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A Survey of Nematode Distribution in California Vineyard Soils[1]

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Abstract. **The spatial distribution of nematodes in the soil of nine California vineyards was surveyed in summer and winter months. Soil samples were taken in the vine row and between rows at 15 cm depth intervals. There were no measurable seasonal changes in nematode distribution. Variation in the distribution of genera amongst vineyards was related to soil physical conditions and vineyard cultural practices. In general, highest concentrations of *Meloidogyne* spp. and *Xiphinema* spp. were in the upper 60 cm of soil in the vine row, whereas *Tylenchulus semipenetrans* was more deeply and uniformly distributed throughout the root zone.**

An investigation of nematode distribution in the root zone of grapevines in a California vineyard (7, 8) raised the question of the applicability of the observations to other vine-growing areas in the state. Such information is a necessary addition to monitoring studies of pre- and postplant nematicide treatments (1, 11, 14, 20). Attempts to integrate pesticide dispersal with target organism location are compatible with basic pest management principles.

California can be divided into 5 climatic regions for grapevine production, based on heat summation above 10°C (21). In selecting sites for a survey of nematode spatial distribution, we attempted to include a range of climatic regions, soil types and texture, vine varieties, and irrigation and cultural practices. The objective of this survey was to determine any basic patterns of nematode distribution, and variations from our initial observations on a Hanford sandy loam soil near Fresno, California (Region V) (7, 8).

Materials and Methods

Nine vineyards were selected throughout California (Table 1). Soil samples were removed from each vineyard in August and Feb. to determine any seasonal differences in nematode distribution. At each location, on each sampling date, 6 vines were selected at random in an area of uniform growth in the vineyard. Samples were taken at two positions relative to the trunk of each vine: in the row, 30 cm from the vine; and between rows; 90 cm from the vine. At each position, soil samples were taken at 15-cm depth intervals with a 7.5-cm diam auger to a depth of 120 cm, unless limited by an impenetrable soil layer.

Nematodes were extracted from the soil samples by an elutriation technique combined with sugar-flotation sieving (4, 6) and *Meloidogyne* egg extraction (5). Plant parasitic nematodes were identified to species. Species of the genus *Meloidogyne* were determined from perineal patterns.

Data were subjected to the spatial distribution analysis techniques of Iwao and Kuno (12) and Lloyd (13). The series of samples from the root zone of each vine was considered as a vertical quadrat, and each sample was a separate component of a vertical grid, 2 samples wide and up to 8 samples deep. The linear relationship of the values for mean crowding (13) and mean density were determined for each vineyard. The Y-axis intercept (a) and the slope (b) are indicative of the distribution pattern (12).

To further analyze and compare the data for each vineyard, percentage distributions in various regions of the soil profile were calculated for each plant-parasitic species. The 2 cores of samples from each vine were divided into 4 quadrants. Samples taken from the upper half of the core in the row (quadrant 1); samples taken from the lower half of this core (quadrant 2); and two similar subdivisions of the core taken between vine rows (quadrants 3 and 4). Percentage distribution in the 4 quadrants for each vine was determined for the plant-parasitic species. Statistical comparisons were made of percentage distribution (a) at different sampling dates, (b) of the nematode species in each quadrant, (c) for a particular nematode species in the same quadrant of each vineyard, and (d) between quadrants for a particular nematode species. Similar comparisons were made of the percentage distribution of nematodes in the upper 30 cm of the vine row. A nematode population was considered for these comparisons only if some individuals of that population were detected around each of the 6 vines sampled in a particular vineyard. Arcsin transformations of the percentage distribution data were made for statistical analysis (19).

Results

The distribution of plant-parasitic nematode species among the vineyards (Table 1) is compatible with the known distribution of nematode species in California (18). Observation of at least 10 perineal patterns of Meloidogyne females from each vineyard revealed the presence of only one species in each case. It is possible that a more detailed survey within each field would have uncovered more than one species (10).

The distribution analysis using the relationship of mean crowding and mean density (12) (Table 2) did not produce values which appeared useful in detecting differences between populations or locations. In the regression between these values, the Y-axis intercept (a) is the "index of basic contagion," and a positive value indicates a tendency for attraction or clumping between individuals. Such a tendency is expected when a species produces egg masses, does not move rapidly, or has a locally isolated food source. The slope of the regression line (b) is the "density-contagiousness coefficient;" a value less than, equal to, or greater than 1 indicates a uniform, random or aggregative distribution pattern, respectively. In most cases (Table 2) the parasitic nematode populations indicated tendencies for clumping and aggregative distribution as would be expected, with some apparent variation in the data from vineyard 6.

In the analysis of nematode distribution in the 4 quadrants of the vine root zone, there was no difference in percent distribution of any nematode population in any vineyard between the 2 sampling dates. Apparently there were no seasonal shifts in percent distribution even though there were numerical

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Table 1. Location, soil type, varieties, and nematode populations in 9 California vineyards.

Vineyard	Region	Location (County)	Soil type	Cultivar	Rootstock	Age (years)	Major plant-parasitic nematode species present				
							Meloidogyne	*Xiphinema*	*Tylenchulus*	*Pratylenchus*	*Trichodoru*
1	V	Fresno	Hanford fine sandy loam	Royalty	own	14	*incognita*	*americanum*	*semipenetrans*		
2	V	Fresno	Exeter sandy loam	Thompson seedless	own	40	*javanica*	*americanum*			
3	V	Fresno	Hanford coarse sandy loam	Thompson seedless	own	53	*incognita*	*americanum* and *index*	*semipenetrans*		*christiei*
4	V	Tulare	San Joaquim loam	Emperor	own	15	*javanica*		*semipenetrans*	*vulnus*	
5	V	Kern	Hesperia loam	Emperor	own	38	*incognita*		*semipenetrans*	*vulnus*	
6	III	San Joaquin	Hanford loamy sand	Tokay	own	45	*hapla*	*americanum*		*vulnus*	*christiei*
7	I	Napa	Boyle gravelly loam	Chardonnay	St. George	17		*index*			
8	I	Monterey	Chualar coarse sandy loam	Cabernet sauvignon	own	9		*americanum*		*vulnus*	
9	V	Riverside	Coachella find sand	Thompson seedless	own	15	*javanica*				

differences in the populations. Differences in distribution among quadrants across all vineyards of the various populations were apparent (Fig. 1). *Meloidogyne* eggs were concentrated 75% in quadrant 1, the upper quadrant in the vine row, and very small numbers in the other quadrants, *Meloidogyne* larvae were 60% in quadrant 1, but had greater depth distribution – 26% in quadrant 2, the lower quadrant in the vine row. *Tylenchulus semipenetrans* was uniformly distributed among the four quadrants, while *Xiphinema* spp. were 75% in quadrant 1 and were fewest in quadrant 4, the lower quadrant between rows. *Pratylenchus vulnus* had the highest concentrations in the upper quadrant between rows, quadrant 3, with lowest percentages in the lower quadrants. *Trichodorus christiei* were concentrated in the upper quadrants, but were at greater concentrations in quadrant 2 than in quadrant 4.

The distribution of populations in the individual vineyards (Fig. 2) followed the overall pattern in most cases, with some local variation.

1) *Meloidogyne* larvae: the only major variation was in vineyard 9 in the Coachella Valley of Riverside County with sandy soil (Table 1) and highest soil temperatures. The population was at greater densities in the lower quadrants at this location (Fig. 2).
2) *Meloidogyne* eggs: the distribution was concentrated in quadrant 1 (Fig. 2); lowest concentrations in this quadrant were again in vineyard 9 where they were more uniformly distributed among quadrants.
3) *Tylenchulus semipenetrans:* in most cases this nematode had the lowest percent distribution in quadrant 1 of all genera present (Fig. 2) and was usually among the highest in quadrants 2, 3, and 4, indicating either a tolerance or an affinity for deeper soil conditions. In a related study we sampled from a vineyard with populations of *Meloidogyne incognita* and *Tylenchulus semipenetrans* at Kearney Horticultural Research Station. The soil was a Hanford sandy loam with rather poor drainage. There was an apparent preference of the *Tylenchulus* for the more moist, deep soil (Table 3). This could be interpreted as a differential survival, or as a measure of relative competitive ability between the nematode species at the various depths.
4) *Xiphinema:* the distribution in most vineyards fitted previously reported patterns for *X. americanum* (7, 8): the nematodes were concentrated in the upper region of soil in the vine row (Fig. 2). Vineyards 6 and 7 were exceptions to this pattern, with a high percentage in quadrant 3. In vineyard 7 the rows are French plowed each year (Table 4), possibly resulting in a relatively lower percentage of the populations in quadrant 1. One of the

Table 2. Values for the Y-intercept and slope of regressions of the relationship between mean crowding and mean density for 3 genera of plant-parasitic nematodes.

Vineyard	*Meloidogyne* sp.		*Xiphinema*		*Tylenchulus*	
	y intercept	slope (b)	y intercept	slope (b)	y intercept	slope (b)
1	1076.7	2.6	18.4	4.4	–4.3	4.1
2	111.3	4.7	31.2	5.1		
3	385.1	2.7	112.9	4.2	44.9	2.3
4	85.3	2.4			148.5	1.8
5	370.0	1.9	5.4	7.9	2099.3	0.8
6	–678.3	5.8	–114.2	9.6		
7			7.7	3.8		
8			41.9	2.3		
9	577.7	2.1				

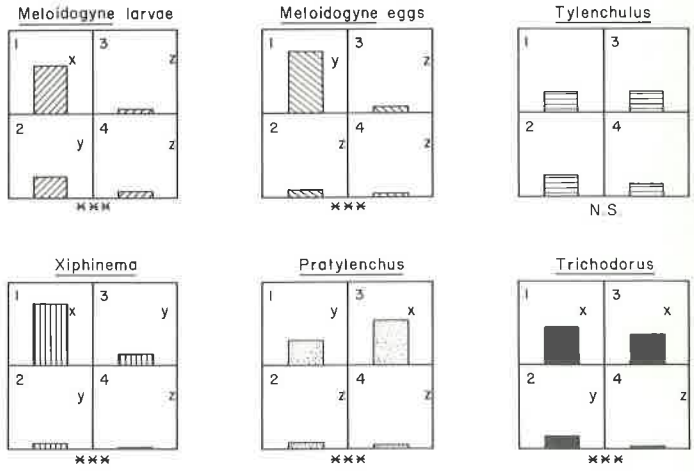

Fig. 1. Percent distribution of plant-parasitic nematode populations in 4 quadrants of the root-zone of grapevines. Data averaged across the number of vineyards in which substantial numbers of each population occurred. Quadrants which have the same letter are not significantly different.

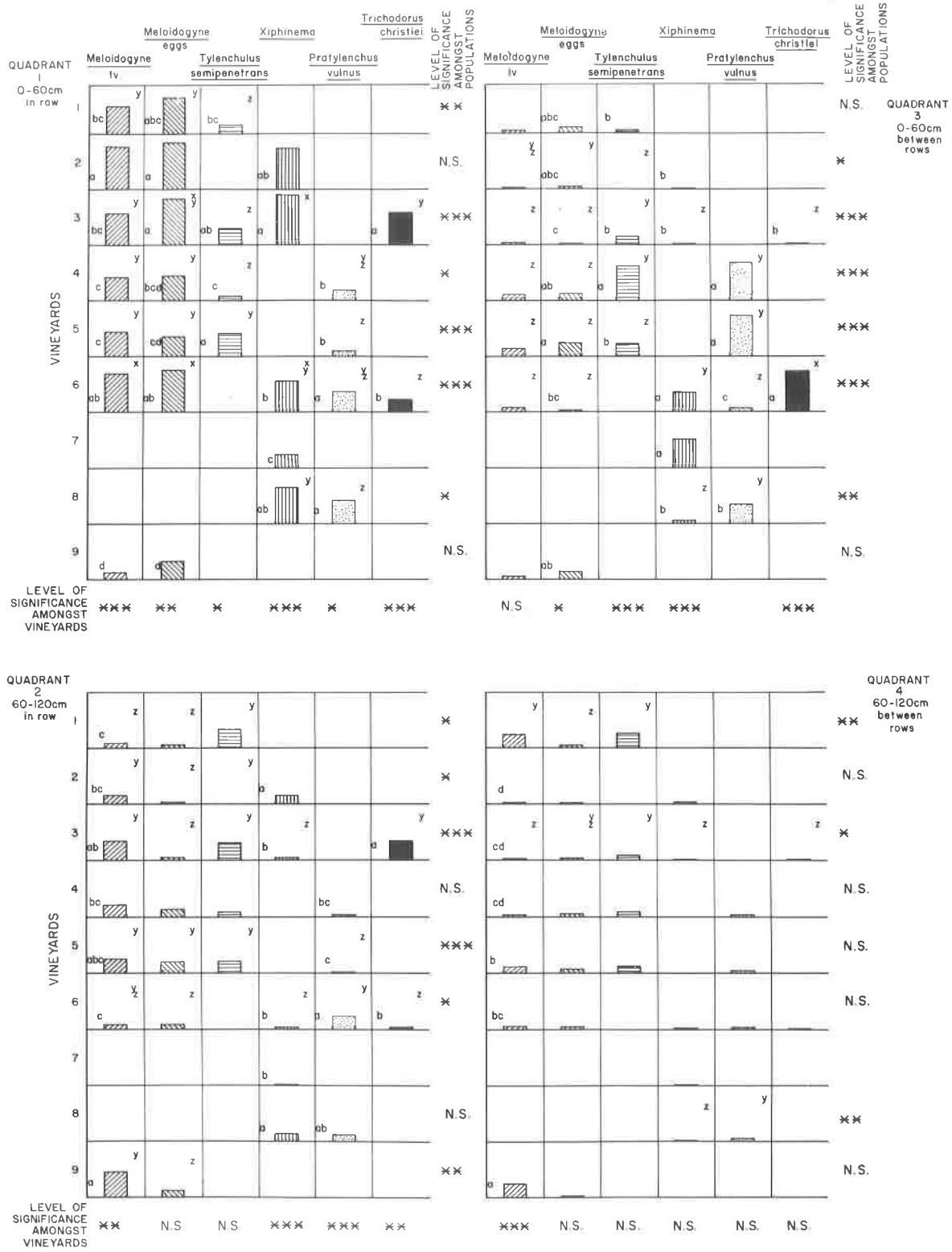

Fig. 2. Percent distribution of plant-parasitic nematode populations in 4 quadrants of the root zone of grapevines in nine California vineyards. Within each quadrant, letters from the beginning of the alphabet signify comparisons of a population among vineyards and letters from the end of the alphabet signify comparisons among populations within a vineyard. Populations with the same letters are not significantly different.

species in vineyard 7 was *X. index,* which may be more tolerant of a range of soil conditions, being readily cultured under greenhouse conditions (17). Vineyard 6 is maintained with a sod cover and there is no soil disturbance between rows; also, this vineyard is sprinkler irrigated (Table 4).

5) *Pratylenchus: P. vulnus* was distributed primarily in the two upper quadrants, except in vineyard 6 where there was a substantial percentage in the lower quadrant in the vine row (Fig. 2). In vineyards 4 and 5 the greatest per-

Table 3. Distribution of *Meloidogyne incognita* and *Tylenchulus semipenetrans* in a vineyard at Kearney Horticultural Research Station.

Depth (cm)	Distribution (%)			
	In row		Between rows	
	M. incognita	*T. semipenetrans*	*M. incognita*	*T. semipenetrans*
15	5.8	0.0	6.7	5.6
30	19.2	5.6	16.1	5.8
45	7.1	5.8	5.7	3.3
60	5.7	6.1	5.7	5.8
75	4.4	18.2	5.3	21.9
90	8.8	13.6	9.5	8.6

cemtage of the population was in the upper quadrant between rows. Vineyard 4 had a rather shallow (30–90 cm) red hardpan soil which may have accounted for a more horizontal root dispersal. The sod centers may have been an additional food source for nematodes and the nontillage resulted in no pruning of vine roots. Vineyard 5 also had undisturbed sod centers, allowing a shallower root system (Table 4). Unfortunately, *X. americanum* was not detected in vineyard 4 and determination of the effect of an undisturbed system on its distribution was not possible. The few *X. americanum* which occurred on some vines in vineyard 5 were still restricted to the upper soil in the vine row.

6) *Trichodorus: T. christiei* occurred in substantial populations in two vineyards. The population was distributed mainly in the vine row in vineyard 3 (Fig. 2) where weeds were controlled between rows by repeated disking and consequent root pruning (Table 4). Weed control in the row was poor. In vineyard 6, a large percentage of the population was in the upper 60 cm between rows. This vineyard has a sod cover, is noncultivated and sprinkler irrigated.

Examination of the percentage distribution of plant-parasitic nematodes in the upper 30 cm of soil in the vine row (Fig. 3) revealed that nearly 50% of the *Xiphinema* population was in this region in most vineyards. In several cases high percentages of the *Meloidogyne* population were in the upper 30 cm region, but *Tylenchulus, Pratylenchus,* and *Trichodorus* populations were lower than the other genera. This upper 30 cm of soil constitutes the ridge or berm along the vine row in most vineyards. Although percentage distribution of the *Xiphinema* population in the upper 30 cm did not differ significantly between vineyards, the lowest percentages were in the sprinkler irrigated vineyard 6 and in the rainfall dependent vineyard 7, neither of which had a real berm. In a related study we followed

Table 4. Cultural, irrigation and soil profile characteristics of the surveyed vineyards.

Vineyard	Irrigation	Tillage	Soil profile
1	Furrow	Centers disked high berm	Compaction in centers
2	Furrow	Centers disked	Hardpan at 100 cm depth
3	Furrow	Centers disked	Uniform
4	Furrow	Grass sod centers	Impermeable hardpan at 90 cm depth
5	Furrow	Grass sod centers	Uniform
6	Sprinkler	Sod cover, no tillage, no berm	Uniform
7	None	Surface rototilled	Hard gravel at 100 cm depth
8	Sprinkler	Rototilled and disked	Compact and pulverized granite at 80 cm depth
9	Furrow	Centers disked	Uniform

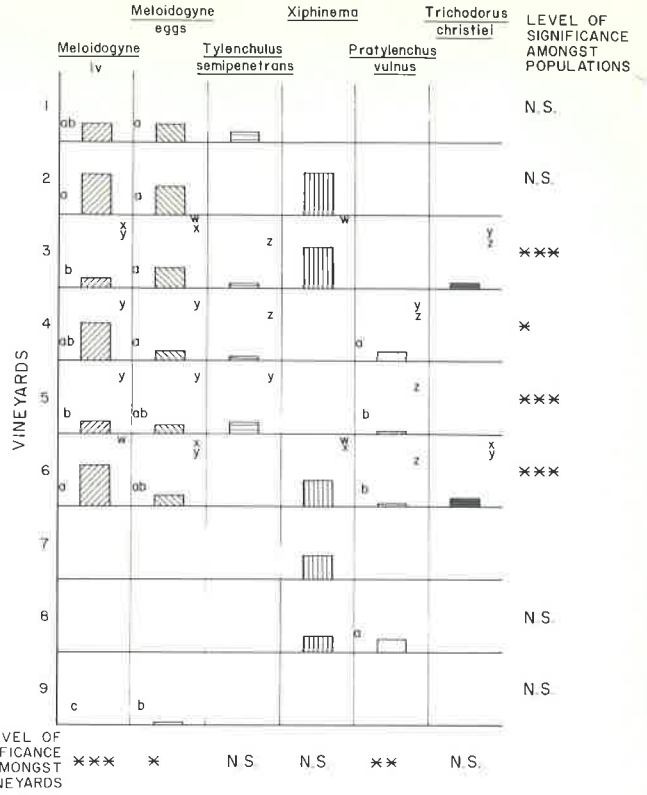

Fig. 3. Percent distribution of plant-parasitic nematode populations in the upper 30 cm of the vine row in 9 California vineyards. Letters from the beginning of the alphabet signify comparisons of a population among vineyards and letters from the end of the alphabet signify comparisons among populations within a vineyard. Populations with the same letter are not significantly different.

the effect of French plowing on the number of *X. americanum* in a berm before and after the treatment. Four 100 g samples taken from the upper 30 cm in the vine row in January 1973 contained 4648 *X. americanum.* The vineyard was French plowed in January 1974. In January 1975 a similar sample set had 3356 *X. americanum,* a significant reduction. The soil samples were taken from the same 6 vines on each date.

Discussion

The distribution of plant-parasitic nematodes in soil can logically be expected to be determined by the availability of their food (i.e. root abundance and distribution), by soil physical factors, and by tillage practices. These determining factors are interrelated. After examining some 6000 soil, root and nematode samples from throughout grapevine root systems (7, 8, 9, and present study) we have developed a perceptual image of the vine root system, its morphology, and the relationship of nematode distribution to the root and to soil conditions.

Under standard cultural and irrigation practices we detect high densities of fine feeder roots in the upper soil in the vine row, characteristically in the berm. In the upper soil regions between rows we find few vine roots, presumably due to the pruning effect of tillage operations and to soil compaction from movement of equipment. At greater depths the roots are thicker, more sparsely distributed, and probably serve a storage and supportive function, except in times of moisture stress. Soil physical problems, such as hardpans or compaction, may restrict root development. The resulting lessening in root surface area may not be noticed except in periods of moisture and nutritional stress. Baker and Cook (3) generalized that plants produce 50% more roots than are necessary for survival and can

therefore withstand considerable root injury without yield reduction. The presence of a parasite in a physically restricted root system would decrease the ability of a vine to tolerate stress. Loss of root surface area, or physiological disruption of roots, would result in decreased plant vigor even during periods of little stress. Nematodes are expected to be of greater significance in vineyards under moisture and nutritional stress, or where root development is restricted.

We hypothesize that the nematodes feeding on the thicker supportive roots are probably of less consequence to the plant than those on the feeder roots, again except in times of moisture stress and when populations become so high as to disrupt the physiological functioning of these roots. Since conditions of soil moisture and aeration may be limiting to the nematodes at the depths at which these roots occur, we feel that physiological disruption of supportive roots will only be a problem with nematode genera that are deeply distributed. Of the nematodes we have studied, *Tylenchulus semipenetrans* is a potential problem in this respect, and *Meloidogyne* spp. in coarse, well drained soils. Control of nematodes deep in the soil may be a problem because of the difficulty of getting a nematicidal chemical to them.

Under most circumstances, the nematodes feeding on the feeder roots in the upper soil in the vine row are probably of most consequence to the vine. Physiological disruption of these active roots will readily occur with the high populations of nematodes in this region of the soil profile and the more optimum physical conditions. We have previously speculated on the distribution of *X. americanum* in the vine row (8). We still feel that lack of soil disturbance and an oxygen requirement (15) are important determining factors. The typical distribution pattern occurred in those vineyards which were furrow irrigated, resulting in periods of soil saturation between rows but not in the well-drained berm, and which were regularly tilled. In non-tilled, sprinkler irrigated vineyards, *Xiphinema* distribution was more widespread in the upper soil layers. French plowing appears to have an effect in reducing the population in the vine row, but may have a corresponding detrimental effect on the root system. Another consequence of the concentration of plant-parasitic nematodes in the berm is that when vines are being grown on a resistant rootstock, root growth from the scion may occur if the soil is piled too high around the trunk. In this case the rootstock degenerates and the vine becomes dependent upon a susceptible root system confined to the area with highest nematode concentrations.

The zones of the soil profile which provide the most suitable environment for root growth and nematode population development should be given primary consideration in developing nematode control strategies. 1,2-Dibromo-3-chloropropane (DBCP) is applied to vineyard soils in California by soil injection, in furrow irrigation water, and in sprinkler irrigation water (16). In the former two cases, it is difficult to get closer than about 45 cm from the vine and lateral movement of the chemical may be limited (2). In sprinkler irrigation it is likely that a high percentage of the chemical is lost to the atmosphere (16). None of these methods appear effective in applying the chemical in the upper soil in the vine row, where the nematodes are concentrated. When DBCP has been applied down the French plow trench, nematode control has been limited by water management problems, and perhaps by timing of the application. We feel that there is a need to develop equipment capable of placing nematicides in the berm. Current application practices probably result in considerable waste of chemical, by loss to the atmosphere or by treatment of parts of the soil profile where nematodes are less numerous or of little consequence to plant vigor.

Literature Cited

1. Abdalla, N., D. J. Raski, B. Lear, and R. V. Schmitt. 1974. Distribution of methyl bromide in soils treated for nematode control in replant vineyards. *Pestic. Sci.* 5:259-269.
2. Baines, R. C., L. H. Stolzy, and R. H. Small. 1963. Controlling citrus nematode for increased yield. *Calif. Citrograph* 48(6):186-211.
3. Baker, K. F., and R. J. Cook. 1974. Biological control of plant pathogens. W. H. Freeman. San Francisco.
4. Byrd, D. W., K. R. Barker, H. Ferris, C. D. Griffin, and R. H. Small. 1976. Two semi-automatic elutriators for extracting nematodes from soil. *J. Nematol.* (in press).
5. _____, H. Ferris, and C. J. Nusbaum. 1972. A method for estimating numbers of eggs of *Meloidogyne* spp. in soil. *J. Nematol.* 4:266-269.
6. _____, C. J. Nusbaum, and K. R. Barker. 1966. A rapid flotation-sieving technique for extracting nematodes from soil. *Plant Dis. Rptr.* 50:954-957.
7. Ferris, H., and M. V. McKenry. 1974a. Observations on the spatial distribution of *Xiphinema americanum* in California vineyard soils. *J. Nematol.* 6:140 (Abstr.)
8. _____, and _____. 1974b. Seasonal fluctuations in the spatial distribution of nematode populations in a California vineyard. *J. Nematol.* 6:203-210.
9. _____, and _____. 1975. Relationship of grapevine yield and growth to nematode densities. *J. Nematol.* 7:295-304.
10. Hackney, R. W. 1974. The use of chromosome number to identify *Meloidogyne* spp. on grapes. *J. Nematol.* 6:141-142 (Abstr.).
11. Hodges, L. R., and B. Lear. 1973. Efficacy of 1,2-dibromo-3-chloropropane for control of *Meloidogyne javanica* as influenced by concentration, exposure time and rate of degradation. *J. Nematol.* 5:249-253.
12. Iwao, S., and E. Kuno. 1971. An approach to the analysis of aggregation pattern in biological populations. p. 461-513 *In* G. P. Patil, E. C. Pielou, and W. E. Waters (eds.) Statistical ecology Vol. I. Spatial patterns and statistical distributions. Penn. State Univ. Press, University Park.
13. Lloyd, M. 1967. Mean crowding. *J. Anim. Ecol.* 36:1-30.
14. McKenry, M. V., and I. J. Thomason. 1974. 1,3-Dichloropropene and 1,2-dibromoethane compounds: I. Movement and fate as affected by various conditions in several soils. *Hilgardia* 42:393-421.
15. Ponchillia, P. E. 1972. *Xiphinema americanum* as affected by soil organic matter and porosity. *J. Nematol.* 4:189-193.
16. Raski, D. J., W. H. Hart, and A. N. Kasimatis. 1973. Nematodes and their control in vineyards. *Calif. Agr. Expt. Sta. Cir.* 533 (revised).
17. _____, and J. D. Radewald. 1958. Reproduction and symptomatology of certain ectoparasitic nematodes on roots of Thompson seedless grape. *Plant Dis. Rept.* 42:941-943.
18. Siddiqui, I. A., S. A. Sher, and A. M. French. 1973. Distribution of plant parasitic nematodes in California. State of California.
19. Snedecor, G. W., and W. G. Cochran. 1967. Statistical methods. Iowa State Univ. Press, Ames.
20. Thomason, I. J., and M. McKenry. 1975. Chemical control of nematode vectors of plant viruses. p. 423-439 *In* F. Lamberti, C. E. Taylor and J. W. Seinhorst (eds.) Nematode vectors of plant viruses. Plenum Publishing Corp., New York.
21. Winkler, A. J. 1962. General viticulture. Univ. Calif. Press, Berkeley.