Supplement to Journal of Nematology 22(4S):783–791. 1990.

Interaction of Three Plant-parasitic Nematodes on Corn and Soybean[1]

D. W. DICKSON AND R. MCSORLEY[2]

Abstract: Interaction of *Belonolaimus longicaudatus, Meloidogyne incognita,* and *Pratylenchus brachyurus* on corn and *B. longicaudatus, M. incognita,* and *Heterodera glycines* on soybean was investigated in microplots during two seasons for corn and one season for soybean. Changes in population densities and effects on plant growth of each nematode on corn or soybean alone and in mixed culture were compared. No interactions occurred on corn in 1987. In 1988, midseason population densities of *B. longicaudatus* were greater in corn plots infested with *M. incognita* ($P \leq 0.05$), but at harvest, population densities of *B. longicaudatus* were less in corn plots infested with *P. brachyurus* ($P \leq 0.05$). Except for stalk weight at harvest, plant growth was not affected by any treatment. In soybean, midseason densities of *M. incognita* were increased in combination with *H. glycines* ($P \leq 0.05$), but this trend reversed at harvest. Soybean yield was reduced in plots infested with *H. glycines* ($P \leq 0.001$), whereas *B. longicaudatus* or *M. incognita* had no effect on plant growth either singly or in mixed culture.

Key words: Belonolaimus longicaudatus, corn, *Glycine max, Heterodera glycines,* interaction, *Meloidogyne incognita, Pratylenchus brachyurus,* soybean, *Zea mays.*

Corn (*Zea mays* L.) and soybean (*Glycine max* (L.) Merr.), two of the most important crops grown in the United States, are hosts for several highly pathogenic nematode species (1,16). Production of these crops is interrelated with a wide range of other cultivated crops, particularly in the southeastern United States. Consequently they influence the population ecology of four important plant-parasitic nematodes—*Meloidogyne incognita* (Kofoid & White) Chitwood, *Belonolaimus longicaudatus* Rau, *Pratylenchus brachyurus* (Godfrey) Filipjev & Schuurmans-Stekhoven, and *Heterodera glycines* Ichinohe.

In most cases, the effects of these nematodes have been reported as individual species, but unfortunately a one-nematode-one-disease occurrence is an atypical situation. Damage by polyspecific communities of plant-parasitic nematodes is common, particularly on corn (12) and soybean (16), but only in a few instances have the combined affects of two or more species been investigated (5,8,9,14,15). Microplot methodology has been particularly useful in evaluating the effects of single and multiple nematodes on host crops (2). Our objectives were to determine the effects on corn and soybean of three nematode genera singly and in various combinations.

MATERIALS AND METHODS

Three separate tests, two on corn and one on soybean, were conducted in 76-cm-d microplots encircled with 60-cm-wide fiberglass sheets inserted 50 cm into the soil (7). The microplots were arranged in rows 1.5 m apart in an Arredondo fine sand (93% sand, 4% silt, 3% clay; pH 5.8; 1% organic matter) treated with 977 kg methyl bromide/ha (98% a.i.) applied broadcast under a 3-mil plastic covering 3–5 months before planting. No plant-parasitic nematodes were detected in the top 20 cm of soil when the microplots were sampled before planting. In each test, the experimental design was a $2 \times 2 \times 2$ factorial replicated six times.

Local populations of *Belonolaimus longicaudatus, Meloidogyne incognita* race 1, *Pratylenchus brachyurus,* and *Heterodera glycines* race 3 were reared in a greenhouse on bahiagrass (*Paspalum notatum* Flugge cv. Pensacola), tomato (*Lycopersicon esculentum* Mill. cv. Rutgers), snap bean (*Phaseolus vulgaris* L. cv. Harvester), and soybean (*Glycines max*

Received for publication 12 March 1990.
[1] Florida Agricultural Experiment Station Journal Series No. R-00551. Supported in part by USDA Competitive Grants 86-CRSR-2-2885 and 86-CRCR-1-1971.
[2] Professors, Department of Entomology and Nematology, Institute of Food and Agricultural Sciences, University of Florida, Gainesville, FL 32611-0611.
We thank Tom Hewlett, Charlotte Zunker, Paul Ruppert, Reggie Wilcox, Jeff Simmons, Philip Cooke, and John Kiefer for technical assistance.

cv. Davis), respectively. A selected initial population density was compared with zero of each nematode species (Tables 1–3). Nematode inocula (juveniles and adults of *B. longicaudatus* and *P. brachyurus*; eggs of *M. incognita* and *H. glycines*) were added and mixed into the top 9 cm of soil. The microplots were planted with Pioneer 304C corn on 29 April 1987 and 8 April 1988 and with Davis soybean on 3 June 1988. Three pairs of corn seed were planted 4 cm deep and 19 cm apart in a row and thinned to three plants per plot in 1987 and four plants per plot in 1988. Soybean seeds were planted 2.5 cm deep and 4 cm apart in a row and thinned to 10 or 11 plants per plot. Border rows (76 cm apart) of corn and soybean were maintained outside the microplots to simulate plant spacings typical of the field. Basic fertilizers, insecticides, and supplemental irrigation were provided as needed. Each soybean plot was infested with a mixture of *Glomus intraradices* Schenck & Smith and *Gigaspora margarita* Hall & Becker at the rate of 300 g soil and bahiagrass roots containing both fungi per plot on 24 May 1988. Soybean seeds were inoculated with a commercial source of *Rhizobium japonicum* (Kirchner) Buchanan.

Soil nematode population densities were determined 3–4 weeks after planting, 12 weeks after planting, and at harvest. Five soil cores (2.5 cm d × 20 cm deep) were collected per plot and bulked. The soil (100 cm^3) was processed by a centrifugal-flotation technique (6). At harvest, three root systems were collected, chopped (5 g) in a blender, and incubated on Baermann trays for 48 hours.

Corn grain yield is reported as shelled corn at 15.5% moisture and soybean seed yield is reported at 10% moisture. Stalk weights and number of ears per plot were determined for each corn plot. In addition, plant growth measurements were taken twice during the growing season.

All nematode densities (number per 100 cm^3 soil) were transformed by $\log_{10}(x + 1)$ before data analysis. Analyses revealed consistent significant relationships with the transformed densities as well as with the raw nematode counts; thus the latter are reported. Data then were subjected to the appropriate analysis of variance for a factorial design (19).

Results

Corn: In weeks 3 and 5 after planting the 1987 and 1988 test plots, respectively, no visual symptoms of nematode damage were apparent. Stalk diameter and extended plant height among plants in all plots were similar (Tables 1, 2). Except for stalk weight at harvest, no plant growth measurements were affected throughout the season by any of the three test nematodes. Parasitism by *P. brachyurus* resulted in a lower stalk weight at harvest in 1987 ($P \leq 0.05$), and in 1988 stalk weight at harvest was reduced by *M. incognita* parasitism ($P \leq 0.05$).

In 1987, 12 weeks after planting, population densities of *B. longicaudatus* were greater in plots infested with *M. incognita* ($P \leq 0.05$) (Table 1). In the same sampling period in 1988 population densities of *B. longicaudatus* were less in plots infested with *P. brachyurus* ($P \leq 0.05$) (Table 2). In 1988, when higher inoculum levels of each of the three nematodes were used, *M. incognita* interacted with *B. longicaudatus* ($P \leq 0.01$) at harvest causing a reduction in the population density of *B. longicaudatus.* In both years the population density of *B. longicaudatus* 0–15 cm deep in the soil was greatly reduced at harvest, relative to the 12-week sampling.

Soybean: By week 11 after planting, an interaction ($P \leq 0.05$) of *B. longicaudatus* and *H. glycines* on plant height was observed (Table 3). Plant height was lower in plots infested with both nematodes than in plots without *H. glycines* ($P \leq 0.05$), whereas *M. incognita* had no effect on plant growth either singly or in combination with *H. glycines.* No early season root abbreviation or stunted foliage growth was attributed to *B. longicaudatus.* Reductions in final soybean yield observed here were all attributed to *H. glycines* (Table 3).

There were numerous interactions

TABLE 1. Population changes of *Belonolaimus longicaudatus* (Bl), *Meloidogyne incognita* (Mi), and *Pratylenchus brachyurus* (Pb) and their effects on plant growth when inoculated singly or in combination on corn microplots, 1987.

Initial nematode population density per plot			Nematodes/ 100 cm³ soil (no.)			Leaves/ plant (no.)	Stalk diameter (mm)	Plant height (cm)	Nematodes/g root dry wt. (no.)		Fresh stalk wt./plot (g)	Ears/plot (no.)	Yield/plot† (g)
Bl	Mi	Pb	Bl	Mi	Pb				Mi	Pb			
						19 May							
0	0	0	0	0	0	6.1	6.9	42					
0	0	80	0	0.2	0	6.8	7.8	48					
0	5,250	0	0	2.8	0	6.1	6.3	38					
0	5,250	80	0	2.3	0	7.1	7.2	47					
525	0	0	0.3	0	0	7.1	7.3	44					
525	0	80	0	0	0	7.5	7.7	46					
525	5,250	0	0.5	4.3	0	7.0	7.7	46					
525	5,250	80	0.2	1.7	0.2	7.4	7.7	47					
Significant effects:			NS	Mi***	NS	Bl*	NS	NS					
						21 July							
0	0	0	0	0.5	0		25	260					
0	0	80	0	0	3.3		24	260					
0	5,250	0	1.0	175	0		24	250					
0	5,250	80	2.2	119	2.0		22	260					
525	0	0	7.6	0	0		24	260					
525	0	80	7.2	0.5	0		25	270					
525	5,250	0	11.8	220	0		24	260					
525	5,250	80	10.2	365	1.3		24	260					
Significant effects:			Bl*** Mi*	Mi***	NS		NS	NS					
						23 September							
0	0	0	0	0.2	0				0	0	896	4.6	352
0	0	80	0	3.7	44.5				1.6	413	756	4.5	449
0	5,250	0	0	1,436	0				19.3	0.75	841	4.3	367
0	5,250	80	0.7	1,472	17.7				17.4	199	718	4.7	408
525	0	0	2.3	0	0.8				0	0.96	907	5.2	316
525	0	80	2.0	0.2	18.2				0	90.7	775	5.3	422
525	5,250	0	0.8	1,021	0.2				10.2	106	931	4.3	422
525	5,250	80	2.7	1,354	6.8				5.5	169	789	5.3	380
Significant effects:			Bl***	Mi***	Pb***				Mi***	Pb*	Pb*	NS	NS

Data are means of six replicates. *, **, *** denote significance at $P \leq 0.05$, 0.01, and 0.001, respectively NS = not significant.
† Corn yield at 15.5% moisture.

TABLE 2. Population changes of *Belonolaimus longicaudatus* (Bl), *Meloidogyne incognita* (Mi), and *Pratylenchus brachyurus* (Pb) and their effects on plant growth when inoculated singly or in combination on corn in microplots, 1988.

Initial nematode population density per plot			Nematodes/ 100 cm³ soil (no.)			Stalk diameter (mm)	Plant height (cm)	Nematodes/g root dry wt. (no.)		Fresh stalk wt./plot (g)	Ears/plot (no.)	Yield/plot† (g)
Bl	Mi	Pb	Bl	Mi	Pb			Mi	Pb			
						28 April						
0	0	0	0	0	0	12.5	72					
0	0	9,200	0	0	0.8	12.5	70					
0	58,300	0	0	3.0	0	12.4	68					
0	58,300	9,200	0	1.5	0.7	12.6	71					
7,120	0	0	1.7	0	0	14.0	72					
7,120	0	9,200	1.0	0	1.0	12.6	72					
7,120	58,300	0	1.3	6.2	0	12.3	69					
7,120	58,300	9,200	1.0	2.5	1.2	9.8	58					
Significant effects:			Bl***	Mi*	Pb***	NS	NS					
						30 June						
0	0	0	0.2	0	0	23	217					
0	0	9,200	0.5	0	1.7	24	225					
0	58,300	0	0.2	305	0	23	217					
0	58,300	9,200	0.3	748	5.2	23	217					
7,120	0	0	54.2	0	0	25	223					
7,120	0	9,200	24.7	0	2.2	25	230					
7,120	58,300	0	42.7	502	0.5	24	219					
7,120	58,300	9,200	20.7	297	3.3	24	222					
Significant effects:			Bl*** Pb* Bl × Pb*	Mi*	Pb***	NS	NS					

TABLE 2. Continued.

Initial nematode population density per plot			Nematodes/ 100 cm³ soil (no.)			Stalk diameter (mm)	Plant height (cm)	Nematodes/g root dry wt. (no.)		Fresh stalk wt./plot (g)	Ears/plot (no.)	Yield/plot† (g)
Bl	Mi	Pb	Bl	Mi	Pb			Mi	Pb			
						15 September						
0	0	0	0.2	0.3	0			0	1.3	907	3.7	403
0	0	9,200	0.2	18.8	40.7			3.5	2,780	930	3.5	383
0	58,300	0	0	4,711	0			472	0.1	780	3.5	344
0	58,300	9,200	0	5,192	168			0	1,738	885	4.0	407
7,120	0	0	2.8	6.7	0.5			0.3	3.7	1,043	3.3	427
7,120	0	9,200	0.8	5.8	70.7			2.1	1,457	885	3.2	466
7,120	58,300	0	0	6,095	6.7			94.7	5.0	830	3.3	363
7,120	58,300	9,200	0	3,955	53.2			0	1,606	794	3.5	494
Significant effect:			Bl** Mi** Bl × Mi**	Mi***	NS			NS	Pb***	Mi*	NS	NS

Data are means of six replicates. *, **, *** denote significance at $P \leq 0.05$, 0.01, and 0.001, respectively. NS = not significant.

† Corn yield at 15.5% moisture.

TABLE 3. Population changes of *Belonolaimus longicaudatus* (Bl), *Meloidogyne incognita* (Mi), and *Heterodera glycins* (Hg) and their effects on plant growth when inoculated singly or in combination on soybean in microplots, 1988.

Initial nematode population density per plot			Nematodes/ 100 cm³ soil (no.)			True leaves/ plant (no.)	Plant height (cm)	Stem diameter (mm)	Cysts/ 100 cm³ soil (no.)	Nematodes/g root dry wt. (no.)		Seed yield (g/plot)†
Bl	Mi	Hg	Bl	Mi	Hg					Mi	Hg	
					23 June							
0	0	0	0	0	0	1.8	15.3					
0	0	62,500	0	0	2.0	1.9	15.8					
0	97,500	0	0	6.0	0	1.9	16.1					
0	97,500	62,500	0.2	0.8	1.2	2.0	15.6					
3,750	0	0	0.8	0	0	1.9	16.0					
3,750	0	62,500	2.8	0	1.7	2.0	15.3					
3,750	97,500	0	1.5	1.7	0	2.0	15.8					
3,750	97,500	62,500	2.5	4.5	2.0	1.8	15.9					
Significant effects:			Bl*** Hg*** Bl × Hg*	Mi*** Bl × Hg* Bl × Mi × Hg*	Hg***	NS	NS					
					16 August							
0	0	0	0.5	0	0		79	5.7				
0	0	62,500	0.5	0.2	994		81.2	6.2				
0	97,500	0	0	1.7	0		80.6	6.8				
0	97,500	62,500	3.2	27	572		83.3	6.6				
3,750	0	0	40.2	0	13.3		83.9	7.0				
3,750	0	62,500	29.2	0.8	486		78.1	6.4				
3,750	97,500	0	22.0	0.7	0		89.2	7.0				
3,750	97,500	62,500	28.8	40	647		83.1	6.5				
Significant effects:			Bl***	Mi* Hg* Mi × Hg*	Hg***		Bl × Hg*	NS				

TABLE 3. Continued.

Initial nematode population density per plot			Nematodes/ 100 cm³ soil (no.)			True leaves/ plant (no.)	Plant height (cm)	Stem diameter (mm)	Cysts/ 100 cm³ soil (no.)	Nematodes/g root dry wt. (no.)		Seed yield (g/plot)†
Bl	Mi	Hg	Bl	Mi	Hg					Mi	Hg	
					2 November							
0	0	0	0.8	1.8	0.5				0.7	0.9	0	188.5
0	0	62,500	0.2	3.7	145				116	0	104	89.7
0	97,500	0	0	94.7	1.5				1.2	40.2	3.6	202.5
0	97,500	62,500	0.2	28.8	420				68.3	7.8	69.2	66
3,750	0	0	61.8	3.8	0.5				0.5	4.7	2.1	214.3
3,750	0	62,500	7.8	1.2	86.2				84	0.1	213	813
3,750	97,500	0	37.2	132	1.0				0	23.1	0.7	185.7
3,750	97,500	62,500	33.0	53.2	53.4				96.2	0.4	39.3	105.3
Significant effects:			Bl***	Mi***	Hg*				Hg**	Mi**	Hg**	Hg***
			Hg***	Hg*						Hg*		
			Bl × Hg***							Mi × Hg*		
			Mi × Hg***									
			Bl × Hg × Mi***									

Data are means of six replicates. *, **, *** denote significance at $P \leq 0.05$, 0.01, and 0.001, respectively. NS = not significant.
† Soybean yield at 10% moisture.

among the three nematode genera (Table 3). Twenty days after planting, the population density of *B. longicaudatus* was greater in combination with *H. glycines* and the population density of *M. incognita* was greater ($P \leq 0.05$) in combination with *H. glycines* when *B. longicaudatus* was present, but decreased when *B. longicaudatus* was absent.

After 11 weeks, population densities of *M. incognita* in soil were greater in combination with *H. glycines* ($P \leq 0.05$). At harvest, there were two-way and three-way interactions involving densities of *B. longicaudatus* in soil. Numbers of this nematode were reduced in combination with *H. glycines* or *M. incognita* ($P \leq 0.001$). The reduction of *B. longicaudatus* in plots also inoculated with *H. glycines* was greater when *M. incognita* was absent, as indicated by the three-way interaction. Soil and root population densities of *M. incognita* were greater in the absence of *H. glycines* ($P \leq 0.05$).

Discussion

Two tests were run on corn in microplots in different years, but the pathogenic affects of *B. longicaudatus, M. incognita,* and *P. brachyurus* either singly or in various combinations were not evident. The yield of soybean, however, was readily reduced in plots infested with *H. glycines,* but not *B. longicaudatus* or *M. incognita.* Others also have failed to demonstrate corn yield reductions by plant-parasitic nematodes in microplots (K. R. Barker & J. R. Rich, pers. comm.). Once corn is beyond the seedling stage of growth, it rapidly produces an extensive root system because of the relatively high fertilization and watering used for corn production. These factors may result in a lack of measurable plant injury from nematodes in microplot tests.

The absence of plant damage to corn or soybean from *B. longicaudatus* was unexpected. This nematode normally attacks corn roots during the seedling stage of growth in the early spring causing abbreviated roots. Plant damage can be extreme and grain yields can be reduced by 73–80% (4). Much less is known about the pathogenicity of *B. longicaudatus* on soybean; however, it is reported as a pathogen on some soybean cultivars (13,18). In 1987–88, in nearby field plots of corn containing indigenous populations of *B. longicaudatus, M. incognita,* and *P. brachyurus,* plant growth—including stand count, grain yield, stalk weight, and size of young plants—was often inversely correlated with densities of *B. longicaudatus* and occasionally with *P. brachyurus* ($P \leq 0.05$), but not with densities of *M. incognita* (8). Also, in 1987 but not in 1988, growth of soybean in nearby field plots was inversely correlated with density of *B. longicaudatus* (9). The effect of *B. longicaudatus* on corn and soybean growth may be related to temperature and distribution within the soil profile. Root injury caused by *B. longicaudatus* on soybean planted in late May or early June is never as severe as that on corn planted in late February through mid-April (8,9). In field soil, 50% of the population densities of *B. longicaudatus* occurred in the upper 15-cm soil layer in May, but the species became more evenly distributed through greater soil depths as the season progressed (10,11). Our plots, which were planted during late April to early June, probably escaped severe root pruning by *B. longicaudatus* because the nematode moved deeper into the soil in response to increased soil temperature in the upper soil depths or other unknown factors (3,10,11).

Neither *M. incognita* nor *P. brachyurus* are known to be severe pathogens of corn, although both nematodes infect the roots and reproduce readily on corn (12). This study confirms that *H. glycines* is a highly virulent pathogen on susceptible soybean cultivars, whereas our population of *M. incognita* caused much less damage either alone or in combination with *H. glycines* or *B. longicaudatus.* An interaction between *H. glycines* and *M. incognita* on growth and yield of soybean has been shown (15), but whether the effect was additive depended on initial population densities of nematodes. In our tests *M. incognita* did not affect the soil or root population densities of *H. glycines*;

however, there is one previous report that population densities of *H. glycines* were greater in plots containing both nematodes than in plots containing only *H. glycines* (16). The suppressive effect of *H. glycines* on the population densities of *M. incognita* and *B. longicaudatus* in this experiment is probably why *H. glycines* had the major impact on soybean yield.

Literature Cited

1. Barker, K. R. 1978. How we learned to find and fight corn nematodes in the South. Pp. 67–85 *in* Midwest corn nematode conference proceedings. Springfield, Illinois: FMC Corporation.

2. Barker, K. R., and T. H. A. Olthof. 1976. Relations between nematode population densities and crop responses. Annual Review of Phytopathology 14:327–353.

3. Boyd, F. T., and V. G. Perry. 1969. The effect of sting nematodes on establishment, yield, and growth of forage grasses on Florida sandy soils. Soil and Crop Science Society of Florida, Proceedings 29:288–300.

4. Dickson, D. W., and T. E. Hewlett. 1987. Effect of two nonfumigant nematicides on corn grown in two adjacent fields infested with different nematodes. Annals of Applied Nematology (Journal of Nematology 19, Supplement) 1:89–93.

5. Ibrahim, K. A., and S. A. Lewis. 1985. Host–parasite relationships of *Meloidogyne arenaria* and *M. incognita* on susceptible soybean. Journal of Nematology 17:381–385.

6. Jenkins, W. R. 1964. A rapid centrifugal-flotation technique for separating nematodes from the soil. Plant Disease Reporter 48:692.

7. Johnson, J. T., J. R. Rich, and A. W. Boatwright. 1981. A technique for establishing microplots in the field. Journal of Nematology 13:233–235.

8. McSorley, R., and D. W. Dickson. 1989. Effects and dynamics of a nematode community on maize. Journal of Nematology 21:462–471.

9. McSorley, R., and D. W. Dickson. 1989. Effects and dynamics of a nematode community on soybean. Journal of Nematology 21:490–499.

10. McSorley, R., and D. W. Dickson. 1990. Vertical distribution of plant-parasitic nematodes in sandy soil under soybean. Journal of Nematology 22:90–96.

11. McSorley, R., and D. W. Dickson. 1990. Vertical distribution of plant-parasitic nematodes in sandy soil under maize. Plant and Soil, in press.

12. Norton, D. C. 1984. Nematodes parasitic on corn. Pp. 61–94 *in* W. R. Nickle, ed. Plant and insect nematodes. New York: Marcel Dekker.

13. Perry, V. G., and H. L. Rhoades. The genus *Belonolaimus*. Pp. 144–149 *in* R. D. Riggs, ed. Nematology in the southern region of the United States. Southern Cooperative Series Bulletin 276, the Arkansas Agricultural Experiment Station, University of Arkansas, Fayetteville.

14. Rodríguez-Kábana, R., and J. C. Williams. 1981. Determination of soybean yield losses caused by *Meloidogyne arenaria* and *Heterodera glycines* in a field infested with the two parasites. Nematropica 11:93–104.

15. Ross, J. P. 1964. Interactions of *Heterodera glycines* and *Meloidogyne incognita* on soybeans. Phytopathology 54:304–307.

16. Schmitt, D. P., and G. R. Noel. 1984. Nematode parasites of soybeans. Pp. 13–59 *in* W. R. Nickle, ed. Plant and insect nematodes. New York: Marcel Dekker.

17. Todd, T. C. 1989. Population dynamics and damage potential of *Belonolaimus* sp. on corn. Supplement to the Journal of Nematology (Annals of Applied Nematology) 21:697–702.

18. Tomerlin, A. H., Jr., and V. G. Perry. 1967. Pathogenicity of *Belonolaimus longicaudatus* to three varieties of soybean. Nematologica 13:154 (Abstr.).

19. Wallace, H. R. 1983. Interactions between nematodes and other factors on plants. Journal of Nematology 15:221–227.