Factors Associated with the Decline of Sweet Cherry Trees in Michigan: Nematodes, Bacterial Canker, Nutrition, Soil pH, and Winter Injury

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ABSTRACT

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Some of the biotic and abiotic factors associated with the decline and death of sweet cherry (*Prunus avium*) trees in Michigan were studied. In a survey of 26 orchards in the summer of 1990, nematodes belonging to *Pratylenchus, Criconemella, Xiphinema, Meloidogyne*, and *Paratylenchus* spp. were detected in samples from 24, 11, 15, 17, and 17 orchards, respectively. *Pratylenchus penetrans* was the most abundant nematode in these orchards. However, populations of all nematodes from healthy and declining trees were not significantly different. *Pseudomonas syringae* pv. *syringae* and *P. s. morsprunorum* were isolated from leaves or branches collected from trees in each orchard. Detailed studies of five 6- to 16-yr-old orchards in 1990 and 1991 indicated that low soil pH, some nutritional disorders, and winter injury were among the abiotic factors associated with tree decline. Soil pH, which appeared to increase available aluminum, was as much as 2.5 units below the recommended level. Leaves from most orchards had insufficient levels of Ca and N. Leaf Al concentrations of 110–392 μg/g were detected in three orchards. Severe winter injury was observed in one orchard. Although several biotic and abiotic factors appeared to result in the decline of sweet cherry trees in Michigan, only one or two factors were associated with decline in individual orchards.

Sweet cherry (*Prunus avium* (L.) L.) is an important stone fruit crop in Michigan (1). As with other species of *Prunus* grown in the United States, the production of sweet cherries has been affected by poor tree health and tree death. The biotic and abiotic causes associated with tree death and/or replant problems of *Prunus* spp. in North America, however, appear to vary by region. For example, some contributing factors appear to be Cytospora canker in Washington (29); interaction between *Criconemella xenoplax* (Raski) Luc & Raski and *Pseudomonas syringae* van Hall and, to a certain extent, *C. xenoplax* and Cytospora canker in California (18,23); association of *P. syringae* and *C. xenoplax* in the southeast (5,26); and association of *Pratylenchus penetrans* (Cobb) Filipjev & Schuur.-Stek. with replant problems in New York (21,22) and Ontario (24). Inadequate soil and orchard management practices and unfavorable environmental conditions also contribute to the decline of *Prunus* spp. (5,27).

In Michigan, *P. syringae* is a known pathogen of sweet cherry trees (11,32), and the presence of *Pratylenchus penetrans* and *C. xenoplax* in sandy soils suitable for the production of grapes and other fruit crops is well established (4,15). There is no evidence, however, of involvement of these or other nematodes in the decline of sweet cherry orchards, either by predisposing trees to bacterial canker or as primary pathogens. Moreover, the extent to which other biotic and abiotic, horticultural, and orchard management factors contribute to the decline of sweet cherry trees in Michigan is not known.

Our overall project goal, as part of a stone fruit decline study, was to inves-

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tigate the role of plant-parasitic nematodes and *P. syringae* in the loss of sweet cherry trees in Michigan orchards. The objectives of this study were to identify and quantify the plant-parasitic nematodes and *Pseudomonas* bacteria associated with sweet cherry trees, to relate the relative abundance of nematodes and bacteria to health status of the trees, and to determine if abiotic factors contribute to the decline of sweet cherry trees.

MATERIALS AND METHODS

Statewide survey. Soil samples were collected from 26 sweet cherry orchards in the summer of 1990. Orchards were located on a belt adjacent to Lake Michigan about 400 km long, extending from Benton Harbor in the southwest to above Traverse City in the northwest. Sampling was concentrated in the cherry-growing regions of southwest (six orchards), west central (seven orchards), and northwest (13 orchards) Michigan. Orchard selection was based on recommendations by extension personnel in each region. Data on cultivar, rootstock, and tree age were obtained from the growers or the extension personnel. Three or four 500-cm^3 bulk soil samples per orchard were collected and analyzed for nematode population density. Plant-parasitic nematodes were identified to genera. A bulk sample came from one or two spots per tree and one or two trees per sample selected randomly. Bacterial canker in each of the surveyed orchards was assessed primarily on the basis of leaf symptoms and was rated as 1 (slight), 2 (moderate), and 3 (severe), corresponding to about 2, 20, and 50% of the leaves with visible symptoms on each tree sampled for nematodes.

Analysis of selected orchards. Five of the 26 orchards in the statewide survey were studied in detail for incidence of bacterial canker, densities of nematode populations, and presence of abiotic disorders during the 1990 and 1991 growing seasons. Orchard 1 was located in Berrien County (southwest), orchard 2 in Oceana County (west central), and orchards 3–5 within about 20 km from each other in Leelanau County (northwest). Orchards 1–5 were planted in 1976, 1986, 1979, 1982, and 1983, respectively. Study sites of 128–432 trees were selected within each orchard for detailed observations on a tree-by-tree basis. The study site area included a portion of each orchard with trees in decline. The cultivars in these orchards were Bing, Hedelfingen, Van, and Vista in orchard 1; Gold and Napleon in orchard 2; Emperor Francis and Nelson in orchards 3 and 4; and Sam in orchard 5. All trees were propagated on mazzard rootstock, and all but those in orchard 1 were trickle-irrigated. The soil texture was sandy in orchard 2 and sandy loam in orchards 1, 3, 4, and 5.

Information on the use of nitrogen fertilizer and lime for the previous 3 yr was obtained from the growers. Orchards 1, 2, and 4 received a single spring application of about 297, 334, and 259 kg/ha, respectively, of ammonium nitrate per year. Orchard 3 received a single application of about 334 kg/ha of ammonium nitrate in the autumn of 1988 and 1991, 315 kg/ha in the spring of 1991, and 89 and 262 kg/ha applied three times in the spring of 1989 and 1990. Orchard 5 received single applications of about 226 kg/ha of nitrogen in the autumn of 1989, 241 kg/ha in the spring and again in the autumn of 1990, and 378 kg/ha in the spring of 1991. Orchard 3 was limed at a rate of 2,808 kg/ha in 1989.

Incidence of bacterial canker, winter injury, and dead trees. Each orchard was assessed for bacterial canker by examining individual trees for cankers on lateral and scaffold branches. Trees were categorized as healthy (no visible cankers), less healthy (cankers on lateral branches), and diseased or declining (cankers on scaffold branches). Trees with trunks with depressed areas of necrotic tissue extending upward from the soil line on the south side were considered winter-injured. Trees obviously younger than other trees were classified as replants. Assessments were made in orchards 3–5 on 25 July and 4 September 1990 and on 3 June and 10 September 1991, in orchard 1 on 29 November 1990, and in orchards 1 and 2 on 28–30 May and 27 August 1991.

Isolation of *Pseudomonas* bacteria. Cankers with gum extending from the bark were removed from trees in each orchard and transported to the laboratory. The surface of the bark was cleaned by scraping away the gum deposits, and the cankerous tissues were dipped into NaOCl (5.25%) for 30 sec. After drying for about 20 min, the bark was pulled back with a sterile knife and 1- to 2-mm-thick segments of exposed necrotic tissue were placed on King's medium B (13). Colonies of fluorescent bacteria that developed around the segments were purified before identifications were made. On each sampling date, two sets of 25 leaves per cultivar were randomly collected, placed in plastic bags, and transported to the laboratory in a cooler on ice for processing the next day. Leaf samples were washed in a 500-ml flask with 200 ml of 0.01 M potassium-phosphate buffer at pH 7.2 by shaking manually for 2 min. The supernatant was serially diluted on King's medium B. Plates were incubated at room temperature for 3–4 days before fluorescent colonies were counted. The pathovars of *P. syringae* were identified by testing for the presence of cytochrome *c* oxidase (16) and results from the GATTa tests (17).

Soil and root sampling for nematode analysis. Sampling was designed to reflect distribution within an orchard as well as status of tree health. In 1990, soil sampling began in early July in orchards 3–5, in late September in orchard 1, and in early October in orchard 2; the last samples were taken in early December. In 1991, sampling started in late May and ended in late October. Samples were collected at approximately 4-wk intervals. On each sampling date, 32, 36, 36, 48, and 72 samples were collected from trees in orchards 1–5, respectively. Each sample was a composite of four to six cores of soil taken to a depth of 15–20 cm with a Hoffer soil sampler between the canopy edge and the trunk from each of four to six trees. On each sampling date, composite soil samples were also collected from declining trees in orchards 1, 3, and 4. At the end of each season, a similar number of soil samples was also collected from healthy trees. In mid-October to early November 1990 and in late October 1991, 16, 18, 18, 24, and 12 root samples were collected from healthy and declining trees in orchards 1–5, respectively,. Root samples were collected with a small shovel to a depth of 15–20 cm from two random locations around four to six trees per sample. A similar number of root samples was collected from each of the cultivars in each orchard.

Nematode population densities were estimated from extractions of 100 cm^3 of soil by the flotation and centrifugation method (10) and by shaking 2 g of fresh root weight for 48 hr in a solution of 10 μg/ml of ethoxyethyl chloride (3). Plant-parasitic nematodes were identified to species (20). Less prevalent or infrequent species were lumped together into a separate category.

Table 1. Mean numbers with standard deviations and relative prominence of plant-parasitic nematodes extracted from soil samples from 26 sweet cherry orchards in northwest (NW), west central (WC), and southwest (SW) Michigan in 1990

Nematode genera	Nematodes per 100 cm^3 of soil[x]			Prominence values[y]			Frequency[z]
	NW	WC	SW	NW	WC	SW	
Pratylenchus	15.0 ± 15.8	21.1 ± 15.5	66.1 ± 28.5	0.59	0.64	0.29	24
Criconemella	1.9 ± 3.9	10.1 ± 19.6	85.5 ± 90.5	0.02	0.22	0.48	11
Xiphinema	4.3 ± 7.7	2.3 ± 4.5	55.5 ± 33.8	0.06	0.05	0.22	15
Meloidogyne	6.5 ± 7.7	2.6 ± 4.4	1.7 ± 1.4	0.11	0.03	0.01	17
Paratylenchus	10.1 ± 9.7	5.1 ± 8.3	3.5 ± 5.9	0.23	0.07	0.01	17

[x]Total samples and orchards in NW, WC, and SW Michigan were 46, 25, and 27 and 13, 7, and 6, respectively.
[y]Prominence = density (abundance) × square root of genera frequency (24).
[z]Number of orchards in which genus was detected.

Soil and leaf analyses. Four, four, five, six, and four soil samples from orchards 1–5, respectively, were analyzed in June 1991 for pH (water extraction) and levels of N, P, K, Mg, and Ca by the Michigan State University Soil Testing Laboratory (12). The samples were composites of soil collected for nematode analysis 3 wk earlier in each orchard. Available soil Al was determined from four soil samples per orchard collected in late August or early September 1991. A 5-g subsample from each soil sample was dissolved in 50 ml of 1 N KCl, and the pH and available Al were determined by the Michigan State University Animal Health Diagnostic and Toxicology Laboratory (2).

A total of 12, 6, 6, 6, and 3 composite leaf samples, three samples per cultivar and per tree health category, were collected on 30 July (orchards 1 and 2) and 2 August 1991 (orchards 3–5). Each sample consisted of 40–50 leaves per tree from three or four trees; each leaf was the fourth from the tip of the current season's growth. Samples were collected at a height of 1.5–2.5 m from around the outside of the canopy of each tree. The samples were analyzed for N, P, K, Mg, Ca, Fe, Mn, Cu, Zn, B, and Al by the Michigan State University Soil Testing Laboratory (12).

Data analysis. Nematode population densities in the soil were analyzed to reflect the species frequency, density, and prominence as described by Norton (25). Tree health assessments and isolation frequencies for *Pseudomonas* spp. were converted to percentages. Means of nematode species, *Pseudomonas* spp., and nutrient data were compared by cultivar, tree health status, and orchard; data were analyzed by one-way ANOVA with unequal number of replications, and the means were separated by Tukey's studentized range test utilizing SAS (30). Unless differences between and among cultivars were observed, data for each factor are presented by orchard.

Table 2. Percentage of trees showing cankers on lateral branches (LB) or scaffold limbs (SL), dead or replanted (DR), healthy (H), or winter-injured (WI) in five sweet cherry orchards in 1990 and 1991

Orchard code	Cultivar	No. of trees	LB		SL		DR		H		
			1990	1991	1990	1991	1990	1991	1990	1991	WI[y]
1	Hedelfingen	32	34.4	62.5	25.0	15.6	9.4	15.6	31.2	6.3	0.0
	Vista	32	25.0	40.6	21.9	15.6	28.1	37.5	25.0	6.3	0.0
	Bing	32	37.5	34.4	25.0	40.6	12.5	18.9	25.0	6.3	0.0
	Van	32	15.6	31.3	6.3	12.5	40.6	50.0	37.8	6.3	0.0
	Total	128	28.1	42.2	19.5	21.1	22.7	30.5	29.7	6.3	0.0
2	Gold	120	ND[z]	3.3	ND	2.5	ND	5.0	ND	89.2	0.0
	Napoleon	96	ND	3.3	ND	5.2	ND	17.8	ND	73.7	0.0
	Total	216	ND	3.2	ND	3.7	ND	10.1	ND	83.0	0.0
3	Emperor Francis	180	75.6	50.0	10.6	28.3	4.4	15.6	9.4	6.1	61.7
	Nelson	36	33.3	13.9	41.7	38.9	22.2	44.4	2.8	2.8	47.2
	Total	216	68.5	44.0	15.7	30.1	7.4	20.4	8.4	5.5	59.3
4	Emperor Francis	144	2.8	13.2	6.9	21.5	0.0	0.0	90.3	65.3	9.0
	Nelson	144	67.4	70.1	22.2	22.9	1.4	3.5	29.0	3.5	4.2
	Total	288	35.1	41.7	14.6	22.2	0.7	1.7	49.6	34.4	6.6
5	Sam	432	1.4	11.6	0.2	0.7	0.9	1.4	97.5	86.3	0.0

[y]The number of winter-injured trees was the same for both seasons.
[z]Not done.

Table 3. Percentage of cankers and leaves from which *Pseudomonas syringae* pv. *syringae* (*PSS*) and *P. s. morsprunorum* (*PSM*) were isolated

Orchard code	Cankers				Leaves			
	Samples (no.)	B[y] (%)	*PSS*[z] (%)	*PSM*[z] (%)	Samples (no.)	B (%)	*PSS* (%)	*PSM* (%)
1	29	31	22	78	23	87	0	100
2	11	27	33	67	6	67	0	100
3	5	100	100	0	8	88	86	14
4	20	30	66	33	4	100	50	50
5	11	18	100	0	4	50	100	0

[y]Percentage of samples from which oxidase-negative fluorescent bacteria were recovered.
[z]Percentage of samples with oxidase-negative fluorescent bacteria that were identified as *PSS* or *PSM*.

Table 4. Numbers of oxidase-negative *Pseudomonas* bacteria and epiphytic bacteria other than oxidase-negative *Pseudomonas* isolated from leaves of healthy and diseased trees from three sweet cherry orchards in 1990 and five sweet cherry orchards in 1991[x]

Orchard code	1990				1991	
	Pseudomonas spp.		Epiphytic bacteria		*Pseudomonas* spp.	
	Healthy	Diseased	Healthy	Diseased	June	September
1	ND[y]	ND	ND	ND	241.1	3.4
2	ND	ND	ND	ND	207.5	6.1
3	180.0	1,900.0 a[z]	42.0	275.0 A	156.0	6.4
4	51.4	751.0 ab	4.4	63.0 C	171.3	1.7
5	51.0	285.0 b	10.4	145.0 B	40.0	0.6
	NS		NS		NS	NS

[x]All numbers are times 1,000.
[y]ND = not done. NS = not significant.
[z]Numbers followed by the same letter are not significantly different by Tukey's studentized range test ($P = 0.05$).

RESULTS

Statewide survey. The average age of the orchards in the northwest, west central, and southwest regions was 13.2 ± 9.8, 14.8 ± 8.1, and 13 ± 8.1 yr, respectively. The soils were predominantly sandy to sandy loam. The cultivars varied widely among orchards (Bing, Emperor Francis, Gold, Hedelfingen, Napoleon, Nelson, Ranier, Sam, Schmidt, Van, Vista, and Windsor), but the rootstocks in most orchards were mazzard seedlings.

Species belonging to *Pratylenchus, Criconemella, Xiphinema, Meloidogyne,* and *Paratylenchus* were detected in soil samples from 24, 11, 15, 17, and 17 of the 26 orchards, respectively (Table 1). *Pratylenchus* was most prominent in the northwest and west central regions, and *Criconemella, Pratylenchus,* and *Xiphinema* were most prominent in the southwest region. *Paratylenchus* and *Meloidogyne* were more abundant in soil samples from orchards in northwest Michigan than in those from the other two regions.

Bacterial canker ratings in the northwest, west central, and southwest regions were 1.5 ± 0.8, 1.3 ± 0.5, and 1.2 ± 0.4, respectively.

Incidence of bacterial canker, winter injury, and dead trees in selected orchards. The number of dead or replanted trees was higher in 1991 than in 1990, whereas the number of trees with canker symptoms on lateral branches or scaffold limbs varied with cultivars between years (Table 2). In orchards 3 and 4 in 1991, more Nelson trees had cankers than did Emperor Francis trees

but proportionally fewer Nelson trees were winter-injured (Table 2). In 1991, orchard 2 had more healthy Gold trees than Napoleon trees. Orchards 1 and 3 had the most dead or replanted trees, and orchards 2 and 5 were the healthiest. Winter injury was severe in orchard 3 and slight or absent in the other orchards (Table 2); however, winter injury was present in all tree health categories.

Isolation of *P. syringae*. Oxidase-negative fluorescent bacteria were isolated from 18–100% of leaves and cankers collected from each orchard (Table 3). *P. s. syringae* van Hall and *P. s. morsprunorum* (Wormald) Young et al were detected in each orchard except orchard 5, where only *P. s. syringae* was detected (Table 3). In 1990, populations of these bacteria were higher on leaves from trees with numerous cankers than on leaves from trees with no cankers (Table 4).

Nematode populations in selected orchards. Soil collected from each of the five orchards contained plant-parasitic nematodes. Nematode population densities were lower in 1991 than in 1990, except that the density of *X. americanum* Cobb in orchard 1 was significantly higher in 1991 (Fig. 1). *Pratylenchus penetrans* was detected in each orchard, with highest numbers in orchard 2 and lowest numbers in orchard 5. Numbers of *C. xenoplax* were highest in orchards 1 and 2, and numbers of *X. americanum* were highest in orchard 1 in 1991 (Fig. 1). Population densities of *M. hapla* Chitwood, *Paratylenchus* spp., and other plant-parasitic nematode species were low or not detectable in these orchards (*data not shown*).

Pratylenchus penetrans was extracted from root samples from each of the five orchards (Table 5). Populations were much higher in samples taken in the autumn of 1990 than in those taken in the summer and autumn of 1991. Root samples from orchard 4 consistently had the highest numbers of *Pratylenchus penetrans*.

The numbers of *Pratylenchus penetrans, C. xenoplax*, and *X. americanum* extracted from 100 cm^3 of soil samples and 1 g of root from declining (cankers on scaffold limbs) trees were 77, 13, and 97, respectively, compared with 90, 49, and 141 from healthy trees. Because there were significant ($P = 0.05$) differences in nematode numbers among tree health categories or orchards, data are means for 1990 and 1991 for orchards 1, 3, and 4.

Soil pH and nutrient status. Soil pH (water extraction) values were 4.8, 4.3, 5.4, 5.4, and 5.7 for orchards 1–5, respectively, and 2,246–4,616 kg/ha of lime was required to raise the pH of the soil to 6.5. Available soil Al concentrations were 0.015, 0.07, 0.013, 0.011, and 0.007 meq/100 g and soil pH (KCl extraction) values were 4.7, 3.8, 4.9, 5.1, and 5.9 for orchards 1–5, respectively. The relationship between soil and leaf nutrient concentration and supplement requirements varied with element and orchard (Fig. 2). For example, P was insufficient in leaves from orchard 3 and a soil supplement of 13 kg/ha of P was required to raise P to sufficient levels. Potassium was insufficient in orchard 2, but supplementary K of 60–202 kg/ha was required to raise soil K to sufficient levels in orchards 1–4. Magnesium was insufficient in leaves from orchards 3 and 5 and N was insufficient in leaves from all orchards except orchard 4, but neither element was insufficient in soil. The corresponding soil and leaf values for Ca were 1.2, 0.9, 3.55, 3.4, and 3.8 meq/100 g and 1.47, 1.54, 1.57, 1.62, and 23.0 ($\times 10^3$) μg/g dry weight for orchards 1, 2, 3, 5, and 4, respectively. Leaf concentrations of Ca were insufficient in all but orchard 4. The analyses for minor elements in leaf samples from the five orchards indicated that Fe, B, and Zn were sufficient in all orchards, Mn was insufficient in orchard 4, and Cu was insufficient in orchards 2–5 (*data not shown*). Leaf Al concentrations were

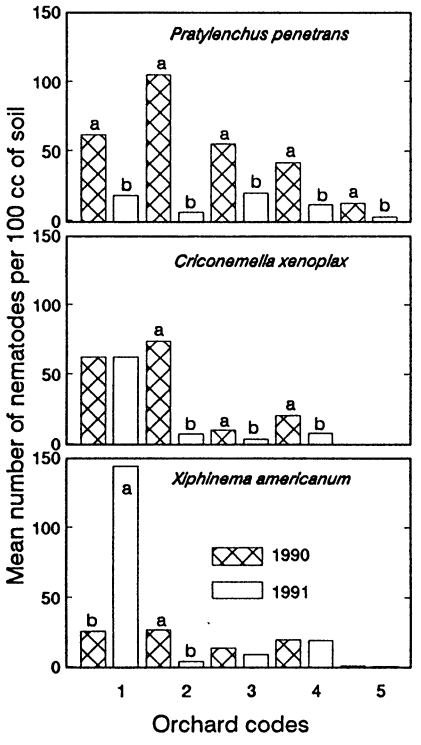

Fig. 1. Population densities of *Pratylenchus penetrans, Criconemella xenoplax*, and *Xiphinema americanum* recovered from soil samples taken in 1990 and 1991 under trees in five Michigan sweet cherry orchards. Bars with the same letters are not significantly different ($P = 0.05$) according to Tukey's studentized range test.

Table 5. Mean number of *Pratylenchus penetrans* nematodes extracted from roots of sweet cherry trees collected from all tree health categories in five Michigan orchards in autumn 1990 (A) and summer (B) and autumn (C) 1991

Orchard code	Nematodes per gram of root tissue[y]		
	A	B	C
1	402.1 bc[z]	8.7 d	39.9
2	150.1 c	14.0 d	43.0
3	711.1 ab	204.4 b	33.4
4	1,011.2 a	425.4 a	70.7
5	631.2 ab	120.2 c	32.3

[y] Each value is the mean of 12–23 root samples.
[z] Numbers followed by the same letter are not significantly different by Tukey's studentized range test ($P = 0.05$).

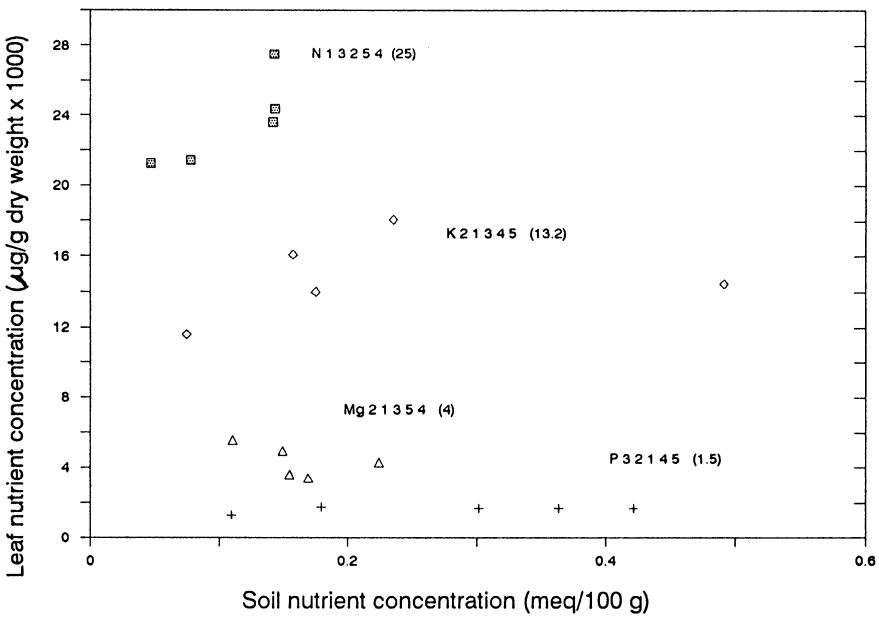

Fig. 2. Relationship between soil and leaf concentrations of nitrogen, phosphorus, potassium, and magnesium in five sweet cherry orchards in Michigan in 1991. Data points are represented by orchard codes. Numbers in brackets represent insufficient levels based on standards used by the Michigan State University Soil Testing Laboratory.

about four to 10 times higher in orchard 1 than in orchards 2–5 (Fig. 3).

DISCUSSION

Although a decline of sweet cherry trees was observed in orchards statewide, the intensity and type of biotic and abiotic factors associated with the decline differed in each orchard. The exceptions were low soil pH, high population densities of *Pratylenchus penetrans*, and the presence of *P. syringae*. Insofar as tree death is concerned, not all of the biotic and abiotic factors appeared to cause tree death by themselves.

Bacterial canker was detected in all of the orchards, which is consistent with previous studies conducted in Michigan (11,28,32), but the incidence did not appear to be sufficient to cause widespread tree loss of the type reported in peach orchards in the southeast (27,35) and in California (18,19). The increase in the number of trees with canker symptoms in 1991 over the number in 1990, particularly on lateral branches (Table 2), is probably due to the epidemic of *P. s. morsprunorum* that occurred in 1990 in northwest Michigan (28). Besides being an important inoculum source, the presence of high levels of *P. syringae* in these orchards may increase the potential for low-temperature damage if the trees are exposed to freezing temperatures in the autumn before they become fully dormant (31).

Information on the role of nematodes in the decline of mature sweet cherry trees is limited. Analysis of the data from the statewide survey and selected Michigan sweet cherry orchards showed that *Pratylenchus* had the highest density and frequency of occurrence (prominence value) of all nematodes (Table 1 and Fig. 1). Although *Pratylenchus penetrans* was detected at numbers higher than those reported to cause replant problems on cherry trees in New York (21,22) and peach trees in Ontario (24), there was no difference in population densities between healthy and declining trees or observable differences in tree growth in the studied orchards. While the lack of differences in numbers of *Pratylenchus penetrans* between healthy and diseased trees in our study suggests that mature trees can tolerate high numbers without apparent reduction in growth, the high population densities detected in these orchards indicate the need for treatment to suppress future nematode problems.

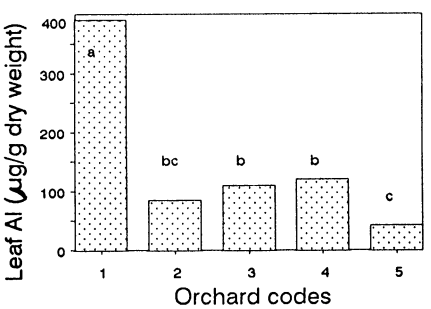

Fig. 3. Mean concentrations of aluminum in leaf samples taken from five Michigan sweet cherry orchards in 1991. Bars with the same letters are not significantly different ($P = 0.05$) according to Tukey's studentized range test.

Populations of other nematode genera were low in most orchards. However, isolated problems may exist in the occasional orchard with high population densities of a particular nematode. The detection of *X. americanum*, even in low densities, is of potential concern because of its role as a virus vector (33). The possibilities of transmission of tobacco ringspot virus by *X. americanum* in orchard 1 is being investigated (H. Melakeberhan). *C. xenoplax* has been shown to predispose peach trees to bacterial canker in California (18,19) and in the southeastern United States (26,35). Except for orchard 1 and possibly orchard 2, however, the population densities that we detected in our study were well below those reported in other studies (18,19,26). Although the presence of *C. xenoplax* might be significant in the particular orchards, it does not appear to be a statewide problem.

Winter injury, observed in all tree health categories, was a significant problem only in orchard 3. Research is needed on methods for assessing the winter hardiness of trunks and scaffold limbs so that procedures can be developed for preventing low-temperature injury to sweet cherry trees. The population density of ring nematodes in orchard 3 was well below those associated with outbreaks of cold injury on peach trees in the southeastern United States (27).

Soil pHs were well below the optimum of 6.5 recommended by the Michigan State University Soil Testing Laboratory for Michigan sweet cherry orchards. Low soil pH values were a common factor to all orchards and may have contributed to the decline problems that we observed. For example, low soil pH was associated with increased susceptibility of peach to infection by *P. syringae* (34). The reasons for low pH appear to be a combination of infrequent liming (as the growers' records show) as well as the use of ammonium nitrate as the common nitrogen-source fertilizer in these orchards. Low pHs affect the uptake and availability of nutrient elements (9). Although it is conceivable that nematodes may have impaired the uptake of some elements (14), it is more likely that low pH reduced the uptake of some of the essential elements (9). Thus, over time, nutritional insufficiencies may contribute to an overall decline in sweet cherry tree health. Moreover, low pH increases available Al in soil, and our detection of high leaf Al concentrations in leaves taken from trees in orchards with low pH values may reflect the greater availability of Al in soils in these orchards. Although Al toxicity levels for sweet cherry trees have not been established, the Al concentrations detected in leaves from trees in orchard 1 were similar to levels reported to be toxic to other *Prunus* spp. (6–8). Raising and maintaining the pH at recommended levels may increase the ability of trees to resist or at least withstand infection by pathogens.

Overall, this preliminary study documents some of the abiotic and biotic factors that may contribute to sweet cherry tree decline in Michigan. While it is not clear what the driving factor(s) is at this time, it is conceivable that low soil pH might be a major factor. In order to separate and explain the factor(s) and sequence of events that lead to sweet cherry tree death, the interactions of pH, soil Al, nematodes, and *Pseudomonas* spp. are being tested experimentally.

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