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Host-parasite Relationship of Carrot Cultivars and *Meloidogyne chitwoodi* Races and *M. hapla*[1]

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Abstract: Most of the 15 carrot cultivars tested were moderate to good hosts to *Meloidogyne chitwoodi* race 1, whereas all except Orlando Gold were nonhosts or poor hosts for *M. chitwoodi* race 2. All carrot cultivars were good hosts for *M. hapla.* The plant weights of the carrot cultivars Red Cored Chantenay and Orlando Gold infected with either race of *M. chitwoodi* were significantly less than uninoculated checks in pots. Under field microplot conditions, however, detrimental effects on quality were rarely observed. *M. hapla* was pathogenic to both cultivars in the greenhouse and the field. The tolerance level of Orlando Gold to *M. hapla* was lower than Red Cored Chantenay.

Key words: carrot, Columbia root-knot nematode, host range, *Meloidogyne chitwoodi, M. hapla,* northern root-knot nematode, pathogenicity, tolerance.

Approximately 4,000 ha of carrots (*Daucus carota* L.) are grown annually for seed production, fresh market, and processing in Washington. Most of the production area is in the Columbia Basin, where *Meloidogyne chitwoodi* Golden et al. (Columbia root-knot nematode) and *M. hapla* Chitwood (northern root-knot nematode) are widespread (9). Root-knot nematodes can cause considerable losses by deforming the carrot roots and rendering them unmarketable (4). Although carrot growers rely heavily on nematicides to control these nematodes, resistant or tolerant cultivars are continually being sought (5,18,22), and cultural practices to reduce the impact of root-knot nematodes are recommended (1).

The effect of *M. hapla* on total yield and quality of carrots is well documented (17,19), but the effect of *M. chitwoodi* is not known. O'Bannon et al. (10) reported that selected carrot cultivars were nonhosts or moderate hosts of *M. chitwoodi* (race 1). Mojtahedi et al. (8) found that *M. chitwoodi* race 2 did not reproduce on Red Cored Chantenay carrot, whereas race 1 increased readily.

The objectives of these studies were to evaluate the host suitability of selected carrot cultivars for *M. chitwoodi* races 1 and 2 and to determine the pathogenicity of these races on commonly grown carrot cultivars. *M. hapla,* a known pathogen of carrot, was included for comparison. A portion of this study has been published (15).

Materials and Methods

The nematode populations used in these experiments are maintained in the Irrigated Agriculture Research and Extension Center collection (13). Those used were WAMC1 (*M. chitwoodi* race 1), ORMC8 (*M. chitwoodi* race 2), and *M. hapla.* Single egg masses of *M. chitwoodi* from Nugaines wheat (*Triticum aestivum* L.) and of *M. hapla* from California Wonder pepper (*Capsicum annum* L.) were increased on Columbian tomato (*Lycopersicon esculentum* Mill). The inocula consisted of eggs collected after shaking the tomato roots in 0.5% NaOCl (6) or second-stage juveniles (J2) collected according to Vrain (20).

The carrot seeds were soaked and incubated at 24 C for 10 days. The germinated seeds were collected daily and stored at 5 C before they were planted to synchronize the exposure of plants to the nematodes. At harvest the feeder roots were severed, washed free of soil, and shaken with NaOCl to extract the eggs.

All greenhouse experiments included Columbian tomato, California Wonder pepper and Nugaines wheat. Tomato, an excellent host for both *M. chitwoodi* and *M. hapla,* was used as a standard. Pepper and wheat, nonhosts to *M. chitwoodi* races and *M. hapla,* respectively, were included as

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checks against impure inocula and contamination during the experiments. These tests were conducted over a 1-year period in a greenhouse where temperatures ranged from 22 to 26 C.

Host suitability of carrot cultivars: The host suitability of 15 carrot cultivars to *M. chitwoodi* races and *M. hapla* was evaluated in a greenhouse experiment. These cultivars included Imperator, Nantes, Chantenay, and hybrid carrot types (21). Ten germinated seeds were grown in 10-cm-d plastic pots containing methyl bromide-fumigated loamy sand (84% sand, 10% silt, and 6% clay). The soil was infested with an initial population (Pi) of 5,000 eggs in 5 ml water 3 weeks after planting. The treatments were arranged in randomized complete blocks with five replications. After 55 days the nematode eggs were extracted to determine the final population (Pf) and reproductive factors (R = Pf/Pi) (11) were determined. Based on R values, the cultivars were grouped into four host suitability categories: R = 0–0.09, nonhost; R = 0.1–0.9, poor host; R = 1–2, moderate host; R > 2, good host.

Pathogenicity tests in the greenhouse: The pathogenicity of *M. chitwoodi* races 1 and 2 and of *M. hapla* to Red Cored Chantenay and Orlando Gold was evaluated in two experiments. Germinated carrot seeds were planted, eight to a pot, in 10-cm-d pots containing 625 cm^3 loamy sand, and the egg inoculum was delivered to grooves made in the soil surface. After inoculation, the grooves were filled with soil and the pots were watered.

In the first test, the effect of treatments on pre-emerged seedlings were compared. The experimental design was a split plot, with the nematode treatments as main plots and the inoculum levels (0, 2,000, and 4,000 eggs/250 cm^3) as subplots. Each treatment was replicated five times. In the second experiment, using 10 randomized complete blocks, the reaction of 10-day-old carrots to 4,000 eggs/250 cm^3 was studied. The first and second experiments were terminated 75 and 55 days after inoculation, respectively. The shoot and root symptoms were evaluated, eggs were extracted from the feeder roots, and shoot and root dry weights were determined. The least significant difference (LSD) ($P = 0.05$) for comparison of treatment means of the first test was calculated, and Duncan's multiple-range test was used to separate the treatment means of the second test.

Pathogenicity tests in the field: The effects of *M. chitwoodi* and *M. hapla* on Red Cored Chantenay and Orlando Gold carrots were tested in two consecutive years in microplots. A split-plot design (nematodes × inoculum levels) was used. Microplots consisted of 19-liter plastic buckets (30 cm d × 35 cm high) with eight 5-cm-d drainage holes in the bottom. Buckets were buried in the ground to within 5 cm of the top and spaced 30 cm apart. Before placement of the buckets the microplot area was fumigated with 1,3-dichloropropene at a rate of 327 liters/ha.

Buckets were filled with methyl bromide-fumigated loamy sand soil (82% sand, 15% silt, and 3% clay), irrigated, and allowed to settle for 1 week before they were inoculated. Twenty germinated seeds were planted immediately after inoculation. The seedlings were thinned to five plants per bucket after 4 weeks, and granular urea fertilizer equivalent to 112 kg N per ha was added. The plants were watered by drip irrigation as needed in cooler days and every 2 days during the warmer periods. At harvest, three cores of soil samples per bucket were mixed and J2 were extracted from 100 cm^3 (2). The buckets were then lifted out of the ground for processing. The intact soil mass was removed from the bucket to a large 1-cm-pore sieve. The roots were washed free of soil with a gentle stream of water and percentages of forked storage root were determined. Fresh shoot and storage root weights were determined. Eggs were extracted from the feeder roots (6) and reproductive factors were calculated. LSD ($P = 0.05$) for comparison of means was determined.

In 1986, *M. chitwoodi* and *M. hapla* J2 were incorporated in the top 15 cm at Pi of 0, 50, 100, 500, and 1,000 J2/250 cm^3.

TABLE 1. Reproduction factor (R = Pf/Pi) of *Meloidogyne chitwoodi* races 1 and 2 (MC1, MC2) and *M. hapla* on 15 carrot cultivars 55 days after inoculation with 5,000 eggs.

Type	Cultivar	Reproduction factor (mean ± SE)†		
		MC1	MC2	*M. hapla*
Imperator	Six Pak II	17.9 ± 6.3	0.5 ± 0.4	18.9 ± 6.7
	Pak More	14.4 ± 5.1	0.2 ± 0.06	14.9 ± 5.3
	Six Pak	12.3 ± 4.4	0.8 ± 0.6	18.2 ± 6.5
	Imperator 58	11.6 ± 4.1	0.01 ± 0.01	11.1 ± 3.9
	Top Pak	2.2 ± 1.3	0.0 ± 0.0	28.6 ± 3.1
	Gold Pak	1.3 ± 0.26	0.0 ± 0.0	49.4 ± 7.6
	Trophy	1.2 ± 0.36	0.0 ± 0.0	31.5 ± 8.7
	Charger	0.4 ± 0.08	0.01 ± 0.01	54.5 ± 9.2
Nantes	Amsterdam Minicor	10.6 ± 3.8	0.01 ± 0.01	6.9 ± 2.4
	Half-Long Nantes	0.05 ± 0.03	0.0 ± 0.0	31.3 ± 5.5
Chantenay	Red Cored Chantenay	4.4 ± 1.0	0.0 ± 0.0	4.5 ± 1.2
Hybrid	Orlando Gold	10.5 ± 3.8	1.1 ± 0.3	16.1 ± 5.7
	Chancellor	6.4 ± 1.6	0.0 ± 0.0	6.4 ± 2.3
	Golden State	4.7 ± 1.7	0.02 ± 0.02	8.9 ± 3.2
	A Plus	2.1 ± 0.7	0.0 ± 0.0	8.3 ± 2.9

Values are means of five replicates.
† R = 0–0.09, nonhost; R = 0.1–0.9, poor host; R = 1–2, moderate host; R > 2, good host.

The buckets were partitioned with a plexiglass, and the opposite sides were planted with either Red Cored Chantenay or Orlando Gold carrots. A separate water emitter was provided for each side of the plot. Initial nematode density was transformed ($\log_{10}$ [Pi + 1]) and Pi was related to storage root deformation. Linear regression analyses were used to calculate the best fit line to the observed data.

The test was repeated in 1987 with *M. chitwoodi* races 1 and 2 at Pi of 0, 500, 1,000, and 2,000 eggs/250 cm^3 soil. Each bucket was planted with either cultivar.

RESULTS

Host suitability of carrot cultivars: On the basis of R values, all 15 carrot cultivars were good hosts for *M. hapla* (Table 1). The reactions of carrot cultivars to *M. chitwoodi* races varied (Table 1). All cultivars except Charger (poor host) and Half-Long Nantes (nonhost) were moderate to good hosts of *M. chitwoodi* race 1. On the contrary, all of the cultivars except Orlando Gold (moderate host) were nonhosts or poor hosts of *M. chitwoodi* race 2. Half-Long Nantes, the only carrot cultivar reacting similarly to both *M. chitwoodi* races, was a nonhost of both.

M. chitwoodi races 1 and 2 and *M. hapla* reproduced well on tomato (R = 100–312). The reproduction of *M. chitwoodi* races on pepper (R = 0) and *M. hapla* on wheat (R = 0.004) was negligible.

Pathogenicity tests in the greenhouse: In the first experiment, *M. hapla* and *M. chitwoodi* race 1 increased on Red Cored Chantenay and Orlando Gold carrots and the R values for the nematodes ranged from 2.8 to 20.4 and 3.1 to 8.1, respectively (Table 2). *M. chitwoodi* race 2 failed to increase on either cultivar, however, and R values ranged from 0.03 to 0.6.

M. hapla lowered stand count and dry shoot, feeder root, and storage root weights ($P = 0.05$) of both carrot cultivars (Table 2). *M. hapla*-infected carrots produced branched feeder roots, which gave a hairy appearance to storage roots (Figs. 1, 2). The galled feeder roots were firmly attached to storage roots. Furthermore, some storage roots failed to increase in girth, remaining slender, whereas others were forked or twisted.

Unlike *M. hapla*, neither *M. chitwoodi* race affected stand count or feeder root growth (Table 2). Both inoculum levels of *M. chitwoodi* race 1 caused lower storage root weight of Red Cored Chantenay and Or-

TABLE 2. Shoot and dry weight of two carrot cultivars 75 days after inoculation with *Meloidogyne chitwoodi* races 1 and 2 and *M. hapla*.

	Eggs/250 cm³ soil	Stand count†	Dry weight (g)			R (Pf/Pi)
			Shoot	Root		
				Storage	Feeder	
			Red Cored Chantenay			
M. chitwoodi						
Race 1	0	7.8	1.70	1.68	0.34	0.0
	2,000	6.8	1.06	1.23	0.27	3.5
	4,000	6.8	1.86	1.30	0.37	3.1
Race 2	0	7.6	2.08	1.87	0.24	0.0
	2,000	7.4	1.84	1.50	0.28	< 0.03
	4,000	7.2	1.68	1.33	0.26	< 0.03
M. hapla	0	7.8	1.89	1.77	0.29	0.0
	2,000	2.6	0.79	0.26	0.10	17.8
	4,000	1.4	0.38	0.13	0.04	2.8
LSD‡		2.95	0.65	0.38	0.09	
LSD§		0.90	0.53	0.30	0.08	
			Orlando Gold			
M. chitwoodi						
Race 1	0	8.0	2.65	2.86	0.24	0.0
	2,000	8.0	2.86	1.90	0.25	8.1
	4,000	7.6	1.92	0.88	0.24	5.3
Race 2	0	8.0	1.93	2.25	0.29	0.0
	2,000	8.0	2.44	2.18	0.38	0.6
	4,000	7.4	2.34	1.81	0.31	0.1
M. hapla	0	8.0	2.29	2.55	0.27	0.0
	2,000	2.8	1.14	0.42	0.16	20.4
	4,000	2.2	0.48	0.24	0.07	7.2
LSD‡		1.1	0.61	0.69	0.11	
LSD§		0.9	0.57	0.63	0.099	

Values are means of five replicates.
† Each replicate initially consisted of eight seedlings per pot containing 625 cm³ soil.
‡ Least significant differences ($P = 0.05$) for different subplot treatments of same main plot treatments.
§ Least significant differences ($P = 0.05$) for different subplot treatments of different main plot treatments.

lando Gold by inhibiting radial growth (Figs. 1, 2). Red Cored Chantenay inoculated with 4,000 *M. chitwoodi* race 2 eggs had lower storage root weight, whereas Orlando Gold was not affected (Table 2). Shoot growth of Orlando Gold at a Pi of 4,000 was inhibited ($P = 0.05$) by race 1 (Table 2).

In the second test, delaying the inoculation of carrots for 10 days after seeding enhanced the reproduction of *M. chitwoodi* race 1 and *M. hapla* on both cultivars and *M. chitwoodi* race 2 on Orlando Gold (Table 3). The results obtained with *M. chitwoodi* race 2 on Orlando Gold was similar to the host suitability test, where inoculation was made 3 weeks after seeding. The R values for these nematodes on their respective hosts were higher ($P = 0.05$) than the first experiment; however, the nonhost status of Red Cored Chantenay to *M. chitwoodi* race 2 did not change ($R > 0.05$) (Table 3).

When inoculation was delayed the nematodes did not affect stand count or shoot growth (Table 3). Although damage by *M. hapla* was less than in the first test, the nematode still induced slender roots, forking, and low storage root weights (Table 3). Compared with *M. chitwoodi;* races, *M. hapla* increased feeder root weight of Red Cored Chantenay by causing more pronounced feeder root proliferation and galling. All three nematodes increased feeder

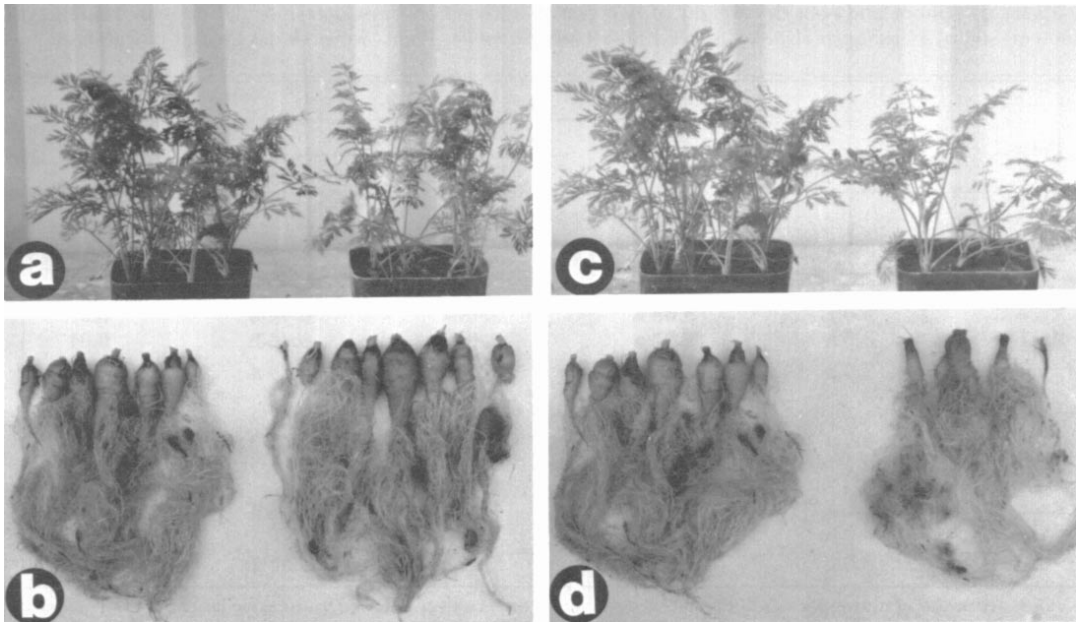

FIG. 1. Shoot and storage roots of Red Cored Chantenay carrots inoculated with 0 and 2,000 eggs/250 cm³ soil of *Meloidogyne chitwoodi* (a, b) and *M. hapla* (c, d) at seeding in the greenhouse.

root proliferation on Orlando Gold. Of the *M. chitwoodi* races, only race 2 on Orlando Gold resulted in storage root weight less than the check ($P = 0.05$) (Table 3).

Pathogenicity in the field: Meloidogyne hapla reproduced well on both carrot cultivars (Table 4) and severely galled feeder roots which were firmly attached to storage roots and were not sloughed off easily at harvest (Fig. 3). *M. hapla* at 1,000 J2/250 cm³

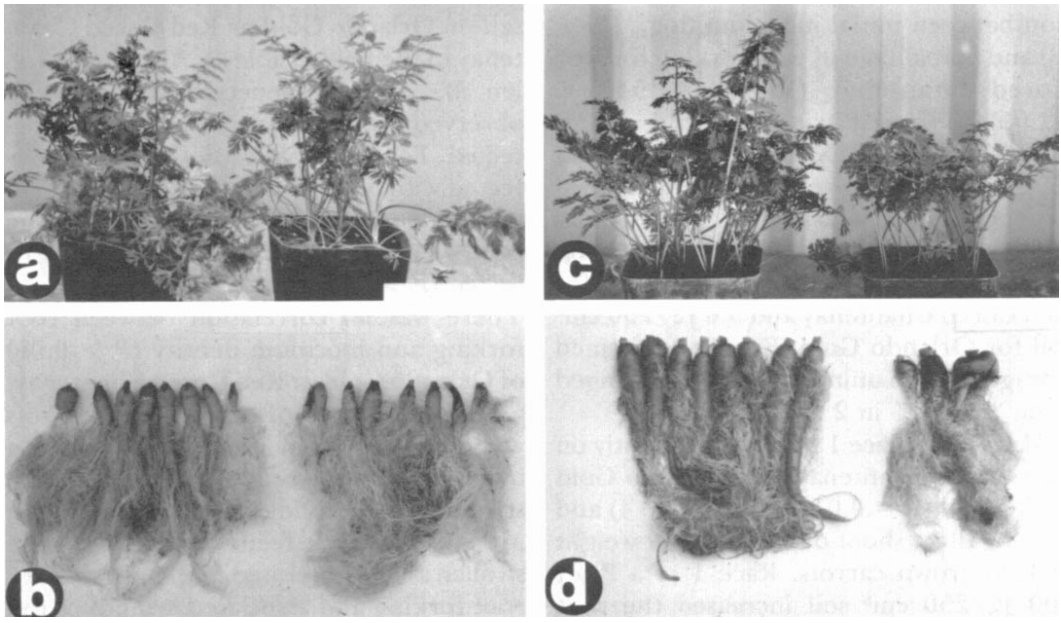

FIG. 2. Shoot and storage roots of Orlando Gold carrots inoculated with 0 and 2,000 eggs/250 cm³ soil of *Meloidogyne chitwoodi* race 1 (a, b) and *M. hapla* (c, d) at seeding in the greenhouse.

TABLE 3. Shoot and root dry weight of two carrot cultivars 55 days after inoculation with 4,000 eggs/250 cm³ soil of *Meloidogyne chitwoodi* races 1 and 2 and *M. hapla*. Plants were 10 days old at inoculation.

Treatment	Stand count†	Dry weight (g)			R (Pf/Pi)
		Shoot	Root		
			Storage	Feeder	
		Red Cored Chantenay			
Control	7.3 a	2.36 a	2.95 a	0.35 b	0.0
M. chitwoodi					
Race 1	8.0 a	3.08 a	3.49 a	0.48 b	6.5
Race 2	8.0 a	2.27 a	2.46 a	0.46 b	0.01
M hapla	7.5 a	1.82 a	1.44 b	0.65 a	55.0
		Orlando Gold			
Control	8.0 a	2.56 a	4.16 a	0.35 b	0.0
M. chitwoodi					
Race 1	8.0 a	2.68 a	4.46 a	0.64 a	12.9
Race 2	8.0 a	2.24 a	2.91 b	0.60 a	2.6
M. hapla	8.0 a	2.45 a	2.62 b	0.55 a	64.7

Values are means of nine replicates. Values in each column of each cultivar followed by the same letter are not significantly different ($P = 0.05$) according to Duncan's multiple-range test.

† Each replicate initially consisted of eight seedlings per pot containing 625 cm³ soil.

caused lower storage root weight of Red Cored Chantenay carrot but not Orlando Gold. The most striking symptom was forking and twisting of the storage roots of Red Cored Chantenay and Orlando Gold (Table 4, Fig. 3). The intensity of damage was positively correlated with inoculum density. The coefficients of linear correlation between initial inoculum ($\log_{10}$ [Pi + 1]) and percentage of root forking for Red Cored Chantenay ($Y = -42.547 + 42.055X$) and Orlando Gold ($Y = -22.312 + 43.294X$) were 0.91 and 0.92 ($P = 0.05$), respectively. Assuming 10% of storage roots unmarketable in the uninoculated soil (19), an estimate of the tolerance level was determined to be 16.7 for Red Cored Chantenay and 5.6 J2/250 cm³ soil for Orlando Gold (Fig. 4). Deformed storage roots in uninoculated plants ranged from 3 to 50% in 2 years.

M. chitwoodi race 1 reproduced lightly on Red Cored Chantenay and Orlando Gold in the field (R = 0.01–1.18) (Table 4) and did not affect shoot or storage root weight of field-grown carrots. Race 1 at a Pi of 500 J2/250 cm³ soil increased the root forking of Orlando Gold in 1986 (Table 4); however, the root deformation in either cultivar was not correlated ($P > 0.05$) with inoculum density. Feeder root sites infected with *M. chitwoodi* race 1 were swollen with no obvious galling or branching of roots, infected roots sloughed off easily, and storage roots did not appear hairy at harvest (Fig. 3).

M. chitwoodi race 2 failed to establish itself on Orlando Gold or Red Cored Chantenay in the field (Table 4). Although swollen *M. chitwoodi* penetration sites were observed, few mature females were detected. Feeder roots of both cultivars infected with *M. chitwoodi* race 2 sloughed off easily at harvest. Shoot growth and storage root wieght of both cultivars were not affected ($P > 0.05$) by *M. chitwoodi* race 2. There was no correlation between root forking and inoculum density ($P > 0.05$) of Orlando Gold or Red Cored Chantenay.

The percentage of forked storage roots was much higher in 1987 ($P = 0.05$) than in 1986. Some storage roots were constricted in the middle, and the horizontal grooves where the feeder roots arose were swollen and proliferated (Fig. 5). Increased root forking and associated symptoms did not appear to be related to the nematode infection ($P > 0.05$).

TABLE 4. Forking percentage and reproduction factor (R) at harvest of two carrot cultivars in two consecutive years in microplots infested with *Meloidogyne chitwoodi* races 1 and 2 and *M. hapla*.

	Inoculum‡	Forked storage root†		R (Pf/Pi)	
		1986	1987	1986	1987
		Red Cored Chantenay			
M. chitwoodi					
Race 1	0	6.7 a	50.8 a	0.00	0.00
	50	12.7 a		0.05	
	100	0.8 a		0.03	
	500	4.9 a	53.7 a	0.03	0.55
	1,000	12.4 a	68.3 a	0.01	0.15
	2,000		73.6 a		0.06
Race 2	0	6.7 a	48.3 a	0.00	0.00
	50	17.9 a		0.00	
	100	5.3 a		0.00	
	500	0.0 a	49.3 a	0.00	0.005
	1,000	6.7 a	53.8 a	0.00	0.009
	2,000		75.0 a		0.004
M. hapla	0	6.7 b		0.00	
	50	8.2 b		142.00	
	100	62.9 a		159.30	
	500	62.9 a		51.80	
	1,000	93.3 a		23.50	
	2,000				
		Orlando Gold			
M. chitwoodi					
Race 1	0	3.5 b	44.9 a	0.00	0.00
	50	6.0 b		0.05	
	100	16.8 ab		0.22	
	500	47.1 a	53.6 a	0.21	1.18
	1,000	16.7 ab	64.5 a	0.23	0.92
	2,000		69.2 a		0.25
Race 2	0	3.5 a	58.8 a	0.00	0.00
	50	12.9 a		0.00	
	100	14.6 a		0.00	
	500	13.6 a	63.6 a	0.001	0.37
	1,000	33.8 a	73.2 a	0.001	0.09
	2,000		73.4 a		0.06
M. hapla	0	3.5 c		0.00	
	50	68.4 b		169.90	
	100	78.7 ab		178.40	
	500	88.9 ab		47.60	
	1,000	99.2 a		32.10	
	2,000				

† Values are means of six replicates in 1986 and seven in 1987 (five carrots per plot). Original percentages were arcsin transformed, analysis of variance was performed, the least significant differences ($P = 0.05$) for subplot treatments of the same main plot treatments were determined, and the means were separated and back transformed to percentages.

‡ No./250 cm^3 soil. Inoculum consisted of second-stage juveniles in 1986 and eggs in 1987.

DISCUSSION

Our greenhouse data shows that the two races of *M. chitwoodi* differed in their ability to reproduce on carrot as they did on alfalfa (14). Red Cored Chantenay can be used as another differential host to separate the two races (8). Both *M. chitwoodi* races invaded Red Cored Chantenay roots, and *M. chitwoodi* race 1 reproduced but race 2 did not mature. Nonetheless, race 2 was harmful to growth of Red Cored Chantenay, a phenomenon called hypersusceptibility (3) or intolerance. The host status of *M. chitwoodi* race 2 on Orlando Gold appeared to be dependent on the time of inoculation. Orlando Gold, considered a none to poor host at seeding, was rated as a mod-

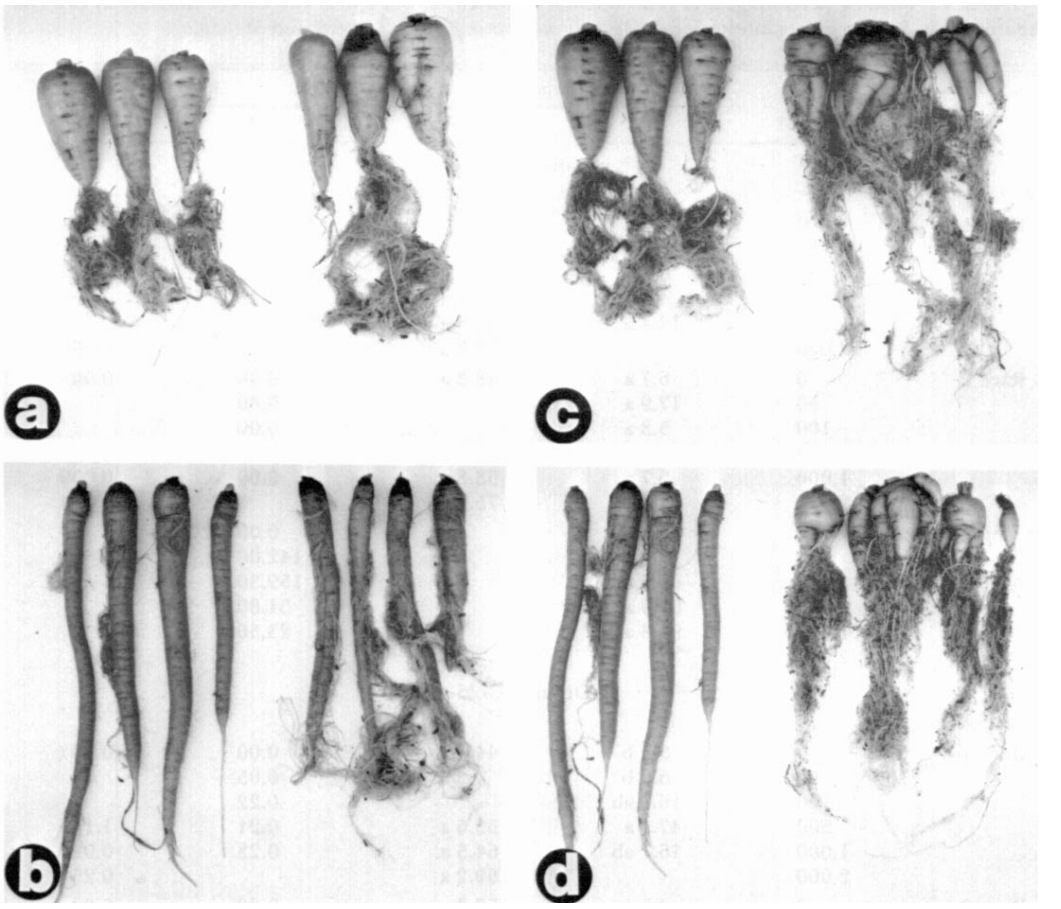

FIG. 3. Storage roots of Red Cored Chantenay (left) and Orlando Gold (right) carrots grown in microplots infested with *Meloidogyne chitwoodi* (a, b) and *M. hapla* (c, d).

erate to good host when inoculation was delayed for 10 to 21 days after seeding.

M. hapla reproduced well on all of the cultivars tested, but Red Cored Chantenay and Orlando Gold exhibited different tolerance levels to *M. hapla* under field conditions (Fig. 4). The tolerance level for Orlando Gold carrot reported here (2.2 J2/100 cm^3) was similar to the value reported from Canada (19) for Gold Pak (2.7 eggs +

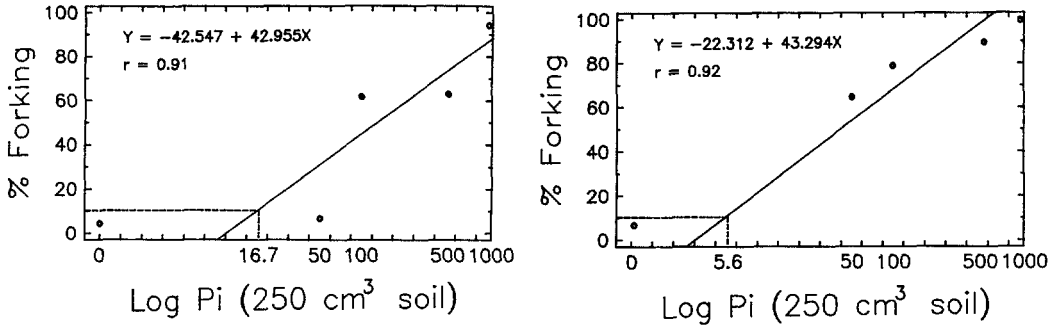

FIG. 4. Relationship of *Meloidogyne hapla* at planting ($\log_{10}$ [Pi + 1]) to forking percentage of Red Cored Chantenay (left) and Orlando Gold (right) carrots grown in microplots.

J2/100 cm^3). Gold Pak is considered a standard susceptible cultivar to *M. hapla* (18,21) and was one of the best hosts in our cultivar trial. Red Cored Chantenay grew more vigorously in the field and produced a larger ($P = 0.05$) root biomass than did Orlando Gold. The vigor and rapid growth of carrots are considered to be partially responsible for their high tolerance to *M. hapla* (18) and *M. javanica* (5).

Although *M. chitwoodi* races suppressed the growth of Red Cored Chantenay and Orlando Gold carrots in pot cultures, they rarely influenced the quality of storage roots in the field. The discrepancies between greenhouse and field trials were due, in part, to the failure of the nematodes to increase on field-grown carrots and to the dissimilar patterns of plant growth under these two conditions. In the field, the carrot plants grew faster and weighed 10–20 times more than those in pot cultures. Seinhorst and Kozlowska (16) noted that increased tolerance of plants to *Rotylenchus uniformis* could be the result of a decrease in nematode density (per unit of volume of root) due to an increase in root biomass.

Delaying the inoculation of *M. hapla* for 10 days improved plant stand and plant vigor; however, this practice did not alleviate damage to carrot roots, and inoculated storage roots weighed less and were more misshapen than the control. These results indicate that early planting, a cultural practice suggested to reduce *M. hapla* damage to carrots (1), may not be sufficient to insure a quality crop from infested fields.

Unusually rough surfaces and constriction of storage roots (Fig. 5) are symptomatic of heat canker (4). The climatological logs collected at the Irrigated Agriculture Research and Extension Center in Prosser in 1987 indicated that in May, when newly sown carrot seeds were emerging, the ambient temperature rose unusually high, with 25 C recorded several times. Carrot seedlings are sensitive to temperatures above 20 C (4,7). The young tissues collapse when exposed to high temperatures at the soil surface, and seedlings wither and die. In fact, some of the microplots were replanted several times before a stand was attained.

FIG. 5. Storage roots of Red Cored Chantenay (left) and Orlando Gold (right) carrots exposed to unusually high temperatures in the spring of 1987.

Carrots for fresh market are harvested before full maturity. For this reason, total yielding capacity is not as important as uniformity. Likewise, the most important factor for processing carrots is uniformity and quality and not maximum yield (12). Thus, even though *M. chitwoodi* race 2 reduced root weight of Red Cored Chantenay in 1986, *M. chitwoodi* is probably not a serious threat to the carrot industry in the Columbia Basin area of Washington.

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