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Response of Resistant Soybean Plant Introductions to *Meloidogyne arenaria* Races 1 and 2[1]

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Abstract: Resistant plant introductions, PI 230977 and PI 200538, and partially resistant Jackson and susceptible CNS were evaluated for seed yield in response to races 1 and 2 of *Meloidogyne arenaria.* Initial soil population densities (Pi) of the nematode were 0, 31, 125, and 500 eggs/100 cm^3 soil. At the highest Pi, yield suppressions of CNS, Jackson, PI 230977, and PI 200538 were 55, 28, 31, and 29%, and 99, 86, 66, and 58% for races 1 and 2 compared with uninfested controls. Numbers of second-stage juveniles (J2) present in roots 14 days after planting increased as Pi increased, but did not differ between the two races. At the highest Pi, fewer race 1 (40–57%) and race 2 (53–68%) J2 were present in roots of the plant introductions than in roots of Jackson. Soil population densities of race 1 J2 at 135 days after planting were 83–89% lower on the resistant genotypes than on CNS. These numbers did not differ for race 2. Reproductive factors were considerably higher for race 2 compared to race 1 for all genotype by Pi combinations, except for CNS at the highest Pi.

Key words: aggressiveness, *Glycine max, Meloidogyne arenaria,* microplots, nematode, plant introduction, resistance, root-knot nematode, soybean, yield response.

The development and use of cultivars with genetic resistance is an effective means of limiting yield losses to soybean (*Glycine max* (L.) Merr.) caused by *Meloidogyne* spp. Although cultivars resistant to *M. arenaria* (Neal) Chitwood are available (9), this resistance is incomplete, which enhances the probability of selecting a more virulent population of *M. arenaria* (12). Soybean genotypes highly resistant to *M. arenaria* have been identified in the Soybean Germplasm Collection (14). Resistance genes in two plant introductions (PI), PI 230977 and PI 200538, could be used to increase the level of resistance to *M. arenaria* in soybean cultivars.

Two host races (race 1, parasitic on peanut and race 2, nonparasitic on peanut) of *M. arenaria* occur in the southeastern United States. These two races can differ greatly in their reproductive potential on soybean (4,7), but this effect on fecundity may vary with population (11,17). Although race 1 is the predominant *M. arenaria* race in the peanut growing region of the United States (15), the incidence of race 2 is increasing (5,13). Of 139 soybean cultivars in Maturity Groups (MG) V-VII evaluated for root-knot resistance in a greenhouse, only 3% had a high level of resistance to *M. arenaria* race 2, further underscoring the need for additional cultivars highly resistant to this nematode (9).

The present study was conducted to determine i) the responses of soybean plant introductions highly resistant to *M. arenaria* to several initial population densities of races 1 and 2 of this nematode, and ii) the aggressiveness of races 1 and 2 on soybean in field microplots.

Material and Methods

Microplot experiments were conducted during 1991 and 1992 at the University of Georgia Plant Sciences Farm near Athens, Georgia. Three genotypes in Mg VII, CNS (susceptible), Jackson (partially resistant), and PI 200538 (highly resistant) were studied in 1991; PI 230977 (MG VII, highly resistant) was added to the experiment in 1992. Two host races of *M. arenaria,* race 1 (GA-7 isolate from Georgia) (17) and race 2 (Govan isolate from South Carolina) (4) were cultured on greenhouse-grown tomato, *Lycopersicon esculentum* Mill. cv. Rutgers. Nematode inoculum was obtained by collecting eggs with 0.5% NaOCl (8).

The soybean genotypes, two nematode races, and four Pi were arranged factori-

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ally with four replications in a randomized complete block design. Fiberglass microplots (6) were fumigated with methyl bromide at 0.12–0.19 kg/m^2. Three to four weeks after fumigation, the soil in each plot was infested by mixing 0, 31, 125, or 500 eggs of *M. arenaria*/100 cm^3 soil into the top 23 cm of soil. Two to three days after infestation, 45 seeds were planted in a center row and another 20 seeds in an off-center row on 24 June 1991 and 1 June 1992. The seedlings in the center row were thinned to 20 per microplot by 3 weeks after planting. Mycorrhizal inoculum and *Bradyrhizobium japonicum* (Kirchner) Jordan were added in the furrow at planting (6). Microplots were irrigated as needed.

Data collected from the center row of each microplot included seed yield, plant mortality, and J2 population densities in the soil. The seedlings in the second off-center row in each microplot were dug at 14 days after planting. Five root systems were selected and stained (3), and the number of J2 per root system determined. J2 in the soil were extracted by a combination of elutriation (2) and centrifugal flotation (10) from 250 cm^3 soil collected 72 and 121 days after planting in 1991, and 72 and 135 days after planting in 1992.

For statistical analysis, nematode population data (x) were transformed to $\log_{10}(x + 1)$ values, and are reported as antilogs. Analysis of variance was conducted for numbers of nematodes in soil and roots, and yield by year. Since results were similar for the three genotypes used both years, all data from 1992 and J2 root penetration and relative seed yield only from 1991 are presented. Means of nematode soil population densities, J2 penetration, and absolute yield for each genotype were

TABLE 1. Seed yield (g/plot) and mortality (%) of susceptible (CNS) and resistant (Jackson, PI 200538, and PI 230977) soybean genotypes in relation to initial population densities of *Meloidogyne arenaria* races 1 and 2 in field microplots in 1992.

		Race 1		Race 2	
Pi†		Seed yield	Mortality	Seed yield	Mortality
		CNS			
0		173.4 a A	1	161.8 a A	3
31		129.3 a A	1	10.2 c B	63
125		120.5 a A	6	1.1 c B	98
500		77.5 b A	15	0.6 b B	96
	Mean	125.1	6	43.4	65
		Jackson			
0		142.2 a A	1	119.3 b A	0
31		117.2 a A	0	89.6 b A	3
125		142.3 a A	3	34.5 bc B	10
500		102.3 ab A	0	17.1 b B	23
	Mean	126.0	1	65.1	10
		PI 200538			
0		179.5 a A	1	142.3 ab A	0
31		148.3 a A	1	154.6 a A	0
125		127.3 a A	1	102.2 a A	1
500		128.1 a A	3	60.4 a B	3
	Mean	145.8	2	114.9	1
		PI 230977			
0		167.3 a A	0	123.0 ab B	0
31		140.5 a A	0	89.6 b B	0
125		126.0 a A	0	51.4 b B	1
500		116.2 ab A	0	41.7 ab B	13
	Mean	137.5	0	76.4	3

Data are averages of four replications. Means within columns followed by different lowercase letters for comparison between genotypes at the same Pi and means within rows followed by different capital letters for comparison between races indicate significant differences based on Fisher's (protected) LSD ($P = 0.05$).

† Pi = initial population densities of *M. arenaria* eggs/100 cm^3 soil.

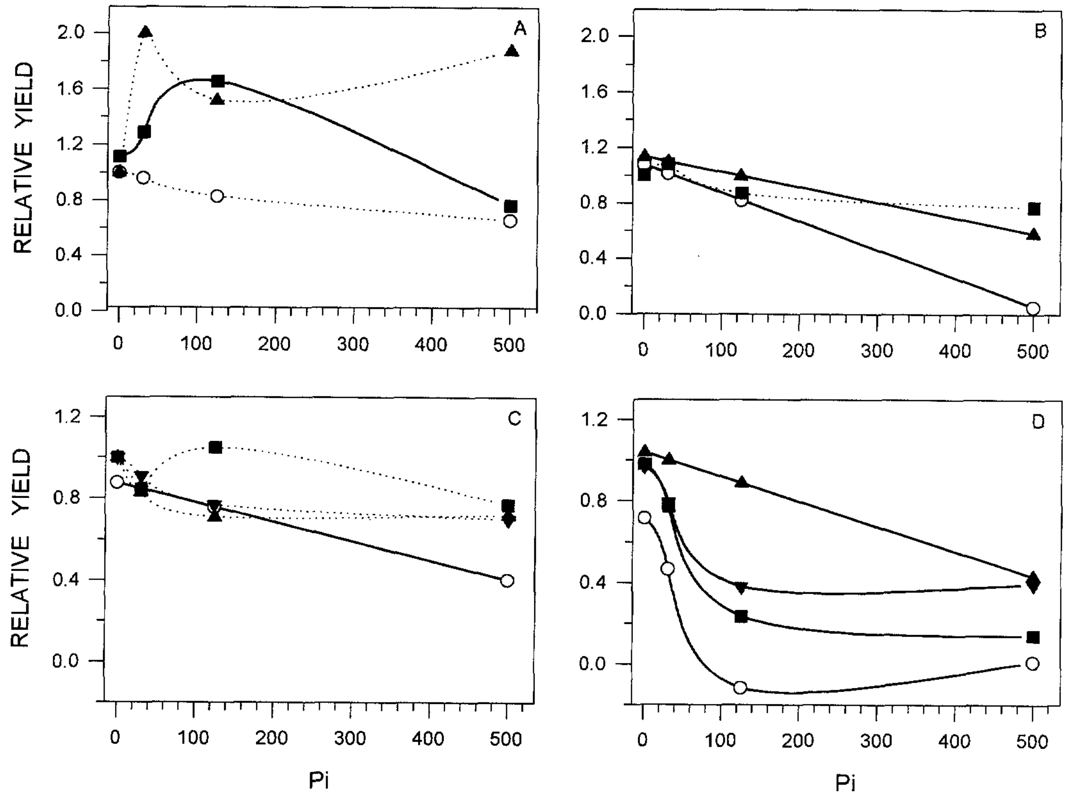

FIG. 1. Relative yield responses of four soybean genotypes to increasing initial population densities (Pi) of *Meloidogyne arenaria* races 1 (A & C) and 2 (B & D) in field microplots in 1991 (A & B) and 1992 (C & D). Dashed lines (----) connect means for genotypes for which there was no significant linear or quadratic regression of relative yield on Pi. Solid lines describe significant ($P \geqslant 0.05$) regressions. CNS (○), Jackson (■), PI 200538 (▲), and PI 230977 (▼).

compared by Fisher's protected LSD (P = 0.05) when the genotype × Pi interaction was significant ($P > 0.05$). Relative seed yield was calculated for 1991 and 1992 on a per replication basis as the yield of each nematode-infested microplot divided by the yield of the noninfested microplot. Regression models (linear and quadratic) were used to determine relative yield response to Pi.

RESULTS

Race 2 of *M. arenaria* had a much greater negative effect on seed yields of the soybean genotypes than did race 1 (Table 1). Yield suppression was greater in 1992 than in 1991 (Fig. 1). In 1992, yield suppressions of CNS, Jackson, PI 230977, and PI 200538 were 55, 28, 31, and 29, and 99, 86, 66, and 58%, respectively, for races 1 and 2, at the highest Pi when compared with uninfested control plots (Table 1).

In 1991, the only significant response of the genotypes to race 1 was with Jackson ($Y = 1.114 + 0.006X - 0.000014X^2$; $R^2 = 0.55^{**}$) (Fig. 1A). Significant responses involving race 2 were observed for PI 200538 ($Y = 1.133 - 0.001X$; $R^2 = 0.31^*$) and CNS ($Y = 1.075 - 0.002X$; $R^2 = 0.25^*$) (Fig. 1B). For race 1 in 1992, no significant linear or quadratic regressions of yield on Pi occurred for Jackson, PI 230977, and PI 200538, whereas CNS yield response was linear ($Y = 0.877 - 0.0009X$; $R^2 = 0.41^{**}$) (Fig. 1C). For race 2, the responses for CNS ($Y = 0.716 - 0.008X + 0.0000014X^2$; $R^2 = 0.63^{**}$), Jackson ($Y = 0.98 - 0.007X +$

TABLE 2. Numbers of *Meloidogyne arenaria* races 1 and 2 second-stage juveniles in root systems of soybean genotypes at 14 days after planting in field microplots in 1991 and 1992.

Pi†	CNS	Jackson	PI 200538	PI 230977
		1991		
Race 1				
31	9 a A	4 a AB	3 a B	
125	17 b A	23 a A	12 a A	
500	131 a A	58 a B	58 a B	
Race 2				
31	9 a A	8 a A	7 a A	
125	50 a A	19 a B	12 a B	
500	114 a A	94 a A	73 a A	
		1992		
Race 1				
31	30 a A	12 a B	6 a B	6 a B
125	102 a A	42 a B	30 a B	40 a B
500	207 a A	162 a AB	97 a B	69 a B
Race 2				
31	17 a A	6 a BC	10 a AB	4 a C
125	70 a A	24 a B	37 a AB	28 a AB
500	211 a A	162 a AB	77 a BC	53 a C

Data are averages of four replications. Means within columns followed by different lowercase letters for comparison between races at the same Pi levels within year and means within rows followed by different capital letters for comparison between genotypes indicate significant difference based on Fisher's (protected) LSD ($P = 0.05$).

† Pi = initial population density of *M. arenaria* eggs/100 cm^3 soil.

$0.00001X^2$; $R^2 = 0.87$*), and PI 230977 ($Y = 0.968 - 0.0059X + 0.000009X^2$; $R^2 = 0.44$**) fit quadratic regression equations. A linear model best fit the observed data for PI 200538 ($Y = 1.038 - 0.0012X$; $R^2 = 0.52$**) (Fig. 1D). Plant mortality of CNS was 3, 63, 98, and 96% for 0, 31, 125, and 500 eggs/100 cm^3 with race 2. It was 1, 1, 6, and 15% with race 1 (Table 1). No or little mortality occurred with race 1 on Jackson, PI 200538, and PI 230977. Race 2 caused 10 and 23% mortality at Pi 125 and 500 on Jackson and 13% on PI 230977 at Pi 500.

Numbers of *M. arenaria* J2 penetrating root systems increased as Pi increased, but differed little between the two races in either year (Table 2). More J2 penetrated the soybean roots in 1992 than in 1991. In 1992, the resistant genotypes had fewer race 1 J2 present in roots at 14 days after planting than the susceptible CNS at the same Pi, except for Jackson at 500 eggs/100 cm^3 soil (Table 2). Although fewer race 2 J2 were present in roots of the resistant genotypes compared to CNS, these differences were not always significant. At the highest Pi, the highly resistant plant introductions had fewer race 1 (40–57%) and race 2 (53–68%) J2 in their roots than Jackson, the partially resistant cultivar (Table 2). In 1991, at the highest Pi, only race 1 had fewer J2 present in roots of the resistant genotypes compared with CNS (Table 2).

Significant interactions (genotype × Pi and genotype × race) were detected among soil population densities of *M. arenaria* J2 at both 72 and 135 days after planting. The mean race 2 J2 population densities across Pi levels at 72 days after planting ranged from 90 to 395 per 100 cm^3 soil whereas race 1 was barely detectable (Table 3). Race 1 J2 soil densities 135 days after planting were 83–89% lower on the resistant genotypes than for CNS, whereas these J2 numbers did not differ for race 2, except they were greater on PI 200538 than CNS. Race 2 had higher reproductive factors (RF = Pf/Pi) than race 1 for most genotype × Pi combinations (Table 3). Reproductive factors were inversely related to Pi on the genotypes except for race 2 on PI 230977.

DISCUSSION

Damage to soybean by *M. arenaria* is genotype–race–environment dependent. A previous study (11) suggested that soybean resistance to *M. arenaria* is independent of host race. However, our results and those of Carpenter and Lewis (4) indicate that race 2 causes more damage and is more fecund on resistant soybean cultivars than race 1. The discrepancies in these studies may be related to differences in the aggressiveness of populations of race 2 used by the different researchers.

The resistance of PI 200538 and PI 230977 to *M. arenaria* (14) is documented by our study. Although no differences in gall indices and nematode reproduction occurred between these two plant intro-

TABLE 3. Soil population densities of *Meloidogyne arenaria* races 1 and 2 second-stage juveniles (J2) on four soybean genotypes at different initial population densities (Pi) in field microplots 72 and 135 days after planting in 1992.

		J2/100 cm³ soil					
		Race 1			Race 2		
Pi		72	135	RF†	72	135	RF
			CNS				
31		3	195	6.3	987	602	19.4
125		2	243	1.9	39	595	4.8
500		10	131	0.3	160	30	0.1
	Mean	5 a B	190 a B		395 a A	409 b A	
			Jackson				
31		1	21	0.7	332	366	11.8
125		2	17	0.1	315	530	4.2
500		4	35	0.1	380	620	1.2
	Mean	2 a B	25 b B		343 a A	505 ab A	
			PI 200538				
31		1	13	0.4	31	573	18.5
125		3	12	0.1	121	1,307	10.5
500		7	40	0.1	117	643	1.3
	Mean	4 a B	21 b B		90 b A	841 a A	
			PI 230977				
31		0	17	0.5	99	216	7.0
125		0	22	0.2	248	977	7.8
500		6	57	0.1	275	248	0.5
	Mean	2 a B	32 b B		207 ab A	480 ab A	

Data are averages of four replications. Means within columns followed by different lowercase letters for comparison between genotypes and means within rows followed by different capital letters for comparison between races at the same sampling date indicate significant difference based on Fisher's (protected) LSD ($P = 0.05$).

† RF = reproductive factor = number of J2 at 135 days/initial number of eggs.

ductions in greenhouse experiments (14), PI 200538 was damaged less than PI 230977 by race 2 of *M. arenaria* in field microplots. Since PI 200538 and PI 230977 possess considerable resistance, they should be valuable as parents for the development of soybean cultivars with increased levels of resistance to *M. arenaria.*

It is possible that different genes condition resistance in these two soybean genotypes. If this assumption is correct, hybridization and recombination could result in progeny with higher levels of resistance than either PI. The level and apparent mechanism of resistance in these two PI to *M. arenaria* differs from that present in PI 96354, which is highly resistant to *M. incognita* (16). Most J2 of *M. incognita* egress roots of PI 96354; in addition, postinfection development, reproduction, and fecundity of the nematodes remaining in roots are suppressed.

Damage to soybean by both races was more severe in 1992 than in 1991. Although the same inoculum levels were used in both years, the higher penetration rate by J2 in the roots by 14 days after inoculation in 1992 compared with 1991 may account for some of the additional damage in 1992. Although damage to crop plants is generally related to the magnitude of the initial nematode population density in the soil, other factors can modify the nematode–host relationship (1). The differences in J2 penetration rates between these two years could be related to environmental conditions and(or) inoculum efficiency.

In conclusion, damage to soybean appears more severe and variable with different populations of race 2 than race 1, particularly on *M. arenaria*-resistant cultivars. The effectiveness of resistant soybean cultivars in suppressing reproduction of race 1 of *M. arenaria* indicates their use should be an effective management tactic.

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