The effect of soil moisture and soil particle size on the survival and population increase of *Xiphinema index*

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SUMMARY

dardize plant screening techniques for resistance to *X. index* and to fanleaf virus.

Materials and methods

Effect of soil moisture on survival

X. index was extracted by wet-screening soil from the root zone of a healthy fig (*Ficus carica* L.) grown in a greenhouse. One hundred g (62.5 cm^3) of washed, oven-dried, sandy loam were placed in each of 210 styrofoam cups (150 cm^3 capacity). Two hundred and fifty *X. index* in 3 ml water were added to the soil in each cup. The cups were divided into six groups. The six groups were adjusted to nominal 0, 5, 10, 15, 20 and 25 % soil moisture on a gravimetric basis; however, the nominal 0 % moisture level was initially 3 % due to the water added with the nematodes. The soil was fully saturated at 25 % moisture.

The styrofoam cups were covered with plastic Petri dishes to reduce water evaporation and were placed on a greenhouse bench maintained at 23 ± 3 °C. At 3-day intervals, each cup was weighed and water added as necessary to maintain the required soil moisture level; a constraint of this method is that a moisture gradient may have developed at moisture levels drier than field capacity. At intervals of 10 days for 60 days, nematodes were extracted and counted by wet-screening the soil from five replicates in each group. The dry series (*ca* 0 % moisture) was discontinued after 40 days as few nematodes were recovered in that treatment beyond 20 days. The surviving nematodes at each incubation interval, where sufficient in number, were used as the test population in the subsequent experiment.

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each time interval and moisture level, 100 *X. index* were divided into groups of 20 to create five replicates. Nematodes were inoculated around the root zone of a single-bud rooting of *Vitis vinifera* L. cv. St. George in sandy loam in a 150 cm^3 styrofoam cup. Control plants were also established. All plants were maintained in a greenhouse at 23 ± 3 °C, watered daily, and supplied with nutrient solution at 2-week intervals. After 5 months, nematodes were wet-screened from the soil in each cup and counted. Root weights were determined for plants inoculated with nematodes and for non-inoculated control plants.

The direct effects and interactions of soil moisture level and incubation time on nematode population increase were determined by analysis of variance as a factorial experiment. Since only two incubation periods were represented at *ca* 0 % moisture (10 and 20 days) and four at all other moisture levels (10, 20, 30 and 40 days), the experiment was not balanced. Consequently, the factorial comparisons were conducted in two sets so that main effect means of one factor would span all levels of the other factor in each set and so be unbiased. The data for all soil moisture levels at 10 and 20 days were analyzed as one set, and those for moisture levels 5, 10, 15, 20 and 25 % for incubation periods 10 through 40 days as the other set.

Effect of soil particle size on *X. index* population increase

Sands of particle size 2360, 850, 534, 373 and 250 µm were washed and steam sterilized. Two kg of sand of each particle size and 2 kg of steam-sterilized sandy loam containing 85 % sand, 13 % silt, and 2 % organic matter were placed in 15-cm diameter clay pots. Single-

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particle size and the sandy loam were developed with tension funnels (Kulte, 1986; Vrain, 1986). Soil water content is related to suction by $\theta_e = (\theta - \theta_r)/(\theta_m - \theta_r) = (h_d - h_c)^a$ where θ is the volumetric water content of the soil (cm^3/cm^3), θ_e is the effective water content, θ_m the maximum water content, θ_r the residual water content, h_d the displacement pressure head (cm), h_c the capillary pressure head (cm) and a the pore size distribution index (from 1 to 5) (Corey, 1977). Linear regression was used to obtain parameter values for the equation (Corey, 1977; Kulte, 1986).

Results

EFFECT OF SOIL MOISTURE ON *X. INDEX* SURVIVAL

Factorial analysis of variance, where the independent variables were treated as classes, indicated highly significant ($P < 0.01$) direct effects and interaction of soil moisture and time of incubation on nematode survival. Greatest survival across all time intervals occurred at 10 and 15 % soil moisture; survival was intermediate at 5 and 20 % moisture, less at 25 and least at 0 % soil moisture, indicating an optimum survival zone in the 10 to 15 % moisture range (Table 1). Nematode survival

Table 1

Main effects of soil moisture level and time of incubation on survival of *X. index.*

Soil Moisture (%)	Survival (%)	Time (Days)	Survival (%)
0	18.4 *d*	0	100.0 *a*
5	24.8 *b*	10	40.2 *b*
10	28.0 *a*	20	17.0 *c*
15	27.3 *a*	30	0.07 *d*
20	24.0 *b*	40	0.03 *e*
25	21.1 *c*	50	0.003 *f*
		60	0.0008 *f*

Data are means of five replications. In each column, means followed by the same letter do not differ significantly from each other at the 5 % level according to a Student-Newman-Keuls test.

EFFECT OF INCUBATION TIME AND SOIL MOISTURE LEVEL ON POPULATION INCREASE OF *X. INDEX*

For the population data obtained at 10 and 20 days, across all moisture levels, the main effects of soil moisture and incubation time were highly significant ($P < 0.01$)

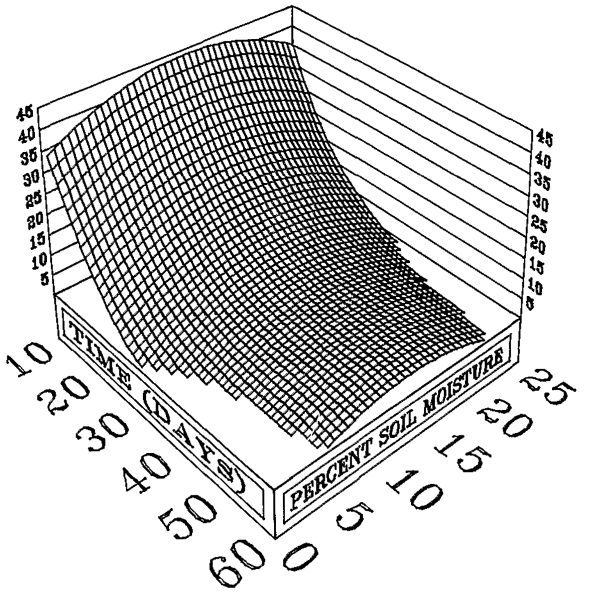

Fig. 1. The relationship between percent survival *(y)* of *Xiphinema index* and soil moisture *(m)* for incubation periods *(t)* of 10 to 60 days, $y = 70.25 + 1.59\ m - 0.06\ m^2 - 4.48\ t + 0.09\ t^2 - 0.0006\ t^3$ (r^2 = 0.89).

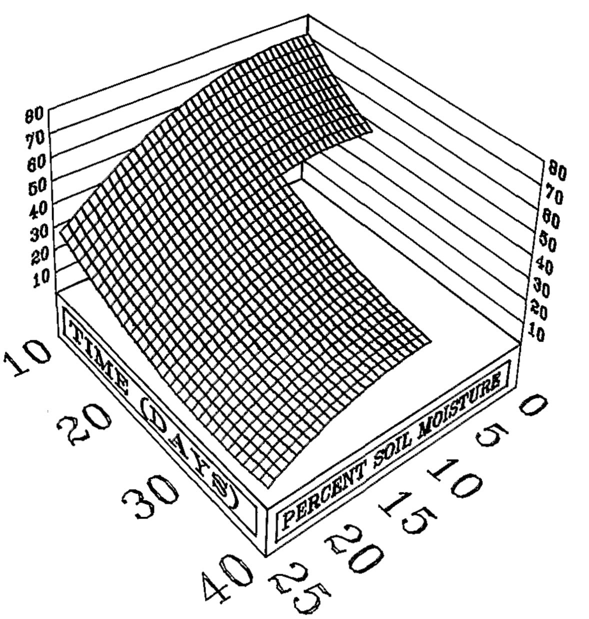

Fig. 2. The effect of period of incubation *(t)* at various soil moisture levels *(m)* on population increase of *Xiphinema index* as a percentage of the population increase of non-incubated nematodes *(y)*. The relationship is described by $y = 104.3 - 0.06\ m - 0.09\ m^2 - 3.54\ t + 0.034\ t^2 + 0.044\ mt$ (r^2 = 0.78).

For the data obtained at soil moisture levels 5 through 25 %, across all time intervals, both the main effects and interactions of soil moisture and incubation time were highly significant ($P < 0.01$) (Table 2). Population increase was again greatest after incubation at 5 and 10 % soil moisture, less at 15 % and least at 20 and 25 % soil moisture. A significant decline in population increase occurred over time; the lowest population increases were observed on days 30 and 40 (Table 2).

The interaction of incubation time and soil moisture on the population increase of *X. index*, expressed as a percentage of the population increase of non-incubated nematodes, was well described by the equation $y = 104.3 - 0.06\ m - 0.09\ m^2 - 3.54\ t + 0.034\ t^2 + 0.044\ mt$ for $t \geq 10$ ($r^2 = 0.78$, $n = 110$) (Fig. 2), where *y* is the final nematode population as an indicator of population increase, *m* is the percent soil moisture and *t* is time in days. At all time intervals, population increase was lower for the surviving nematodes incubated at higher moisture levels.

There was a linear relationship between root weight of *X. index* host plants and the final nematode population (Fig. 3). The relationship was described by the equation $y = 15.91 - 0.0215\ x$ ($r^2 = 0.77$, $n = 110$), where *y* is root weight and *x* is the final population level of *X. index*.

Effect of sand particle size on population increase of *X. index*

Differences in population increase of *X. index* in sands of different particle size were highly significant ($P < 0.01$). Highest levels of *X. index* population increase were observed in the sandy loam control; however, the population increase in sand of 250 µm particle size was not significantly lower than the control (Table 3).

Table 3

Effect of sand particle size on population increase of 100 *X. index* and on root weight of host plants and root weight of nematode-inoculated plants relative to non-inoculated plants after 5 months.

Particle Size (µm)	Final Population	Root Weight (g)	Relative Root Weight
2 360	139 *c*	19.5 *a*	1.08 *a*
850	179 *c*	16.2 *b*	0.92 *ab*
534	291 *c*	15.7 *b*	0.91 *ab*
373	1 020 *b*	11.9 *c*	0.76 *b*
250	1 174 *ab*	11.7 *c*	0.72 *b*
Sandy loam	1 590 *a*	11.1 *c*	0.72 *b*

Data are means of five replications of one factor averaged over all levels of the other factor. In each column, means followed by the same letter do not differ significantly from each other at the 5 % level according to a Student-Newman-Keuls test.

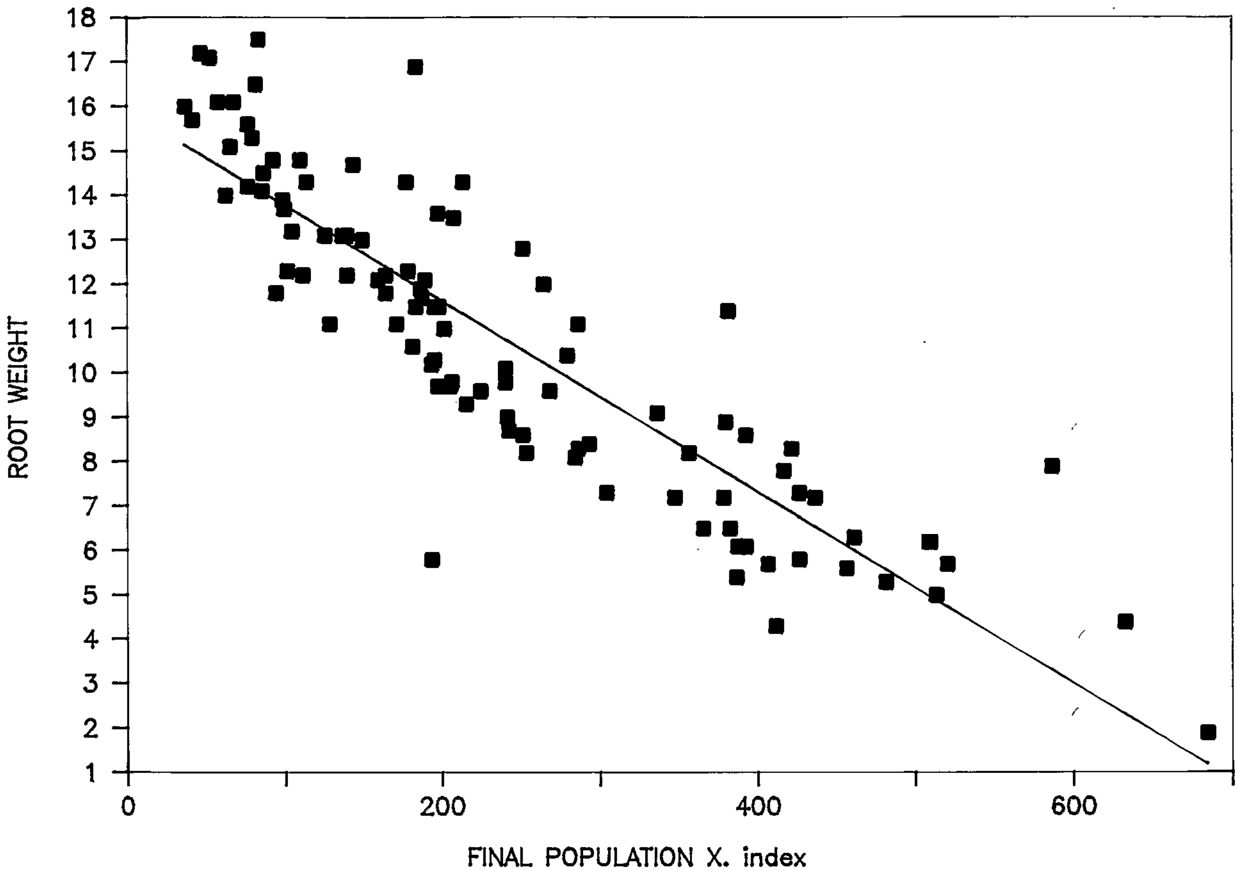

Fig. 3. The relationship between grape root weight (grams, *y*) and final population density *(x)* of *Xiphinema index*, $y = 15.91 - 0.0215\,x$ ($r^2 = 0.77$), after 5 months of exposure.

Population increase in 373 µm sand was not significantly lower than in 250 µm sand, while population increase in coarser sands of particle size 2 360, 850 and 534 µm was significantly lower than in sands of finer particle size (Table 3). Relative plant root weight (inoculated/control, for each particle size) was greatest in 2 360 µm sand, less in sands of 850 and 534 µm, and least in sands of 373 and 250 µm particle size and in sandy loam. As root weight decreased, nematode reproduction increased in sand of all particle sizes and in sandy loam (Table 3). The interaction between nematode population and particle size on root weight was significant ($P < 0.05$) and was related to reduced root growth in sands of finer particle size when nematodes were present.

MOISTURE RELEASE CURVES

Moisture release curves for coarse-textured sands of 2360 and 850 µm were virtually identical to each other

almost identical, but differed substantially from the curves for coarse-textured sand. The greatest water retention occurred in sandy loam (Fig. 4).

Discussion

In the absence of a host for 60 days, the low survival of *X. index* at intermediate soil moisture levels (10 and 15 %) and very low survival in dry and saturated soils (Fig. 1) are qualitatively similar to previous studies. Harris (1979) observed survival of less than 50 % over 69 days under favorable soil moisture conditions and low survival in both dry and saturated soil. Low survival in dry soil may reflect an inability of *X. index* to withstand desiccation (Harris, 1979), while low survival in wet soil may result from oxygen deprivation (Van Gundy *et al.*, 1962).

Temperatures maintained in these studies were fav-

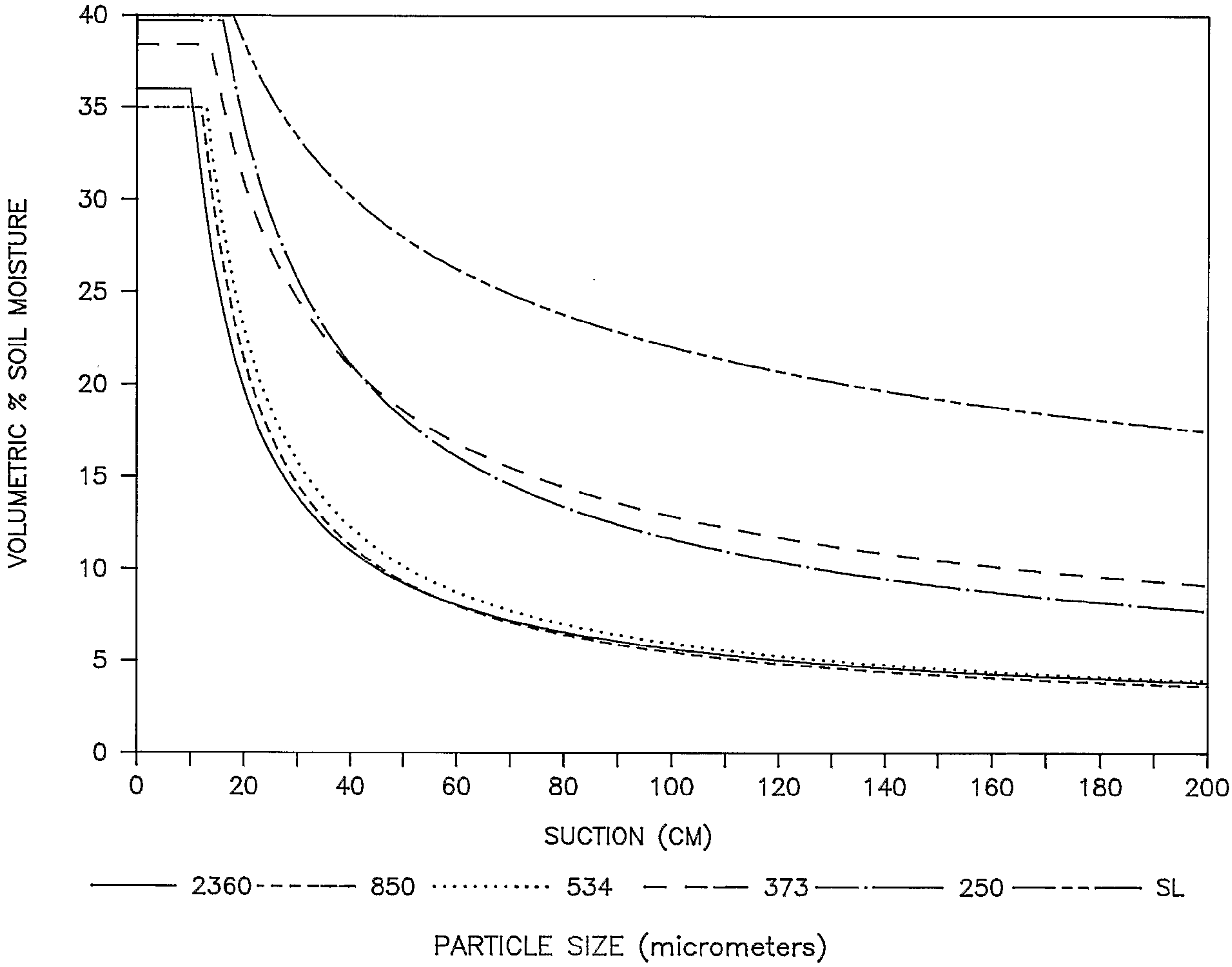

Fig. 4. Moisture release curves for sands of different particle size and sandy loam used in these experiments.

because internal food reserves were depleted and nematodes aged. Population increase of *X. index* observed in this study was greatest following incubation in intermediate to dry soil (Fig. 2). The reproductive potential was lower after incubation in moist soil, possibly reflecting increased utilization of food reserves associated with [redacted]

may not be effective (Meagher *et al.*, 1976); maintaining field soil in a dry state t› a substantial depth is difficult to achieve and is affect :d by climate.

Nematode population increase was greatest in both sandy loam and fine-textured sand. Population increase in coarse-textured sand of particle sizes ≥ 534 μm was [redacted]

850 and 534 μm particle size had similar, low water retention capacities; *X. index* population increase was uniformly low in these sands. Sands of particle size 373 and 250 μm had higher, similar moisture holding capacities and supported greater, uniform levels of population increase and resultant damage to host plant roots. Sandy loam exhibited the highest moisture retention and supported the greatest nematode population increase; however, root damage in sandy loam and in fine-textured sands did not differ substantially. Similar results have been observed for reproduction of *Belonolaimus longicaudatus* (Rau) in sands of comparable particle size

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