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Effects of Seasonal and Site Factors on *Xiphinema index* Populations in Two California Vineyards

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Abstract: Sampling of *Xiphinema index* for 2 years (1993–95) in two California vineyards indicated that a greater number of nematodes occurred during the winter months. The number of juveniles increased four-fold from December 1993 to January 1994, indicating a high reproductive rate during this time. Extremely high or low soil temperatures corresponded to low nematode numbers. Samples were taken from 0 to 31 cm and 31 to 62 cm deep both within and between the vine rows. Numbers of nematodes were greatest at the 0- to 31-cm depth in one vineyard with a loamy sand soil, and at a depth of 31 to 62 cm in the second vineyard, which had a silt loam soil. In both vineyards, *X. index* population densities were greater within the vine row.

Key words: nematode, population dynamics, soil moisture, soil temperature, soil texture, vertical distribution, *Vitis* spp., *Xiphinema index*.

The dagger nematode, *Xiphinema index* Thorne and Allen, damages grape (*Vitis vinifera* L.) roots and transmits grapevine fanleaf virus (GFLV) (Hewitt et al., 1958; Raski and Radewald, 1958). *Xiphinema* spp. and *X. index* in particular are present in all major grape-growing regions of the world (Raski, 1988). In California, *X. index* is found in approximately 5% of the entire grape-growing area and predominantly in the coastal and northern San Joaquin regions (M. V. McKenry, pers. comm.). Root-knot nematodes, *Meloidogyne* spp., and *Xiphinema americanum* Cobb are thought to cause more direct damage to grapes and have been researched more intensively in California vineyards (M. V. McKenry, pers. comm.). Although not as widespread, the *X. index*-GFLV complex causes significant economic damage to many California vineyards (Raski, 1988).

Most established vineyards in the coastal and northern San Joaquin regions of California are planted to grape cultivars AXR1, Saint George, or other traditional rootstocks susceptible to *X. index*. Several rootstocks such as 171-13, 122-16, 88-113, 171-52, 106-38, and 116-11 have been shown to have resistance to *X. index* (Harris, 1988). *Vitis* germplasm screening has resulted in at least three GFLV-resistant accessions (Walker et al., 1985). Recently, *X. index*-resistant rootstocks 039-16 and 043-43 were released in California (Walker et al., 1994). These rootstocks derived from crosses of *V. vinifera* × *Muscadinia rotundifolia* Small (VR hybrids) made by H. P. Olmo in 1948 (Patel and Olmo, 1955).

Traditionally, both preplant and postplant management of *X. index* has been achieved with nematicides (Raski and Lear, 1962). Even if resistant rootstocks are used, the use of nematicides is still recommended for optimum performance (Roberts, 1993). Information on the seasonal variation of *X. index* in different California locations is needed to develop management programs to minimize the use of chemical treatments. Seasonal fluctuation studies have been done for *X. index* in northeastern Victoria, Australia (Harris, 1979), Spain (Pinochet and Cisneros, 1986), Italy (Amici, 1967), and Israel (Cohn, 1969). Discrepant results between the locations in which these studies were conducted indicated the need for similar investigations in California.

Seasonal population fluctuation studies of *X. index* in California vineyards should provide data that can be used to optimize sampling strategies and to direct the course of future research for developing nematode management recommendations. In this

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study, the effects of soil moisture, soil temperature, soil texture, grape root density, and growers' cultural practices on *X. index* populations were monitored in a field setting. We hypothesized that *X. index* populations fluctuate in California vineyards and that a simple correlation exists between nematode counts and environmental factors such as soil temperature, soil moisture, soil depth, distance from the vine, soil composition, and grape vine root density.

Materials and Methods

Two commercial California vineyards with a history of *X. index* infestations were selected for a two-year study (July 1993 to June 1995). One was located near Healdsburg (38°40′ latitude, 122°51′ longitude) in Sonoma County, and the other near Lodi (38°11′ latitude, 121°21′ longitude) in San Joaquin County. A rootstock-scion combination characteristic of each sampling location was chosen. For Healdsburg, this combination was 'Cabernet Sauvignon' on AXR1. For Lodi, 'Zinfandel' on Saint George was chosen. The sampling design was a split plot in space and time. At each site, a plot consisted of three rows of 40 vines each. Rows were 360 cm apart and 40 vines long (vines 210 cm apart). Five vines were sampled at random in two of the rows, at two depths (space), and every month for 2 years from July 1993 to June 1995 (time). Approximately 1,400 cm^3 of soil were taken per sample with a 7.5-cm-diam. auger. In previous studies, *X. index* was more abundant in the upper 15 cm of soil (Harris, 1979) or the upper 40 cm of soil (Esmenjaud et al., 1992), and *X. americanum* was more abundant in the upper 60 cm of soil (Ferris and McKenry, 1974). Soil samples were taken at two depth ranges (0 to 31 cm and 31 to 62 cm) within and between vine rows for a total of 40 samples per vineyard per month (5 vines × 2 rows × 2 locations per vineyard × 2 depths). For the second year (July 1994 to June 1995), due to low nematode numbers between the vine rows during the previous year, only samples within the vine rows were taken, reducing the number of samples to 20 samples per vineyard per month. Soil from each sample was thoroughly mixed, and approximately 500 cm^3 was placed in a plastic bag. Samples were transported in insulated containers and placed in cold storage at 5 °C within 3 hours of sampling. A 250-cm^3 aliquot of each soil sample was processed by elutriation through screens with openings of 147 µm (100 mesh), (W. S. Tyler, Screening Division, Mentor, OH) and filtered through cheesecloth over Baermann funnels for 2 days (Seinhorst, 1956). Nematode extraction efficiency using the elutriator was compared to hand-processing, in which soil was crumbled and passed once through a screen with openings of 147 µm. Extracted nematodes were examined under a dissecting microscope (×30 and ×60), and the number of juveniles, adult males, and females were recorded. Following nematode extraction, the soil from each Baermann funnel was filtered through a screen with openings of 246 µm (60 mesh). The volume of grape roots from each funnel was rated by the same observer on each sampling date on a scale of 0 to 5, with the highest number corresponding to the greatest number of roots observed on that date.

In Healdsburg, regular irrigation began after bloom (late June) and continued every 2 weeks until harvest in October. Irrigation was applied 12 hours/day through drip emitters (3.7 liters/hour), with one emitter between each two vines, for a total of 45 liters of water per emitter. Fertilizer was applied with post-harvest irrigation in October, with the amount determined by leaf-petiole analysis. The post-harvest irrigation and fertilizer schedule was irrigation without fertilizer for 3 hours, then irrigation with fertilizer for 2 hours, and finally irrigation without fertilizer to allow infiltration for an additional 19 hours, to give 90 liters of water per day. Plots were disked four times a year, once each season except for winter 1995. Roots between rows were pruned with a chisel at a depth of approximately 61 cm each year in April. Wild mustard was allowed to establish between rows each spring and was not disked until June. Grapes were harvested at the end of September 1993 and

during the first week of October 1994, with yields of 8.9 t/ha (4 tons/a) in 1993, 9.6 t/ha (4.3 tons/a) in 1994, and 8.4 t/ha (3.7 tons/a) in 1995. Vines were pruned in early January.

In Lodi, irrigation was applied at a rate of 3.7 liters/hour for 4 hours every day from June to September 1993 and then for 15 hours twice a week from June to September 1994, through two drip emitters (1.9 liters/hour), with one emitter between each two vines. Calcium nitrate was applied with irrigation several times from June to September at a rate of 28 kg N/ha. Post-harvest fertilizer was applied with irrigation at a rate of 9 kg N/ha and 28 kg potash/ha in September. Disking between every other row was performed for weed control in March, twice in April, and between every row in May. A cereal-legume cover crop that included barley, oat, and vetch was seeded between every other row during the winter and disked in May. Grapes were harvested in September, with yields of 7.4 t/ha (3.3 tons/a) in 1993, 6.7 t/ha (3 tons/a) in 1994, and 6.7 t/ha (3 tons/a) in 1995. Vines were pruned in early January. A composite soil sample was analyzed by the University of California DANR Analytical Laboratory for physical and chemical properties. The Healdsburg soil was a silt loam, and the Lodi soil was a loamy sand (Table 1).

Soil moisture was determined on each sampling date by weighing small amounts of soil from a mixture of samples taken from 10 vines at each depth. Each soil sample was allowed to dry at room temperature for 2 weeks, then reweighed. Maximum and minimum monthly temperatures were obtained from continuous recording soil temperature recorders (Model 18153, Dickson, Addison, IL) placed at depths of 31 and 62 cm in one row of the vines at each site. Soil temperatures and precipitation were obtained from California Irrigation Management Information System (CIMIS) weather stations maintained by the California Department of Water Resources—one in Windsor (15 km from Healdsburg) and the other in Lodi (4 km from the vineyard). Analysis of variance (ANOVA) and Fisher's pairwise comparison were performed using Minitab. Statistics and correlation for time series analyses were performed with SigmaPlot (SPSS, Chicago, IL). Nematode counts were transformed with the formula $(\sqrt{x+0.5})$ (Little and Hills, 1978). To determine if monthly nematode counts varied according to soil temperature, time series analysis was used. Transformed mean soil temperatures recorded in the vineyard at a depth of 31 cm were advanced by 1 month to best fit the nematode count curve. Total monthly nematode counts within rows at both depths were plotted against time. A mean temperature of 14 °C and the transformation were determined by trial and error with regression analysis. Transformed soil temperatures (T) were calculated as follows: $T = t - 4$ when $t \leq 14$ °C, and $T = (14 + [14 - t]) - 4$ when $t > 14$ °C,

TABLE 1. Soil physical characteristics of vineyards surveyed at Healdsburg and Lodi, California.

Location[a] and depth (cm)	pH (millimhos/cm)	Electrical conductivity (meq/100g)	Cation exchange capacity (%)	Organic matter (%)	Sand (%)	Silt (%)	Clay (%)
			Healdsburg				
R 0–30.5	6.7	1.42	20.9	1.75	19	62	19
R 30.5–61	6.8	0.64	23.9	1.52	16	63	21
S 0–30.5	6.7	0.71	20.0	1.81	21	60	19
S 30.5–61	6.9	0.22	24.7	1.78	15	63	22
			Lodi				
R 0–30.5	6.4	0.67	4.8	0.55	76	15	9
R 30.5–61	6.4	0.34	3.8	0.12	82	11	7
S 0–30.5	5.9	1.29	3.7	0.49	80	12	8
S 30.5–61	6.6	0.3	3.2	0.16	82	11	7

[a] Samples were taken within rows (R) and between rows (S) at depths of 0–30.5 and 30.5–61cm.

where t is the recorded temperature. Since time series analysis is usually performed for data collected over more than 2 years to obtain a higher coefficient of correlation, it was performed only for Healdsburg because the primary vineyard in Lodi was removed by the grower and an adjacent plot had to be sampled during the second year. Differences reported in the text were significant at the $P = 0.05$ level.

Results

In Healdsburg, the highest number of Cabernet Sauvignon-on-AXR1 grape roots occurred in samples taken in January 1994. In Lodi the highest number of Zinfandel-on-St. George roots occurred in October 1994, while the highest root number of Cabernet Sauvignon-on-AXR1 roots occurred in December 1993 and January 1994. Nematode extraction efficiency using the elutriator was the same as hand-processing. In Lodi, *X. index* was more abundant in the upper soil level (0 to 30.5 cm), while in Healdsburg *X. index* was more common in the deeper soil level (30.5 to 61 cm). In Healdsburg adult numbers peaked in May 1994 and juvenile numbers in December 1993. Adult and juvenile numbers were lowest in July 1993 (Fig. 1). In Lodi, for Zinfandel-on-St. George grape, the highest numbers of adults and juveniles occurred in January 1994 (Fig. 1). Lowest adult numbers occurred in October 1993 and the lowest number of juveniles in July 1993 (Fig. 1). In Lodi, for Cabernet Sauvignon-on-AXR1, the highest numbers of adults and juveniles were found in November 1993, the lowest number of adults in March 1994, and the lowest number of juveniles in July 1993 (Fig. 1). Similar results were obtained during the year starting July 1994 to June 1995, with the highest numbers of juveniles recorded in January 1995 in Healdsburg and in Lodi.

During the first year of sampling in Healdsburg, more samples without *X. index* were recorded in the space between the vine rows than between the vines in the rows (data not shown). The highest numbers of

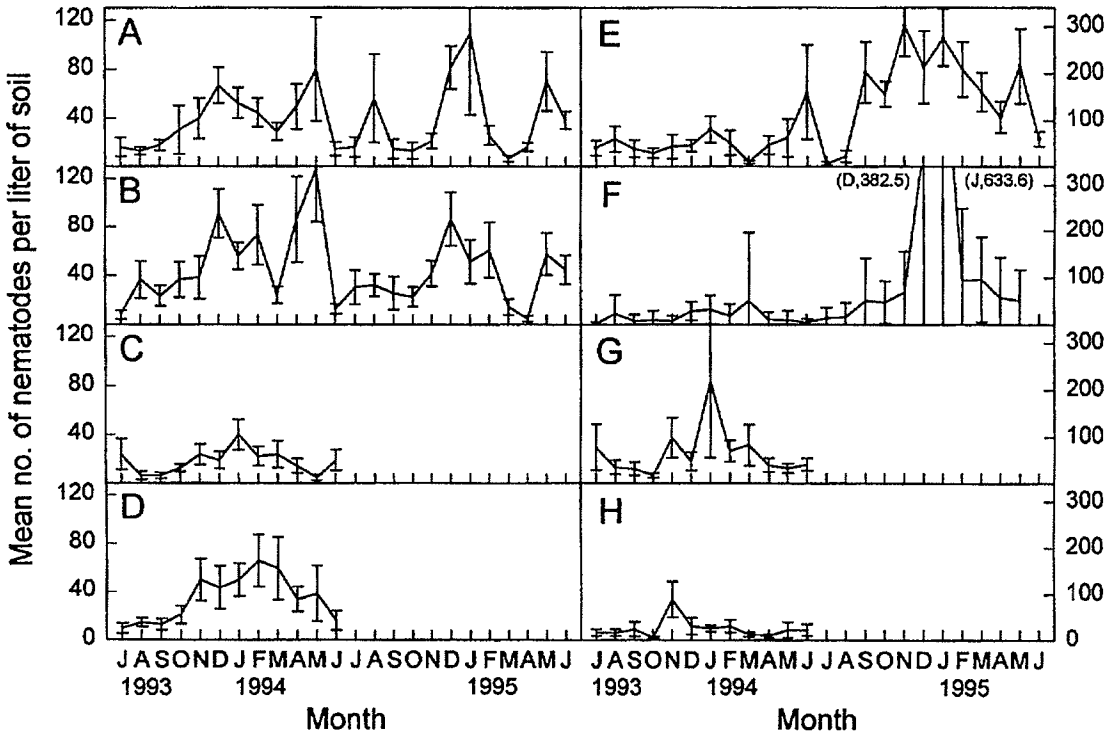

FIG. 1. *Xiphineama index* monthly counts at two depths for two surveyed California vineyards, 1993 to 1995. A–D) Healdsburg. E–H) Lodi. A,E) Samples taken within rows, 0 to 30.5 cm deep. B,F) Samples taken within rows, 30.5 to 61 cm deep. C,G) Samples taken between rows, 0 to 30.5 cm deep. D,H) Samples taken between rows, 30.5 to 61 cm deep. Bars represent standard errors.

nematodes recorded in a single sample for each year occurred within the upper soil level (30.5 cm), within the row, but at different times: May 1994 (448 *X. index*/liter of soil) and January 1995 (516/liter of soil). The highest mean number of nematodes within the upper 30.5 cm of soil occurred in May 1995, and the lowest in August 1993 and June 1995 (Fig. 1). Averaged over both years, *X. index* were most abundant in December and May (Fig. 1).

During the first year in Lodi more total numbers of *X. index* were recorded from the upper soil level (0 to 30.5 cm) than the lower soil level, and the highest number recorded in a single sample (1,680/liter of soil) occurred in January 1994 in the upper soil level (0 to 30.5 cm) between the rows. During the second year, highest numbers occurred in January 1995 (2,960/liter of soil) in the deeper soil level (30.5 to 61 cm) in the row. The highest number of nematodes for Zinfandel-on-St. George within the rows was recorded in January 1995 (3,640/liter of soil), and the lowest nematode number occurred in July 1994 (21/liter of soil) (Fig. 1). Over the 2 years combined, the highest counts were recorded in January (1,022/liter of soil) (Fig. 1). The highest soil moisture occurred during the winter, but soil moisture was also high during the summer months when the vineyards were being irrigated (Fig. 2). In Healdsburg during the 2 years of this study, soil moisture was highest during winter 1995 and lowest in the fall and spring, before the winter rains and the summer irrigation, respectively (Fig. 2). In Lodi, within the vine row the highest soil moisture occurred in March 1995 and the lowest in March and October 1994 (Fig. 2). In Lodi, soil moisture was frequently lower between than within rows. Soil temperatures had a greater range of extreme values at Lodi than at Healdsburg, with expected seasonal variations at both sites (Fig. 3). In Windsor, next to Healdsburg, the highest precipitation recorded by the CIMIS station, as obtained from UCIPM, occurred in January 1995 (35 cm) and the lowest during the summer months. Soil temperatures ranged from 6 °C in January to 20 °C in August. In Lodi, the highest precipitation recorded by the CIMIS station occurred in January 1995 (24 cm) and the lowest in the summer months. Soil temperatures ranged from 7 °C in January to 30 °C in July.

Large differences were observed among nematode counts between depths and between months (Table 2). For Lodi, transformed *X. index* numbers differed between depths and months, and between years (Table 2). Monthly root ratings or soil moisture were not correlated with monthly nematode counts, and nematode counts and soil temperature of the previous month were highly correlated ($r = 0.58$) (Fig. 4). Standard deviations of *X. index* numbers for each sampling date were highly variable (7.7 to 209.4). For the first year at both locations, nematode densities were higher within vine rows than between rows.

Discussion

Nematode densities within the vine rows were higher than those between rows, possibly because within-row soil moisture was maintained at a higher level by drip irrigation and the root system was not disrupted by cultural practices. *Xiphinema index* numbers were greater at the 30.5- to 61-cm depth in Healdsburg, but in Lodi numbers were higher at the of 0- to 30.5-cm depth. A higher soil moisture deeper in the silt loam soil of Healdsburg could account for the difference in nematode distribution. The higher soil moisture in the silt loam soil may have promoted root growth that provided a greater food source for the nematodes. In this study, according to the root ratings at both locations, more grape roots were observed within the vine rows and in the upper 30.5 cm and, although the correlation was not significant, the higher grape root ratings corresponded frequently to the greatest numbers of nematodes. A flush of root growth occurred in October in Lodi, which may have contributed to the increase in nematode numbers in November and December. This increased food resource could have stimulated *X. index* reproduction, which may explain the great number of *X.*

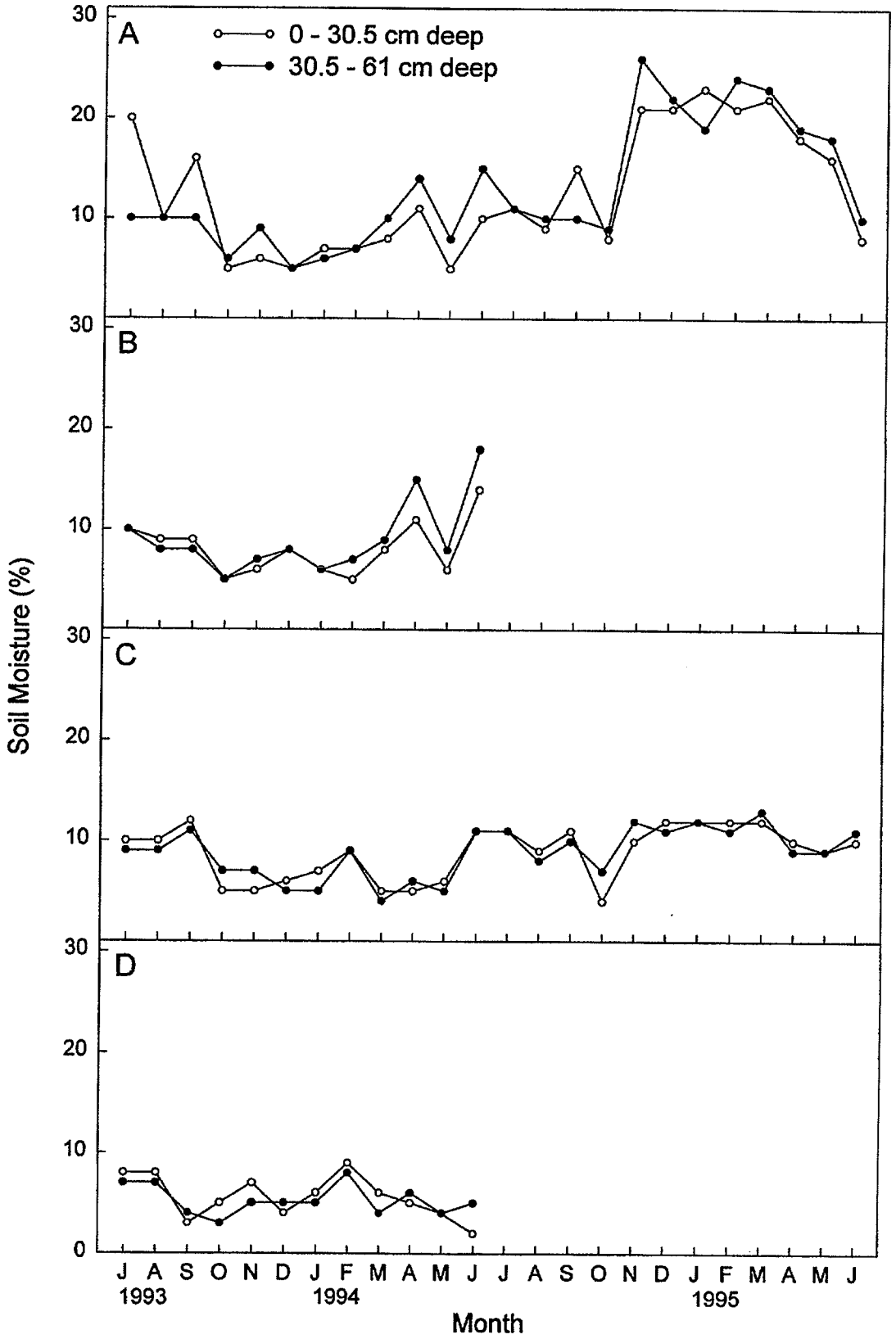

FIG. 2. Monthly soil moisture at two depths for two California vineyards, 1993 to 1995. A,B) Healdsburg. C,D) Lodi. A,C) Within rows. B,E) Between rows.

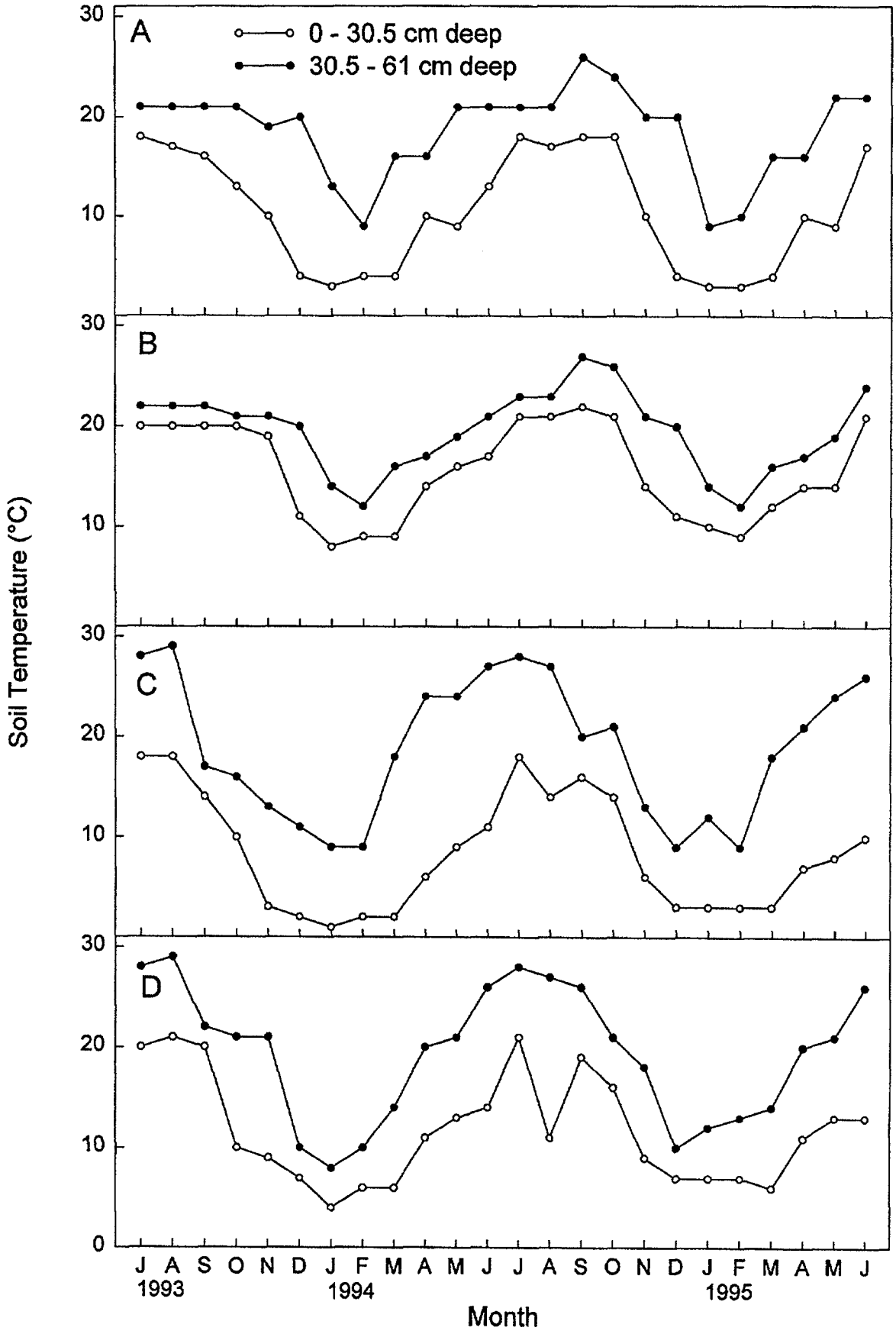

FIG. 3. Monthly soil temperature at two depths for two California vineyards, 1993 to 1995. A,B) Healdsburg. C,D) Lodi. A,C) Samples taken 0 to 30.5 cm deep. B,D) Samples taken 30.5 to 61 cm deep.

TABLE 2. Analysis of variance for transformed ($\sqrt{x+0.5}$) *Xiphinema index* count data by depth, month, and year for two surveyed California vineyards during the years 1993 to 1995.

Source of variance	*df*	Mean square	*F*	*P*
		Healdsburg		
Depth	1	5.27	5.82	0.03
Month	11	11.53	12.73	0.00
Depth × month	11	0.38	0.42	0.92
Year	1	3.58	3.95	0.07
Month × year	11	3.06	3.38	0.02
Error	12	0.90		
Total	47			
		Lodi		
Depth	1	104.73	22.27	0.00
Month	11	18.00	3.83	0.02
Depth × month	11	2.45	0.52	0.86
Year	1	254.38	54.10	0.00
Month × year	11	11.48	2.44	0.07
Error	12	4.70		
Total	47			

index juveniles observed during the winter months. However, females and juvenile stages were recorded throughout the year at both locations. The reported number of juveniles probably was underestimated since first-juvenile stage nematodes were not recorded.

Host susceptibility is another factor that influences nematode population levels. In this study, the rootstocks under investigation were AXR1 and St. George, two of the most susceptible rootstocks to *X. index* (Walker et al., 1985). Soil composition and texture also have an effect on nematode populations. *Xiphinema index* has been reported to increase more rapidly in sandy loam or in fine sands under greenhouse conditions (Sultan and Ferris, 1991). Contradictory results have been recorded in France, where the greatest *X. index* populations were observed in loamy clay soils (Esmenjaud et al., 1992). The soil in Healdsburg was a silt loam; in Lodi it was a loamy sand. The sandy soil of Lodi had a greater number of nematodes than the silt loam soil of Healdsburg, which supports the findings of previous studies (Sultan and Ferris, 1991). Movement of *X. index* may have been impeded in the Healdsburg soil. Due to its relatively large size, *X. index* probably moves more efficiently in a porous soil, such as the Lodi sandy loam. However, because the Lodi soil had a lower water-holding capacity, it tended to dry out more quickly between irrigations in summer, which may explain the lower nematode numbers at that time. A similar result has been obtained under greenhouse conditions, suggesting that nematodes slow their reproduction in dry soil as well as in saturated soil (Sultan and Ferris, 1991).

Low soil moisture was observed at both sites in October when irrigation was discontinued, and the low soil moisture corresponded to low nematode numbers. Low soil moisture tensions may increase nematode mortality (Norton, 1978). In the greenhouse under favorable moisture conditions and in the absence of a host, *X. index* populations had greater survival than under dry conditions. However, reproduction subsequently increased for nematodes that survived incubation in dry soil and decreased for those incubated under favorable conditions (Sultan and Ferris, 1991). In the present study, the period of soil dryness that occurred in October may have increased *X. index* rate of reproduction, thereby increasing population levels during the winter months. Some information about the life cycle can be inferred from the data collected. The number of juveniles increased four-fold from December 1993 to January 1994, implying a period of time between oviposition and hatch of about a month. Radewald (1962) reported that *X. index* required 27 days for development from egg to adult. In this study, assuming that the *X. index* life cycle was 27 days, the high *X. index* juvenile counts of November to January probably indicated that adult females laid many eggs in October. Another possibility is that *X. index* eggs were laid in September but, due to dry soil conditions in October, did not hatch until November.

Soil temperature has been found to affect nematode metabolism; for example, cold temperatures can put nematodes in a physiologically quiescent state (Norton, 1978). In laboratory experiments, *X. index* survived storage in soil at temperatures between −11 °C and 37 °C (Harris, 1979). Popula-

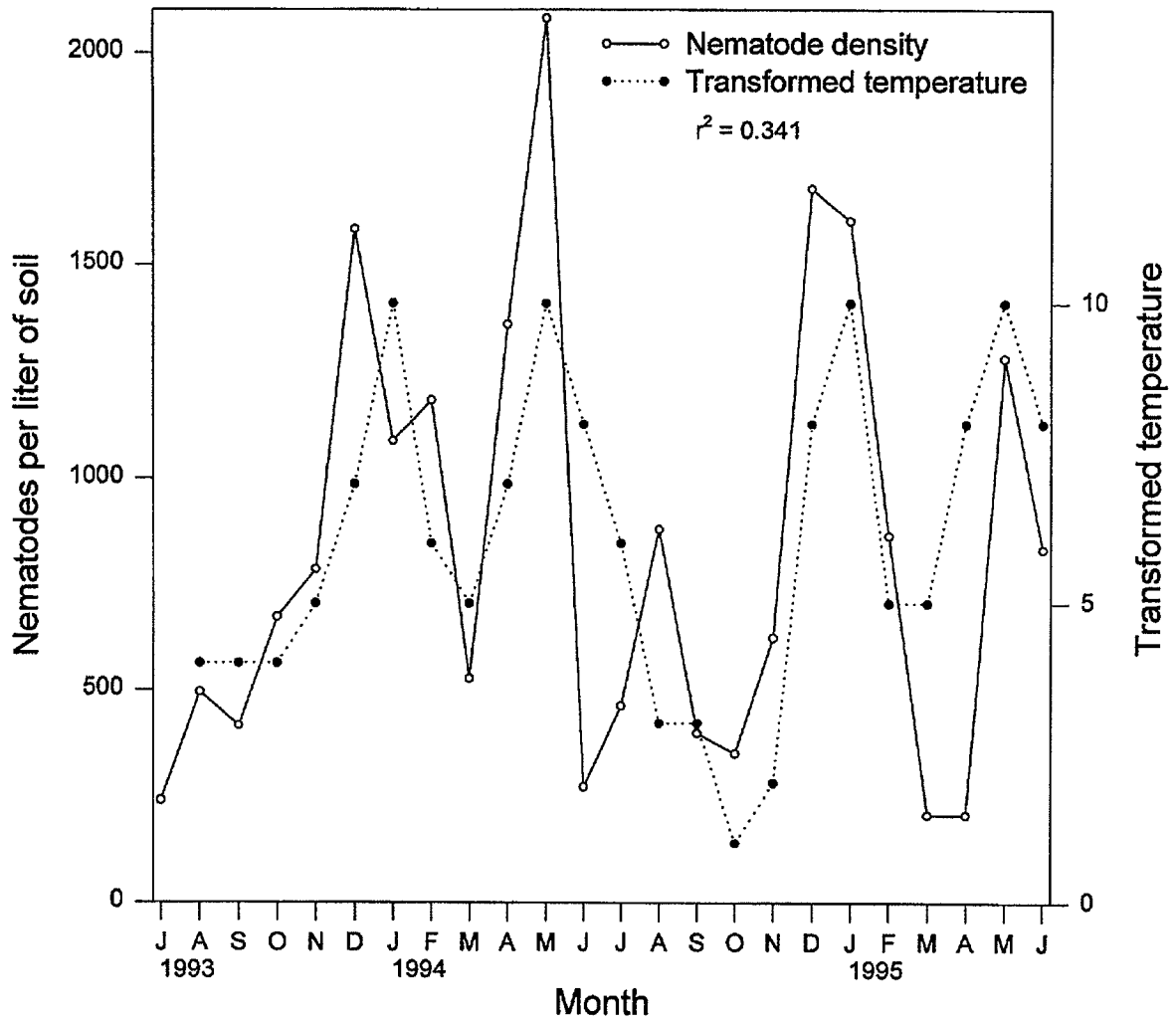

FIG. 4. Time series analysis of *Xiphinema index* within-row counts vs. soil temperature for the Healdsburg, California, vineyard, 1993 to 1995. A mean temperature of 14 °C and the transformation were determined empirically with regression analysis. Transformed soil temperatures (T) were calculated as follows: $T = t - 4$ when $t \leq 14$ °C, and $T = (14 + [14 - t]) - 4$ when $t > 14$ °C, where t is the recorded temperature.

tions of *X. americanum* increased after 5 months on potted strawberry in a water bath of 21 °C under greenhouse conditions (Lownsbery and Maggenti, 1962). In this study, the high number of nematodes observed in Healdsburg in May and in the summer, as compared to the low nematode numbers found in Lodi, could be due to the fact that summer soil temperatures were 6 °C lower in Healdsburg than in Lodi. Soil temperatures greater than 22 °C also corresponded to decreased *X. index* populations. Low winter temperatures of 2 °C to 6 °C corresponded to lower *X. index* populations in February. Moderate soil temperatures of 10 °C to 18 °C in October and April at both locations preceded increases in *X. index* counts during the following months.

Seasonal fluctuations of *Xiphinema* spp. vary geographically. Populations of *X. index* in vineyards in northeastern Victoria, Australia, reached a peak in spring (October to December) (Harris, 1979), and in vineyards of Spain they peaked in summer (Pinochet and Cisneros, 1986). In Israel, no seasonal fluctuations were discerned for 10 *Xiphinema* spp. (Cohn, 1969). In England, populations of *X. diversicaudatum* and *X. index* were highest in autumn and lowest in spring (Cotten et al., 1970). In parts of California and Florida, nematode populations were low during the summer or early fall when temperatures were high, soil was dry, and the crop was not in lush growth (Norton, 1978). In California, population levels of *X. americanum* were higher in fall and winter than in

spring and summer (Ferris and McKenry, 1974). In the current study, *X. index* counts were always highest in the winter months. Temperature likely limits *X. index* reproduction in California because the summers are hotter and the growing season is longer than in most other grape-growing regions of the world.

The findings of this study show that *X. index* populations fluctuate throughout the year and can be correlated with soil temperature. The possibility of detecting *X. index* in a vineyard can be maximized by sampling within the row during the winter months. Because of high variability within a field, *X. index* samples from a single location have a high probability of yielding no nematodes. Therefore, samples taken for analysis should contain a number of subsamples and should be thoroughly mixed prior to extraction. Based on the findings of this study, evaluations of control methods should be done when populations are at their highest during the fall and winter months. Weather data provided from the CIMIS stations yielded similar results to those recorded in the field and could be used for future studies.

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