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Effects of Planting Date, Small Grain Crop Destruction, Fallow, and Soil Temperature on the Management of *Meloidogyne incognita*[1]

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Abstract: The effects of planting date, rye (*Secale cereale* cv. Wren Abruzzi) and wheat (*Triticum aestivum* cv. Coker 797), crop destruction, fallow, and soil temperature on managing *Meloidogyne incognita* race 1 were determined in a 2-year study. More *M. incognita* juveniles (J2) and egg-producing adults were found in roots of rye planted 1 October than in roots of rye planted 1 November and wheat planted 1 November and 1 December. Numbers of *M. incognita* adults with and without egg masses were near or below detectable levels in roots of rye planted 1 November and wheat planted 1 November and 1 December. *Meloidogyne incognita* survived the mild winters in southern Georgia as J2 and eggs. The destruction of rye and wheat as a trap crop 1 March suppressed numbers of J2 in the soil temporarily but did not provide long-term benefits for susceptible crops that followed. In warmer areas where rye and wheat are grown in winter, reproduction of *M. incognita* may be avoided by delaying planting dates until soil temperature declines below the nematode penetration threshold (18 C), but no long-term benefits should be expected. The temperature threshold may be an important consideration in managing *M. incognita* population densities in areas having lower winter soil temperatures than southern Georgia.
Key words: fallow, *Meloidogyne incognita*, root-knot nematode, rye, *Secale cereale*, trap crop, *Triticum aestivum*, wheat.

Wheat, *Triticum aestivum* L. em Thell, and rye, *Secale cereale* L., are important winter forage crops for livestock in Georgia (11). These crops are planted in the fall and used for grazing, greenchopped material for immediate feeding or silage, and grain.

Wheat and rye, planted as winter cover crops, were suggested as rotational crops (1,7). Much of the wheat and rye in the Southeast is double-cropped with soybean (10). Rye and all commercial cultivars of bread wheat that have been evaluated under greenhouse conditions are hosts for *Meloidogyne incognita* (Kofoid & White) Chitwood and *M. javanica* (Treub) Chitwood (12,15,19). Some wheat cultivars are resistant to *M. incognita* (1,9).

Thomason (19) reported that soil temperature, rather than host suitability of cereal crops for *M. javanica,* was the critical factor in controlling nematode population levels. In southern California, *M. incognita* juveniles penetrated wheat roots in the autumn only when soil temperature was above 18 C (15). Nematode development and reproduction, however, can occur at temperatures as low as 10 C (14,15,19). In mild winter regions, soil temperatures of 18–25 C occur only during the seedling and maturation stages of the crop (14,15).

The objective of this study was to determine the effects of planting date, rye and wheat crop destruction, clean fallow, and soil temperature on *M. incognita* population densities.

Materials and Methods

The experiment was established on Tifton loamy sand (fine, loamy, siliceous, Thermic Plinthic Paleudults: 85% sand, 10% silt, 5% clay; 0.5% O.M.) infested with *Meloidogyne incognita* race 1. The land was previously planted to cowpea (*Vigna unguiculata* (L.) Walp. cv. Pinkeye Purplehull) as a summer cover crop and hairy vetch (*Vicia villosa* Roth) as a winter cover crop.

Test plots, each 18 m wide × 15.2 m long, were maintained in the same location and managed similarly during both years of the study. The soil temperature at 20 cm deep was recorded continuously near the field plots from 30 September 1982

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TABLE 1. Accumulated heat units and numbers of *Meloidogyne incognita* in roots of Wren Abruzzi rye and Coker 797 wheat as influenced by planting date, 1982.

Crop	Date Planted	Date Sampled	Accumulated heat units from planting†		Number per root system: Juveniles	Adults: With egg masses	Adults: Without egg masses
Rye	1 Oct.	3 Nov.	18,700		53	5.0	13.0
		3 Dec.	27,885		115	20.0	12.0
		3 Jan.	33,061		123	21.0	12.0
				Mean	97 a	15.0 a	12.0 a
Rye	1 Nov.	3 Dec.	9,647		12	0.0	0.0
		3 Jan.	14,823		22	0.0	0.5
				Mean	17 b	0.0 b	0.3 b
Wheat	1 Nov.	3 Dec.	9,647		19	0.0	0.0
		3 Jan.	14,823		42	0.6	2.0
				Mean	31 b	0.3 b	1.0 b
Wheat	1 Dec.	3 Jan.	5,944		10	0.0	0.0
				Mean	10 b	0.0 b	0.0 b

Values are means of four replications across sampling. Means across sample dates in columns followed by the same letter are not different ($P \leq 0.05$) according to Waller-Duncan's multiple-range test.
† Degree-days above 18 C.

through 31 July 1983. The soil temperature data were used to calculate numbers of heat units (degree-days above a basal temperature of 18 C—the penetration threshold for *M. incognita*) as described by others (15,17). Initially the field plots were disked 10–15 cm deep and moldboard plowed 28–30 cm deep to bury crop residue. All plots received 560 kg/ha 5-10-15 fertilizer (nitrogen 5%, phosphoric acid 10%, soluble potash 15%, calcium 9%, and sulphur 7%) after tillage. The fertilizer was incorporated 5–10 cm deep and the soil surface was leveled with a disk harrow equipped with an attachment to smooth the soil. Wren Abruzzi rye or Coker 797 wheat seeds were planted 84 kg/ha with a grain drill 1 October, 1 November, and 1 December as described in Table 1. Rye and wheat plots received 168 kg/ha ammonium nitrate (33% N) 60 days after planting.

The randomized complete block design included 14 treatments replicated four times. A fallow plot was established for each planting date for rye or wheat and served as a control. All fallow plots were maintained during the growing season, plowed similarly to the planted plots, and rototilled 5–8 cm deep with a tractor-powered rototiller to destroy weeds as needed. All plots were irrigated with overhead sprinklers to keep the soil moist. Weeds in established rye and wheat plots were removed by hand as needed. Analysis of variance incorporating linear contrasts was performed on some data. Treatment means and results of significance tests at $P \geq 0.05$ of the linear contrasts for various response variables were calculated.

Immature rye and wheat were mowed, disked, and plowed 28–30 cm deep for complete inversion of crop residue 1 March in selected plots. In other plots the mature rye and wheat were mowed 10 June, plots were disked and plowed, and beds were established. All plots received an additional 560 kg/ha 5-10-15 fertilizer broadcast and incorporated into the top 5 cm of soil each year before planting the summer crops.

In 1983, the herbicides bensulide (4.5 kg a.i./ha) and naptalam (2.2 kg a.i./ha) in 187 liters water/ha were sprayed on the soil surface and incorporated into the top 5-cm soil layer with a tractor-powered rototiller. Squash (*Cucurbita pepo* (L.) Alef. cv. Dixie Hybrid) was planted 30 cm apart in rows 0.9 m apart. All plots were cultivated and plants were sidedressed with 560 kg/ha 5-10-15 fertilizer 24 days after planting and 336 kg/ha ammonium nitrate (33% N) 34 days after planting. Fruit of squash was harvested by hand twice each week from 28 July until 19 August. The field plots remained undisturbed from harvest until 29 September when crop residue was mowed, plots were disked and plowed, and fertilizer was applied for rye and wheat as before.

On 10 June 1984 trifluralin (0.56 kg a.i./ha) was applied broadcast over the beds and incorporated in the top 5 cm of soil with a tractor-powered rototiller for weed control. Okra (*Hibiscus esculentus* L. cv. Emerald) seeds were planted 15 cm apart in rows 0.9 m apart. Okra was sidedressed with 560 kg/ha ammonium nitrate (33% N) 35 days after planting and sprayed with methomyl (0.67 kg a.i./ha) in 187 liters water/ha for insect control as needed. Pods of okra were harvested by hand twice each week from 6 August to 31 August.

After the final harvests of squash and okra, 20 plants were dug from each plot and rated on the following scale for percentage of roots galled by *M. incognita*: 1 = no galling, 2 = 1–25, 3 = 26–50, 4 = 51–75, and 5 = 76–100. Soil was assayed for plant-parasitic nematodes at various intervals beginning 30 September 1982 through 6 September 1984. Twenty cores of soil, 2.5 cm × 25 cm deep, were collected from each plot and mixed thoroughly. A 150-cm^3 sample was processed by centrifugal-flotation (6).

Roots of four rye and four wheat plants per plot were dug at monthly intervals from planting in 1982 until 3 January 1983, stained with 0.05% acid fuchsin in lactophenol, and cleared in lactophenol (2). The stage of development and number of *M. incognita* per root system were recorded.

Ten soil cores (5 × 5 cm) were collected 2 May 1984 in increments of 0–8, 8–16, 16–24, and 24–32 cm deep in selected plots. The 10 soil cores from each depth were composited and mixed thoroughly, and a 150-cm^3 sample was processed by centrifugal-flotation for nematode assay. The remainder of each sample was placed in a 10-cm-d plastic pot, planted to a 3-week-old tomato (*Lycopersicon esculentum* Mill. cv. Rutgers) seedling and placed in a randomized complete block design on a greenhouse bench. After growing for 36 days, roots were carefully removed from the soil, washed, stained with 0.05% acid fuchsin in lactophenol, and cleared in lactophenol; numbers of *M. incognita* in the total root system were counted under a stereoscopic microscope.

Results

Maximum soil temperatures 20 cm deep at planting in 1982 were 28 C on 1 October, 26 C on 1 November, and 24 C on 1 December (Fig. 1). Maximum soil temperatures continued to decline and remained near or below the 18-C penetration threshold for *M. incognita* from 4 December 1982 to 27 March 1983, then increased to 37 C on 28 July.

In 1982 more *M. incognita* J2 and adults with and without egg masses were found in roots of rye planted 1 October than in roots of rye planted 1 November and wheat planted 1 November and 1 December (Table 1). Total numbers of *M. incognita* adults in roots of rye planted 1 November and wheat planted 1 November and 1 December generally were <1.0. There was a positive correlation between numbers of J2 ($r = 0.98$), adults with egg masses ($r = 0.94$), adults without egg masses ($r = 0.86$), and number of accumulated heat units from planting.

Numbers of *M. incognita* J2 in plots when the experiment was established ranged from 138 to 611/150 cm^3 soil and declined thereafter (Table 2). Numbers of J2 in the plots sampled 1 December 1982, 3 January, 1 March, 8 June, 8 July, and 4 August 1983 ranged from 0 to 80/150 cm^3 soil and were not different ($P \leq 0.05$) among treatments (data not included). Numbers of J2 on squash in 1983 were not different among treatments, except on 4 September when numbers were greater in plots following wheat planted 1 November and plowed 10 June than in other plots.

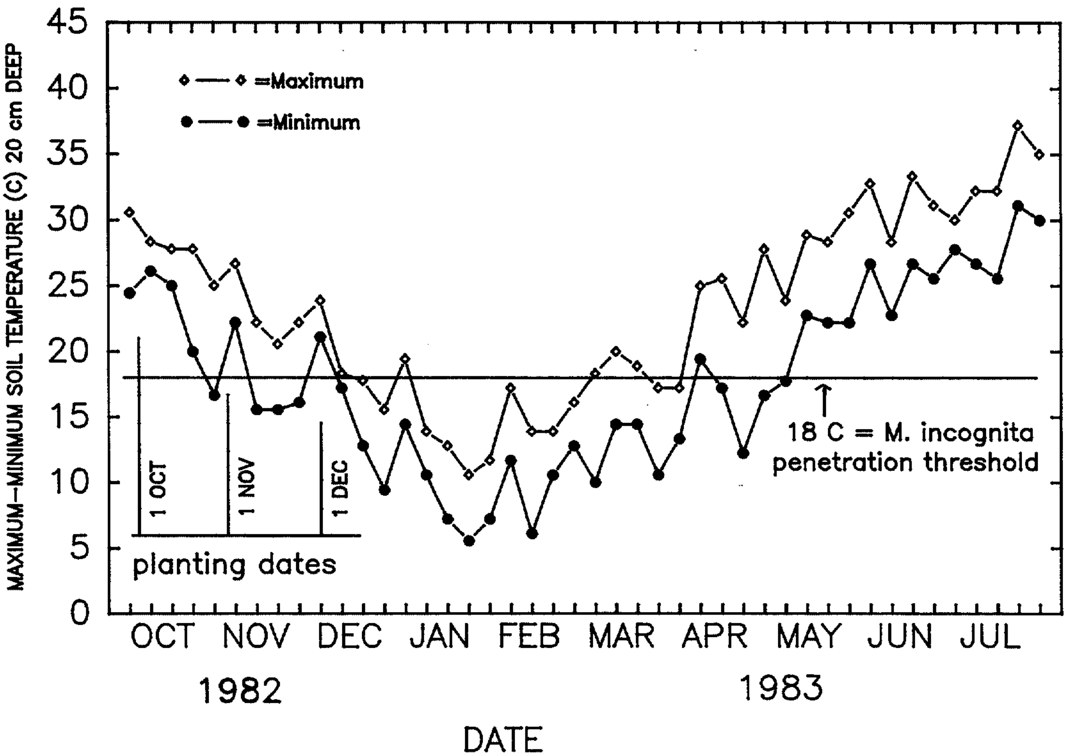

FIG. 1. Maximum and minimum soil temperatures (C) 20 cm deep in field plots of Wren Abruzzi rye, Coker 797 wheat, and clean fallow.

Yields of marketable squash ranged from 1,338 to 2,407 kg/ha. Root-gall indices after the final harvest ranged from 2.95 to 4.08. Yield and root-gall indices were not different among treatments (data not included).

When the plots were prepared for planting rye 1 October 1983, numbers of *M. incognita* J2 were greater in plots previously planted to rye 1 October 1982 than in plots planted to wheat 1 December 1982 and the fallow plots tilled 1 October and 1 November (Table 2). Numbers of J2 in the soil declined and on 30 November were not different among most treatments. Numbers of J2 in the soil 3 January, 1 March, 5 April, 7 June, 9 July, and 6 August 1984 ranged from 0 to 45/150 cm^3 soil and were not different among treatments (data not included). Numbers of J2 in the soil increased in okra plots; on 6 September 1984, they ranged from 53 to 470/150 cm^3 soil and were greater in plots previously planted to rye 1 October and plowed 10 June than in all plots of wheat, except those planted 1 November and plowed 1 March, and fallow plots. Numbers of J2 in fallow plots were not different from treatments planted to rye or wheat.

Yield of okra following clean fallow was generally lower than yield following wheat or rye (Table 2). Greatest yield of okra was from plots that followed wheat planted 1 November and plowed 10 June. Root-gall indices of okra ranged from 1.18 to 1.68 on 23 July and from 3.83 to 4.68 on 6 September 1984 and were not different ($P \leq 0.05$) among treatments (data not included).

Data on the vertical distribution of *M. incognita* in the soil (Table 3) indicated no differences in numbers of J2 at various depths in plots of rye planted 1 October and 1 November and plowed 1 March. In plots of rye planted 1 October and plowed 1 March, 53% of the nematodes extracted were 24–32 cm deep. These results were supported by the numbers of nematodes

TABLE 2. *Meloidogyne incognita* juveniles per 150 cm^3 soil and yield of okra as influenced by crop and soil management.

	Date		1982		1983†			1984†	
Treatment	Planted	Moldboard plowed‡	1 Oct.	1 Nov.	4 Sept.	1 Oct.	30 Nov.	6 Sept.	Yield (kg/ha)
			Wren Abruzzi rye						
1	1 Oct.	10 June	604	78	80	168	46	470	859
2	1 Oct.	1 Mar.	530	155	85	168	81	300	667
3	1 Nov.	10 June	400	188	83	115	20	173	764
4	1 Nov.	1 Mar.	289	235	80	88	13	133	496
			Coker 797 wheat						
5	1 Nov.	10 June	389	80	233	155	6	230	956
6	1 Nov.	1 Mar.	611	160	105	95	19	280	512
7	1 Dec.	10 June	138	115	120	18	21	145	732
8	1 Dec.	1 Mar.	423	80	38	26	13	53	590
			Fallow§						
9	1 Oct.	10 June	253	73	45	25	13	98	585
10	1 Oct.	1 Mar.	533	176	25	16	28	89	309
11	1 Nov.	10 June	273	114	18	29	13	91	379
12	1 Nov.	1 Mar.	355	63	18	38	50	80	358
13	1 Dec.	10 June	286	28	28	78	28	258	428
14	1 Dec.	1 Mar.	261	65	38	60	25	90	260
			Linear contrast						
1 + 2 vs. 3 + 4			*	*	NS	NS	*	*	NS
1 + 2 vs. 5 + 6			NS	NS	*	NS	*	NS	NS
1 + 2 vs. 7 + 8			*	NS	NS	*	*	*	NS
1 + 2 vs. 9 + 10			NS	NS	NS	*	*	*	*
3 + 4 vs. 5 + 6			NS	*	*	NS	NS	NS	NS
3 + 4 vs. 7 + 8			NS	*	NS	*	NS	NS	NS
3 + 4 vs. 11 + 12			NS	*	NS	NS	NS	NS	*
5 + 6 vs. 7 + 8			*	NS	*	*	NS	*	NS
5 + 6 vs. 11 + 12			*	NS	*	*	NS	*	*
7 + 8 vs. 13 + 14			NS	NS	NS	NS	NS	NS	*

Data in body of table are means of four replicates. * indicates significant difference at $P = 0.05$; NS = no significant differences.

† 1983 values for all plots are from the immediately preceding squash crop and the 1984 values are from the okra crop.

‡ Plots of rye and wheat were rotary mowed, incorporated 10–15 cm into the soil with a disk harrow, and moldboard plowed 28–30 cm deep with complete inversion of the crop residue.

§ For each rye or wheat planting date, a fallow plot was established, maintained during the growing season, and moldboard plowed on 1 March or 10 June.

observed in tomato roots in the bioassay (data not included). Numbers of nematodes increased with soil depth in plots of wheat planted 1 November and 1 December and left undisturbed until 10 June. Means across soil depths indicate that numbers of nematodes were lower in plots of wheat planted 1 November and plowed 1 March than in other wheat plots. Numbers of *M. incognita* J2 in fallow plots plowed 1 March were $<7/150cm^3$ soil and were not affected by soil depth. Numbers of J2 in fallow plots left undisturbed until 10 June increased with soil depth, and 45% of the population was found 24–32 cm deep. Means across soil depths indicate that more nematodes were extracted from soil in wheat and fallow plots left undisturbed until 10 June than in most other plots. Generally, these results were supported by the numbers of nematodes observed in tomato roots in the bioassay test (data not included).

DISCUSSION

The potential economic importance of *M. incognita* reproduction on winter rye and wheat is in the increase of primary inocu-

TABLE 3. *Meloidogyne incognita* juveniles per 150 cm^3 soil collected 2 May 1984 from field plots.

Depth (cm)	Rye		Wheat			Fallow	
	A†	B	C	D	E	F	G
0–8	6	5	3	5 c	4 b	6	3 b
8–16	8	3	8	14 bc	8 b	1	5 b
16–24	3	1	1	26 ab	21 a	0	15 ab
24–32	19	1	1	38 a	33 a	5	19 a
Mean	9 yz	3 z	3 z	21 x	17 xy	3 z	11 xyz

Values are means of four replications. Means in columns within each test or in mean rows followed by the same letter or no letter are not different ($P \leq 0.05$) according to Waller-Duncan's multiple-range test.

† A = planted 1 Oct., plowed 1 Mar.; B = planted 1 Nov., plowed 1 Mar.; C = planted 1 Nov., plowed 1 Mar.; D = planted 1 Nov., plowed 10 June; E = planted 1 Dec., plowed 10 June; F = plowed 1 Mar., and G = plowed 10 June.

lum and damage to the following susceptible crop (12,15). The soil temperature threshold for root penetration of *M. incognita* J2 is 18 C (15). When the soil temperature was above 18 C from the 1 October planting date until early December, *M. incognita* J2 were active in the soil, penetrated the roots of rye planted 1 October and 1 November and wheat planted 1 November and 1 December, but completed one generation only on the earlier rye planting.

Nematode feeding, development, and egg production can proceed in roots of October-planted Anza wheat at soil temperatures well below the threshold for migration and penetration (15). The threshold temperature for development of *M. incognita* is ca. 10 C (20); the maximum soil temperature at 20 cm deep was above 10 C throughout the 1982–83 winter months during this study and is usually above 10 C during winter months in southern Georgia (13).

Although rye and wheat may be suitable hosts for *M. incognita* at optimum temperatures, the J2 population densities did not increase during two winters at Tifton, Georgia. In the absence of reproduction on rye and wheat, numbers of *M. incognita* J2 in the soil decreased during the winter, similar to those under clean fallow. On the basis of root-gall indices and yields of squash and okra following rye, wheat, and fallow, it appears that *M. incognita* overwinters in the soil as J2 and eggs. It is likely that survival and development are optimum at different soil depths. Mean soil temperatures between October and May are relatively warm but vary greatly in the 0–10-cm soil layer. This could account for more rapid development of nematodes in roots nearest the soil surface, but it would also result in the most damage to the nematodes by cold injury. At 10–30 cm deep, nematode development would be slower, because of lower average temperature and lower oxygen tensions, but survival would be greater than in the upper layers, because temperatures never decline below 0 C. These findings are similar to those reported by others (15,21). Eggs of some *Meloidogyne* spp. survive for several months in moist soil at 10–15.5 C (19), and survival is not affected by soil type (22).

Previous studies report the developmental time of stages of *Meloidogyne* species at various temperatures, and a threshold temperature can be calculated (21). Davide and Triantaphyllou (3) reported a value of 10.4 C for *M. incognita* in tomato. Tyler (20) reported the minimal temperature for development of a *Meloidogyne* sp. to be between 9 and 10 C and that 6,500 to 8,000 heat units (base 10 C) were required for the most rapidly developing nematodes in tomato roots to develop from J2 to egg-laying females and an additional 5,000 heat units were required for development and hatch of eggs.

The soil temperatures in our studies were above that considered minimal for *M. incognita* development during the time rye and wheat were growing. The time and temperature relations can be expressed in heat units (20). From 1 October, 1 November, and 1 December until 3 January, 33,061, 14,823, and 5,944, respectively, heat units were accumulated. Theoretically, at least one generation of *M. incognita* should have developed during the growth of the rye and the first planting of wheat. However, infection was poor, J2 did not develop, and egg masses were not seen, except in trace amounts, on the roots of rye or wheat planted 1 November, and none was seen on roots of wheat planted 1 December. Whereas penetration of roots of rye and wheat by *M. incognita* J2 and development of adult females in the field were positively correlated with the accumulated heat units from planting to the sampling dates, there was no increase in numbers of J2 in soil planted to these crops when compared with population densities in clean fallow plots.

The rate of development of the nematodes inside the roots is a function not only of temperature but also of the plant's status as a host. Roots of rye and wheat are physiologically active and available for penetration and feeding sites before heading and maturity are complete. The destruction of rye and wheat as a trap crop on 1 March suppressed numbers of J2 in the soil temporarily but did not provide long-term protection for susceptible crops that followed.

Our results support other observations (4,5,8,12,15,16,21) that *M. incognita* can reproduce on susceptible crops during winter in the southern United States. In warm areas where rye and wheat are grown in winter, reproduction of *M. incognita* may be avoided by delaying planting dates on infested fields until soil temperature declines below the root penetration threshold, but no long-term benefits should be expected. In other intensive cropping system studies (7,10,18), Wren Abruzzi rye, Oasis wheat, or clean fallow did not provide sufficient suppression of *M. incognita* population densities without the use of a nematicide.

The temperature threshold considerations may become an important component in developing strategies for managing nematode population densities in areas that have lower winter soil temperatures than southern Georgia. Use of resistant rye or wheat (9) also may be beneficial in managing nematode population densities in intensive cropping systems in areas with mild winters thus reducing the dependence on nematicides.

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