MELOIDOGYNE KONAENSIS AND COFFEE ROOTSTOCK INTERACTIONS AT TWO MOISTURE REGIMES IN FOUR SOILS

Mario Serracin[1] and D. P. Schmitt[2]

[1]Junior Researcher, [2]Professor. University of Hawaii at Manoa, Department of Plant and Environmental Sciences, 3190 Maile Way, Honolulu, HI 96822 U.S.A.

ABSTRACT

Serracin, M. and D. P. Schmitt. 2000. *Meloidogyne konaensis* and coffee rootstock interactions at two moisture regimes in four soils. Nematropica 32:65-76.

Three experiments were conducted to evaluate the reproduction and damage potential of *Meloidogyne konaensis* on resistant and susceptible rootstocks of coffee in four soils under two moisture regimes representative of areas where coffee is grown in Hawaii. Reproduction of *M. konaensis* occurred readily in all soil types, but lowest in the Hydric Dystrandept soil where the holotype was first founded. Root galling, however, was greatest in this soil. *M. konaensis* suppressed growth of coffee in all four soils. Greater galling occurred under constant moisture (33kPa) than under fluctuating moisture (33-1500 kPa). Fifty percent more eggs were produced at constant moisture than under fluctuating moisture conditions. Development of *M. konaensis* was completed in *C. arabica*, as expected for a good host. *Coffea liberica* var. *dewevrei* was resistant to *M. konaensis* and *C. arabica* was susceptible. *C. liberica* var. *dewevrei* allowed development of only a few adult females and males.

Key words: Coffea arabica, Coffea liberica var. *dewevrei*, coffee, genetic resistance, Hawaii, irrigation, Kona coffee root-knot nematode, *Meloidogyne konaensis*, rootstocks.

RESUMEN

Serracin, M. and D. P. Schmitt. 2000. *Meloidogyne konaensis* y la relacion entre portainjertos, cuatro tipo de suelos differentes y dos regimenes de riego. Nematrópica 32:65-76.

Se estudio la reproduccion y daño a café por *Meloidogyne konaensis* en tres experimentos. *Coffea arabica* fue evaluado en cuatro suelos y dos niveles de humedad diferentes, pero representativos de las areas en cultivo de cafe en Hawaii. La reproduccion de *M. konaensis* ocurrio en todos los suelos en *C. arabica*, suprimiendo el crecimiento de las plantas. A pesar de la reproduccion fue menor en el Dystrandept Hidrico, el suelo donde el holotipo fue descubierto, el agallamiento radicular fue mayor en este tipo de suelo. Mas huevos fueron producidos por *M. konaensis* bajo condiciones de humedad constante (33 kPa) que con humedad oscilante (33-1500 kPa). El desarrollo de *M. konaensis* se completo en *Coffea arabica*, hospedero suceptible, pero no en *Coffea liberica* var. *dewevrei*, el cual demostro resistencia determinada en base a una menor reproducion, lento e incompleto desarrollo de hembras a estado adulto y por la presencia de nematodos machos.

Palabras clave: Café, *Coffea arabica*, *Coffea liberica* var. *dewevrei*, Hawaii, *Meloidogyne konaensis*, nematodo agallador de Kona, portainjertos, resistencia genetica.

INTRODUCTION

Plant responses to soil physical properties are determined by the plant genetic constitution (Flor, 1946; Vanderplank, 1963) and by pulses in the environment. Although the genotype determines its potential for growth and yield, environmental conditions, pests or human intervention can modify the extent to which that potential is realized (Wallace, 1989). A complex array of interactions occur in the soil environment that influence the growth potential of plants and the popula-

tion densities of soil inhabitants, including plant obligate parasitic nematodes.

Coffee production in Hawaii occurs in a wide variety of soils and with different moisture characteristics and water management practices. Coffee yield potentials are not realized in Hawaii for numerous reasons but draught, improper management and damage by nematode are among primary cause. Most of the fields on the island of Hawaii (1000 ha) are planted on Andisols and Inceptisols composed of fragments of 'Pahoehoe' lava rock and volcanic ash (Powers, 1932). On Kauai, 2 000 ha of coffee are planted on weathered Oxisols. The coffee estates on Molokai (200 ha), Maui (300 ha), and Oahu (70 ha) are established largely on Mollisols and Oxisols. This situation presents a wide range of growing conditions to study plant-parasitic nematodes and to evaluate different coffee management practices in relation to nematode infestations.

Rainfall patterns are different across the islands and growers who irrigate use different systems and quality of water. In the Kona district of the island of Hawaii, the Kona coffee root-knot nematode, *Meloidogyne konaensis* (Eisenback *et al.*, 1994), is the most important organism causing damage to coffee (Zhang and Schmitt, 1995a). Under optimal nematode control and production practices, values for the 1999-2000 coffee crop was estimated at U.S. $30 million. However, actual revenues for the 1999-2000 crop was U.S. $21 million (Statistics of Hawaiian Agriculture, 2000). Presently, *M. konaensis* is known to occur only in the Kona area on the island of Hawaii (Schmitt and Serracin, unpublished data, 2001). Surveys conducted in 1999-2000 indicate that the nematode was spread through planting of infected seedlings. An important concern is the potential of *M. konaensis* spread to more coffee plantations throughout the state.

Associations between soil physical properties and nematodes damaging coffee have been documented worldwide (Sasser, 1954; Campos, 1994). At least some species of nematodes have soil type preferences. In Brazil, *M. paranaensis* and *M. exigua* occur primarily in sandy soils (Jaehn and Rebel, 1984; Campos *et al.*, 1990). Conversely, in Central America, *M. arabicida* (Lopez and Salazar, 1989), *M. exigua* (Schieber, 1974), and *M. incognita* (Chitwood and Berger, 1960) are widespread, and are considered very damaging to coffee cultivated on fine-textured volcanic soils. The broad category of soil types may not adequately explain environmental or tolerance factors that influence nematode behavior.

The amount and frequency of precipitation and irrigation has a major effect on coffee growth and nematode activity (Schmitt *et al.*, 2001). The seasonal rainfall in the Kona region of Hawaii is greatest from April to August and least from December to March. This is opposite to that of other areas of the islands were the greatest precipitation occurs from November to February. Nematode population densities are normally greatest in July and lowest from November through February (Schmitt *et al.*, 2001). Nematode infected coffee plants in Hawaii express symptoms primarily between July and November (Serracin *et al.*, 1999). Irrigation has been use to reduce symptoms of stress (wilting) associated to *M. konaensis* infection. However, lack of oxygen alone due to excessive moisture often leads to the detrimental effects to coffee roots (Wrigley, 1988).

Because *M. konaensis* is often detected in soils in the Kona district and on the island of Hawaii, it is important to determine its potential to establish and cause damage to coffee in other areas. The role of soil moisture on nematode reproduction and coffee growth, and the response of *C.*

liberica W. Bull ex Hiern var. *dewevrei* to nematode infection are also equally important to ascertain. Zhang and Schmitt (1995a) demonstrated in greenhouse studies that *M. konaensis* is very damaging to coffee grown in sand, and that arabica cultivars vary in their reaction to the nematode. The use of nematode resistant rootstocks has been the most effective management tactic to increase vigor and productivity (Reyna, 1949; Campos, 1990; Schmitt *et al.*, 2001). Rootstocks have been used since 1870 to manage nematodes in coffee (Cramer, 1934). In Brazil and Guatemala, scions of *C. arabica* cultivars 'Mundo Novo' and 'Red Catuai' are often grafted onto *C. canephora* rootstock as a management strategy against *M. exigua* and *Pratylenchus* spp. (Schieber, 1968). *C. liberica* W. Bull ex Hiern var. *dewevrei* appears resistant to *M. exigua* (Curi *et al.*, 1970; Fazuoli and Lordello, 1976); in Hawaii, scion of *C. arabica* 'Typica' selection Guatemala were grafted onto *C. liberica* W. Bull ex Hiern var. *dewevrei* and later evaluated for cup quality; the coffee retained the high coffee quality expected from arabica coffee (Cavaletto, pers. comm.).

This research was undertaken to determine the reproduction and damage potential of *M. konaensis* on 1) coffee in four soils with different chemical and physical properties representative of conditions where coffee is grown in the state of Hawaii, 2) under two moisture regimes, and 3) on two coffee species.

MATERIAL AND METHODS

Experiments: Three experiments were conducted in a greenhouse at Whitmore, Oahu, Hawaii, elevation 420 feet and with diurnal temperatures fluctuating from 18-28°C. The first experiment examined the effects of four soil types on reproduction and damage potential of *M. konaensis* on coffee. The second experiment tested the effects of two extreme irrigation levels (constant -33kilo Pascals (kPa), and fluctuating between -33 to 1500 kPa) on nematode reproduction in a Hydric Dystrandepts. The third experiment was designed to determine and compared the resistance response of *C. arabica* and *C. liberica* W. Bull ex Hiern var. *dewevrei* to *M. konaensis*. The Hydric Dystrandept soil was watered to achieve a desired soil water potential. Soil in the pots was managed to keep its content near -33 kPa for 7 days before adding the nematodes. The duration of all the experiments was 120 days.

Plants: Seeds of *Coffea arabica* cv. Typica selection 'Guatemala' and *C. liberica* W. Bull ex Hiern var. *dewevrei* were collected at the Kona Experiment Station, Kainaliu, Hawaii, and scarified to accelerate germination. Seeds were sown in Sunshine® mix and placed on greenhouse benches under 30% shade cloth to provide optimum conditions for coffee growth. Seedlings at the cotyledon stage were transplanted into 10-cm-diam tubes filled with Sunshine® mix. Immediately after transplanting some scions of *C. arabica* were grafted onto *C. liberica* W. Bull ex Hiern var. *dewevrei* rootstocks (Reyna, 1966; Ito, 1989, unpublished). These grafted the non-grafted *C. arabica* were grown in the greenhouse for an additional 3 months before being inoculated with the nematodes.

Soils and irrigation regimes: Soils were collected from 4 of the primary coffee production regions of Hawaii (Table 3). The soils were steam pasteurized at 76°C for 5 hours. Analysis of soil pH, salinity, N, P, K, B, Mg, and % organic carbon was performed on all soil (Table 3) before heat treatment by the University of Hawaii soil testing laboratory. All soils were used for Experiment 1. For Experiments 2 and 3, the Hydric Dystrandepts from Kona was selected.

Irrigation for experiments 1 and 3 was programmed to maintain the soil water potential around -33 kPa and to prevent water stress. Irrigation was provided by an automated drip system programmed to deliver approximately 300 ml of water/day and modified to 750 ml/day as the plants grew older, thus maintaining the soil water potential around 33 kPa. For experiment 2, irrigation goals were: 1) -33 kPa and 2) allowing the soil to dry until the water potential reached 1500 kPa, then watering to -33 kPa. All plants were fertilized once a week with 100 ml of a soluble 20-20-20 (N-P-K) fertilizer (Rapid Grow®, Chevron Chemical Company, San Ramon, CA).

Nematode treatments: Two nematode infestations levels were used: 0 and 2,500 J2/pot (1 liter of soil). *Meloidogyne konaensis,* collected from galled coffee roots at the Kona Research Station, was cultured in the greenhouse on tomato (*Lycopersicon esculentum (*L). cv. Pixie. Eggs of *M. konaensis* were released from the gelatinous matrix with NaOCl (Hussey and Barker, 1973) and placed on Baermann funnels for hatching. Second stage juveniles (J2) that emerged during the first 24 hours were discarded and those that emerged during the following 24 hours were used as inoculum. Control treatments were inoculated with 10 ml of water.

Data: Seedling height and number of new leaf pairs were determined at monthly intervals. At the termination of the experiments, plants were weighed and root galling was evaluated. A modified galling index (Carneiro, 1995): 0 = No galls (all roots normal in appearance and quantity); 1 = small galls visible in secondary roots and root tips; 2 = swelling and discoloration of primary roots with few secondary roots present; 3 = swelling of tap root, with cracking and corkiness of primary roots; 4 = necrosis and cracking of most roots; and 5 = intense corkiness and complete necrosis of tap root, no secondary roots present. Nematode reproduction factors (RF) were calculated for each experiment using RF = Pf/Pi, where Pi = 2500 and Pf = the population density at the termination of the experiment. Nematodes were recovered from 250 ml of soil by a combination of elutriation (Byrd *et al.*, 1976) and centrifugal flotation (Jenkins, 1964). The roots were divided into two portions: one portion was placed in the mist chamber for 5 days (Seinhorst, 1956) to assay nematode root population; eggs were collected from the remaining portion of the root system using a NaOCl method (Hussey and Barker, 1973). After the extraction process was completed, the roots were dried at 70 C for 1 week and weighed. In addition, for Experiment 3, nematodes within the roots were stained with acid fuchsin (Daykin and Hussey, 1985) to facilitate characterization of life stages.

Experimental design and data analysis: Experimental units were completely randomized with 6 replications per treatment. Nematode quantitative data were normalized by transforming to $\log_{10}$ (x + 1) values before performing an analysis of variance using Statistical Analysis System (SAS Institute, Cary, NC). The Waller-Duncan K-ratio T-test was used as a multiple range test for comparing treatment means. For Experiment 1, differences in soil effects on galling indices, number of eggs per plant and root fresh weights were tested using orthogonal contrasts. The comparisons were 1) Hydric Dystrandepts (HD) vs. other soils, 2) Oxic Haplustoll (OH) vs. Aridic Haplustoll (AH) and Vertic Haplustoll (VH), contrast 3) Aridic Haplustoll vs. Vertic Haplustoll.

RESULTS

Experiment 1: (Effect of soil type). Plant and root growth were both affected by soil (Table 1) with root growth being affected

Table 1. Coffee (*Coffea arabica* cv. Typica selection Guatemala) growth response to soils and *Meloidogyne konaensis*.

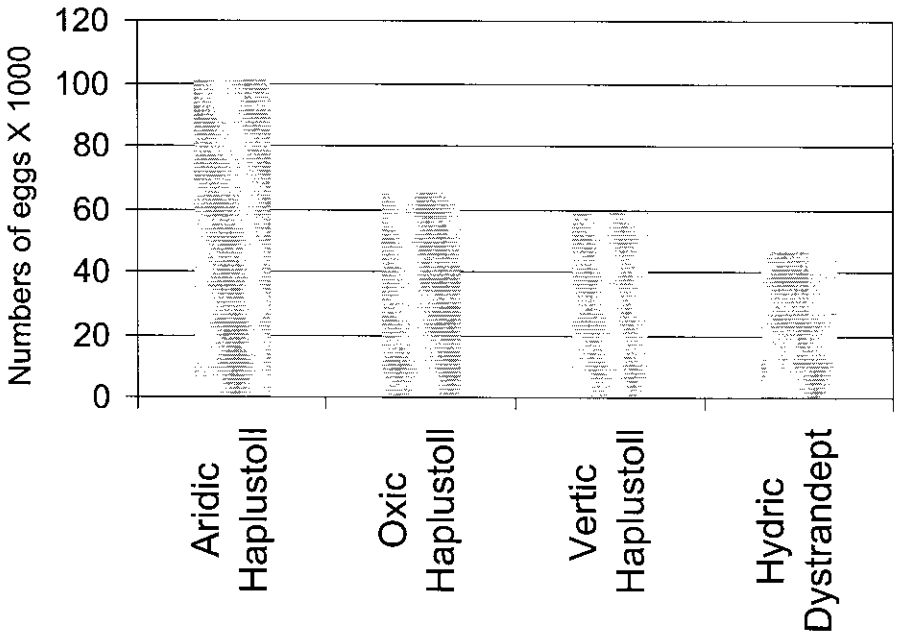
Soil classification	Nematode Pi (J2/soil)	Plant height (cm)	Shoot dry weight (g)	Root dry weight (g)
Aridic Haplustoll (AH)	0	29.0 a	15.5 a	11.9 a
Mollisol	2500	27.5 a	14.5 a	6.0 a*
Oxic Haplustoll (OH)	0	24.3 b	14.0 a	8.4 b
Oxisol	2500	26.7 a	15.3 a	4.8 b*
Vertic Haplustoll (VH)	0	22.7 ab	9.8 b	6.4 b
Mollisol	2500	18.5 c*	7.7 b	3.4 c*
Hydric Dystrandepts (HD)	0	21.3 ab	8.2 b	5.1 c
Andisol	2500	21.0 b	7.7 b	3.1 c*

Data are means of 6 replicates. Means of soil effects (combined data for inoculated and control treatments) were compared and separated at $P< 0.05$ level according to Waller-Duncan k ratio t-test. Similar letters within each column do not differ significantly from each other.
Asterisk (*) indicates significant ($P< 0.05$) difference from non -inoculated controls.

by soil and *M. konaensis*. Plant height was greatest in the Aridic Haplustoll (AH) and least in the Hydric Dystrandept (DH). Plants were 33% shorter in the Vertic Haplustoll (VH) soil, 24% shorter in the Hydric Dystrandept (HD), and 3% shorter in the Oxic Haplustoll (OH) than they were in the Aridic Haplustoll (AH) if nematodes were present. *M. konaensis* suppressed root development in all soil types (Fig. 1). Root weight was 29%, 46% and 5% less, in the Aridic Haplustoll than in the Oxic Haplustoll, Vertic Haplustoll, and Hydric Dystrandept respectively. The nematode suppressed root biomass development by 39-50% depending of the soil.

Reproduction occurred readily in all soils tested (Fig. 1). The Hydric Dystrandept, the soil collected from the naturally infested areas of Kona, was the least suitable soil for egg production compared to other soils tested. The number of eggs produced were 2.15, 1.70 and 1.55 times greater ($P = 0.05$) in the Aridic Haplustoll than in the Hydric Dystrandept, Vertic Haplustoll and Oxic Haplustoll, respectively (Fig. 1). In contrast to egg production, more galling and necrosis ($P = 0.02$) occurred in the Hydric Dystrandepts than in other soils (Fig. 2). Galling was intermediate in the Oxic Haplustoll and least in the Aridic and Vertic Haplustoll.

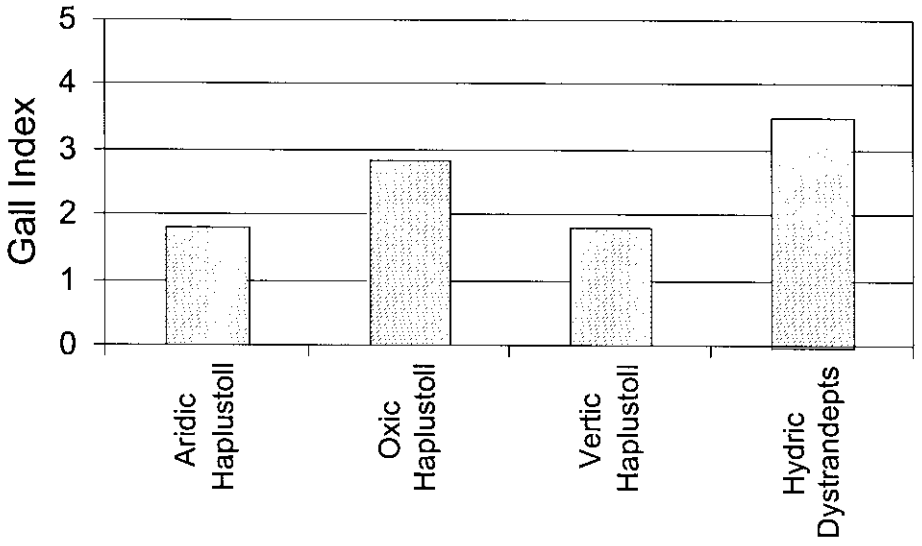
Experiment 2: (Influence of soil moisture extremes). Shoot and root weights were only slightly affected ($P > 0.05$) by the irrigation regime in the presence of nematodes (Table 2). Irrigation also affected coffee overall growth; at the end of the experimental period nematode infected plants under constant irrigation had lowest total biomass than non inoculated coffee plants. Less galling ($P = 0.004$) occurred under fluctuating moisture than under constant moisture of -33 kPa. Nematode fecundity was also affected by irrigation. The number of eggs produced was 1.5 times greater at constant moisture than under fluctuating moisture conditions. The total number of nematodes per pot was greater at constant 33 kPa than in the fluctuating of soil moisture treatment ($P = 0.03$).



Orthogonal Contrasts	Pr >F
Hydric Dystrandepts vs Others	0.05
Oxic Haplustoll vs Aridic Haplustoll and Vertic Haplustoll	0.81
Aridic Haplustoll vs. Vertic Haplustoll	0.25

Fig. 1. Number of eggs of *Meloidogyne konaensis* per plant (*Coffea arabica* Typica selection Guatemala) grown in four different soils for 120 days.

Experiment 3: M. konaensis reproduces poorly in *C. liberica* var. *dewevrei* rootstock indicating moderate to high resistance (Table 4). When *C. arabica* was infected with *M. konaensis* its shoot fresh weight and root dry weight were less (but not statistically significant, $P = 0.17$ and $P = 0.23$, respectively) than those of grafted onto *C. liberica* var. *dewevrei* seedlings. Differences in plant height were also evident ($P = 0.005$) among rootstocks. Susceptible *C. arabica* cv. Typica selection 'Guatemala' plants infected with *M. konaensis* were approximately 45% shorter than *C. liberica* var. *dewevrei*. Galling was greater on *C. arabica* ($P < 0.0001$) in contrast to *C. liberica* var. *dewevrei* which showed little galling (Table 4). Nematode reproduction rates also differed among rootstocks ($P = 0.0019$). The reproductive factor (RF) was 1.96 on *C. arabica* Typica and 0.51 on *C. liberica* var. *dewevrei*. After one generation cycle (approximately 120 days), *Meloidogyne konaensis*-infected *C. arabica* plants had seven times more eggs of than did *C. liberica* var. *dewevrei*. The results indicate that development of *M. konaensis*



Orthogonal Contrasts	Pr >F
Hydric Dystrandepts vs Others	0.02
Oxic Haplustoll vs Aridic Haplustoll and Vertic Haplustoll	0.19
Aridic Haplustoll vs. Vertic Haplustoll	0.25

Fig. 2. Root-gall indices on coffee infected with *Meloidogyne konaensis* in four different soils. Gall index was modified: 0 = no galls, all roots are normal in appearance and quantity; 1 = small galls visible in secondary roots and root tips; 2 = swelling and discoloration of primary roots with few secondary roots; 3 = swelling of tap root, cracking and corkiness of primary roots; 4 = necrosis and cracking of most roots; and 5 = complete corkiness and necrosis of tap root, no primary or secondary roots present.

on *C. arabica* was typical of that previously observed on a sensitive host, whereas juveniles in *C. liberica* var. *dewevrei* failed to develop beyond the fourth stage and males were present. No males were observed in *C. arabica* rootstock.

DISCUSSION

Soils

Damage of coffee plants (*C. arabica*) by *Meloidogyne konaensis* is usually more severe under low moisture conditions. This association of damage to coffee from root-knot nematodes in sandy soils has been well documented in Brazil (Jaehn and Rebel, 1984). In Hawaii, Zhang and Schmitt (1994) determined that even at the low inoculum level of 150 eggs/plant, *M. konaensis* causes considerable root damage to coffee grown in a mixture of sterilized sand and clay soil. A similar level of sensitivity was observed in our experiments with different soils.

Seinhorst and Kozlowska (1977) first related the response and tolerance threshold of plants infected by nematodes to

Table 2. Effects of two extreme soil moisture levels on *M. konaensis* and *Coffea arabica* seedlings growth.

Moisture level	Dry weights (g)		Galling	Eggs/pot
	Shoot	Root		
Fluctuating (33-1500 kPa)				
Nematode +	1.90	0.55	1.8*	1620*
Nematode -	3.58*	0.71	0	0
Constant (33 kPa)				
Nematode +	0.90	0.64	2.0**	2222*
Nematode -	3.22*	0.82	0.0	0

Data are the means of five replications.
Asterisks (*) indicate significance ($P < 0.05$) between +, - nematode treatment.
[1]Initial population Pi = of 2500 juveniles per 1 liter pot.

changes in nematode density per root volume or length. In our experiments, clay soils that support the best root growth provide the most and best feeding sites for nematode invasion and reproduction. However, *Meloidogyne konaensis* caused more damage to coffee roots in the Hydric Dystrandept, a well drained silty clay loam that formed in volcanic ash. This is the soil in which the Kona coffee nematode naturally occurs. Due to mineralogical and physical properties, particle formation from fine volcanic ash have variable water retention capacity (Table 3) and often aggregate to form particles with sand-like behavior, thus explaining the greatest damage in this soil.

The Aridic Haplustoll (AH) supported the largest root system and the greatest number of egg production by *M. konaensis*. This clay soil also had the lowest percentage of organic carbon and it has been under cultivation for many years. The lack of organic carbon may affect the activity of soil-inhabiting microorganisms that would naturally suppress nematode as shown by Lindford *et al.* (1938) in a similar Hawaiian clay soil undergoing decomposition of organic matter. The Aridic Haplustoll also had the lowest water capacity at -33 and 1500 kPa and the greatest bulk density. Therefore it probably had a favorable soil pore and air ratio for root development. Pore size distribution regulates soil moisture and air relationships in soil microbial communities (Hassink *et al.*, 1993) including nematodes (Wallace, 1956).

Irrigation

Water is one of the most important constituents of the coffee soil environment, yet, insufficient data is available on water requirements in nematode infested coffee farms. The relationship of soil moisture in relation to plant damage induced by nematodes has resulted in conflicting data, thus, it is difficult to separate effects because the soil phases are complex and interrelated with the corresponding soil moisture characteristics (Simons, 1973). In addition, coffee plants are sensitive to moisture extremes and experience irreversible symptoms of stress if waterlogged or exposed to sudden moisture deficit (Nunes, 1976).

In the present experiment *M. konaensis* population development was greater when soil water conditions were constant (-33

Table 3. Physico-chemical parameters of four soils representatives of the major coffee producing areas in the Hawaiian Islands.

Parameters	Source of soil			
	Kualapuu, Molokai	Eleele, Kauai	Waimanalo, Oahu	Kainaliu, Hawaii
Depth (cm)	0-20	0-18	0-18	0-25
Water content at				
1500 kPa	21.6	24.4	27.5	58.8
33 kPa	29.2	36.8	dna	84.8
Field capacity	dna*	dna	dna	82
Bulk density (g/cc)	1.26	1.09	1.18	0.48-0.72
Chemical analysis				
pH (in water)	6.20	7.4	6.8	5.70
Salinity (EC)	0.98	0.44	0.80	0.28
P (ppm)	175	99	395	26.0
K	540	620	600	340
Ca	2200	3800	5800	2200
Mg	280	500	1700	360
B	0.84	108	0.40	0.60
OC (%)	1.22	2.44	1.31	7.54
Soil series	Hoolehua silty clay	Makaweli silty clay loam	Waialua clay variant	Honuaulu, silty clay loam hydric
Classification (great group)	Aridic Haplustoll, Mollisol	Oxic Haplustoll, Oxisol	Vertic Haplustoll, Mollisol	Dystrandept, Andisol
Minerology	Fine kaolinitic, isohyperthermic	Fine kaolinitic, isohyperthermic	Very fine, kaolinitic, isohyperthermic	Thixotropic over fragmental, Isothermic

*dna = data not available.

kPa) than when they fluctuated. This relationship between *M. konaensis* population density and irrigation regimes was similar to that previously reported for *M. hapla* by Couch and Bloom (1960). However, according with Dropkin and Martin (1957) and Barker (1982), egg production by *M. incognita* was slightly favored by low moisture. Johnson *et al.* (1994), concluded that population densities and life cycle of *Heterodera glycines* Ichinohe, were highest and occurred faster when under soil conditions with relatively high soil water potential. Egg production may also be affected by different nematode species, soil type, initial population density and by changes in the physical environment inside the pots in which the experiment was conducted. The growth we observed in the nematode infected coffee plants could be attributed to an initial response of plants to nematode infection. Inherent chemical properties of each soil may also be involved. However, once a nematode generation cycle is developing,

Table 4. Interactive effects of *Meloidogyne konaensis* and *Coffea arabica* cv. Typica selection Guatemala and *C. liberica* var. *dewevrei* on plant and nematode response.

	Rootstocks			
	C. arabica cv. *Typica*		*C. liberica* var. *dewevrei*	
	Nematode *Pi*		Nematode *Pi*	
Parameters measured	2500	0	2500	0
Shoot dry weight (g)	0.41	0.53	0.61	0.65
Root dry weight (g)	0.19	0.35	0.29	0.27
Height (cm)	15.2	16.0	17.3	16.9
Gall index (1-5)	3.9	0	1.0	0
Rep. factor	2.0	0	0.50	0
Eggs/pot	30,266	0	4,245	0
Males	0	0	9	0

Values are the means of 6 replications. Significant differences were found among rootstocks in shoot dry weight ($P = 0.1680$), root dry weight ($P = 0.2306$); height ($P = 0.0057$), galling index ($P = 0.0001$), eggs ($P = 0.0001$), males ($P = 0.0705$), and reproductive factor ($P = 0.0019$).

stress conditions would reduce root development and coffee growth.

Plant Resistance

Our data also show that host-plant resistance in *C. liberica* var. *dewevrei* was very effective in suppressing *M. konaensis* development and reproduction. It is known that Robusta type coffee genotypes (such as *C. liberica* var. *dewevrei* and *C. canephora*) exhibit broad horizontal resistance to multiple pests and pathogens compared to *C. arabica* (Campos, 1990). In previous field work, *C. liberica* var. *dewevrei* showed moderate field resistance (Zhang and Schmitt, 1995a), but expressed high resistance in the present work. The difference in response in *C. liberica* var *dewevrei* between the two tests may be due in part to genetic segregation of the resistance component. Genetic variability is characteristics of species of coffee which are cross-pollinated (Wrigley, 1988). Greater galling indices, reproductive factors and numbers of eggs of *M. konaensis* indicated that *C. arabica* was a better host to the nematode than was *C. liberica* var. *dewevrei*. Similar results were found in Brazil (Curi *et al.*, 1970; Fazuoli and Lordello, 1976) for resistance response of *C. dewevrei* (De Wild.) to *M. exigua*.

Little is known about the mechanism of root-knot nematode resistance in *C. liberica* var. *dewevrei*. The presence of males and arrested development of fourth stage juveniles we observed suggests the inhibition of giant cell formation or some other event that adversely affects the nematode development and egg production. Mazzafera *et al.*, (1990) determined that compounds in a nematode-resistant coffee rootstock, peroroxidases, and polyphenolxoidase were detectable in *C. canephora* soon after infection by *M. incognita*. These substances are deposited in the cell wall and can impair development of pathogens (Agrios, 1997). Another component of the resistance mechanism in 'Robusta' type

coffee was proposed by Goncalves *et al.*, 1995). A comparison of the mineral and organic content between selection 'Robusta C2258' and *M. incognita* susceptible *C. arabica* cv. Mundo Novo, indicated that nematode infection altered the absorption and translocation of essential nutrients within the plant. Potassium and zinc concentrations were greater in leaves of nematode-resistant *C. canephora*, whereas phosphorus, magnesium, iron, boron and calcium concentrations were less (Goncalves *et al.*, 1995). Further characterization of the cellular response of resistant rootstocks when infected to *M. konaensis* infection is required.

Genetic resistance can provide a practical way to manage *M. konaensis* as demonstrated by the resistant rootstock *C. liberica* var. *dewevrei*. Furthermore, other rootstocks and scion combinations should be evaluated in an effort to deploy multiples sources levels of resistance as a means of managing the Kona coffee root-knot nematode. The interaction among soil environment, host and nematode also must be recognized when managing *M. konaensis* in the field. Another important conclusion is the relative insensitivity of reproduction to soil types. This nematode emphasized the need to avoid the movement of infested soil and plants to prevent further spread of this important coffee pathogen.

ACKNOWLEDGMENTS

We thank Drs. Brent Sipes, Scot Nelson, R. Green and H. C. Bittenbender for valuable suggestions to the manuscript; to the Hawaii Coffee Growers Association for assistance in collections of soils, and to the staff at the Nematology Laboratory at the University of Hawaii at Manoa for their support during completion of this project.

LITERATURE CITED

AGRIOS, G. N. 1997. Plant Pathology. Fourth Edition. Academic Press. San Diego, CA, U.S.A.

BARKER, K. R. 1982. Influence of soil moisture, cultivar, and population density of *Meloidogyne incognita* on soybean yields in microplots. Journal of Nematology: 14:429.

BYRD, D. W., JR., K. R. BARKER, H. FERRIS, C. J. NUSBAUM, W. E. GRIFFIN, R. H. SMALL, and C. A. STONE. 1976. Two semi-automatic elutriators for extracting nematodes and certain fungi from soil. Journal of Nematology 8:206-212.

CAMPOS, V. P., P. SIVAPALAN, and N. C. GNANAPRAGASAM. 1990. Nematode Parasites of Coffee, Cocoa and Tea. Pp. 387-429 *in* M. Luc, R. A. Sikora, and J. Bridge, eds. Plant Parasitic Nematodes in Subtropical and Tropical Agriculture. CAB International. Wallingford, U.K.

CARNEIRO, R., 1995. Reaction of 'Icatu' coffee progenies to *Meloidogyne incognita* race 2 under field conditions. Nematologia Brasileira 19:53-59.

CHITWOOD, B. E., and C. A. Berger. 1960. Preliminary report on nemic parasites of coffee in Guatemala with suggested and interim control measures. Plant Disease Reporter 44:841-847.

COUCH, H. B., and J. R. BLOOM. 1960. Influence of soil moisture stresses on the development of the root-knot nematode. Phytopathology 50:319-321.

COOPER, A. F., S. D. VAN GUNDY, and L. H. STOLTZY. 1970. Nematode reproduction in environments of fluctuating aeration. Journal of Nematology 2:182-188.

CRAMER, P. J. 1934. Early experiments on grafting coffee in Java. Empire Journal of Experimental Agriculture 2:200-204.

CURI, S. M., A. CARVALHO, F. P. DE MORAES, L. C. MONACO, and H. V. de ARRUDA. 1970. Novas fontes de resistencia genetica de *Coffea* no controle do nematoide do cafeeiro, *Meloidogyne exigua*. O Biologico 36:293-295.

DAYKIN, M. E., and R. S. HUSSEY. 1985. Staining and histopathological techniques in nematology. Pp. 39-48 *in* K. R. Barker, C. C. Carter, and J. N. Sasser, eds. An Advanced Treatise on *Meloidogyne*. Vol. II: Methodology. North Carolina State University Graphics, Raleigh, NC. U.S.A.

EISENBACK, J. D., E. C. BERNARD, and D. P. SCHMITT. 1994. Description of the Kona root-knot nematode, *Meloidogyne konaensis* n. sp. Journal of Nematology 26:363-374.

FAZUOLI, L. C., and R. R. A. LORDELLO. 1976. Resistencia de *Coffea liberica* e *C. dewevrei* a *Meloidogyne exigua*. Pp. 197-199 *in* Trabahlhos Apresentados a Reuniao de Nematologia, 2. 14-16 Setembro. Piracicaba, Brasil.

FLOR, H. H. 1946. Genetics and pathogenicity in *Melampsora lini*. Journal of Agricultural Research, Washington D.C. 73:335-357.

GÖLDI, E. A. 1892. Relatorio sobre a molestias do caffeiro na Provincia do Rio Janeiro. Archivo do Museu Nacional Rio de Janeiro 8: 7-123.

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.

IKAWA, H., H. H SATO, A. K. S. CHANG, S. NAKAMURA, E. ROBELLO, and S. P. PERIASWAMY. 1985. Soils of the Hawaii Agricultural Experiment Stations, University of Hawaii: Soil survey, laboratory data, and soil descriptions. HITAR Research Station Series 022. College of Tropical Agriculture. University of Hawaii. Honolulu, HI, U.S.A.

JAEHN, A., and E. K. REBEL. 1984. Sobrevivencia do nematoides de galhas *Meloidogyne incognita* em substrato infestado, para producao de mudas de caffeiros sadios. Nematologia Brasileira 8:319-324.

JENKINS, W. R. 1964. A rapid centrifugal-flotation technique for separating nematodes from soil. Plant Disease Reporter 48:692.

JOHNSON, A. B., H. D SCOT, and R. D. RIGGS. 1994. Response of soybean in cyst nematodes-infested soils at three soil water regimes. Journal of Nematology 26:329-335.

KUMAR, A. C., and S. D. SAMUEL. 1990. Nematodes attacking coffee and their management—A review. Journal of Coffee Research 20:1-27.

LOPEZ, R., and L. SALAZAR. 1989. *Meloidogyne arabicida* sp. n. (Nemata: Heteroderidae) native of Costa Rica: a new and severe pathogen of coffee. Turrialba 39:313-323.

MAZZAFERA, P., W. GONCALVES, J. A. R. FERNANDES. 1990. Phenols, peroxidase and polyphenoloxidase in the resistance of coffee to *Meloidogyne incognita*. Bragantia 48:131-42.

NORTON, D. C. 1978. Ecology of Plant Parasitic Nematodes. John Wiley & Sons Inc., New York, NY, U.S.A.

NORTON, D. C. 1979. Relationship of physical and chemical factors to populations of plant-parasitic nematodes. Annual Review of Phytopathology 17:279-299.

NUÑES, M. A. 1976. Water relations of coffee. Significance of plant water deficits to growth and yield: a review. Journal of Coffee Research 6:4-21.

POWERS, H. A., J. C RIPPERTON, and Y. B. GOTO. 1932. Survey of the physical features that affect the agriculture of the Kona district of Hawaii. Hawaii Agriculture Experiment Station Bulletin 66. Honolulu, HI, U.S.A.

REYNA, E. H. 1966. La tecnica del injerto hipocotiledonar del cafeto para el control de nematodos. Café 7:5-11.

SAS INSTITUTE, INC. 1999. The SAS system for Windows, Version 7. Cary, NC.

SASSER, J. N. 1954. Identification and host-parasite relationships of certain root-knot nematodes (*Meloidogyne* spp). University of Maryland Agriculture Experiment Station Bulletin A-77, 30.

SCHIEBER, E. 1974. El problema de nematodos en el cafeto. Hacienda 69:18-21. 1974.

SCHIEBER, E. 1968. Nematode problems of coffee. Pp. 81-92 *in* Smart, G. Tropical Nematology. Gainesville, University of Florida, 1968.

SEINHORST, J.W. 1956. The quantitative extraction of nematodes from soil. Nematologica 1:249-267.

SERRACIN, M., D. P. SCHMITT, and S. NELSON. 1999. Coffee Decline caused by Kona Coffee Root-knot nematode. Plant Disease PD-16. Cooperative Extension Service. College of Tropical Agriculture. University of Hawaii. Honolulu, HI, U.S.A.

SIMONS, W. R. 1973. Nematode survival in relation to soil moisture. Department of Nematology, Agriculture University, Wageningen, The Netherlands.

VANDERPLANK, J. E. 1963. Plant Diseases: Epidemics and Control. Academic Press, New York. 349 pp.

VRAIN, T. C. 1986. Role of soil water in population dynamics of nematodes. *In*: Plant Disease Epidemiology and Management. Vol 1. Chapter 5. 121-129. Leonard and Fry, eds. New York: Macmillan Pub. Co; London.

WALLACE, H. R. 1973. Nematode Ecology and Plant Disease. Edward Arnold, London, U.K.

WALLACE, H. R. 1989. Environment and plant health: a nematological perception. Annual Review of Phytopathology 27:59-75.

WHITEHEAD, A. G. 1969. The distribution of root-knot nematodes (*Meloidogyne* spp.) in Tropical Africa. Nematologica 15: 315-333.

WRIGLEY, G. 1988. Coffee. Longman Scientific, England.

ZHANG, F. R., and D. P. SCHMITT. 1995a. Relationship of *Meloidogyne konaensis* population densities to coffee growth. Plant Disease 79:446-449.

ZHANG F. R., and D. P. SCHMITT. 1995b. Spatial-temporal patterns of *Meloidogyne konaensis* on coffee in Hawaii. Journal of Nematology 27:109-113.

Received: *27.XII.2000*

Recibido:

Accepted for publication: *5.VII.2001*

Aceptado para publicacion: