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Influence of *Glomus intraradices* and Soil Phosphorus on *Meloidogyne incognita* Infecting *Cucumis melo*

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Abstract: The interaction among *Glomus intraradices, Meloidogyne incognita,* and cantaloupe was studied at three soil phosphorus (P) levels in a greenhouse. All plants grew poorly in soil not amended with P, regardless of mycorrhizal or nematode status. In soil amended with 50 μg P/g soil, *M. incognita* suppressed the growth of nonmycorrhizal plants by 84%. In contrast, growth of mycorrhizal plants inoculated with *M. incognita* was retarded by only 21%. A similar trend occurred in plants grown in soil with 100 μg P/g soil. Mycorrhizal infection had no effect on the degree of root-knot gall formation and did not affect the number of nematode eggs per egg mass. Mineral levels in plant shoots generally declined as soil P levels increased and were not significantly influenced by *G. intraradices* or *M. incognita.*

Key words: cantaloupe, *Cucumis melo, Glomus intraradices,* interaction, *Meloidogyne incognita,* mineral element, mycorrhizae, root-knot nematode, soil phosphorus.

Vesicular-arbuscular mycorrhizal fungi variously influence a number of plant–nematode interactions (1,6,8). Several studies report an antagonistic effect of mycorrhizal fungi on plant-parasitic nematodes (5,6,12). Sitaranaiah and Sikora (18) found that *Glomus mosseae* increased the resistance of tomato plants to *Rotylenchulus reniformis* infection. Baltruschat et al. (2) reported that 75% fewer juveniles of *Meloidogyne incognita* developed into adults when tobacco was infected with a mycorrhizal fungus. MacGuidwin et al. (12) found that *M. hapla* more readily penetrated nonmycorrhizal onion roots than mycorrhizal roots. Other workers (1,8) reported that mycorrhizae suppress the effect of the nematode on the host plant. Growth suppression of lemon seedlings was reduced when plants were concomitantly infected with a mycorrhizal fungus and the plant-parasitic nematode *Tylenchulus semipenetrans* (13).

Meloidogyne incognita (Kofoid and White) Chitwood and *Glomus intraradices* Schenck and Smith occur frequently in cantaloupe fields of the Rio Grande Valley of Texas; however, the influence of mycorrhizal fungi alone or in combination with *M. incognita* on the growth of cantaloupe and on nematode infection and reproduction is not known. To determine the interactions among *G. intraradices, M. incognita,* and cantaloupe a greenhouse experiment was conducted using soils with various phosphorus (P) levels.

Materials and Methods

Two cantaloupe (*cucumis melo* L. cv. Magnum 45) seeds were sown in individual 15-cm-d plastic pots containing 2,400 cm^3 sterilized riverbottom sand (pH 7.2, < 1% O.M.). The soil, which contained 1.6 μg P/g soil, was amended with finely ground superphosphate ($Ca[H_2PO_4]_2 \cdot H_2O$) at 0, 50, or 100 μg P/g soil.

Glomus intraradices inoculum, originally, isolated from citrus in South Texas, was increased on sudangrass (*Sorghum vulgare* Pers.). Inoculum for each pot of cantaloupe consisted of 20 cm^3 roots and soil which contained hyphae, vesicles, and chlamydospores (200–300 spores/25 cm^3 mycorrhizal fungus. The inoculum was placed about 3 cm under the seeds in one-half of the pots. After germination, the seedlings were thinned to one plant per pot.

Meloidogyne incognita, originally isolated from cantaloupe (*Cucumis melo* cv. Perlita) was increased on tomato (*Lycopersicon esculentun* cv. Homestead 24) in a greenhouse. Four weeks after the seeds were planted, each nematode treatment received 1,200

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second-stage juveniles (J2) per pot. The experimental design consisted of a 3 × 2 × 2 factorial arrangement of treatments (phosphorus, nematode, mycorrhiza) in a randomized block design with 10 blocks. Plant response and mineral analysis data were analyzed using analysis of variance procedures. Regression procedures were used in evaluating mycorrhizal infection.

At the time the seedlings were inoculated with nematodes, root samples were collected and stained with 0.05% trypan blue in lactophenol (15), placed on a grid of 1-mm² divisions, and examined for structures of the mycorrhizal fungus in 100 or more 1-mm² root sections. Root tissue infected with the mycorrhizal fungus ranged from 54 to 82% and did not differ among the soil P levels. The plants were grown in a greenhouse at 22–32 C with a relative humidity of 66–100% and watered every other day with a modified Hoagland's solution (7) lacking P.

After 15 weeks the plants were harvested and measured. Samples of roots were stained as previously described to estimate percentages of root tissue infected with the mycorrhizal fungus and were rated for root-knot nematode infection by a gall rating of 1 to 5, where 1 = no galls, 2 = 1–25%, 3 = 26–50%, 4 = 51–75%, and 5 = > 75% of the roots galled. To quantify egg production per female, 10 egg masses were collected for each treatment and treated with a 1% sodium hypochlorite solution for 3 minutes to free the eggs before counting. Shoots and roots were separated, dried, and analyzed for P (9) or other minerals using atomic absorption spectroscopy.

Results

Plant response: Plant growth and mineral analyses were affected by the interactive action of phosphorus, nematode, and mycorrhizae (significant three-way interaction). The soil used in this study required additional P in order to sustain plant growth. At the zero P level the nematode or mycorrhizal treatments did not affect vine length and root or shoot dry weight (Fig. 1); however, there were some small reductions in stem diameter caused by the nematode alone. As P concentration increased, the interactive effects of nematodes and mycorrhizal fungus became more pronounced. *Meloidogyne incognita* significantly suppressed all plant growth responses compared with the check at of 50 and 100 μg P/g soil. The average total dry weight of the *M. incognita* inoculated plants was about 16% of the control. In fact, there were no significant differences between vine lengths or shoot dry weights in plants infected with the nematode alone at any P level.

Stem diameter increased slightly as P concentrations increased. In contrast to the *M. incognita* treatment, *G. intraradices* significantly increased plant growth in soils amended with 50 or 100 μg P/g soil. Root dry weights of mycorrhizal plants increased significantly between 50 and 100 μg P/g soil, whereas vine length, stem diameter, and shoot dry weight did not increase significantly.

The combination of *G. intraradices* + *M. incognita* significantly suppressed most plant responses, compared with the plants infected with *G. intraradices* alone (Fig. 1). The plant response of the combination of *G. intraradices* and *M. incognita* did not generally differ from those of the noninoculated plants.

Nematode infection and fecundity: Mycorrhizal infection or soil P level had no effect on the degree of root infection by *M. incognita.* All plants inoculated with nematodes were equally galled (gall rating = 5) regardless of the P or *G. intraradices* treatments. Plants with large root systems (*G. intraradices* + *M. incognita* treatments) were as heavily infected as plants with small root systems (*M. incognita* alone). In soil amended with 50 μg P/g soil, there were significantly ($P = 0.05$) fewer eggs (113 eggs/mass) in the egg masses recovered from nonmycorrhizal roots than in the *G. intraradices* + *M. incognita* treatment (265 eggs/mass). In soil amended with 100 μg P/g soil, the number of eggs per egg mass (261 eggs) was similar in both nonmycorrhizal and mycorrhizal plants.

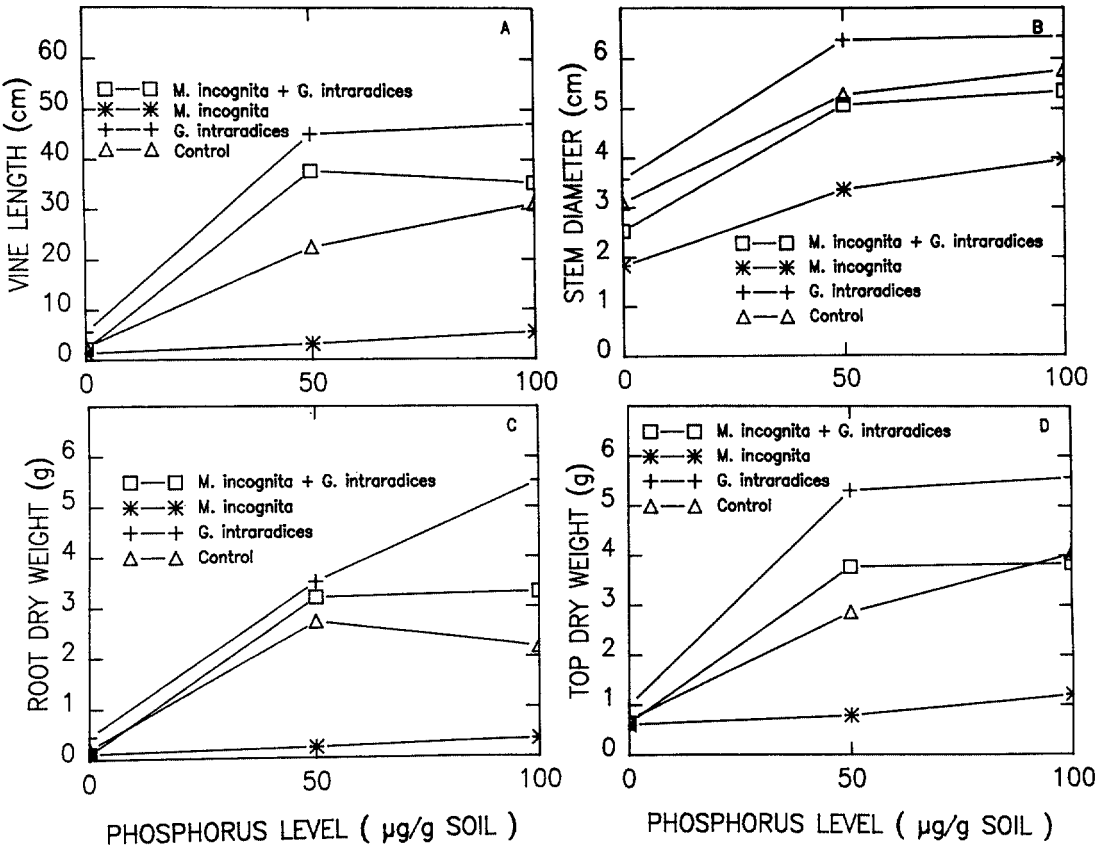

FIG. 1. Effect of *Glomus intraradices, Meloidogyne incognita,* and superphosphate on *Cucumis melo.* A) Vine length. B) Stem diameter. C) Root dry weight. D) Top dry weight.

Mineral analysis: The mineral level in shoots in uninfected or in nematode-infected plants declined as soil P levels increased from 0 to 50 and 100 µg/g soil with the exception of P, K, and CA (Table 1).

In soil not amended with P, the concentration of minerals were generally greater in nonmycorrhizal plants than in mycorrhizal plants. P levels in tops of dually infected and mycorrhizal plants only increased with increasing levels of soil P. Mineral concentrations in the roots were inconsistently influenced by the mycorrhizal fungus, nematode, and soil P (data not presented).

Degree of mycorrhizal infection: In soil not amended with P, 91.9% of the sections were colonized by *G. intraradices.* When *M. incognita* was added to these soils, mycorrhizal root infection was significantly reduced to 58.8%. As soil P increased to 100 µg P/g soil, the mycorrhizal infection of plant roots inoculated with *M. incognita* increased to 76% (predicted mycorrhyzial infection = 58.7 + 0.19P, sy·x = 13.3, R^2 = 0.97). In contrast, the mycorrhizal colonization of roots in the absence of *M. incognita* decreased from 91.9 to 72% (predicted mycorrhizal infection = 92.7 − 0.20P, sy·x = 24.1, R^2 = 0.98).

Histological examination of the roots showed a lack of mycorrhizal colonization near root-knot nematode galls.

DISCUSSION

Glomus intraradices can significantly improve growth of cantaloupe in nutrient-deficient soil, parallel to the beneficial effects of mycorrhizal fungi in other plants (1,4,11). *Meloidogyne incognita* suppressed growth of both nonmycorrhizal and my-

TABLE 1. Mineral analysis of leaves and stem of cantaloupe infected with *Meloidogyne incognita* and *Glomus intraradices*, alone or in combination, at three soil phosphorus levels.

Treatment										
Mycorrhiza	Nematode	Phosphorus (μg/g)	P (%)	K (%)	Mg (%)	Ca (%)	Fe (μg/g)	Zn (μg/g)	Mn (μg/g)	Cu (μg/g)
−	−	0	0.37	1.29	0.75	8.54	993.30	242.40	130.60	312.80
+	−		0.32	2.04	0.59	4.23	217.60	73.60	55.20	33.30
−	+		0.35	0.59	0.56	8.98	1,315.90	134.30	89.40	169.10
+	+		0.36	0.78	0.69	6.94	344.20	113.40	51.80	88.50
−	−	50	0.40	2.50	0.72	4.92	241.30	82.30	77.70	79.70
+	−		0.47	1.33	0.57	5.56	141.50	48.90	34.10	26.20
−	+		0.31	0.68	0.67	10.12	908.50	82.10	81.90	81.70
+	+		0.46	1.35	0.65	6.88	83.80	40.30	33.70	15.60
−	−	100	0.40	2.50	0.68	5.10	138.30	42.90	58.70	14.80
+	−		0.53	1.57	0.58	4.73	86.10	45.40	29.80	18.60
−	+		0.33	1.14	0.69	9.91	498.80	66.60	73.50	53.60
+	+		0.50	1.33	0.60	8.74	97.30	38.90	33.10	16.40
		LSD†	0.06	0.43	0.13	2.15	195.20	66.00	12.60	113.60

† Fisher's protected least-significant difference ($P = 0.05$).

corrhizal cantaloupe, but the growth inhibition was greater in the nonmycorrhizal plants than in plants inoculated with *G. intraradices*. Since gall development and nematode reproduction were not influenced by mycorrhizae, the improved growth of dually infected plants may be related to improved nutrient uptake relative to nonmycorrhizal plants. Several investigators (1,3,16,17) have suggested that increased nutrient intake by mycorrhizal fungi enhances plant tolerance relative to the detrimental effects on nematodes.

The lack of mycorrhizae near nematode galls may account for the reduction in total root colonization by *G. intraradices*. These observations agree with those of Grandison and Cooper (6), who found that nematodes significantly retard mycorrhizal infection of a susceptible cultivar of alfalfa. Kellam and Schenk (10) found an absence of arbuscules in *M. incognita* galls on roots also infected with mycorrhizae. They noted, in some cases, fungal structures of mycorrhizae appeared to decompose within the gall, whereas those structures above and below the gall appeared normal.

Cantaloupe is apparently highly dependent on mycorrhizae for optimum growth, at least where phosphorus is a limiting factor. Optimum P nutrition as measured by plant growth and P-tissue concentration was not reached at 100 μg P/g soil. The elevated levels of many of the minerals (other than P) in the nonmycorrhizal plants compared to those in the plants infected with *G. intraradices* were apparently due to luxury consumption. This biomass "dilution effect" by the mycorrhizal plants has been explained in situations such as our cantaloupe experiment where a single nutrient limits plant growth but doesn't directly impair uptake of other minerals (14). Because of the larger size of the mycorrhizal plants, concentrations of certain minerals were reduced relative to the concentrations in the stunted nonmycorrhizal plants.

Since different species and strains of mycorrhizal fungi can influence plant growth in dissimilar ways (17), those fungi that provide the greatest growth responses in cantaloupe may confer the greatest degree of tolerance to parasitic nematodes. Also, those fungi that resist disruption of nutrient uptake by nematode colonization may optimize tolerance to nematode infection. In any case, no direct resistance mechanisms that inhibit nematode infection were apparent in our study.

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