Influence of Orchard Ground Cover Management on the Development of Phytophthora Crown and Root Rots of Apple

I. A. MERWIN, Assistant Professor, Department of Fruit and Vegetable Science, Cornell University, Ithaca, NY 14853; W. F. WILCOX, Associate Professor, Department of Plant Pathology, New York State Agricultural Experiment Station, Cornell University, Geneva 14456; and W. C. STILES, Professor, Department of Fruit and Vegetable Science, Cornell University, Ithaca 14853

ABSTRACT

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Eight tree-row ground cover vegetation management systems—including a crown vetch "living mulch," close-mowed and chemically growth-regulated sod grasses, pre- and postemergence herbicide strips, a straw mulch, and monthly rototillage—were established in a newly replanted apple (*Malus domestica*) orchard. After 4 yr, Phytophthora crown or root rots (PCRR) had developed on 35% of the trees in straw mulch plots, whereas disease incidence was only 0–6% in other treatments. *Phytophthora cactorum*, *P. megasperma*, and *P. cambivora* were isolated from diseased trees. Stepwise regression and principal component analyses of soil physical and edaphic variables indicated that prolonged soil saturation and high soil K concentrations were closely associated with both straw mulch and PCRR incidence, although soil K was not considered to be a functionally causal or predisposing factor for PCRR. Soil temperature and bulk density varied significantly among the vegetation management systems but appeared not to be significantly correlated with PCRR occurrence. MM.111 clonal apple rootstocks were very susceptible to PCRR in this site. Trees in the sod grass and crown vetch plots remained free of symptoms of PCRR during the 4 yr of observation.

Crown and root rots caused by several species of *Phytophthora* often lead to weak growth and/or extensive mortality of deciduous fruit trees in the northeastern U.S. and elsewhere (3,16,24–26). Growers and researchers often have remarked on the close association between seasonally flooded or poorly drained orchard sites and the occurrence of Phytophthora crown and root rots (PCRR) (25,35). During the past decade, several controlled-environment studies have demonstrated that periods of soil saturation or flooding usually are needed to induce development of PCRR on seedlings of apple (*Malus domestica* Borkh.) and cherry (*Prunus mahaleb* L.) growing in sterilized soil media infested with *Phytophthora* spp. (5,37–39). However, the need for field data to corroborate these findings under actual orchard conditions has been noted (24,37).

In a survey of apple trees obtained from 15 commercial nurseries in the United States and Canada, Jeffers and Aldwinckle (15) found that 88% of grafted planting stock and 97% of unbudded rootstocks were infested with *Phytophthora cambivora* (Petri) Buisman and/or *P. cactorum* (Lebert & Cohn) Schröt. They also found 61% of orchard soils sampled in New York to be infested with five *Phytophthora* spp. and concluded that viable inoculum for PCRR probably was present in most newly planted apple orchards. Matheron et al (23) isolated *P. cactorum*, *P. cambivora*, *P. drechsleri* Tucker, and *P. parasitica* Dastur from trees or soil in 36 commercial apple orchards in Arizona, as well as from nursery planting stock. Such reports indicate that modification of the rhizosphere environment by chemical or cultural practices may provide a more feasible tactic for control of PCRR in apple rootstocks than exclusion of *Phytophthora* spp. from sites.

The objectives of this study were to determine the effects of various ground cover management systems on soil moisture, temperature, physical structure, and nutritional conditions over 4 yr in a newly planted apple orchard and to relate these effects to the development of PCRR. A brief report of this work was published previously (36).

MATERIALS AND METHODS

Experimental treatments and design. The experiment was established in a former apple orchard at Ithaca, NY, which had been fallowed the previous 8 yr. The soil was a Hudson type silty clay loam (Udic hapludalf) with 4–8% slopes, pH of 5.2–7.0, and a clay plowpan layer restricting internal drainage at a depth of 35–40 cm. Before planting, tile drains were installed at 30-m spacing throughout the site.

A mix of 70% Elka perennial ryegrass (*Lolium perenne* L.) and 30% Ensylva red fescue (*Festuca rubra* L.) was seeded over the entire site with an Astro oat (*Avena sativa* L.) nurse crop in April 1985. Trees of Empire and Jonagold apple on MM.111 rootstock from a single nursery source were randomized and planted the following April into augured holes 60 cm wide and 75 cm deep, backfilled with soil from the site. The plowpan layer at a depth of 35–40 cm was completely penetrated when auguring,

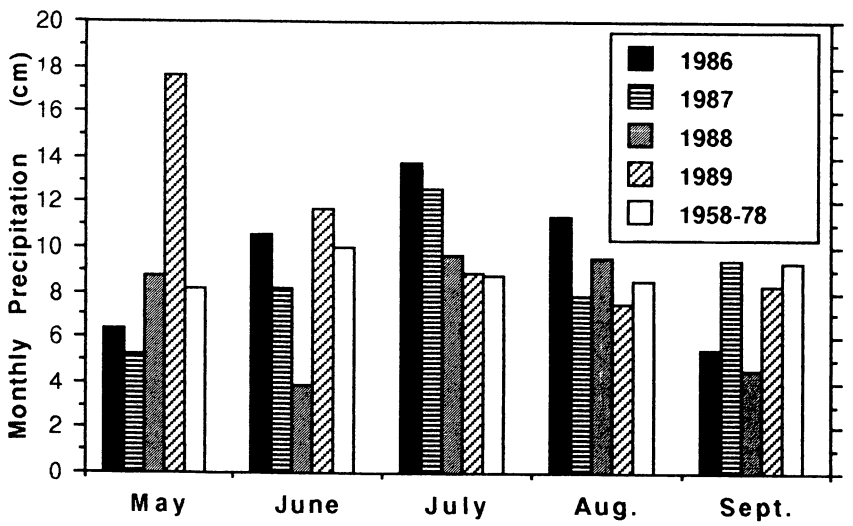

Fig. 1. Monthly rainfall recorded during the 1986–1989 growing seasons at an apple orchard at Ithaca, NY, and 20-yr precipitation averages.

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and the outer walls of every hole were roughened with a shovel to minimize root restriction and facilitate drainage through the planting holes. Individual trees were spaced 3 m within rows, and alternating rows of cultivars were spaced 6 m apart. After trees were planted, eight ground cover treatments were randomly assigned to individual experimental units consisting of eight adjacent trees within a row, in a split-block design with six replications of the following: 1) a "living mulch" leguminous ground cover of Penngift crown vetch (*Coronilla varia* L.); 2) a 1.5-m-wide "killed sod" strip provided by annual applications of the herbicide glyphosate (2 kg a.i./ha) each May and July; 3) a 2.5-m-wide killed sod strip, provided as above; 4) bare or nearly bare ground provided by annual applications of the herbicides norflurazon, diuron, and paraquat (tank-mixed at 3.0, 2.5, and 0.5 kg a.i./ha, respectively) each May; 5) the sod-grass mixture of red fescue and perennial ryegrass, mowed to maintain a height of 8–10 cm; 6) the same sod-grass mixture unmowed but treated annually in May and July with a growth suppressant (maleic hydrazide applied at 5 kg a.i./ha) and a broadleaf selective herbicide (2,4-D amine applied at 1.5 kg a.i./ha); 7) a hay-straw mulch of 15-cm depth (30 kg/tree), renewed annually in May; and 8) a clean-cultivated strip, provided by rototilling to a 10-cm depth monthly, May–August.

Evaluation of soil moisture and physical conditions. Soil matric potential was monitored at depths of 10–20 and 25–35 cm weekly from June through September 1986–1988, using two tensiometers in each plot. In 1988 and 1989, we also used a Model 503-DR neutron-source hydroprobe (CPN Corp., Pacheco, CA) to evaluate soil moisture. Actual measurements of the hydrogen-atom density around a single access tube near the center of each plot were converted to soil moisture content by calibration with gravimetric analyses of simultaneously extracted soil samples on two sampling dates, one with relatively wet and another with dry soil conditions. Moisture release characteristics and bulk density of soil samples from each of the 48 replicates were determined using standard techniques (27). Gravimetric water-content data then were converted to kiloPascals (kPa) of soil matric tension by least squares fitting of a quadratic regression using the moisture-release curve and field calibration data.

Soil also was sampled at depths of 0–20 and 20–40 cm each year in April, and extractable soil nutrient concentrations were determined in the Cornell University Soil Nutrient Analysis Laboratories, Ithaca, NY. Leaf samples were taken each August for nutrient analysis (dry-weight basis) by inductively coupled argon-plasma photospectrometry in the Fruit and Vegetable Science Department's Plant Tissue Analysis Lab at Cornell University. Soil temperatures at 5-cm depths within treatment plots, but outside tree shadows, were measured from May to September 1989 using a thermistor probe. Average soil bulk density at a depth of 2–10 cm was determined in July and October 1989 by taking 7.6 × 8.0 cm cylindrical cores from each row with a Coile-type sampling tube. Data were subjected to analysis of variance and treatment mean separations based on Tukey's honestly significant difference (HSD) using a microcomputer statistical package (1). Multivariate statistical methods were deemed appropriate for the large number of variables and possible interactions in this study; data were, therefore, also subjected to principal component and multiple regression analyses (13).

Disease evaluation and identification of causal agents. Trees were examined each autumn from 1986 to 1988 for foliar symptoms of PCRR (i.e., premature leaf reddening, sparse terminal growth, and wilt). In 1988, disease incidence was assessed by excavating soil from around the trunks of symptomatic trees, then removing the outer bark from portions of the crown and roots to reveal a reddish brown cortical necrosis characteristic of PCRR. Field diagnoses were confirmed by removing necrotic cortical tissues from every third tree, transporting these samples to the laboratory in an ice chest, and isolating *Phytophthora* spp. on a selective medium containing cornmeal

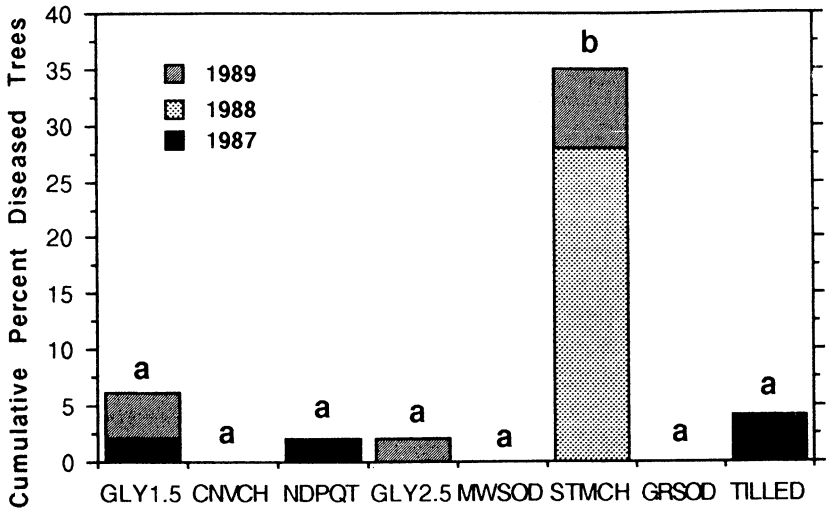

Fig. 2. Cumulative percentage of trees in each treatment with Phytophthora crown and root rots, 1987–1989. Columns beneath same letter are not significantly different at $P < 0.05$, based on Tukey's HSD for means of six replicates. GLY1.5 and GLY2.5 = glyphosate herbicide strip, 1.5 and 2.5 m wide; CNVCH = crown vetch "living mulch"; NDPQT = norflurazon + diuron + paraquat herbicides; MWSOD = mowed sod grass; STMCH = hay straw mulch; GRSOD = growth-regulated sod; and TILLED = rototilled.

Table 1. *Phytophthora* species isolated from symptomatic trees in July 1989

Treatment	Row-Tree[z]	Tissue	*Phytophthora* species recovered
Straw mulch	4-2	Crown	*P. cactorum*
Straw mulch	7-3	Crown	*P. cactorum*
	7-7	Crown	*P. megasperma* AC
		Root	*P. megasperma*; *P. megasperma* AC
	7-8	Crown	*P. cactorum*; *P. megasperma*; *P. megasperma* AC
		Root	*P. megasperma*
Glyphosate (1.5 m)	10-6	Root	*P. cactorum*
	10-8	Crown	*P. cactorum*
Straw mulch	22-1	Crown	*P. cactorum*
	22-3	Crown	*P. cambivora*
	22-6	Crown	*P. cactorum*
		Root	*P. megasperma*
	22-7	Crown	*P. megasperma*
Straw mulch	29-2	Crown	*P. megasperma*; *P. megasperma* AC
	29-3	Crown	*P. megasperma*
	29-4	Crown	*P. cactorum*
	29-8	Crown	*P. cambivora*; *P. megasperma* AC
Straw mulch	34-6	Crown	*P. megasperma*
Straw mulch	37-3	Crown	*P. cactorum*; *P. cambivora*
	37-6	Crown	*P. cactorum*; *P. cambivora*; *P. megasperma*

[z] Tree numbers designate position within rows, with higher numbers lower on slope.

agar, pimaricin, ampicillin, rifampicin, PCNB, and hymexazol (i.e., P_5ARPH [15]), using previously described procedures (35). Disease incidence was assessed again on the basis of foliar symptoms in July 1989. Root and/or crown tissue samples then were collected from every symptomatic tree, and 20 tissue pieces from each tree were surface-disinfested in 70% ethanol and plated onto P_5ARPH medium, as before. Emerging colonies resembling *Phytophthora* spp. were subcultured onto Difco cornmeal agar (CMA) and subsequently identified to species based on colony morphology on CMA and V8 juice agar, cardinal temperatures for growth, morphologies and dimensions of sporangia, and the production and morphologies of oogonia and antheridia, using techniques described previously (17,34). Isolates identified as *P. megasperma* Drechs. were further identified as belonging to the BHR and AC subgroups (10) based on oospore size and vegetative growth characteristics (40).

RESULTS

Disease incidence and *Phytophthora* species isolated. The first year after establishment, a few trees with symptoms characteristic of PCRR died and were replaced. During the relatively dry summer of 1987 (Fig. 1), a few more trees began to show symptoms of PCRR, but in neither year was there a statistically significant association between treatments and apparent disease incidence. However, by autumn of 1988, 13 of 48 trees in the straw mulch treatment had foliar symptoms and cortical necroses typical of PCRR, and *Phytophthora* spp. were isolated from root and crown tissues of every symptomatic tree. By July 1989, cumulative disease incidence had reached 35% in the straw mulch treatment but was only 0–6% in all other treatments (Fig. 2). Chi-square tests of cumulative PCRR incidence from 1986 to 1989 indicated a highly significant ($P < 0.001$) deviation from expected values across treatments, and analysis of variance of arcsine square root transformed data showed that the percentage of trees with PCRR was significantly higher ($P < 0.05$) in the straw mulch treatment than in all others (Fig. 2). *Phytophthora* spp. were isolated from each of the 17 trees sampled in July 1989. Species were identified as *P. cactorum* (10 trees), *P. cambivora* (four trees), and both the BHR and AC subgroups of *P. megasperma* (nine trees). Frequently, more than one *Phytophthora* sp. was isolated from a single tree (Table 1).

Effects on soil moisture. Moisture content in the upper 35 cm of the soil profile was greatly affected by ground cover treatments (Figs. 3 and 4) and varied among years, as well as months, during each growing season. Tensiometers were used to measure soil water matric tension in 1986 and 1987, and these instruments are accurate only within the range of zero to 85 ± 3 kPa of matric tension. In several treatments, soil water tension often exceeded 85 kPa during 1986 and 1987; thus, monthly mean water tensions >60 kPa (Fig. 3) are only approximations and probably underrepresent actual mean tensions because a value of 99 kPa was recorded on monitoring dates when soil water tension exceeded the operational range of tensiometers. Data for these 2 yr are presented for reference without statistical analysis. Because the straw mulch treatments remained within the tensiometer range for all readings, the monthly means for this treatment in 1986 and 1987 are accurate and indicate that soil matric tension remained substantially lower under the straw mulch than in other treatments during the first 2 yr of this study.

The higher range of soil matric tensions in the graphs for 1988 and 1989 (Fig. 4) are converted values based on hydroprobe counts, which are accurate over the observed range of soil moisture. Analysis of variance and HSD mean separations indicated that straw-mulched soil was significantly ($P < 0.05$) more moist than any other treatment in 1988 and 1989. Matric potential in early summer was near zero under straw mulch but decreased substantially during the course of each season as quackgrass (*Agropyron repens* L.) invaded these plots and increased soil water evapotranspiration.

Effects on soil temperature and structure. Soil temperatures also differed significantly among treatments and months (Fig. 5). Within each month, temperatures generally were lowest in the crown vetch and straw mulch treatments, and highest in the herbicide and rototilled treatments with bare soil more exposed to sunlight. No apparent differences related to treatment or soil temperature were observed in anthesis, leaf abscission, or the onset of dormancy. However, trees in the herbicide and straw mulch treatments continued shoot growth during the drought in June and July 1988; in contrast, trees in the sod grass and crown vetch treatments ceased growth, formed terminal buds, and did not resume growth even when the drought ended later that summer (Fig. 1). Soil bulk density was higher in herbicide treatments and lower under vegetative ground covers, but the observed values (1.08–1.26 g/cm^3) for all treatments remained within ranges generally

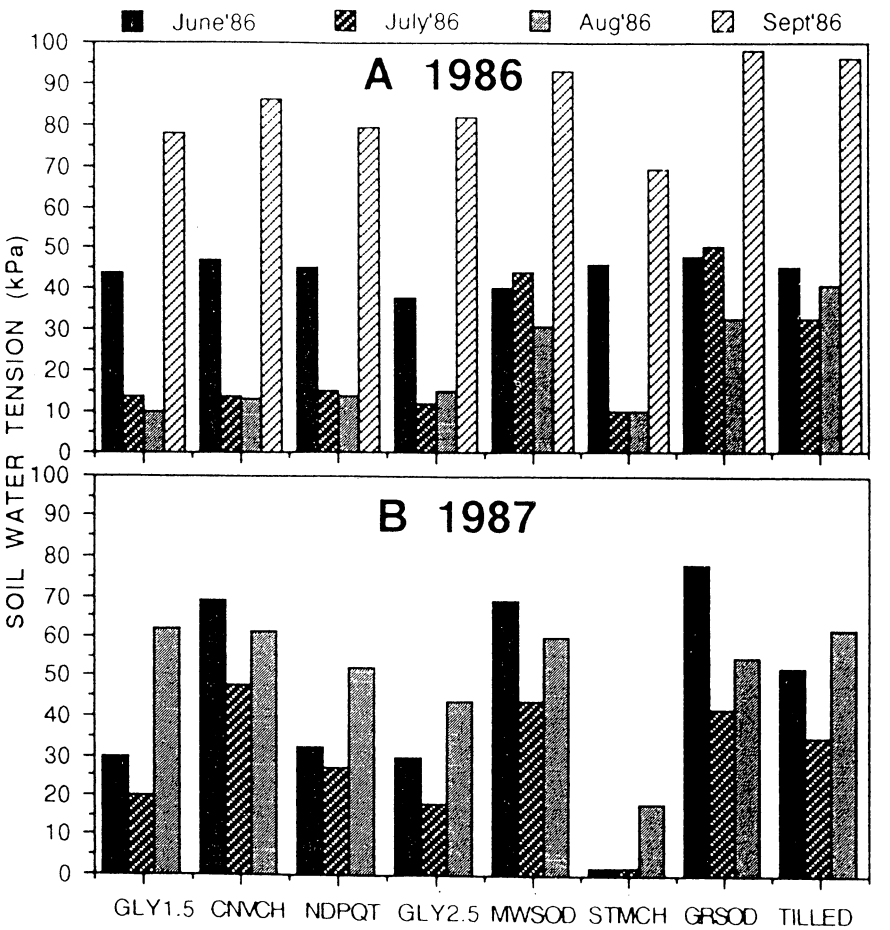

Fig. 3. Monthly mean soil water tension at depths of 10–35 cm under each ground cover treatment in **(A)** 1986 and **(B)** 1987, determined with tensiometers. Mean values above 85 kPa underrepresent actual soil matric tensions, due to operational limitations of the tensiometers.

considered suitable for normal apple root metabolism and growth (2,28,32).

Effects on soil nutrients, pH, and organic matter. Potassium was the only essential soil nutrient affected significantly by treatments, and by 1989, extractable soil K concentrations were twofold to threefold higher under straw mulch than in other treatments (375 vs. 123–149 kg/ha). However, soil K concentrations in all treatments remained within ranges generally considered optimal for K supply in apple trees. Soil pH ranged from 6.3 to 6.8 and organic matter from 3.8 to 5.0%, with no significant differences among treatments. All other essential soil nutrients remained within ranges sufficient for apple trees during the 4 yr of observations.

Relationship between soil conditions and PCRR incidence. To explore the association between PCRR, tree physiology, and edaphic conditions, which varied among treatments and might affect root disease incidence, 32 variables (extractable P, K, Ca, Mg, Mn, Fe, Cu, Zn, and B; pH; organic matter; 1987, 1988, and 1989 seasonal and monthly means for soil moisture content and temperature; soil bulk density; soil pore size distribution; and relative rates of increase in trunk circumference) were subjected to multivariate statistical analyses. An initial stepwise regression model indicated that available soil K and soil matric tension during July 1988 were significant predictor variables for cumulative PCRR incidence. The regression equation is as follows: % PCRR = −0.3 (July 1988 kPa) + 0.58 (soil K) + 0.04, with all variables standardized, adjusted $R^2 = 0.52$, $F = 24.3$, df = 43. Because the likelihood of multicolinearity among so many predictor variables is high, principal component (PC) analysis was used to transform the original variables into a smaller set of orthogonal variables to evaluate the latent dependence structure within variables (13). Variables with relatively large coefficients and significant positive loadings or correlations with a PC are interpreted as the major factors characterizing each component; those with significant negative loadings vary inversely with the other positively loaded variables within that PC (1). Four principal components accounted for 62% of the total variance in the data (Table 2). Soil matric tension was highly correlated with the first PC and the incidence of PCRR, and availability of soil base cations and Fe varied inversely with matric tension within that PC. The second PC was highly correlated with soil pH and available Mg and Ca and negatively correlated with soil K and PCRR incidence. The third PC was positively correlated with soil P and Cu, which were negatively correlated with relative trunk growth rates and soil bulk density. The fourth PC was positively correlated with soil temperatures, bulk density, and available B. When these four PCs were used as input variables for analysis of variance and treatment mean separation, the straw mulch effect appeared to be the major influence upon the first two PCs, relative to the other ground cover treatments (Table 3).

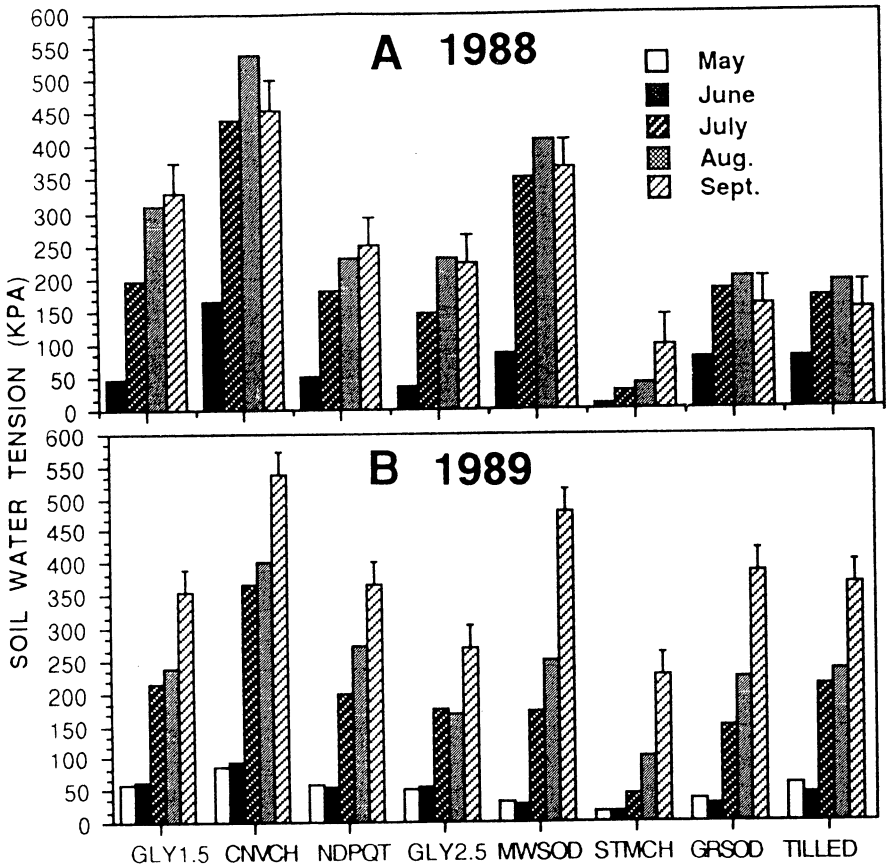

Fig. 4. Monthly mean soil water tension at depths of 10–35 cm under each ground cover treatment during **(A)** 1988 and **(B)** 1989 growing seasons, determined using neutron-source hydroprobe. Pooled standard error bars shown are for means of six replicates and can be used for comparisons across treatments.

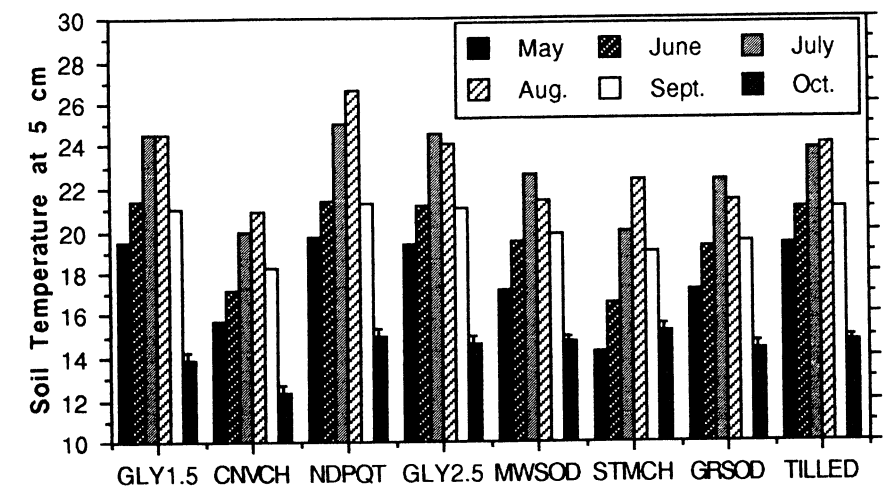

Fig. 5. Monthly mean soil temperatures at 5 cm under each treatment during the 1989 growing season, with pooled standard error bars for means of weekly observations in six replicates.

DISCUSSION

The high incidence of PCRR disease that developed on trees in the straw mulch treatment provided an opportunity to compare and validate data from earlier controlled-environment studies with field measurements of edaphic variables associated with an epidemic under orchard conditions. Previous reports that extended periods of soil saturation greatly increase both the incidence and severity of infection by *P. cactorum*, *P. cambivora*, and *P. megasperma* on several deciduous fruit and nut tree root-

stocks (5,6,22,38,39) were supported by our field data. Although we could not quantify the duration of soil saturation episodes precisely enough to determine the minimum periods required for initiation of disease, average weekly soil water tensions under the straw mulch remained near zero throughout late spring and early summer during 1987–1989 in this study (Figs. 3 and 4), even during a very dry June 1988 (Fig. 1). It appears, therefore, that even periods of moderate rainfall resulted in periods of soil saturation in the root zone under straw mulch, allowing the initiation and development of PCRR.

Bloom time has been widely reported as the period when apple trees are most susceptible to infection by several *Phytophthora* spp. (8,14,29). It is also a period when soils are commonly saturated in northeastern apple orchards (Fig. 4B), due to accumulated snowmelt, rainfall, and low evapotranspiration rates. Although we did not measure soil moisture during May 1988, most of the rainfall that month occurred during bloom (5 cm from May 18 to 26), and visual observations of standing water and substantial surface runoff in the orchard at that time suggested the soil was saturated in all treatments for several days. A severe drought occurred during June and July 1988; above-average temperatures further depleted soil moisture content in most of the ground cover treatments (Fig. 4A). Drought stress curtailed the growth of trees in the sod grass and crown vetch plots during 1988, while soil water supply in the herbicide and tilled plots remained within ranges marginally adequate for normal growth and physiology of apple (9,18). No significant increase in PCRR infection occurred in these treatments during 1988. In contrast, soil water tension averaged 6 and 19 kPa under straw mulch in June and July 1988, respectively, significantly lower than all other treatments ($P < 0.05$) during the onset of the PCRR epidemic in those plots. These observations suggest that both episodic infection periods and subsequent seasonal soil moisture conditions may be important determinants of PCRR in apple tree rootstocks.

The stepwise regression results indicate that both soil matric tension during July 1988 and soil K availability were significant predictor variables for PCRR incidence. The fact that July, rather than June, matric tension remained in the model further suggests the importance of seasonal as well as episodic soil moisture in PCRR etiology. We are not aware of any evidence that a causal relationship exists between elevated soil or plant tissue K content and host susceptibility to PCRR. Extractable soil K did increase substantially in the straw mulch treatment, which is consistent with previous observations (12). Therefore, we suggest that soil K remained in the multiple regression model as a covariate closely associated with the straw mulch treatment, rather than a functionally causal or predisposing factor for PCRR. The PC analysis results support this interpretation, because PCRR incidence and soil K were significant negative correlates of soil matric tension in the first and second PCs (Table 2), and the mean scores for those two PCs were highest in the straw mulch treatment (Table 3).

The question of soils "suppressive" to diseases caused by *Phytophthora* spp. has received some attention (21), with evidence of reduced PCRR incidence in soils high in organic matter and decomposing plant litter (30). We observed decreases in soil organic matter over the course of this study in all treatments, although hay straw mulches have been widely reported to increase soil organic matter over longer time spans (11). Apple orchards in the Tatura Valley of Australia with fine-textured soils and restricted rooting depth have benefited from regular additions of straw mulch, with reported improvements in soil structure, organic matter, aeration, and tree growth (33). However, in another silty clay loam site in Australia, Black (4) reported responses similar to our own observations—an increase in saturated pore space and soil moisture content and higher mortality of peach trees under straw mulch. These apparent contradictions may be a function of site-specific physical/chemical characteristics, the availability of *Phytophthora* spp. and/or potential antagonistic microflora, or particular environmental conditions occurring in some studies but not others. They underline the need for more long-term experiments under a wide variety of field conditions to examine the relationship between ground cover management and tree root disease. Nevertheless, our data suggest that management systems that maintain high levels of soil moisture for prolonged periods may promote development of PCRR when inoculum availability and constitutive soil factors are otherwise conducive to this disease.

Effects of temperature on the survival and germination of sporangia of *Phytophthora* spp. have been well documented (7,19,20,31) and correlated with

Table 2. Principal components (PC)[x] of soil physical and nutritional conditions and arcsine square root transformed cumulative percentage of trees with Phytophthora crown or root rots (PCRR), PC regression coefficients (C), and significance of correlation coefficients or loadings (L)

Variable[y]	PC1		PC2		PC3		PC4	
	C	L	C	L	C	L	C	L
% PCRR	0.32	−0.63**[z]	0.30	−0.55**	0.02	−0.02	0.08	−0.12
RGRate 1987–1989	0.15	−0.30	0.20	−0.36	0.36	−0.57**	−0.08	0.12
Soil kPa 1987	−0.37	0.73**	−0.23	0.43*	−0.21	0.34	−0.01	0.02
Soil kPa 1988	−0.36	0.72**	−0.18	0.33	−0.05	0.09	−0.20	−0.28
Soil kPa 1989	−0.37	0.74**	−0.18	0.33	0.11	−0.17	0.14	−0.20
Soil temperature 1989	−0.07	0.13	−0.05	0.10	0.24	−0.38	−0.48	0.68**
Bulk density	0.05	−0.09	−0.08	0.15	0.38	−0.60**	−0.37	0.52**
Soil P 1987–1989	0.10	−0.19	0.20	−0.36	−0.43	0.68**	−0.17	0.24
Soil K 1987–1989	0.33	−0.65**	0.26	−0.48*	0.02	−0.03	0.30	−0.42
Soil Ca 1987–1989	0.30	−0.59**	−0.37	0.68**	−0.10	0.16	−0.01	0.02
Soil Mg 1987–1989	0.27	−0.53**	−0.40	0.73**	0.02	−0.03	−0.05	0.08
Soil Fe 1987–1989	−0.27	0.54**	0.33	−0.60**	0.10	−0.15	−0.07	0.09
Soil Cu 1987–1989	−0.04	0.07	0.10	−0.19	−0.45	0.70**	−0.31	0.44*
Soil B 1987–1989	−0.05	0.10	0.23	−0.42	−0.20	0.32	−0.41	0.58**
Soil pH 1987–1989	0.27	−0.54**	−0.38	0.71**	−0.09	0.14	−0.05	0.07
Eigenvalue	3.9		3.4		2.5		2.0	
% Total variance	21		18		13		10	

[x] Variables in the principal component analysis without a significant loading on the first four PCs were excluded from the table.
[y] %PCRR = arcsine-square root transformed cumulative percentage of trees with Phytophthora root or crown rot in 1989. RGRate = average relative growth rate of trees during 1987–1989. Soil kPa values are yearly growing season means for matric tension at a depth of 5–35 cm. Soil nutrient values are averages at depths of 0–20 cm during 1987–1989 observations.
[z] Significance levels of loadings are designated * for $P < 0.05$ and ** for $P < 0.01$.

Table 3. Relationship between ground cover management systems and principal components (PC) of soil physical and edaphic conditions

Treatment[y]	PC1	PC2	PC3	PC4
CNVCH	−0.86 a[z]	−0.81 a	−0.28 ab	1.13 c
GLY 1.5	−0.37 a	0.18 b	0.74 b	−0.62 ab
MWSOD	−0.36 a	−0.35 ab	−0.83 ab	0.60 bc
GRSOD	−0.24 ab	−0.15 ab	−0.97 a	−0.35 a–c
TILLED	−0.24 ab	0.07 ab	−0.04 ab	−0.16 a–c
NDPQT	−0.08 ab	0.13 ab	0.81 b	−1.11 a
GLY 2.5	0.53 b	−0.63 ab	0.73 b	−0.65 ab
STMCH	1.57 c	1.45 c	0.07 ab	0.86 bc
SE	0.19	0.20	0.35	0.32

[y] CNVCH = crown vetch living mulch. GLY 1.5 and 2.5 = wide and narrow strips of glyphosate herbicide. MWSOD = close-mowed sodgrass. GRSOD = growth-regulated sod. TILLED = rototillage. NDPQT = norflurazon-diuron-paraquat herbicide strip. STMCH = hay-straw mulch.

[z] Means within a column followed by the same letter are not significantly different at the $P < 0.05$ level of probability, based on Tukey's HSD for mean of six observations.

disease development (7,40). In our study, the treatments most dissimilar in PCRR incidence were most similar in soil temperature, with seasonal means of 17.4 C under crown vetch and 17.9 C under straw mulch. Thus, while soil temperature varied significantly among treatments in this study, such differences apparently had no demonstrable effect on the incidence of PCRR.

The association of individual species of *Phytophthora* with diseased trees varied within the orchard in relation to slope and microsite drainage. In particular, *P. megasperma* was isolated exclusively from trees planted on the downslope end (trees six to eight) of rows, and in one especially wet, low-lying area within the field (row 29) (Table 1). This observation is consistent with previous reports that significant root rot of Mahaleb cherry was caused by *P. megasperma* only after longer periods of soil saturation than those required for initiation of disease by *P. cryptogea* (37) and that root rot of red raspberry apparently is caused by *P. megasperma* only under extremes of soil moisture beyond those required for pathogenesis by more virulent *Phytophthora* spp. (34).

All trees in this study were on MM.111 rootstock, a clonal line often recommended as the rootstock of choice in poorly drained orchard sites and purportedly "field resistant" to PCRR (14). Our data suggest that MM.111 is probably not resistant or even tolerant of PCRR under seasonally wet field conditions, a hypothesis further supported by many isolations of *P. cactorum* and *P. megasperma* from diseased MM.111 rootstocks throughout New York during 1984–1989 (W. F. Wilcox, *unpublished*). Mulches of plastic, straw, and other materials are widely used for weed control and moisture conservation in horticultural plantings and are generally reported to increase soil moisture, promote rapid tree growth and development, and enhance nutrient availability (12). Our field study demonstrated that hay straw mulches may also considerably increase the risk of PCRR outbreaks in some sites, at least on silty clay soils with restricted internal drainage. Although the healthy straw-mulched trees initially outgrew and outyielded all others in this study, nearly 35% were dead or dying of PCRR after 4 yr, indicating that soil moisture levels that optimize apple-tree growth are perilously close to those that can lead to PCRR disease.

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