Phytophthora Root and Stem Rot of Apple Rootstocks from Stool Beds

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ABSTRACT

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Phytophthora stem and root rot occurred on EMLA.106 apple rootstocks in stool beds as early as May, and new infections occurred throughout the growing season. *Phytophthora cactorum* and *P. cambivora* were recovered from infected shoots or roots and were identified as the causal agents of the disease; *P. cactorum* was isolated more frequently. Isolates of both species caused necrosis on excised stem pieces at 15 or 24 C, but isolates of *P. cactorum* were more virulent than those of *P. cambivora*. Field applications of fosetyl-Al and metalaxyl to apple rootstocks reduced disease severity in the field, reduced lesions on excised stem pieces inoculated with *P. cactorum*, and reduced disease development on apparently healthy rootstocks while in cold storage for 3–9 mo. Short-duration root dipping of healthy or mildly infected rootstocks before cold storage in high concentrations of benalaxyl, etridiazol, fosetyl-Al, or metalaxyl reduced disease, but the degree of reduction varied. Fosetyl-Al and metalaxyl consistently produced the best results. None of the materials were phytotoxic.

Phytophthora crown and collar rots of orchard apple trees occur worldwide. A number of species of *Phytophthora* have been associated with the disease in orchards, including *P. cactorum* (Lebert & Cohn) Schröt., *P. cambivora* (Petri) Buisman, *P. megasperma* Drechs., and *P. syringae* (Kleb.) Kleb. (10,13,17).

There has been controversy over whether disease in the orchard is the result of planting contaminated nursery stock or infection by pathogens in inoculum indigenous to the orchard site or already present as a result of a previously infected crop. Some studies have noted that *Phytophthora* spp. may be indigenous in native habitats (10,23), while others indicated that tree deaths in an apple orchard from *Phytophthora* spp. are caused by the presence of these fungi in residue of a previously infected crop (21) or from contaminated irrigation water (8,18,19,24). Based on the recovery of *Phytophthora* spp. from unbudded apple rootstocks (2,9,10,15,17), however, it is highly likely that *Phytophthora* spp. in some orchards could have originated with the nursery stock. Such findings suggest that *Phytophthora* spp. are present in stool beds and that infected rootstocks are one source of primary inoculum in young orchards. Although rootstocks are graded for quality, health, and size before shipping, contaminated (but symptomless) plant material apparently still leaves production sites (2,9,10,15,17).

To our knowledge, nursery stool beds have not been examined previously to confirm the presence of *Phytophthora* spp. Since a small number of nurseries produce the majority of apple rootstocks used by orchardists in both Canada and the United States, our study was conducted to understand better the etiology, epidemiology, and potential control of Phytophthora stem and root rot as it occurs in apple stool beds

MATERIALS AND METHODS

Field procedures. Infected shoot samples were selected in 1985 and 1986 from a commercial field of EMLA.106 apple rootstocks in the Pacific Northwest. The field was known to be heavily diseased by *Phytophthora* spp. The semidwarfing rootstock EMLA.106 is particularly susceptible to *Phytophthora* infection (2,10,15,20,31) and we considered it ideal for studying the disease and the effects of various control measures.

Experimental stool bed rows were selected and treated with different fungicides by the grower. Fungicide treatments applied to rootstocks in the field plots in 1985 included fosetyl-Al applied twice during the season at 3.4 kg a.i./ha; fosetyl-Al applied three times at 3.4 kg a.i./ha; and fosetyl-Al and metalaxyl each applied once to the same plot (fosetyl-Al at 3.4 kg a.i./ha and metalaxyl at 8.9 kg a.i./ha). There was also an untreated control plot.

Experimental plots received the following fungicide treatments beginning in May 1986: four applications of fosetyl-Al applied at 2.2 or 4.5 kg a.i./ha every 2 mo; three applications of metalaxyl applied at 8.9 kg a.i./ha every 3 mo; and seven monthly applications of fosetyl-Al applied at 1.1 or 2.2 kg a.i./ha. Again, a control plot received no fungicide treatments.

Visibly diseased roots, mother stocks, and shoots from the current season's growth that appeared healthy or that showed various characteristic symptoms of the disease were collected. In 1985, samples were collected biweekly between June and November. In 1986, samples were collected at monthly intervals between July and November.

Sawdust used in the stool beds was qualitatively assayed for the presence of *Phytophthora* spp. Collections were made at midsummer in 1985 and 1986 from the source pile and from between and within rows of apple stool beds. In autumn 1986, samples also were taken from adjacent to visibly diseased stems.

Isolation techniques. Diseased stems and roots collected from the experimental blocks were surface-disinfested with 0.5% sodium hypochlorite. Stems were disinfested for 10 min, roots for 5 min. Stem and root samples were then rinsed twice for 5 min in sterile distilled water and plated on two types of *Phytophthora*-selective isolation media. The first type included two different cornmeal agar media: CMPV (17 g Difco cornmeal agar, 20 mg/L pimaricin, 20 mg/L vancomycin, 1 L distilled water) and PVRPH (30) containing pimaricin, vancomycin, PCNB, rifampicin, and hymexazol, but modified by adding vancomycin at 250 mg/L and rifampicin at 10 mg/L. The second was Schmitthenner's selective V-8 medium (27). Clarified V-8 juice concentrate was prepared using the procedures of Pratt and Mitchell (25). V-8 agar amended with beta-sitosterol was used to enhance oospore production (26). Ten pieces each were taken from symptomatic stem and root tissues. Five pieces were plated on a petri dish containing V-8 agar; the other five pieces were plated on a dish containing cornmeal agar. The plates were then incubated in the dark at room temperature (20–23 C) or at 15 C.

The floating eucalyptus leaf disk bait assay of Linderman and Zeitoun (16) was used to isolate *Phytophthora* spp. from roots, soil, and sawdust collected from apple stool beds. Five to ten leaf disk baits (0.4-cm diameter) from each sample assay were plated on the selective media described above.

Pathogenicity tests. Pathogenicity tests for recovered isolates of *Phytophthora* spp. were conducted using the

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excised-stem-piece assay of Jeffers et al (12), in which stem pieces 6.5 cm in length were inserted into *Phytophthora* colonies on 1-cm deep agar in 473-cc (1 pt) canning jars. This same method was used to assay residual chemicals in stem pieces collected from the field plots or from harvested rootstocks. Each jar was a treatment replicate containing five stem pieces; there were five replicate jars per treatment.

The test jars were incubated in the dark at 15 or 24 C. For the 15 C test, stem pieces collected from dormant shoots were inoculated with three isolates of *P. cactorum* (P-58, P-91, P-115), two isolates of *P. cambivora* (P-112, P-108), and one isolate of *P. syringae* (P-85), all of which were originally recovered from apple rootstocks taken from stool beds. Experiments were terminated after a 4-wk incubation period and lesion lengths on individual stem pieces were measured. For the test at 24 C, the stem pieces were cut from actively growing stool bed shoots in the untreated control block. The stem pieces were inoculated with two isolates of *P. cactorum* and two isolates of *P. cambivora* and then incubated for 10 days. Lesion lengths were measured at the end of the 10-day period.

To test for residual fungicide effects in apple shoots after field application, stem pieces were collected from stool bed shoots that had been treated in the field during 1986. The stem pieces were inoculated as previously described with a virulent isolate of *P. cactorum* and then incubated in the dark at 24 C.

Chemical root dips. We conducted an experiment to study the efficacy of post-harvest chemical dip treatments in eliminating *Phytophthora* spp. on EMLA.106 apple rootstocks. Each of three chemical solutions was used at three concentrations and compared with a tap water control. The chemical solutions were prepared at the following concentrations: benalaxyl and metalaxyl at 1,000, 2,000, and 4,000 mg/L; etridiazol at 155, 233, and 468 mg/L; and fosetyl-Al at 6,000, 12,000, and 24,000 mg/L. Trees were separated into two health classes. Those in health class 1 showed neither signs nor symptoms of disease and were graded as apparently healthy. Trees in health class 2 had a few small lesions, generally located at one of the underground nodes of the stem, and were graded as infected. (Trees in the health class 2 are normally discarded by nursery operators.) Trees from the two classes were dipped in chemicals before cold storage, after cold storage, or at both times. All trees were planted in containers in the greenhouse after the post-cold storage chemical treatments.

Trees in each treatment were tied with string into bundles of 10 and dipped for 10 min. All trees within a health class received simultaneous pre-cold storage dips, with the trees in health class 1 being dipped before those of class 2. After dipping, the excess solution was allowed to drain from the bundles. Each bundle was then placed into a plastic bag containing 2 L of pasteurized (aerated steam, 60 C for 30 min) sawdust, tied with string, and stored in a dark, cold room at 2 C for 3 mo. After removal from cold storage, trees in two of the treatment groups were dipped again.

Greenhouse procedures. Trees collected from field trials or treated with chemicals in the root dip trial were grown in the greenhouse in 9-cm square plastic pots (15 cm deep), each with its own saucer. Pots contained a pasteurized (aerated steam, 60 C for 30 min) soil mixture composed of equal volumes of sand, peat, and field soil. Potted plants were placed on the benches in a completely randomized treatment design. The plants were maintained in the greenhouse for 3 mo during spring and summer without supplemental lighting. The average day temperature in the greenhouse was 24 C; the average night temperature was 15 C. The trees were flooded with water for 48 hr once every 2 wk to enhance the activity of *Phytophthora* spp. The first flooding was 2 wk after planting and the last flooding was 2 wk before harvest.

Plants grown in the greenhouse were rated for disease at the time of harvest. The ratings used a 1–5 scale based on the percentage of underground stem length with lesions, where 1 = no visible lesions, 2 = 1–25% with lesions, 3 = 26–50% with lesions, 4 = 51–75% with lesions, and 5 = 76–100% with lesions.

Data analysis. One-way analysis of variance, followed by mean separation using Fisher's protected Bayes LSD test, was used to analyze the results of all experiments except the chemical root-dip experiment; for it, we used a three-way analysis of variance. Duncan's multiple range test was used to determine significant differences between the means of trees graded for health and disease development after 9 mo of cold storage.

RESULTS

Disease description. Symptoms of Phytophthora root and stem rot in apple stool beds were observed as early as May and continued to develop throughout the growing season, which ended in October. The disease was more widespread in low-lying areas in a field, although it was not restricted to those areas. Bare patches were visible where the disease had spread along a row (Fig. 1A).

Infected shoots died with the wilted leaves still attached to the stem. Shoots that died early in the season were soon masked by growth of the surrounding, apparently healthy stems. As the growing season progressed, additional shoots wilted and died; some of these shoots had rust-brown, bronzed leaves that did not abscise readily, even when dead. Brownish purple discoloration of leaves on otherwise healthy-appearing stems occurred in the autumn as temperatures decreased; these leaves readily abscised when touched. Lesions were not always apparent on the underground portion of shoots showing the various leaf symptoms just described.

Stem infections by *Phytophthora* spp. appeared as sunken, moist, brown-black cankers localized around a root node (Fig. 1C) or extended over part or all of the underground portion of the stem. In many cases, the lesions were continuous with the clonal (mother) rootstock (Fig. 1B). Occasionally, white mycelium extended from the lesion area. The upper margins of stem lesions were often irregular. Some stem lesions were yellow-brown with narrow, dark brown markings forming concentric, wavy-margined rings up the stem. In some cases, the bark split at the site of infection, peeled back at the edges of the split, and produced a rust-colored exudate. Roots often were absent at infected nodes or, if present, were red-brown and rotted; this contrasted with the white color of healthy-appearing roots.

Metalaxyl applied during the growing season had no effect on the characteristic symptoms of the disease. Disease symptoms on trees treated with fosetyl-Al were slightly altered, however. While the veins of infected leaves on these trees remained brown-bronze, they had less purpling in the late season than leaves on untreated plants. However, plants treated with fosetyl-Al did have yellow-orange or red-orange leaves not associated with autumn leaf coloring and abscission. Stems treated with fosetyl-Al exhibited a general mottling (red-brown and yellow-brown), making lesions much less distinct than on untreated stems. *Phytophthora* spp. were isolated from shoots treated with fosetyl-Al. These shoots—even those with stem lesions—characteristically showed enhanced root development when compared to untreated shoots or shoots treated with metalaxyl, especially at nodes just above or below obvious lesions.

Phytophthora spp. were isolated from mother stock and from current-season shoots and roots. They were recovered both from tissues that appeared healthy on the surface and from tissues with visible lesions. In both cases, the leaves on infected shoots either appeared healthy or showed light bronzing at the distal end of the shoot, sometimes with purpling at the proximal end of the shoot.

Phytophthora spp. were readily recovered from the heavily infested area in a field of EMLA.106 rootstocks and from the experimental replicate blocks with fungicide treatments. Both *P. cactorum* and *P. cambivora* mating type A1 were isolated, although *P. cactorum* was isolated much more frequently than

P. cambivora. *P. cactorum* was recovered from June to November, with peak recovery (from 32–51% of samples) occurring between mid-August and early September. *P. cambivora* was recovered from mid-June to mid-August (recovery from 3–5% of samples).

In 1985, *P. cactorum* was recovered from all of the plots treated with fosetyl-Al, metalaxyl, or both; *P. cambivora* was isolated only from the untreated control plots and those treated once with fosetyl-Al. In 1986, *Phytophthora* spp. were isolated less readily from field samples. The peak recovery of *P. cactorum* from stems, roots, and mother-stock tissue occurred in October. *P. cambivora* was undetectable in any of the field samples. Overall recovery of *Phytophthora* spp. was particularly low in plant tissues without obvious symptoms of disease.

Phytophthora spp. were not recovered in either 1985 or 1986 by baiting from sawdust within the rootstock row, from between the rows, or from the source piles used for stool bed production. In 1986, however, baiting from sawdust directly adjacent to diseased stems with visible lesions (not attempted in 1985) yielded *P. cactorum* and *P. cambivora* mating type A1. Some samples contained both species, while others contained only one.

Pathogenicity tests. The pathogenicity of isolates recovered from apple stems taken from stool beds was tested on excised stem pieces. In tests conducted at 15 C (Table 1), all isolates except *P. cambivora* isolate P-112 and *P. cactorum* isolate P-58 were pathogenic compared to the uninoculated controls. These pathogenic isolates included two isolates of *P. cactorum* (P-91, P-115), one isolate of *P. cambivora* (P-108), and one isolate of *P. syringae* (P-85). In the pathogenicity test conducted at 24 C (Table 1), *P. cactorum* isolates P-91 and P-115 and *P. cambivora* isolates P-108 and P-112 were also pathogenic. While there were no significant differences in virulence between isolates, the two isolates of *P. cactorum* produced slightly longer lesions at 24 C than at 15 C, while lesions caused by *P. cambivora* were two times (P-108) or four times (P-112) longer at 24 C than at 15 C.

Stem piece bioassays for persistence of fungicide effects indicated that, in 1986, the treatments applied to rootstocks in the field any time from 4 days to 3 wk before sampling showed residual activity when challenged by *P. cactorum*. All field-applied chemical treatments reduced lesion length significantly ($P = 0.05$) to 3.7–5.2 mm on excised shoots, compared to an average length of 9.6 mm on the untreated controls. Disease severity among the chemical treatments was not significantly different.

Residual effects of fungicides on plant health during cold storage. Rootstock plants from stool beds that had been treated chemically in the field in 1985 and graded as healthy were put into cold storage for 3 mo and then planted in the greenhouse. Significant differences in the development of disease symptoms were seen between treatment groups after a 3-mo growing period. A separation of disease index means showed that trees treated in the field two times or three times with fosetyl-Al each had disease index ratings of 1.4. This was significantly lower ($P < 0.01$) than the ratings of trees treated once each with fosetyl-Al and metalaxyl (1.8) or the untreated control trees (2.0), although the ratings of the latter two treatments were also significantly different from each other. Both *P. cactorum* and *P. cambivora* (A1) were isolated from control and treated trees after the 3-mo growing period.

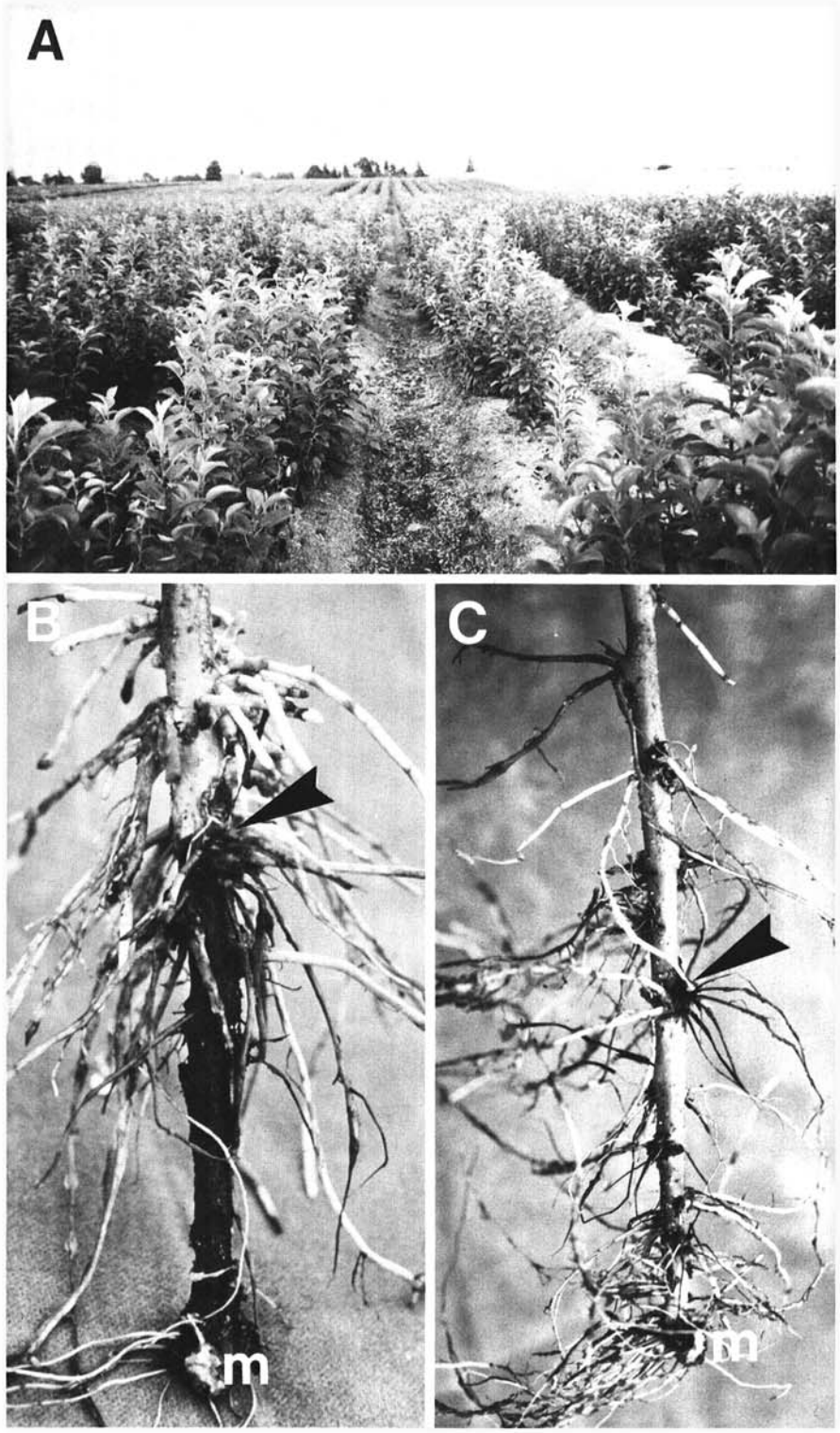

Fig. 1. Phytophthora stem and root rot symptoms in apple stool beds: **(A)** Bare areas in stool bed rows where shoot production has been eliminated due to severe infections of mother stock. **(B)** Lower shoot base lesions from basal connection to mother stock (m) up the stem to the arrow. **(C)** Localized root and stem infections at a node (arrow).

After the chemical treatments were applied in the field in 1985, some apple rootstocks were harvested. Those graded as healthy were held in cold storage for 9 mo and then evaluated for disease incidence. Rootstocks that had been treated chemically had significantly ($P < 0.01$) less disease than the nontreated controls. The percentage of rootstock plants that exhibited any root and stem rot symptoms was 58% for the untreated controls, 27% for plants treated twice with fosetyl-Al, 22% for plants treated three times with fosetyl-Al, and 19% for plants treated once each with metalaxyl and fosetyl-Al. The differences in disease control between the chemical treatments were not significant. *P. cactorum* and *P. cambivora* were isolated from stem tissue or recovered by baiting from root washings of trees after the cold storage period.

Postharvest chemical root dips. Chemical root dipping of EMLA.106 rootstocks harvested from the stool beds produced variable results. However, some of the treatments significantly reduced disease incidence and severity compared to the untreated controls (Table 2). There was no evidence of phytotoxicity for any of the chemicals used at any concentration in this experiment.

Benalaxyl treatments. Analysis of disease ratings for trees treated with benalaxyl showed that chemical concentration had a significant effect on plant health. With trees in health class 1, disease decreased as chemical concentration increased. A separation of means showed that disease ratings in the 2,000 mg/L treatment were significantly lower than ratings of the control at the 0.05 significance level, while disease ratings in the 4,000 mg/L treatment were significantly lower than the control at the 0.01 significance level. Trees in health class 2 had significantly less disease than the control for benalaxyl concentrations of 1,000 mg/L ($P < 0.01$) and 2,000 mg/L ($P < 0.05$). Analysis of the disease ratings also showed significant differences between dip treatments. Benalaxyl treatments applied before cold storage were less effective ($P < 0.05$) at reducing disease than those applied after or both before and after cold storage.

Etridiazol treatments. When etridiazol was the dip chemical, there was a significant ($P < 0.05$) difference in disease ratings between treatments in terms of the interaction between plant health, dip treatment, and chemical concentration. After separating the mean ratings for trees within each health class, only the 468 mg/L concentration applied before or after cold storage to health class 1 resulted in significantly ($P < 0.05$) less disease than in the control.

Fosetyl-Al treatments. Fosetyl-Al treatments showed significant ($P < 0.01$) differences in disease ratings in terms of the interaction between plant health, dip treatment, and chemical concentration. Mean separation for trees in health class 1 showed that all three chemical concentrations significantly ($P < 0.05$) reduced disease compared to the control when applied either after or both before and after cold storage. Treatment with fosetyl-Al after cold storage treatment at 24,000 mg/L and treatment before and after cold storage at 12,000 mg/L significantly reduced ($P < 0.01$) disease compared to the control. There was no significant difference between any of the chemical concentrations for any dip treatment.

Among trees of health class 2 treated before cold storage, disease decreased as the chemical concentration of the treatment increased. However, only concentrations of 12,000 mg/L and 24,000 mg/L reduced disease below that in the controls at either the 0.01 or 0.05 significance levels. Disease was significantly less in trees treated after cold storage at fosetyl-Al concentrations of 6,000 and 12,000 mg/L ($P < 0.01$) and 24,000 mg/L ($P < 0.05$) than in untreated controls. There was no difference in disease level between control trees and those treated both before and after cold storage.

Metalaxyl treatments. The analysis of disease ratings on trees dipped in metalaxyl indicated significant ($P < 0.05$) differences between treatments in terms of the interaction between plant health, dip treatment, and chemical concentration. Mean separation for the trees in health class 1 showed that the control trees had higher ($P < 0.01$) disease ratings than trees treated with metalaxyl at 2,000 mg/L in any dip treatment or trees treated with metalaxyl at 4,000 mg/L before or after cold storage. At the 0.05 significance level, trees treated with metalaxyl at any concentration with any dip treatment (except before cold storage at 1,000 mg/L) had lower disease ratings than the controls.

Trees in health class 2 treated at any chemical concentration either before or after cold storage had less ($P < 0.05$) disease than the control trees. Of all the chemical treatments, however, the 2,000 mg/L concentration gave better disease control, with the greatest control when trees were dipped before cold storage.

DISCUSSION

Our study of a field of EMLA.106 rootstocks in the Pacific Northwest demonstrates that *Phytophthora* spp. occur in stool beds and cause stem and root rot disease of apple rootstocks. As mentioned by Julis et al (15), however, there are many plantings in a stool bed nursery and a problem caused by *Phytophthora* spp. in one field may not be present elsewhere in a nursery. Since these studies focused on one particular field, the results do not represent a range of rootstock varieties. Likewise, our results are not representative of the entire nursery that was sampled or of all the apple rootstock nurseries in the Pacific Northwest. The results do, however, indicate that there is the potential for *Phytophthora* spp. to cause disease problems, especially if the pathogens are present in the plants used to establish stool beds.

The semidwarfing rootstock EMLA.106 is particularly susceptible to *Phytophthora* infection (2,9,10,15,20,31). The symptoms of stem and root rot disease of rootstocks, both recently shipped and in young orchard plantings, have been described in part by some workers (2,10,15,20,21); these symptoms were similar for rootstocks still within the stool bed production system.

Isolations from stool bed plants indicated that several *Phytophthora* spp. were involved in the disease, and that the activities of the different species could be correlated with seasonal and host physiological conditions (1,5,11,28,29). *P. cactorum, P. cambivora,* and *P. syringae* have been isolated previously from shipped rootstocks (2,10,15,17). Our data demonstrate that *P. cactorum* and *P. cambivora* caused infection of rootstocks in stool bed plantings and

Table 1. Comparison of lesion size on excised stem pieces inoculated with *Phytophthora* isolates from apple stool beds and incubated at 15 or 24 C

Inoculation treatment	Lesion length (mm)[y]	
	Incubation at 15 C	Incubation at 24 C[z]
Uninoculated control	0 d	0 b
Phytophthora cactorum		
Isolate P-58	8 cd	...
Isolate P-91	27 a	34 a
Isolate P-115	22 ab	38 a
Phytophthora cambivora		
Isolate P-112	8 cd	37 a
Isolate P-108	15 bc	31 a
Phytophthora syringae		
Isolate P-85	11 c	...

[y] Means were separated independently for the two temperatures using Fisher's protected Bayes LSD test. Values followed by the same letter are not significantly different ($P = 0.01$).
[z] *P. cactorum* isolate P-58 and *P. syringae* isolate P-85 were not included in the 24 C test.

support the contention that rootstocks are a source of orchard tree infections. *P. syringae* was not recovered in this study, either because it was not present in the stool beds sampled or because it was masked by faster-growing *Phytophthora* spp. However, the *P. syringae* isolate P-85 used in our inoculation studies has been isolated from stool beds.

Isolations from shoots in chemically treated field plots indicated that fosetyl-Al or metalaxyl (singly or in combination) significantly reduced, but did not eradicate, *Phytophthora* spp. in the stool beds. Based on visual observations, plots treated in consecutive years had less disease overall than plots treated only in a single year.

In the stool bed production system, sawdust is applied as a side-dressing to hold moisture around the apple stems and enhance rooting. It is not removed from the field at the end of a production year and could be a potential inoculum source for crops in consecutive years. However, we recovered *Phytophthora* spp. only from sawdust directly adjacent to stems with well-developed lesions, indicating that inoculum may not be widespread in the rooting medium. Furthermore, it is not known how long propagules of *Phytophthora* spp. could survive in the sawdust, separated from host tissue; survival time could be extended if infected roots remained in the sawdust after harvest. Many of the stem infections observed were continuous with the mother plants; thus, the mother plants are probably the major source of shoot infections.

The presence of mycelium on the bark of rootstock stems in the field and an observation of mycelial development by *P. cambivora* on twigs in the pathogenicity tests are potentially significant. Because *P. cambivora* does not produce chlamydospores and only one mating type was identified among the isolates recovered from the field, it is not known whether oospores are involved in overwintering. Consequently, the development of external mycelia may be important for the persistence and movement of *P. cambivora* in the stool bed.

Our data indicate that *P. cactorum* is more virulent than *P. cambivora* at 15 C and that *P. cactorum* is active both earlier and later in the growing season than *P. cambivora*. In addition, *P. syringae*—a species with low cardinal temperatures that was not isolated from the field plots in this study but which has been isolated from stool beds—was shown to be virulent at 15 C. Consequently, both *P. syringae* and *P. cactorum* could cause infections in the stool bed in early spring and continue activity into the autumn. In lab studies, Jeffers and Aldwinckle (11) have shown that disease severity may depend partly on the change in rootstock susceptibility over the growing season. Furthermore, Gupta and Singh (6) reported that twigs from the same plant were equally susceptible throughout the growing season when inoculated in the lab, but that plants inoculated in the field were differentially susceptible over the growing season. They also had smaller lesions than lab-inoculated plants. Harris et al (7) noted that, even with ample inoculum and wet conditions, disease development in field trials was not consistent even on a susceptible rootstock. Thus, we are cautious about interpreting our observations and any apparent correlations between field and lab studies.

Field applications of metalaxyl or fosetyl-Al apparently have some residual effect after harvest. In our tests with fosetyl-Al, however, stems were treated only 4 days before removal from the field, making it hard to judge this effect. Metalaxyl treatment was last applied 3 wk prior to the tree sampling for the bioassay and reduced disease as well as fosetyl-Al. This indicates that metalaxyl has residual activity, too, even though it appears to be less effective in the field than fosetyl-Al. Further studies over a longer time period are needed to determine the residual effects of these two chemicals. Testing other *Phytophthora* spp. with fosetyl-Al and metalaxyl would also be valuable in assessing the differential residual effects of these chemicals.

Trees initially graded as healthy showed significant disease development after 3 mo in cold storage followed by a 3-mo growing period. In our tests, any chemical treatment in the field was better than no treatment at all, but fosetyl-Al reduced disease more than metalaxyl. The results indicate that disease development may continue to progress in cold storage on trees that appeared healthy before storage. These findings are consistent with reports that disease is present on shipped trees, possibly because it developed after grading and during cold storage.

Our observation that disease development on trees was reduced even after a 9-mo cold-storage period suggests that there is a long-term residual effect of chemicals applied in the field during the growing season. Studies have shown that both fosetyl-Al and metalaxyl remain active in root tissue of citrus for at least 2 mo (22) and that metalaxyl is readily translocated upward from the roots into woody tissue after application as a soil drench (4). Furthermore, injecting avocado trees with fosetyl-Al every 6 mo appeared to control *P. cinnamomi* effectively (3). It is not known, however, just how long these chemicals remain active in woody stem tissue stored at low temperatures. The effect of treatment may carry over much longer than the chemical itself. Regardless of the mechanism, it is evident that treatments with metalaxyl or fosetyl-Al reduce disease development in the field and that treated trees maintain their health advantage over untreated controls while in cold storage.

The purpose of the chemical dip experiment was to see whether *Phytophthora*-infected rootstock plants (whether surface-contaminated or slightly infected and symptomless) could be cured of or protected from disease development during storage and shipping (14). The chemicals chosen all had known activity against *Phytophthora* spp., although

Table 2. Effects of chemical dip treatments with benalaxyl, etridiazol, fosetyl-Al, and metalaxyl on the incidence and severity of Phytophthora stem and root rot of EMLA.106 apple rootstocks

Chemical treatment[x]	Chemical concentration (mg/L)	Disease ratings[y]					
		Health class 1			Health class 2		
		Pre	Post	Pre/post	Pre	Post	Pre/post
Benalaxyl	0	2.6 a[z]	...	...	2.5 ab[z]	...	...
	1,000	2.3 abc	...	...	1.8 d	...	...
	2,000	2.1 bcd	...	...	2.0 cd	...	...
	4,000	1.8 d	...	...	2.2 abcd	...	...
Etridiazol	0	3.2 ab	3.3 a	2.7 abc	2.6 abc	2.0 bc	2.6 abc
	156	3.4 a	2.8 abc	2.2 bc	2.0 bc	2.2 abc	2.7 ab
	234	2.4 abc	2.7 abc	2.9 abc	1.6 c	2.1 bc	3.2 a
	468	2.1 c	2.0 c	2.7 abc	2.6 abc	2.5 abc	2.3 abc
Fosetyl-Al	0	2.1 bc	2.4 ab	2.9 a	2.6 ab	3.1 a	2.1 bcd
	6,000	1.7 bcd	1.6 cd	1.6 cd	2.3 bc	1.6 cde	1.7 cde
	12,000	1.2 d	1.6 cd	1.4 cd	1.5 de	1.6 cde	2.1 bcd
	24,000	1.5 cd	1.4 cd	1.5 cd	1.2 e	2.3 bc	1.6 cde
Metalaxyl	0	2.5 bc	2.7 ab	3.3 a	2.3 ab	2.9 a	2.2 bc
	1,000	1.9 cd	1.6 de	1.6 de	1.5 de	2.0 bcd	1.8 bcde
	2,000	1.4 de	1.5 de	1.5 de	1.3 e	1.6 cde	2.1 bcd
	4,000	1.4 de	1.1 e	1.7 de	1.5 de	1.9 bcde	1.3 e

[x] Chemical treatments were applied to apparently healthy (class 1) or slightly infected (class 2) rootstocks before, after, or both before and after cold storage.

[y] Mean disease ratings were separated independently for health class 1 and health class 2 using Fisher's protected Bayes LSD test. Values followed by the same letters are not significantly different ($P = 0.05$).

[z] Data for the three postharvest benalaxyl treatments were not significantly different. The three results were combined and evaluated only for chemical concentration effects.

their modes of activity were different. Even though the results were generally too inconsistent to theorize about how the chemicals worked, both metalaxyl and fosetyl-Al were significantly effective, benalaxyl was partially (though inconsistently) effective, and etridiazol was ineffective. Etridiazol is not systemic and may not reach early internal infections effectively.

High-concentration dips with fosetyl-Al and metalaxyl after harvest do not totally eliminate the *Phytophthora* disease, but they do greatly reduce it, especially if applied before cold storage. Fosetyl-Al appeared to be a slightly better postharvest dip than metalaxyl, possibly because of its different mode of action. It could be useful to study the efficacy of these two chemicals when used in combination or in succession, both in the field and in postharvest dips. Present labels would need to be modified for these uses, since the application rates we used in our study are higher than those presently recommended. Furthermore, the current label for metalaxyl specifically prohibits its use as a root dip on apples, although our data indicated no justification for that restriction.

Menge (22) cautions that both fosetyl-Al and metalaxyl can suppress pathogens without eradicating them, and recommends using the two chemicals as preventive rather than curative treatments in nurseries. We do not suggest that root dips using these compounds be the sole means of disease control. Instead, they should be used with other field and storage management practices to encourage and ensure the sale of healthy apple rootstocks.

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