Journal of Nematology 29(1):117–126. 1997.

Interaction of *Fusarium oxysporum* f. sp. *ciceri* and *Meloidogyne javanica* on *Cicer arietinum*

T. Uma Maheswari,[1] S. B. Sharma,[1] D. D. R. Reddy,[2] and M. P. Haware[1]

Abstract: Interaction of *Meloidogyne javanica* and *Fusarium oxysporum* f. sp. *ciceri* was studied on Fusarium wilt-susceptible (JG 62 and K 850) and resistant (JG 74 and Avrodhi) chickpea cultivars. In greenhouse experiments, inoculation of *M. javanica* juveniles prior to *F. oxysporum* f. sp. *ciceri* caused greater wilt incidence in susceptible cultivars and induced vascular discoloration in roots of resistant cultivars. Nematode reproduction was greatest ($P = 0.05$) at 25 °C. Number of galls and percentage of root area galled increased when the temperature was increased from 15 °C to 25 °C. Wilt incidence was greater at 20 °C than at 25 °C. Chlorosis of leaves and vascular discoloration of plants did not occur at 15 °C. The nematode enhanced the wilt incidence in wilt-susceptible cultivars only at 25 °C. Interaction between the two pathogens on shoot and root weights was significant only at 20 °C, and *F. o. ciceri* suppressed the nematode density at this temperature. Wilt incidence was greater in clayey (48% clay) than in loamy sand (85% sand) soils. The nematode caused greater plant damage on loamy sand than on clayey soil. Fusarium wilt resistance in Avrodhi and JG 74 was stable in the presence of *M. javanica* across temperatures and soil types.

Key words: Chickpea, *Cicer arietinum*, *Fusarium oxysporum*, interaction, *Meloidogyne javanica*, predisposition, root-knot nematode, soil type, temperature.

Chickpea (*Cicer arietinum* L.), an important cool-season food legume, is a prominent component of cropping systems of subsistence farming in the Indian subcontinent. Wilt, caused by *Fusarium oxysporum* f. sp. *ciceri*, is one of the most serious soilborne diseases in India, and it is reported from almost all the major chickpea growing regions of the world (Nene et al., 1981, 1989). *Meloidogyne incognita* and *M. javanica* are major nematode pests of chickpea and have been reported from the chickpea growing regions in Bangladesh, Brazil, Egypt, India, Malawi, Nepal, and Pakistan (Nene et al., 1989; Sharma and McDonald, 1990; Sharma et al., 1992). The presence of these nematodes in soils infested with *Fusarium* spp. enhances the incidence, rate of disease development, and severity of Fusarium wilt in grain legumes (Goel and Gupta 1986; Ribeiro and Ferraz, 1984; Sharma et al., 1992). Interactions between *Meloidogyne* and *Fusarium* have been extensively studied on several plant species such as cotton, tobacco, and tomato, and many factors (including species, race, and population density of the nematode; age of the plant at the time of the nematode and (or) fungus infection; associated microflora and fauna; soil temperature; and moisture) influence the type and nature of interrelationships between the nematode and the fungus (Abawi and Barker, 1984; Dropkin, 1969; Newhall, 1958; Porter and Powell, 1967; Sleeth and Reynolds, 1955). There is extensive evidence that influence of *Meloidogyne* spp. on Fusarium-wilt resistance may differ with the host cultivars within a crop species. For example, in banana, cabbage, chrysanthemum, cucumber, date palm, melons, and summer squash, presence of *Meloidogyne* spp. did not influence the wilt response of the resistant cultivars, while in tomato, cotton, soybean, and cucumber, the wilt resistance was altered (Bergeson, 1975; Caperton et al., 1986; Fassuliotis and Rau, 1969; Johnson and Littrell, 1969; Newhall, 1958; Price et al., 1980). *Fusarium oxysporum* f. sp. *ciceri* (*Foc*) and *M. javanica* (*Mj*) occur together in many chickpea growing regions, and combined infection of chickpea plants by these two pathogens increases the severity of Fusarium wilt (Goel and Gupta, 1986; Nath and Dwivedi, 1980; Sharma and Cerauskas, 1985; Thakar et al., 1986; Uma Maheswari et al., 1995; Upadhyay and Dwivedi, 1987). Because edaphic, environmental,

Received for publication 2 November 1994.
Journal Article No. 1740 of International Crops Research Institute for the Semi-Arid Tropics (ICRISAT).
[1] Research Scholar, Scientist, Nematologist, and Senior Scientist, Plant Pathology, ICRISAT, Patancheru P.O. 502 324, Andhra Pradesh, India, and [2] Professor, Department of Entomology, Andhra Pradesh Agricultural University, Rajendranagar, Hyderabad 500 036, Andhra Pradesh, India.
E-mail: s.sharma@cgnet.com

and cultural conditions alter the damage caused by pathogens as well as interactions between the pathogens, we investigated the interactions of *Foc* and *Mj* at three temperatures and two soil types on wilt-resistant and wilt-susceptible chickpea cultivars. Influence of the two abiotic factors on pathogenic effects of *Mj* and *Foc* on plant growth, of *Foc* on nematode reproduction, and of *Mj* on wilt incidence are described here, and implications of these results on Fusarium-wilt resistance are discussed.

Materials and Methods

Experiments were conducted at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh, India. *Meloidogyne javanica* was collected from a Vertisol (Typic Pellusterts) field at the ICRISAT research farm and maintained on tomato (*Lycopersicon esculentum*) cv. Rutgers in 25-cm-diam. pots containing a steam-sterilized soil (mixture of sand, soil [25% sand, 27% silt, and 48% clay] and farmyard manure [2:1:1;v/v]) in a greenhouse. Nematode inoculum of second-stage juveniles (J2) was obtained by extracting egg masses from roots and incubating them at 28 °C to collect the emerged J2 in water. The J2 were collected daily, rinsed with distilled water, and stored at 15 °C. The inoculum was not stored for longer than two days.

Fusarium oxysporum f. sp. *ciceri* (race 1) was isolated from roots of a wilt-infected chickpea plant. A single-spore culture of the fungus was maintained on potato dextrose agar medium (PDA) and stored at 25 °C in an incubator. A sand-chickpea flour medium was prepared by mixing 10 g chickpea flour with 90 g sand in a 250-ml conical flask containing 20 ml of distilled water. The flasks were autoclaved for one hour. The flasks containing medium were inoculated with *Foc* race 1 obtained from an actively growing culture on PDA, and were maintained at 25 °C for 15 days. The inoculum from one flask was mixed with 2 kg soil medium to fill a 15-cm-diam. pot. The number of *Fusarium* propagules, estimated by spreading 20 mg soil on modified Czapek-Dox medium (Haware et al., 1978), ranged between 1,250 and 1,500 g soil. Soil in pots was kept moist for two days and then used for nematode inoculation and sowing of chickpea seed.

Experiment 1: Effect of *Mj* and *Foc* on growth of two wilt-susceptible cultivars (JG 62 and K 850) and a wilt-resistant cultivar (Avrodhi), effect of *Mj* on Fusarium wilt incidence, and effect of *Foc* on root-knot nematode were studied in greenhouse experiments. The maximum and minimum ambient temperature ranged from 32 to 22 °C. The treatments were: inoculation (per 12.5-cm-diam. pot) with 2,500 J2 of *Mj*, inoculation with 50 g *Foc* culture, inoculation with 2,500 J2 of *Mj* + 50 g of *Foc* culture together, inoculation of *Mj* 4 days before inoculation of *Foc* culture, inoculation of *Foc* culture 4 days before inoculation of *Mj*, and uninoculated control. Each treatment consisted of five pots with three plants per pot. The fungal inoculum was added to the soil as described, and J2 in water suspension were placed in depressions where seeds were placed. The factorial treatments were arranged in a randomized complete block design, and data on shoot and root weights, gall index, egg and juvenile density, and wilt incidence were recorded and subjected to analysis of variance.

Experiment 2: To study the effect of *Foc* on nematode invasion in roots of the wilt-resistant (JG 74, Avrodhi) and wilt-susceptible (JG 62, K 850) cultivars, 100 10-cm-diam. pots were filled with 500 g steam-sterilized soil. In 50 pots, 25 g *Foc* inoculum was thoroughly mixed with soil. Two seeds per pot of JG 62, K 850, JG 74, and Avrodhi were sown in all the pots, and 750 J2/pot were placed in depressions where seeds were sown. At 2, 4, 5, 8, 10, 15, 20, 25, 30, and 35 days after germination, roots of four seedlings from each of the *Mj*-alone and *Mj* + *Foc* treatments were stained in 0.05% cotton blue lactophenol for 2–3 minutes. The roots were spread on 22.0-cm × 9.5-cm glass plates, and number of juveniles in the roots was determined by observation with a stereoscopic microscope. The data on number of juveniles in the roots were subjected to analysis of

variance. Correlation coefficients were calculated between nematode densities in roots of the cultivars in *Mj* and *Mj* + *Foc* treatment with days after inoculations, and the relationship was further examined by linear and quadratic regression analyses.

Experiment 3: Seeds of chickpea cultivars JG 62, K 850, JG 74, and Avrodhi were sown in 12.5-cm-diam. pots containing 1 kg steam-sterilized soil. These pots were placed at 15, 20, and 25 °C with 12-h photoperiod in growth chambers. The treatments at each temperature were uninoculated control, addition of 2,500 J2 of *Mj*, addition of 50 g of *Foc*, and addition of both 2,500 J2 of *Mj* + 50 g of *Foc* inoculum/pot. The fungal inoculum was added to the soil as described, and nematode J2 in water suspension were placed in depressions where seeds were placed. The experiment was in a randomized complete block design, and each treatment was replicated in five pots, each containing three plants. The plant growth data, root-knot, and wilt incidence data were recorded and subjected to analysis of variance.

Experiment 4: Interactions of *Mj* and *Foc* on JG 62, K 850, JG 74, and Avrodhi were studied on loamy sand (85% sand, 7% silt, 8% clay, pH 5.5) and clayey (25% sand, 27% silt, 48% clay, pH 7.8) soils. Seeds were sown in steam-sterilized soil in 15-cm-diam. pots. The treatments were uninoculated control, 5,000 J2 of *Mj*, 100 g *Foc* inoculum, and 5,000 J2 of *Mj* + 100 g *Foc* inoculum. There were five pots, each containing three seedlings. The factorial experiment was a randomized complete block design, and data on plant growth, wilt incidence, nematode density, and root galling were subjected to analysis of variance.

Dry shoot weights, fresh root weight, number of galls, and percentage galled area of the roots were measured after 8 weeks. Number of nematode-caused galls on roots were rated on a 1-to-9 scale where 1 = no galls, 3 = 1–10 galls, 5 = 11–30 galls, 7 = 31–50 galls, 9 = >50 galls. Percent galled area of root was based on visual assessment of root area covered by galls to the total root area: 1 = 0–10% galled area, 3 = 11–20%, 5 = 21–30%, 7 = 31–50%, 9 = > 50% galled area (Sharma et al., 1993). For Fusarium wilt reaction, days taken for drooping of leaves, chlorosis, and vascular discoloration in root and stem were recorded at various intervals. Chlorosis of leaves was visually assessed by counting the number of yellow leaves compared to the total number of leaves. Cultivars with vascular discoloration above the collar region were regarded as wilt-susceptible. To confirm infection by *Foc*, roots were washed free of soil and the regions below and above the collar were split open and examined for internal discoloration. Transverse sections of root portion showing vascular discoloration were surface-sterilized with a 2.5% aqueous solution of sodium hypochlorite for 3 minutes and then placed on PDA in plates. Three days later, the tissues on PDA were observed for the presence of *Foc*.

The number of J2 was estimated in 250-cm^3 soil samples collected from each pot at 8 weeks after planting. The samples were processed by sieving and decanting (Cobb, 1918) by suspending them in water, passing through 850-µm (20 mesh) and 38-µm (400 mesh) pore-size nested sieves, and placing the residue from the 38-µm-pore sieve on modified Baermann funnels (Schindler, 1961). To estimate the egg number, roots were washed in running water, cut into small pieces, and soaked in a 0.25% aqueous solution of sodium hypochlorite to extract the eggs on 38-µm-pore size sieves.

Results

Experiment 1: Initially, *Mj* did not influence the appearance of foliar symptoms of marginal chlorosis and drooping leaves caused by *Foc* infection; however, within 8 weeks, marked increase in chlorotic leaves was observed in treatments with pre- and concomitant inoculations of *Mj*. Inoculation of *Mj* 4 days later than *Foc* did not greatly affect leaf chlorosis (Table 1). Marginal chlorosis of leaves in chickpea K 850 appeared 5 weeks after seedling emergence in *Foc*-alone treatment. All plants of K 850 inoculated with *Foc*-alone or together with *Mj* in all sequential inoculations showed vascu-

Table 1. Effects of inoculation with *Meloidogyne javanica* (*Mj*) and *Fusarium oxysporum* f. sp. *ciceri* (*Foc*) on leaf chlorosis in chickpea after 8 weeks' inoculation.

Treatment	Leaf chlorosis (%)[d]		
	K 850	JG 74	Avrodhi
Control	0.0	0.0	0.0
Mj	20.0	10.0	20.0
Foc	40.0	5.0	5.0
Mj + *Foc*[a]	60.0	25.0	50.0
Mj → *Foc*[b]	50.0	40.0	30.0
Foc → *Mj*[c]	40.0	20.0	20.0
LSD ($P = 0.05$): Treatment × cultivar = 13.4			

[a]Nematode (2,500 J2/kg soil) and fungus (50 g/kg soil) were inoculated simultaneously.
[b]Nematode inoculated 4 days before fungus.
[c]Nematode inoculated 4 days later than fungus.
[d]Leaf chlorosis was estimated as number of chlorotic leaves × 100/total number of leaves.

lar discoloration. The fungus-alone treatment caused 100% wilt in K 850 within 8 weeks; *Mj* reduced the latent period by about 1 week. Vascular discoloration in roots of JG 74 and Avrodhi and growth of the fungus in vascular bundles below the collar region were observed in soils preinoculated with *Mj*.

Meloidogyne javanica reduced dry shoot weight by 13% in K 850, 17% in JG 74, and 20% in Avrodhi (Table 2). Mild chlorosis appeared in K 850, JG 74, and Avrodhi, but no vascular discoloration in roots was observed when soils were infested with only *Mj*. The fungus alone significantly reduced the dry shoot weight of K 850 and root weight of JG 74, while shoot and root weights of Avrodhi were unaffected. Mean dry shoot weight across the cultivars was reduced when preinoculated with *Mj* (data not shown). Pre- and concomitant inoculations of *Mj* with fungus caused 29% reduction in shoot and root weights of Avrodhi, and 20–35% increase in shoot and root weights in JG 74 (Table 2).

All cultivars had gall indices between 7 and 9. Effect of the fungus on gall indices was more visible on JG 74 and Avrodhi than on K 850. Percentage galled area of the root in all the cultivars ranged between 7 and 9. The fungus did not affect the galled area on K 850, while reduction in galled area on Avrodhi and JG 74 was apparent. Large variations in egg and J2 densities of *Mj* were observed; however, the differences between treatments were not significant.

Experiment 2: Invasion of chickpea roots by *Mj* was rapid and increased very little 6 days after inoculation, particularly on K 850 (Fig. 1). About 40% of J2 invaded the roots of JG 62 and K 850 between days 4 and 6 of inoculation, while penetration in JG 74 and Avrodhi roots was greatest between days 2 and 4. In the presence of *Foc*, the mean number of juveniles dropped 40% in JG 62 and JG 74, and 30% in K 850 and Avrodhi. In JG 62, *Foc* initially stimulated the penetration of J2 while in other cultivars the rate of J2 penetration was always lower in the *Mj* + *Foc* treatment than in *Mj*-alone treatment. The numbers of J2 penetrated in *Mj* and *Foc* + *Mj* treatments were positively correlated

Table 2. Effects of inoculation with *Meloidogyne javanica* (*Mj*) with *Fusarium oxysporum* f. sp. *ciceri* (*Foc*) on shoot and root weights of chickpea cultivars.

Treatment	Fresh shoot weight (g)			Dry shoot weight (g)			Fresh root weight (g)		
	K 850	JG 74	Avrodhi	K 850	JG 74	Avrodhi	K 850	JG 74	Avrodhi
Control	29.3	25.9	23.4	6.5	5.4	4.3	11.6	20.2	20.8
Foc	32.1	29.6	23.2	5.7	6.9	3.9	14.5	16.7	18.9
Mj	28.0	23.3	21.0	5.7	4.5	3.4	16.2	14.0	18.2
Mj → *Foc*[a]	29.2	29.0	25.3	5.7	7.8	4.1	16.1	9.3	15.6
Foc → *Mj*[b]	31.3	33.0	19.7	6.4	6.5	3.0	17.8	13.2	14.6
Mj + *Foc*[c]	28.2	30.2	20.5	5.9	5.9	3.1	14.4	11.8	14.4
LSD ($P = 0.05$):									
Cultivar × treatment	3.41			0.70			3.46		

[a]Nematode inoculated 4 days before the fungus.
[b]Nematode inoculated 4 days later than fungus.
[c]Nematode (2,500 J2/kg soil) and fungus (50 g/kg soil) inoculated simultaneously.

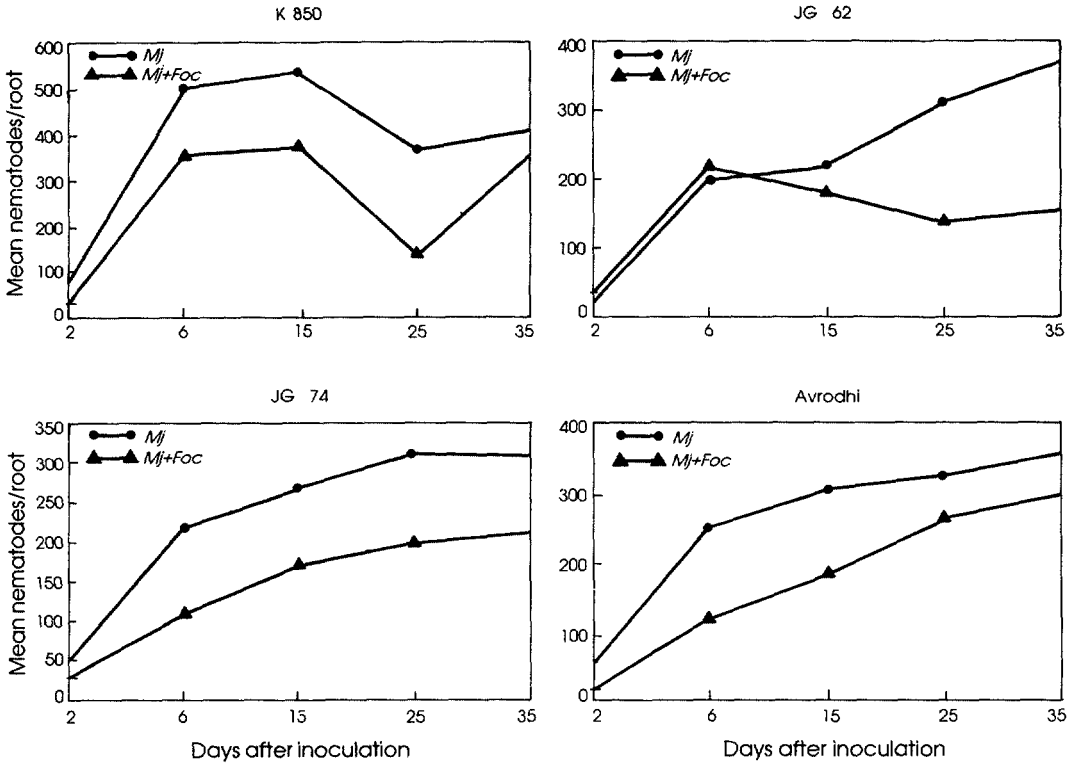

FIG. 1. Effect of *Fusarium oxysporum* f. sp. *ciceri* (*Foc*) on penetration of *Meloidogyne javanica* (*Mj*) in Chickpea roots. LSD ($P = 0.05$) = 23.1 (JG 62), 22.9 (K 850), 18.2 (JG 74), and 20.2 (Avrodhi).

with days after inoculation and correlation coefficients were generally greater, except in the nematode-alone treatment on JG 62, for the wilt-resistant cultivars (for JG 74, *Mj* = 0.81, $P = 0.05$, *Foc* + *Mj* = 0.90, $P = 0.05$; for Avrodhi, *Mj* = 0.85, $P = 0.05$, *Foc* + *Mj* = 0.89, $P = 0.05$) than for the wilt-susceptible cultivars (for JG 62, *Mj* = 0.93, $P = 0.05$, *Foc* + *Mj* = 0.27; for K 850, *Mj* = 0.27, *Foc* + *Mj* = 0.48). The life cycle of *Mj* was not influenced by the presence of *Foc*, and adult females were observed within 25 days of inoculation; nevertheless, the adult female number was reduced by 50% (data not shown). Egg density in egg masses was not affected by *Foc*.

Experiment 3: JG 74 and Avrodhi grew better and produced greater root and shoot weights at 20 °C than at 15 °C and 25 °C. Interactions between the cultivars and the two pathogens were significant at 20 °C (Fig. 2). Wilt developed rapidly, and wilt incidence was higher at 20 °C; about 35% more plants of JG 62 wilted in 3 weeks at 20 °C than at 25 °C. Marginal chlorosis of leaves in K 850 in the *Foc*-alone treatment was first observed after 3 weeks at 20 °C and after 4 weeks at 25 °C. No wilt symptoms developed on any cultivar at 15 °C. Mild chlorosis of leaves in JG 74 and Avrodhi was observed at 20 °C and 25 °C, but no vascular discoloration was found. In *Mj* + *Foc* treatments, wilt on JG 62 appeared 1 week earlier than in *Foc*-alone treatment at 25 °C. Marginal chlorosis of leaves in K 850 was first observed after 3 weeks of inoculations at 20 °C and 25 °C; extent of chlorosis was greater at 25 °C than at 20 °C. About 80% of K 850 plants showed vascular discoloration within 6 weeks. No wilt symptoms except slight chlorosis of leaves were observed on JG 74 and Avrodhi in the *Mj* + *Foc* treatment.

Dry shoot weights of JG 62 at 20 °C, and of JG 74 and Avrodhi at 25 °C, were reduced by *Mj*. Fresh root weight of JG 62 was reduced at 20 °C. At 15 °C, no adverse effect of nematode infection on shoot and root weights of the cultivars was observed. Fresh and dry shoot weights of K 850 were not affected by

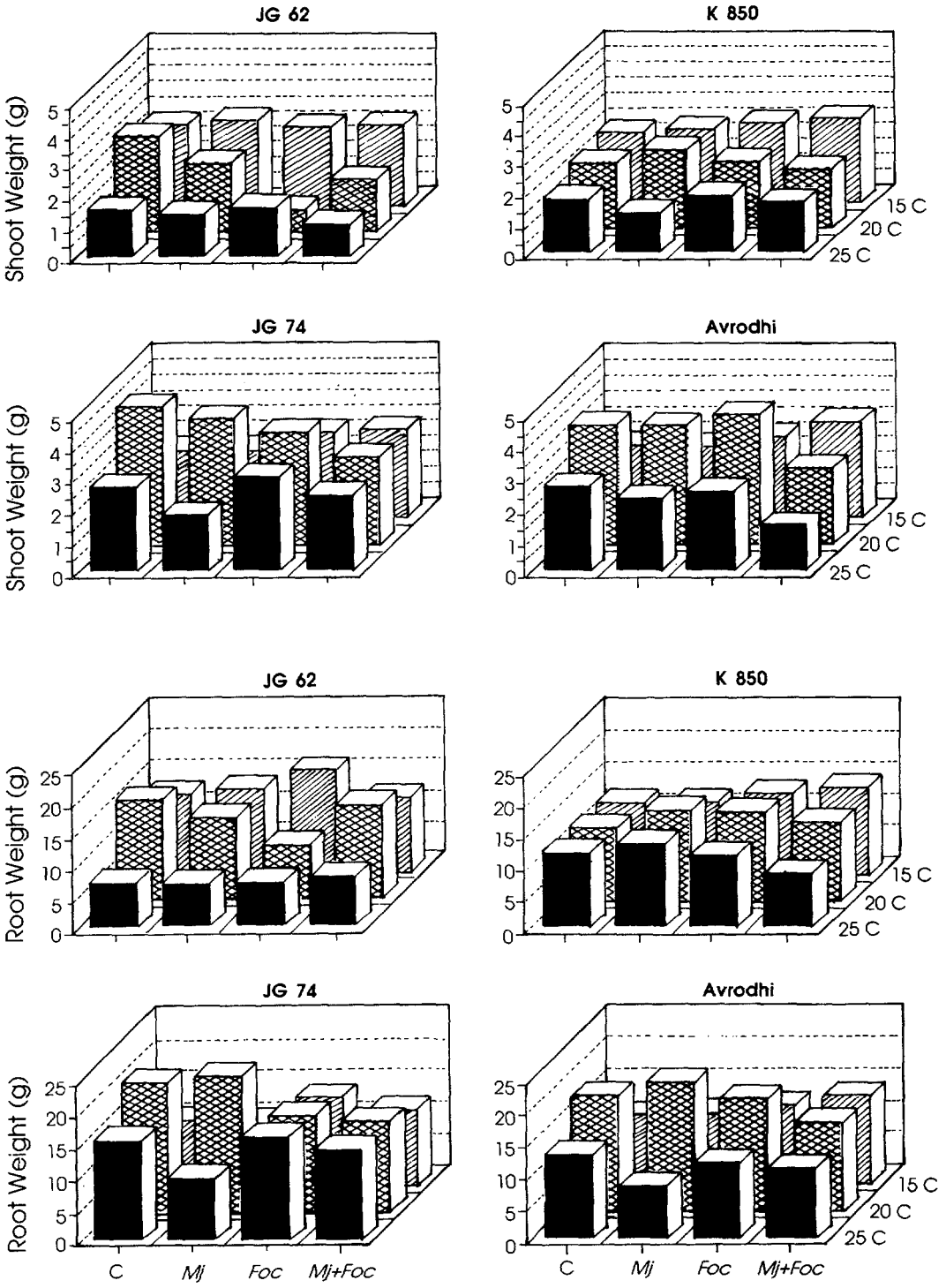

FIG. 2. Effect of *Fusarium oxysporum* f. sp. *ciceri* (*Foc*) and *Meloidogyne javanica* (*Mj*) on dry shoot and fresh root weights of four chickpea cultivars at three temperatures. C = Uninoculated control. LSD ($P = 0.05$) = 3.75, 0.72, and 2.35 for fresh and dry shoot weights and fresh root weights, respectively, at 20 °C.

the nematode at any temperature. Root weight of JG 74 was greater in *Mj*-infested soil at 20 °C. Effect of nematode infection on root weights of K 850 and Avrodhi was not significant.

Dry shoot weights of JG 62 and JG 74 were reduced (P = 0.05) by *Foc* at 20 °C, while at 25 °C the dry shoot weight of JG 74 was increased (P = 0.05). Fresh root weight of JG 74 was reduced at 20 °C, and root weights of K 850 and Avrodhi at 25 °C were increased in *Foc*-inoculated pots. Interactions between the pathogens on dry shoot and root weights were significant only at 20 °C (Fig. 2). Dry shoot weights of JG 62, JG 74, and Avrodhi and fresh root weight of JG 62 were significantly reduced.

Number of galls, percentage of galled area of root, and size of galls increased when temperature increased from 15 °C to 25 °C. Gall indices of all the cultivars ranged between 3 and 4 at 15 °C, 5 and 7 at 20 °C, and at 9 at 25 °C. Temperature had a marked effect on galled area of root, and at 15 °C only 20% of the root area was galled; at 25 °C more than 50% of the root area was galled. The galled area of K 850, JG 74, and Avrodhi was enhanced when temperature increased from 15 °C to 25 °C. Reduction in galled area of roots in the presence of *Foc* was noticed at 15 °C and 20 °C. Densities of eggs and J2 in root and soil increased significantly as temperature increased (data not shown).

Experiment 4: Foliar symptoms of marginal chlorosis and drooping leaves on JG 62 first appeared 2 weeks after inoculation in *Foc*-alone treatment on both the soils. Marginal chlorosis of leaves on K 850 appeared after 4 weeks on clayey and after 6 weeks on loamy sand. Mild chlorosis of leaves without any vascular discoloration was observed on JG 74 and Avrodhi on both soils. Wilt symptoms first appeared on JG 62 a week after inoculation in *Foc* + *Mj*-infested soils. Wilt incidence on JG 62 was 100% on clayey and 87% on loamy sand within 8 weeks of inoculation. Wilt in K 850 was not affected by soil type. Effects of *Mj, Foc,* and their interactions differed with cultivar and soil type (Fig. 3). Shoot weight of JG 62 was lower on loamy sand than on clayey soils. Mean shoot weight across cultivars was reduced (P = 0.05) by *Mj* and increased (P = 0.05) by *Foc.* The nematode reduced the shoot weight of JG 74 by 32% on loamy sand; when compared with that in the uninoculated control, *Foc* had no significant effect (Fig. 3). Shoot weight of Avrodhi was not altered by the pathogens and their interactions. *Meloidogyne javanica* reduced (P = 0.05) the dry shoot weights of JG 62 and K 850 by 20% and 10%, respectively. The fungus reduced (P = 0.05) the shoot weight of JG 62 by 40% and increased the shoot weight of K 850. The increase in shoot weight by *Foc* was 30% greater on clayey than on loamy sand. Dry shoot weights of JG 74 and Avrodhi were not affected by the pathogens (Fig. 3). Fresh root weights of JG 62 and JG 74 were 50% and 45% greater on loamy sand than on clayey soil, respectively. Nematode infection increased the root weights of JG 62, K 850, and Avrodhi; *Foc* reduced the root weight of JG 62 and K 850. Gall indices, galled area of root, and egg and J2 densities of *Mj* were similar on all cultivars. The average galled area score on JG 74 was 7 on clayey soil and greater than 8 on sandy soil.

Discussion

In this study, resistance in chickpea cultivars JG 74 and Avrodhi to Fusarium wilt was stable at all temperatures in the presence of the nematode. This is contrary to the report from northern India where *Mj* modified the Fusarium wilt resistance in Avrodhi (Upadhyay and Dwivedi, 1987). Reasons for this dissimilar response were not explored; however, pathogen variability and differences in virulence could be major factors. In tomato, the presence of nematode and fungus together at 25 °C and 30 °C did not influence wilt resistance (Abawi and Barker, 1984). The stability of wilt resistance across a range of temperatures suggests that resistant chickpea cultivars can be used in many agroecosystems in temperate as well as tropical regions. In a multiple-disease situation, the

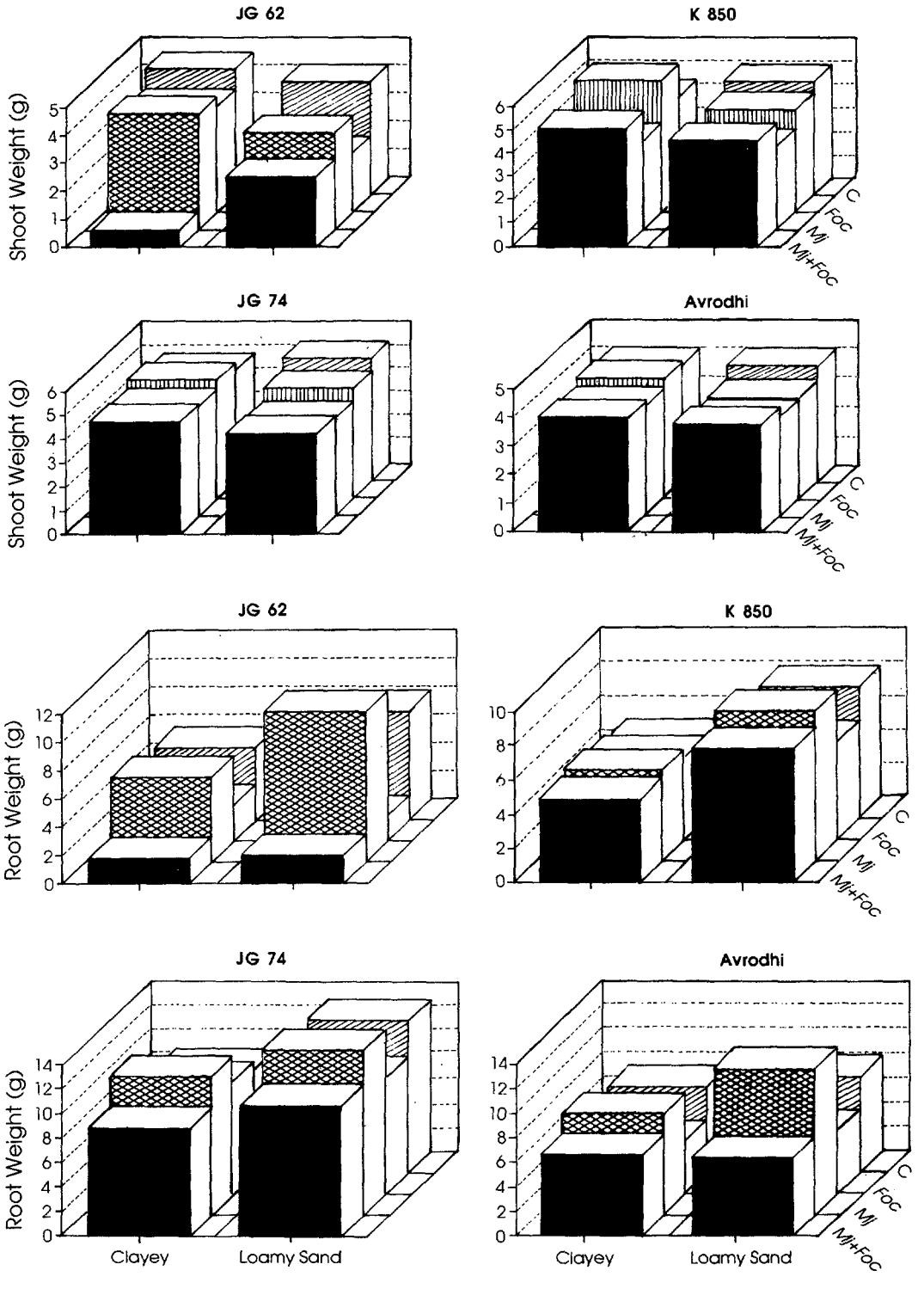

FIG. 3. Effect of *Fusarium oxysporum* f. sp. *ciceri* (*Foc*) and *Meloidogyne javanica* (*Mj*) on dry shoot and fresh root weights of four chickpea cultivars in loamy sand and clayey soils. C = Uninoculated control. LSD ($P = 0.05$) = 2.59 and 0.48 for fresh and dry shoot weights, respectively, for soil × *Mj* × *Foc* interactions.

host response is actually a composite response to parasite-parasite interactions and to abiotic influences (Webster, 1985). *Fusarium oxysporum* f. sp *ciceri* generally suppressed nematode density and root galling, and *Mj* increased wilt development. Foliar symptoms of leaf chlorosis and drooping leaves were typically more obvious on plants in *Foc* + *Mj* treatment than on plants in the *Foc*-alone treatment. No vascular discoloration in the stem region was observed 8 weeks after inoculations (observations were not recorded later); however, *Foc* invaded the vascular region of roots of wilt-resistant cultivars in the presence of *Mj*. It is possible that in some long-duration chickpea cultivars, *Foc* in the presence of *Mj* may gradually invade the stem region and cause wilting. Development of wilt and suppression of root galling by *Foc* was most favored at 20 °C and not at 25 °C (Chouhan, 1963). Temperature had a marked effect on gall index, galled area of root, and gall size, and 25 °C was conducive for development and reproduction of *Mj*. This clearly indicates that evaluation of genotypes for resistance to *Mj* should be done at temperatures optimum for nematode development and multiplication (Dropkin, 1969). Soil type affected the root knot and wilt incidences. Increased moisture retention in heavier soil that favors fungal growth is one plausible explanation for this result. The high silt and clay content probably suppressed *Mj* activity (Prot and Van Gundy, 1981). Sleeth and Reynolds (1955) also reported that *Meloidogyne* spp. caused more damage and reproduced better in coarse-textured soils than in finely textured soils. The two pathogens varied in their reaction to temperature and soil niche. In peninsular India, chickpea is cultivated on heavier soils that are unsuitable for *Mj*. In northern India and Nepal, chickpeas are cultivated on coarse-textured sandy loam soils, and ambient temperatures are greater than 25 °C during mid-crop growth period. The presence of *Mj* in these soils is prone to escalate wilt incidence in this region, while chances of any such interactions in the chickpea growing regions in peninsular India are remote. Currently, there is a greater emphasis on development and cultivation of wilt-resistant chickpea cultivars in India. These cultivars are likely to alleviate the suppressive effect of *Foc* on *Mj*, which may lead to greater damage of chickpea by *Mj*. Resistance to Fusarium wilt in chickpea is oligogenic (Singh et al., 1986; Upadhyaya et al., 1983a, 1983b), and resistance due to some genes is not stable in presence of *Mj* (Uma Maheswari et al. 1995). Therefore, breeding for chickpea cultivars with multiple resistance to both pathogens, and development of Fusarium wilt-tolerant chickpea cultivars, will help to reduce crop losses associated with these pathogens.

Literature Cited

Abawi, G. S., and K. R. Barker. 1984. Effect of cultivar, soil temperature, and levels of *Meloidogyne incognita* on root necrosis and Fusarium wilt of tomato. Phytopathology 74:433–438.

Bergeson, G. B. 1975. The effect of *Meloidogyne incognita* on the resistance of four muskmelon varieties to *Fusarium* wilt. Plant Disease Reporter 59:410–413.

Caperton, C. M., R. D. Martyn, and J. L. Starr 1986. Effects of *Fusarium* inoculum density and root-knot nematodes on wilt resistance in summer squash. Plant Disease 70:207–209.

Chouhan, S. K. 1963. Influence of different soil temperatures on the incidence of *Fusarium* wilt of gram (*Cicer arietinum* L.). Proceedings of Indian Academy of Science B 33:552–554.

Cobb, N. A. 1918. Estimating nematode population of the soil. USDA Agricultural Technical Circular No. 1.

Dropkin, V. H. 1969. The necrotic reaction of tomatoes and other hosts resistant to *Meloidogyne*: Reversal by temperature. Phytopathology 59:1632–1637.

Fassuliotis, G., and G. J. Rau. 1969. The relationship of *Meloidogyne incognita acrita* to the incidence of cabbage yellows. Journal of Nematology 1:219–222.

Goel, S. R., and D. C. Gupta. 1986. Interaction of *Meloidogyne javanica* and *Fusarium oxysporum* f. sp. *ciceri* on chickpea. Indian Phytopathology 39:112–114.

Haware, M. P., Y. L. Nene, and R. Rajeshwari. 1978. Eradication of *Fusarium oxysporum* f. sp. *ciceri* transmitted in chickpea seed. Phytopathology 68:1364–1367.

Johnson, A. W., and R. H. Littrell. 1969. Effects of *Meloidogyne incognita, M. hapla,* and *M. javanica* on the severity of *Fusarium* wilt of chrysanthemum. Journal of Nematology 1:122–125.

Nath, R., and R. P. Dwivedi. 1980. Effect of root-knot nematode on development of gram caused by *Fusarium oxysporum* f. sp. *ciceri* and root rot by *Rhizoctonia* spp. Indian Journal of Mycology and Plant Pathology 11:46.

Nene, Y. L., M. P. Haware, and M. V. Reddy. 1981. Chickpea diseases. Resistance-screening techniques. ICRISAT Information Bulletin No. 10.

Nene, Y. L., V. K. Shiela, and S. B. Sharma. 1989. A world list of chickpea (*Cicer arietinum* L.) and pigeon-

pea (*Cajanus cajan* (L.) Millsp.) pathogens. ICRISAT Legumes Pathology Progress Report 7.

Newhall, A. G. 1958. The incidence of Panama disease of banana in the presence of root-knot and the burrowing nematodes (*Meloidogyne* and *Radopholus*). Plant Disease Reporter 42:853–856.

Porter, D. M., and N. T. Powell. 1967. Influence of certain *Meloidogyne* species on Fusarium wilt development in flue-cured tobacco. Phytopathology 57:282–285.

Price, T. V., R. W. McLeod, and J. B. Suneghy. 1980. Studies on interactions between *Fusarium oxysporum* f. sp. *lycopersici, Verticillium dahliae,* and *Meloidogyne* spp. in resistant and susceptible tomatoes. Australian Journal of Agricultural Research 31:1119–1127.

Prot, J. C., and S. D. Van Gundy. 1981. Effect of soil texture and clay component on migration of second-stage juveniles of *Meloidogyne incognita.* Journal of Nematology 13:200–217.

Ribeiro, C. A. G., and S. Ferraz. 1984. The interaction between *Meloidogyne javanica* and *Fusarium oxysporum* f. sp. *phaseoli* in snap bean (*Phaseolus vulgaris*). Fitopatologia Brasileira 8:439–446.

Schindler, A. F. 1961. A simple substitute for a Baermann funnel. Plant Disease Reporter 45:747–748.

Sharma, R. D., and R. F. Cerauskas. 1985. Interaction between *Meloidogyne javanica* and *Fusarium oxysporum* f. sp. *ciceri* on chickpea. Nematologia Brasileira 9:113–121.

Sharma, S. B., and D. McDonald. 1990. Global status of nematode problems of peanut, pigeonpea, chickpea, sorghum, and pearl millet and suggestion for future work. Crop Protection 9:453–458.

Sharma, S. B., P. Remanandan, and D. McDonald. 1993. Resistance to *Meloidogyne javanica* and *Rotylenchulus reniformis* in wild relatives of pigeonpea. Supplement to the Journal of Nematology 25:824–829.

Sharma, S. B., D. H. Smith, and D. McDonald. 1992. Nematode constraints of chickpea and pigeonpea production in the semi-arid tropics. Plant Disease 76:868–874.

Singh, H., J. Kumar, M. P. Haware, and J. B. Smithson. 1986. Genetics of resistance to fusarium wilt in chickpeas. Pp. 329–332 *in* P. R. Day and G. J. Jellis, eds. Genetics and plant pathogenesis. Oxford: Blackwell Scientific Publications.

Sleeth, B., and H. W. Reynolds. 1955. Root-knot nematode infestation as influenced by soil texture. Soil Science 88:459–461.

Thakar, N. A., H. R. Patel, B. K. Patel, and C. C. Patel. 1986. Breaking of resistance to *Fusarium* wilt in resistant chickpea by root-knot nematode. Madras Agricultural Journal 73:410–411.

Uma Maheswari, T., S. B. Sharma, D. D. R. Reddy, and M. P. Haware. 1995. Co-infection of wilt-resistant chickpeas by *Fusarium oxysporum* f. sp. *ciceri* and *Meloidogyne javanica.* Supplement to the Journal of Nematology 27:649–653.

Upadhyaya, K. D., and K. Dwivedi. 1987. Root-knot nematode *Meloidogyne javanica* breaks wilt resistance in chickpea variety Avrodhi. Current Science 11:132–133.

Upadhyaya, H. D., M. P. Haware, J. Kumar, and J. B. Smithson. 1983a. Resistance to wilt in chickpea. I. Inheritance of late-wilting in response to race 1. Euphytica 32:447–452.

Upadhyaya, H. D., J. B. Smithson, M. P. Haware, and J. Kumar. 1983b. Resistance to wilt in chickpea. II. Further evidence for two genes for resistance to race 1. Euphytica 32:749–755.

Webster, J. M. 1985. Interaction of *Meloidogyne* with fungi on crop plants. Pp. 183–192 *in* J. N., Sasser and C. C. Carter, eds. An advanced treatise on *Meloidogyne.* Vol. 1: Biology and control. Raleigh: North Carolina State University Graphics.