plots following fallow than untreated plots following fallow. In 1994, the percentage of sound, mature kernels was greater in flutolanil + aldicarb-treated plots following rye than untreated plots following fallow. Based on mean data across cropping sequences, cover crops, and soil chemical treatments, the percentage of sound, mature kernels was not affected by cropping sequence or cover crop but was greater from aldicarb + flutolanil-treated plots than untreated plots in 1988, 1989, 1990, and 1992.

DISCUSSION

Our results showed that peanut can be used as a rotation crop with cotton to suppress population densities of *M. incognita* and *B. longicaudatus*. In 4-year rotations

TABLE 7. Effects of cropping sequences, cover crops, and soil chemical treatments on yield (MT/ha) of cotton and peanut during a 7-year rotation experiment at Tifton, Georgia.

		Yield (MT/ha)									
		Cropping sequence						Cover crop		Soil chemical treatment[a]	
Year	Crop	Cotton-cotton	Peanut-peanut	Cotton-peanut		Peanut-cotton		Rye	Fallow	Control	Aldicarb + flutolanil
1988	Cotton	2.79	—	2.56	—	—	—	2.68	2.67	2.20 b	3.16 a
	Peanut	—	5.37	—	—	5.47	—	5.52	5.32	4.29 b	6.55 a
1989	Cotton	3.91 b	—	—	—	—	4.17 a	4.29 a	3.78 b	3.82 b	4.26 a
	Peanut	—	4.12 b	—	5.16 a	—	—	4.78	4.50	3.69 b	5.60 a
1990	Cotton	2.76 b	—	3.42 a	—	—	—	3.09	3.09	2.81 b	3.37 a
	Peanut	—	3.85 b	—	—	4.34 a	—	4.32	3.87	3.60 b	4.59 a
1991	Cotton	3.43	—	—	—	—	3.66	3.61	3.48	3.28 b	3.82 a
	Peanut	—	4.37	—	5.13	—	—	4.76	4.74	4.17 b	5.33 a
1992	Cotton	3.13	—	4.54	—	—	—	4.08	3.59	3.60 b	4.07 a
	Peanut	—	5.13	—	—	5.14	—	5.30	4.97	4.19 b	6.08 a
1993	Cotton	3.50	—	—	—	—	4.82	4.29	4.03	3.70 b	4.63 a
	Peanut	—	4.22	—	4.65	—	—	4.34	4.53	4.18 b	4.68 a
1994	Cotton	2.60 b	—	4.70 a	—	—	—	4.03	3.27	3.03 b	4.27 a
	Peanut	—	4.99	—	—	5.53	—	5.45	5.07	5.02 b	5.50 a

Data are means of four replications. The means in rows under cropping sequence, cover crop, and soil chemical treatment followed by different letters are different ($P \leq 0.05$). Means followed by no letters are not different ($P \leq 0.05$).

[a] Treatments were aldicarb 15 G at 3.36 kg a.i./ha for cotton, aldicarb 15 G at 3.36 kg a.i./ha plus flutolanil 50 WP at 1.12 kg a.i./ha for peanut, and untreated control. Aldicarb was applied to both crops in a 31-cm-wide band at planting and incorporated 3 to 5 cm deep. Flutolanil was applied at 0.56 kg a.i./ha to peanut 70 days after planting in a 31-cm-wide band and 3 weeks later in 124 liters of water/ha.

TABLE 8. Effects of cropping sequence, cover crop, and soil chemical treatment on peanut kernel quality during a 7-year rotation experiment at Tifton, Georgia.

		Percent sound mature kernels				Mean				
		Untreated		Aldicarb + flutolanil			Cover crop		Soil chemical treatment[a]	
Year	Cropping sequence	Rye	Fallow	Rye	Fallow	Cropping sequence	Rye	Fallow	Untreated	Aldicarb + flutolanil
1988	Peanut-peanut	76.6	76.0	77.3	77.3	76.8				
	Peanut-cotton	76.5	75.4	76.6	77.9	76.6				
	Mean	76.6 ab	75.7 b	76.9 ab	77.6 a		76.8	76.7	76.2 B	77.3 A
1989	Peanut-peanut	73.4	73.3	76.2	75.2	74.5				
	Peanut-cotton	74.5	74.1	75.6	76.8	75.3				
	Mean	74.0	73.7	75.9	76.0		75.0	74.9	73.9 B	76.0 A
1990	Peanut-peanut	71.9	72.0	73.8	72.7	72.6				
	Peanut-cotton	70.7	71.6	73.7	73.9	72.5				
	Mean	71.3	71.8	73.8	73.3		72.5	72.6	71.6 B	73.5 A
1991	Peanut-peanut	75.5	74.8	76.1	76.6	75.7				
	Peanut-cotton	75.0	75.8	75.9	75.1	75.4				
	Mean	75.2	75.3	76.0	75.8		75.6	75.6	75.3	75.9
1992	Peanut-peanut	73.1	72.2	75.6	76.1	74.2				
	Peanut-cotton	72.9	72.1	74.3	75.5	73.7				
	Mean	73.0	72.2	74.9	75.8		74.0	74.0	72.6 B	75.3 A
1993	Peanut-peanut	69.1	67.6	69.1	70.7	69.1				
	Peanut-cotton	70.2	70.9	69.8	70.1	70.2				
	Mean	69.7	69.3	69.5	70.4		69.6	69.8	69.4	69.9
1994	Peanut-peanut	75.1	72.9	74.7	75.5	74.5				
	Peanut-cotton	73.7	73.5	75.8	74.5	74.4				
	Mean	74.4 ab	73.2 b	75.3 a	75.0 ab		74.8	74.1	73.8	75.1

Data are means of four replications. Means in rows comparing rye vs. fallow in untreated plots, aldicarb + flutolanil-treated plots, cover crop, and untreated vs. aldicarb + flutolanil-treated plots followed by different letters are significant ($P \leq 0.05$). Means followed by no letter are not significantly different ($P \leq 0.05$).

[a] Treatments were aldicarb 15 G at 3.36 kg a.i./ha for cotton, aldicarb 15 G at 3.36 kg a.i./ha plus flutolanil 50 WP at 1.12 kg a.i./ha for peanut, and untreated control. Aldicarb was applied to both crops in a 31-cm-wide band at planting and incorporated 3 to 5 cm deep. Flutolanil was applied at 0.56 kg a.i./ha to peanut 70 days after planting in a 31-cm-wide band and 3 weeks later in 124 liters of water/ha.

tested by Johnson et al. (1975), peanut suppressed subsequent population densities of *M. incognita* on cotton compared to monocropped cotton, but the influence of nematodes on crop yields could not be determined because no nematode control treatments, except crop rotation, were included in the study. Peanut is a nonhost crop for *M. incognita* (Good, 1972; Johnson et al., 1974, 1975; Sasser, 1954; Sasser and Nusbaum, 1955) and the Georgia population of *B. longicaudatus* (Good, 1968, 1972; Minton, 1984; Minton and Baujard, 1990; Robbins and Barker, 1973). When peanut was planted in the cotton-peanut sequences of this study, population densities of *M. incognita* J2 and *B. longicaudatus* were never different ($P \geqslant 0.05$) from zero. The suppressive effect of peanut on *M. incognita* and *B. longicaudatus* also was evident by the effect of the crop on final nematode population densities in cotton following peanut. The numbers of *B. longicaudatus* in the continuous cotton were fewer than those reported from other studies (Johnson, 1970a) but higher than the damage threshold established for cotton in Georgia (Davis et al., 1996). The different cotton cultivar used in those studies might be a more favorable host than cultivars used in this study. *Pasteuria* sp. was observed parasitizing *M. incognita* J2 and juvenile and adult *B. longicaudatus*. This bacterium may have suppressed the natural field population of *M. incognita* and *B. longicaudatus*, but more research is needed to prove this hypothesis.

Criconemella ornata has been reported most frequently from soils in the southeastern United States (Norton et al., 1985). As in other studies (Johnson et al., 1974, 1975), continuous peanut supported greater numbers of *C. ornata* than cotton. *Criconemella ornata* has been associated with poor growth and yellowing of peanut. Barker et al. (1982) reported that 178 freshly introduced *C. ornata*/500 cm^3 of soil stunted peanut. In contrast, large residual population densities of *C. ornata* following tobacco, a poor host crop, had little effect on the growth of peanut.

Reviews of nematodes attacking cotton have omitted *C. ornata* (Heald and Orr, 1984; Riggs and Niblack, 1993; Starr and Page, 1990). Evidence of pathogenicity of *C. ornata* on cotton is lacking (Brodie et al., 1970). Results of our study indicate that cotton is a poor host for *C. ornata*. *Criconemella ornata* population densities in continuous cotton plots at planting and at harvest followed generally the same trend as in continuous peanut plots, but at much lower levels (Johnson et al., 1974, 1975). Johnson (1970b) found that, in mixed populations, numbers of *C. ornata* were greatly suppressed when *B. longicaudatus* was present on bermudagrass. Those results indicate that *B. longicaudatus* is an aggressive competitor at lower population densities than *C. ornata* on bermudagrass.

Neither cotton nor peanut was a good host for *P. minor* or *P. brachyurus*. Maximum population densities of *P. minor* and *P. brachyurus* on cotton and peanut were less than 30/150 cm^3 soil, which confirms results of other studies (Good, 1968; Johnson et al., 1974, 1975).

Root-gall indices of cotton caused by *M. incognita* were generally low and were not affected during most years by cropping sequence, cover crop, or aldicarb soil treatment. The low root-gall indices resulted from the moderate level of resistance to *M. incognita* and the wilt fungus (*Fusarium oxysporum* Schlect. f. sp. *vasinfectum* (Atk.) Snyd. & Hans.) in cultivars Tifcot 56 and Georgia King (Johnson, 1992), and the high level of resistance to *M. incognita* in the M-240 breeding line.

The low cotton yields during the first year of the study (1988) were attributed to a poor stand and the large numbers of *B. longicaudatus*, *M. incognita* J2, and parasitic fungi in the soil. Both cotton and peanut yields in the cotton-peanut rotations were generally improved over those in monoculture and following rye as a winter cover crop as compared to fallow. Even though the average yield increase of cotton across cropping sequences and aldicarb treatments was not significantly ($P \geqslant 0.05$) affected by rye, the winter cover crop was beneficial. The greatest influence of rye over fallow occurred in the untreated continuous cotton with a mean 51% yield increase over the 7 years. As the yield of cotton increased in rotation with peanut and aldicarb treatment, the beneficial effects of rye decreased. The results showed that when cotton was planted in soil treated with aldicarb and rotated with peanut, the effect of winter rye became minimal.

Rye is a poor host of *M. incognita,* but it does support some reproduction of this nematode (Johnson and Motsinger, 1989, 1990; Opperman et al., 1988). Sayre et al. (1965) found that during the decomposition of residues of rye and other grasses butyric acid and other nematicidal compounds were released. A rye winter cover crop had no effect on *M. incognita* population densities or root galls on snapbean in the presence or absence of a nematicide (Smittle and Johnson, 1982). Winter rye did not affect yield in continuously planted peanut (R. A. Flowers, unpubl.). *Meloidogyne incognita* population densities increased more slowly than *M. arenaria* on rye (McSorley, 1994). Rye residue treatments did not influence population densities of *Rhizoctonia solani* AG-4 or AG2-2 in soil, or root disease severity or pod rot in peanut (Sumner and Bell, 1992). The results from use of rye as a winter cover crop may depend on many factors. For example, in this test, a drought in 1990 minimized the benefits of rye as a winter cover crop in continuous cotton. The rye was intensively managed (high seeding and fertilization rates), and it is unknown if less intensively managed rye would result in similar yield responses. Also, the rye was moldboard-plowed as a green manure crop following simulated grazing rather than used for seed production before planting cotton and peanut. Johnson and Motsinger (1989, 1990) suggested that reproduction of *M. incognita* on rye in the field may be limited by late planting and low winter temperatures.

Soil treatment of aldicarb for cotton and aldicarb + flutolanil for peanut increased yields of both crops each year compared to the untreated controls. The yield increases of both cotton and peanut resulting from soil chemical treatments in comparable monocultures of cotton and peanut and cotton-peanut rotations agree with those previously reported (Rodríguez-Kábana et al., 1987, 1991) in fields infested with *M. arenaria.* The increases in cotton and peanut yields obtained in response to the cotton-peanut rotations, rye winter cover crop, and soil chemical treatments cannot be attributed solely to suppression of *M. incognita, B. longicaudatus, and C. ornata* population densities. Due to the severe stem rot present in this experimental area, the increased peanut yields probably were due in large part to suppression of that disease by the flutolanil treatment as reported by Culbreath et al. (1992). Also, increases in peanut grades due to use of effective fungicides for soilborne peanut disease have been reported (Brenneman and Culbreath, 1994). Since the populations of *M. incognita* and *B. longicaudatus* present at this site do not parasitize peanut, we interpret yield increases as the result of the integration of the suppressive effects of the crop rotations, rye winter crop, and soil chemical treatments on several major and minor nematodes, soilborne fungal pathogens, thrips of cotton and peanut, and improved tilth of the soil. Our data demonstrate the sustainable benefits of using cotton-peanut rotations, winter rye, and soil chemical treatments to manage plant-parasitic nematodes and other pests and pathogens and improve yield.

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