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Relative Damage Functions and Reproductive Potentials of *Meloidogyne arenaria* and *M. hapla* on Peanut[1]

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Abstract: The reproductive potential and damage functions for *Meloidogyne hapla* and *M. arenaria* race 1 on Virginia-type peanuts (*Arachis hypogaea* cv. Florigiant) were determined over 2 years in microplot experiments in North Carolina. Peanut yield suppression and damage to pods as a result of galling were greatest in response to *M. arenaria* ($P = 0.01$). Damage functions for the two species were adequately described by the quadratic models: yield (g/plot) = $398 - 17.1\ (\log_{10}[\text{Pi} + 1]) - 17.0(\log_{10}[\text{Pi} + 1])^2$; ($R^2 = 0.83$, $P = 0.0001$) for *M. arenaria;* and yield = $388 - 10.2(\log_{10}[\text{Pi} + 1]) - 7.5(\log_{10}[\text{Pi} + 1])^2$, ($R^2 = 0.30$, $P = 0.0001$) for *M. hapla.* Both species caused galling on pods, but this was more severe in response to *M. arenaria.* Reproduction of *M. arenaria* race 1 was greater than *M. hapla* on peanut, which accounts in part for the more severe pod galling. Peanut was an excellent host for both *M. arenaria* race 1 and for *M. hapla,* but reproduction by *M. hapla* was more variable.

Key words: Arachis hypogaea, damage function, *Meloidogyne arenaria, Meloidogyne hapla,* nematode, peanut, reproductive potential, root-knot nematode.

Peanut (*Arachis hypogaea* L.) is subject to damage by many nematode species in the United States (5). The most serious of these are *Meloidogyne arenaria* (Neal) Chitwood and *M. hapla* Chitwood. Ninety percent of peanut fields in North Carolina are infested with *Meloidogyne* spp. (11). In earlier years, *M. hapla* was considered to be the only root-knot nematode species infesting peanut fields in the state (10). Recently, however, *M. arenaria* was detected in several North Carolina peanut fields causing severe damage (3). There are no commercial peanut cultivars resistant to these nematode species (6). *Meloidogyne hapla* usually is not considered to be a major problem in peanut production, although it can cause yield losses (5). In contrast, *M. arenaria* may cause yield losses in excess of 30% (8,9,12,13). Both species may increase the severity of black root rot disease in peanut caused by *Cylindrocladium crotolariae* (Loos) Bell & Sobers (3). Fumigant nematicides were used extensively to control nematodes in peanuts until DBCP and EDB were banned from production in the United States.

The current research was undertaken to characterize the relative damage potentials of *M. hapla* and *M. arenaria* on Virginia-type peanut. The specific objectives of this research were 1) to develop damage functions for these two nematodes on peanut and 2) to assess the relative reproduction of the two nematode species on peanut in North Carolina.

Materials and Methods

Experiments were conducted in 1987 and 1988 at the Central Crops Research Station, Clayton, North Carolina. The soil was a Fuquay sand (93% sand, 4% silt, 3% clay; pH 5.9, O.M. <0.5%). Microplots were fumigated with ca. 98 g a.i. methyl bromide + 2 g a.i. chloropicrin per square meter 6 weeks prior to peanut planting in 1987. The mycorrhizal fungus, *Glomus macrocarpus* Tul. & Tul., was added in 1987 to each microplot by broadcasting a suspension containing ca. 1,000 chlamydospores onto the soil surface and incorporating to a depth of 20 cm. Peanut seeds were inoculated with a commercial preparation of *Bradyrhizobium* sp. (*arachis*) Jordan prior to planting. Nematode inoculum was reared in the greenhouse on tomato (*Lycopersicum esculentum* Mill. cv. Manapal).

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The culture of *M. hapla* came originally from tobacco-peanut plots, approximately 25 years ago, and has been reared in the greenhouse since that time. The culture of *M. arenaria* was a recent acquisition from a peanut field in Martin County, North Carolina. Eggs of the two species of nematodes were extracted from roots in 1987 using the NaOCl method (4). Aliquants of extracted eggs were added to sufficient water to bring the volume to 1 liter to dispense onto the soil surface of individual microplots at the desired concentration. Inoculum was incorporated immediately to a depth of 15–20 cm. The experiment was a factorial design with 0, 35, 70, 140, 280, 560, and 1,120 eggs/500 cm^3 soil and two nematode species (*M. hapla* and *M. arenaria*) in 1987. Treatments were arranged in randomized complete blocks with six replicates. Twelve peanut seeds cv. Florigiant were planted 2–3 cm deep in a furrow in the center of each microplot.

Microplots were not fumigated in 1988, as the damage potentials of carryover nematode populations were studied in the same plots. Microplots containing *M. hapla* received supplemental inoculum (0, 195, 390, 780, 1,560, 3,120, 6,240 eggs and juveniles/500 cm^3 soil) because April soil samples indicated the population densities were low. Supplemental inoculum preparation in 1988 consisted of tomato roots infected with *M. hapla,* which were cut into 1-cm long pieces and mixed with infested soil. Nematodes in infested soil and roots were quantified by elutriation and centrifugation (2), and eggs were extracted from roots (1). Aliquants of infested soil were mixed (1:1) with sand and loamy sand (80% sand, 15% silt, and 5% clay) to achieve a final volume of 2 liters of soil. Pasteurized soil and uninfested tomato roots were prepared for addition to control microplots and those containing *M. arenaria.* Infested or uninfested soil was added to selected microplots and incorporated before planting peanut in 1988. All microplots were assayed for eggs and second-stage juveniles 2 weeks prior to planting peanut in 1988. Initial population density (Pi) for 1988 was considered to be the numbers of juveniles per 500 cm^3 soil from the preplant samples for *M. arenaria* and *M. hapla* eggs and juveniles added supplementally plus the overwintered *M. hapla* juveniles. Microplots were inoculated and planted 2 weeks earlier in 1988 than in 1987, and final season population density estimates were taken 1 week later in 1988 than in 1987.

Data collection for each microplot included midseason and harvest nematode samples each year in addition to the preplant samples taken in 1988. Nematode samples consisted of 12 cores (2.5-cm-d × 20-cm deep). Nematode population densities were assayed from 500-cm^3 subsamples processed by elutriation and centrifugation to extract juveniles (2). Eggs were separated from peanut roots collected from the elutriator and processed by the NaOCl method (1).

Peanuts were harvested, and the air-dried weight of pods was determined. Pods were visually rated for galling on the basis of the percentage of peanut hull surface that was galled (0–100). The percentage of peanut hull exhibiting necrosis also was estimated. Data were subjected to analysis of variance (ANOVA) and regression analysis. Nematode data were transformed ($\log_{10}[x + 1]$) to standardize the variance. Regression analysis was used exclusively for the 1988 data because initial inoculum densities of *M. arenaria* were much greater than densities of *M. hapla.*

Results

Peanut yield suppression was much greater for *M. arenaria* than *M. hapla* (Fig. 1A,B). The interaction term (nematode species × Pi) for ANOVA of the 1987 data was highly significant ($P = 0.0001$), indicating the greater yield suppression caused by *M. arenaria.* The pod-gall indices associated with *M. arenaria* were greater ($P = 0.0001$) than those associated with *M. hapla* in 1987 (Table 1). Two-year mean yield and pod-gall indices were evaluated to determine the relative damage potentials of

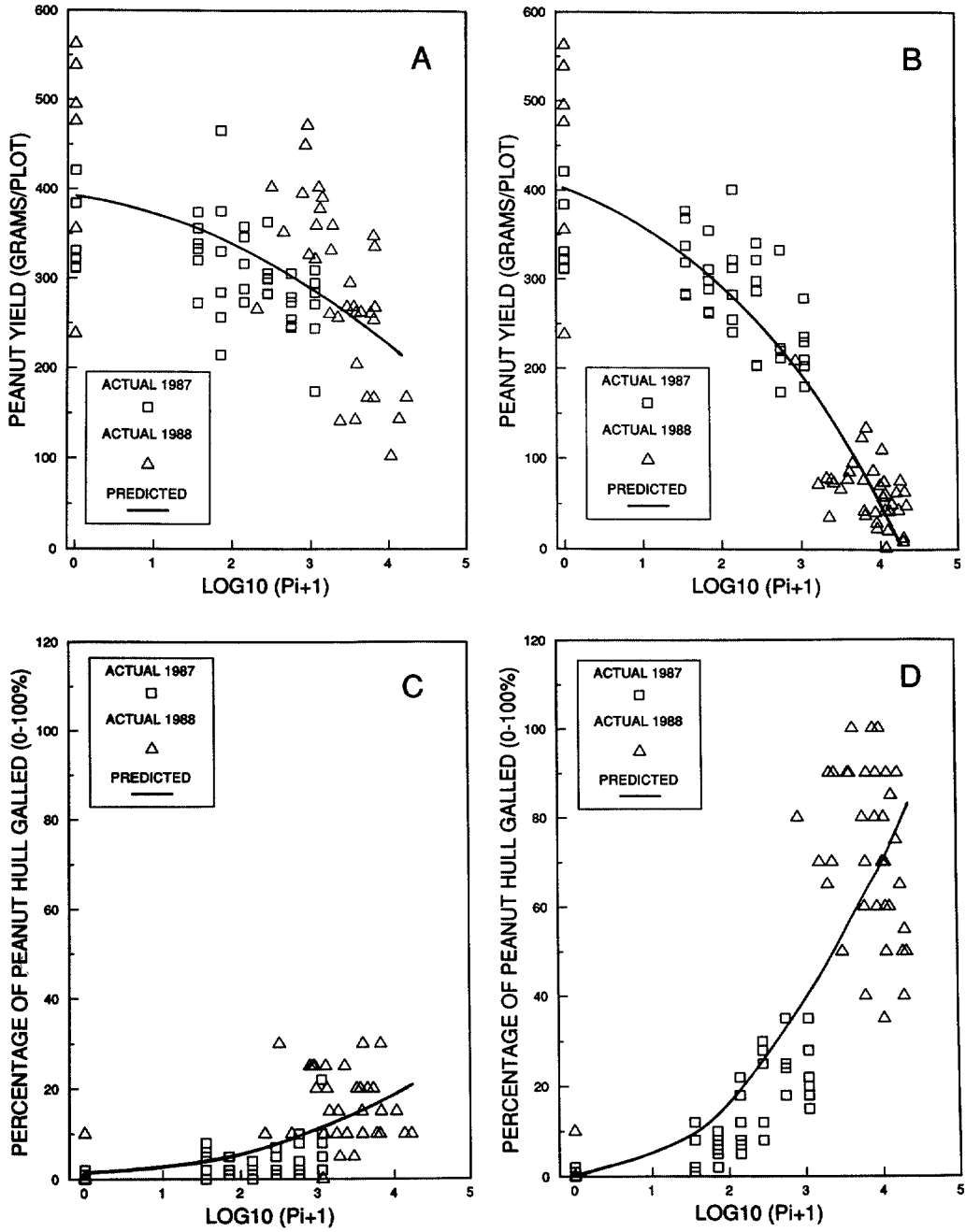

FIG. 1. Influence of inoculum density (Pi) of *Meloidogyne hapla* or *M. arenaria* per 500 cm^3 soil on peanut yield and percentage of peanut hulls galled 1987–1988. A) *M. hapla*, yield = $388 - 10.2x - 7.5x^2$, $R^2 = 0.30$ ($P = 0.0001$). B) *M. arenaria*, yield = $398 - 17.1x - 17.0x^2$, $R^2 = 0.83$ ($P = 0.0001$). C) *M. hapla*, pod-galling percentage = $1.6 - 0.25x + 1.1x^2$, $R^2 = 0.34$ ($P = 0.0001$). D) *M. arenaria*, pod-galling percentage = $-0.48 - 1.84x + 4.9x^2$, $R^2 = 0.71$ ($P = 0.0001$).

the two species. The relationships between Pi, peanut yield, and pod-gall indices were adequately described by quadratic models (Fig. 1). Effects of *M. hapla* and *M. arenaria* on peanut yields were greater in 1988 than in 1987 as a result of higher inoculum densities used (Fig. 1A,B). Pod galling also was more severe in 1988 than in 1987 because

TABLE 1. Percentage of peanut pods galled (0–100%), mid-season (Pm), and end-of-season (Pf) numbers of *Meloidogyne hapla* and *M. arenaria* eggs and juveniles per 500 cm³ soil on *Arachis hypogaea* cv. Florigiant in 1987.

	M. hapla			*M. arenaria*		
Inoculum density (eggs/500 cm³ soil)	Pod galling (0–100%)	Pm (in 1,000s)	Pf (in 1,000s)	Pod galling (0–100%)	Pm (in 1,000s)	Pf (in 1,000s)
0	–	–	–	–	–	–
35	4†	0.4	1.9	5	0.5	46.1
70	2	1.7	7.8	6	1.7	34.0
140	2	3.9	1.8	12	1.1	29.0
280	4	1.3	5.7	19	3.0	37.1
560	6	2.8	1.5	29	3.6	43.8
1,120	8	3.1	4.4	23	19.2	71.2

† Data are means of six replicates. ANOVA: inoculum density (P = 0.0001), nematode species (P = 0.0001), inoculum density × nematode species (P = 0.0001).

of increased inoculum densities. Plants were visibly stunted in *M. arenaria*-infested plots, whereas plants in *M. hapla*-infested plots exhibited no measurable growth suppression (data not included). Pod galling and yield suppression of peanut were more consistently related to Pi (higher R^2) for *M. arenaria* than for *M. hapla*. The percentage of pods galled was usually less than 20% in *M. hapla*-infested plots (Fig. 1C), whereas nearly 100% of the pods were galled in 1988 for *M. arenaria* (Fig. 1D). Pod necrosis was positively (P = 0.01) related to nematode density both years (data not included). Necrosis ratings were less consistently related to Pi than were gall ratings. Necrosis of pods differed little between the two species.

Mid-season population densities (Pm) of *M. arenaria* were greater (P = 0.0001) than those of *M. hapla* in 1987 (Table 1) and slightly greater in 1988 (Table 2). Final population densities in 1987 of *M. hapla* increased by factors (Rf) of from 2.6 to 111, whereas Rf for *M. arenaria* varied from 63 to over 1,300, depending on initial density (Table 3). The relationship between Pi and Pf of *M. hapla* was described

TABLE 2. Pre-plant, midseason (Pm), and end-of-season (Pf) population densities of *Meloidogyne hapla* and *M. arenaria* eggs and second-stage juveniles (J2) per 500 cm³ soil on peanut (*Arachis hypogaea* cv. Florigiant) in microplots in 1988.

Inoculum level (eggs/500 cm³ soil 1987)	Inoculum added (J2 and eggs/ 500 cm³ soil 1988)	Measured J2 2 weeks before planting†	Eggs and J2/500 cm³ soil (×1,000)	
			Pm	Pf
		M. hapla		
35	195	570 ± 170	4.5	191.4
70	390	4,600 ± 2,500	10.1	121.0
140	780	570 ± 220	10.3	205.1
280	1,560	1,250 ± 560	12.8	164.9
560	3,120	1,820 ± 1,160	4.6	70.7
1,120	6,240	1,480 ± 1,170	12.7	64.3
		M. arenaria		
35		8,180 ± 2,480	18.9	49.2
70		5,830 ± 1,760	24.5	133.2
140		7,190 ± 2,940	14.9	76.7
280		12,330 ± 2,470	20.5	61.9
560		10,830 ± 2,500	18.8	42.7
1,120		11,913 ± 2,110	17.3	48.5

† Means of six replicates ± the standard error.

TABLE 3. Regression equations with independent variable LPi = $\log_{10}$(Pi + 1), dependent variables reproductive factor (Rf = Pf/Pi) and $\log_{10}$ final population density (LPf) for *Meloidogyne hapla* and *M. arenaria* for 1987 and 1988.

Species	Year	Equation†	R^2	P
M. hapla	1987	LPf = 3.6 − 0.12 LPi	0.011	0.55
	1988	LPf = 0.1 + 313 LPi − 0.494 LPi^2	0.18	0.0611
	1987	Rf = 212.8 − 73.2 LPi	0.33	0.0002
	1988	Rf = 499.8 − 121.8 LPi + 1.27 LPi^2	0.68	0.0001
M. arenaria	1987	LPf = 5.44 − 1.02 LPi + 0.29 LPi^2	0.12	0.12
	1988	LPf = 10.87 − 2.53 LPi + 0.24 LPi^2	0.36	0.0006
	1987	Rf = 2,222.8 − 1,323.7 LPi + 196.9 LPi^2	0.40	0.0001
	1988	Rf = 7,079 − 5,323.6 LPi + 999.3 LPi^2	0.54	0.0001

† All data are based on 36 observations.

by a quadratic model (P = 0.01) in 1988 (Table 3). Final population density of *M. arenaria* was inversely related to Pi in 1988 but not in 1987, because the 2 years differed greatly as a result of initial population levels (Table 3). *Meloidogyne hapla* reproduction was greater than *M. arenaria* in 1988 (Table 2), largely as a result of the severe damage to peanut caused by the latter, which resulted in a low Pf for this nematode. Numbers of *M. arenaria* juveniles that survived over winter (1987–1988) were much greater than those of *M. hapla* (Table 2), but this resulted largely from the higher densities at the end of the 1987 growing season (Table 1). A greater percentage of *M. hapla* survived over winter than did *M. arenaria,* although these data are difficult to evaluate due to the large differences in 1987 Pf.

DISCUSSION

Meloidogyne arenaria is much more damaging than *M. hapla* on peanut. Our research verifies earlier observations that *M. hapla* is a less severe pathogen of peanut compared to *M. arenaria* (5). Although *M. hapla* is less damaging than *M. arenaria,* significant peanut yield suppression occurred at relatively low inoculum levels. Damage as a result of *M. hapla* infections is insidious because the plants appear to be relatively healthy. Growers may not be aware that problems exist in fields infested with *M. hapla.* Researchers in Virginia and North Carolina, however, obtained positive results with nematicide treatments in *M. hapla*-infested fields (7). The low gall indices associated with *M. hapla* are possibly the result of two factors: 1) because *M. hapla* has a lower temperature optimum (12), nematode activity is probably minimal at plant pegging, when soil temperature is relatively high; and 2) galls caused by *M. hapla* typically are much smaller than those caused by *M. arenaria.*

The reproductive potential of the two nematode species on peanut was somewhat different. Peanut was an excellent host for *M. arenaria,* although damage at high initial population densities resulted in suppressed reproductive rates. Peanut supported less reproduction of *M. hapla* in 1987 compared to *M. arenaria.* Peanut would be considered a moderate host for *M. hapla* under the experimental conditions of 1987, but 1988 was more conducive to population increase (up to 250-fold). *Meloidogyne hapla* has a low optimum temperature for reproduction, and is considered to be a species of colder climates (12). Poor reproduction of *M. hapla* in 1987 vs. 1988 may be the result of a shorter growing season in 1987. Seeds were planted earlier and harvested later in 1988, resulting in a growing season 3 weeks longer than the previous year. Reproduction by this pathogen probably occurs primarily in early spring and fall when soil temperatures are lower. Thus, delayed planting and early harvest may have a profound effect on overall repro-

duction of *M. hapla*. Another possibility is that egg viability and (or) hatch of *M. hapla* was lower than that of *M. arenaria* in 1987.

Infestation of North Carolina peanut fields with *M. arenaria* race 1 (while still less frequent than *M. hapla*) is a cause for concern because of its high reproductive potential and aggressiveness on peanut. The reproductive factor (Rf) of this pathogen at low population densities on peanut was in excess of 1,000. The rationale for using overwintered populations in 1988 was to test the assumption that *M. arenaria* race 1 would not overwinter well in North Carolina because it has only recently been detected. Based on limited data, this assumption appears to be incorrect because *M. arenaria* survived the 1987–1988 winter at high population densities, as evidenced by the high Pi in 1988. The potential spread of *M. arenaria* race 1 in peanut-producing areas of North Carolina represents a significant threat to this industry.

Damage thresholds and management tactics for root-knot nematodes on peanut must be adjusted to the type of peanut grown as well as the species present. Virginia-type peanuts are long-season cultivars compared to Runner-type peanuts grown in more southerly locales. The shorter growing season with Runner-type peanut would favor *M. arenaria* over *M. hapla* because these types are planted and harvested when soil temperatures are higher. Degree-day accumulation may be higher or lower in different peanut-growing regions, depending on local climatic factors and length of growing season. Variations in accumulation of degree days likely influence the amount of pod infection that would have a deleterious effect on quality. The damage potential to peanut from *M. arenaria* is clearly greater than that of *M. hapla*. The high damage potential of *M. arenaria* likely results from both its greater fecundity and relative aggressiveness on peanut.

Literature Cited

1. Byrd, D. W., Jr., H. Ferris, and C. J. Nusbaum. 1972. A method for estimating numbers of eggs of *Meloidogyne* spp. in soil. Journal of Nematology 4:266–269.

2. Byrd, D. W., Jr., K. R. Barker, H. Ferris, C. J. Nusbaum, W. E. Griffin, R. H. Small, and C. H. Stone. 1976. Two semi-automatic elutriators for extracting nematodes and certain fungi from soil. Journal of Nematology 8:206–212.

3. Culbreath, A. K., M. K. Beute, B. B. Shew, and K. R. Barker. 1992. Effects of *Meloidogyne hapla* and *Meloidogyne arenaria* on black root rot severity in new cylindrocladium-resistant peanut genotypes. Plant Disease 76, in press.

4. Hussey, R. S., and K. R. Barker. 1973. A comparison of methods of collecting inocula for *Meloidogyne* spp., including a new technique. Plant Disease Reporter 57:1025–1028.

5. Minton, N. A. 1984. Nematode parasites of peanuts. Pp. 373–394 *in* W. R. Nickle, ed. Plant and insect nematodes. New York: Marcel Dekker.

6. Nelson, S. C., C. E. Simpson, and J. L. Starr. 1989. Resistance to *Meloidogyne arenaria* in exotic *Arachis* spp. germplasm. Supplement to the Journal of Nematology 21:654–660.

7. Phipps, P. M., and A. P. Elliott. 1982. Control of northern root-knot nematode on peanut. Fungicide and Nematicide Tests 38:4–5.

8. Porter, D. M., D. H. Smith, and R. Rodríguez-Kábana. 1982. Peanut diseases. Pp. 326–410 *in* H. E. Pattee, ed. Peanut production and technology, 2nd ed. Yoakum, Texas: American Peanut Research and Education Society.

9. Rodríguez-Kábana, R., J. C. Williams, and R. A. Shelby. 1982. Assessment of peanut yield losses caused by *Meloidogyne arenaria*. Nematrópica 12:279–288.

10. Sasser, J. N., K. R. Barker, and L. A. Nelson. 1975. Chemical soil treatments for nematode control on peanut and soybean. Plant Disease Reporter 59:154–158.

11. Schmitt, D. P., and K. R. Barker. 1988. Incidence of plant-parasitic nematodes in the Coastal Plain of North Carolina. Plant Disease 72:107–110.

12. Taylor, A. L., and J. N. Sasser. 1978. Biology, identification and control of root-knot nematodes (*Meloidogyne* species). Raleigh: North Carolina State University Graphics.

13. Wheeler, T. A., and J. L. Starr. 1987. Incidence and economic importance of plant-parasitic nematodes on peanuts in Texas. Peanut Science 14:94–96.