Table 1. Estimates of bloom intensity on Navel orange trees at three test sites in Indian River County.

Dates Buttons Removed	Mean bloom intensity[z]		
	Grove #1	Grove #2	Grove #3
		27 Feb. 1989	
21 Aug. 1988	0.6	0.3	2.1
24 Oct. 1988	0.5	0.4	2.1
19 Apr. 1989	0.6	0.3	2.8
Control group	0.6	0.6	2.1
		19 Mar. 1989	
21 Aug. 1988	1.9	0.5	0.9
24 Oct. 1988	1.6	0.8	0.9
19 Apr. 1989	0.6	0.3	0.9
Control group	1.3	0.3	1.3

[z]Rating system:
0 = 1-25% tree in bloom
1 = 26-50% tree in bloom
3 = 51-75% tree in bloom
4 = 76-100% tree in bloom
Eight single-tree replicates for each treatment at each site.

Tests or experiments which would refine this study could include observations of trees which have buttons removed soon after they are formed, which is usually during the major bloom period from Feb. to Apr. In addition, a longer term study may be appropriate.

This experiment indicates that any effort to remove persistent calyxes will probably have little or no effect on either blossom production or fruit yield.

Table 2. Number of fruit present on Navel orange trees at three test sites in Indian River County on 21 Aug. 1989.

Dates Buttons Removed	Mean number of fruit[z]		
	Grove #1	Grove #2	Grove #3
21 Aug. 1988	30.6	18.1	36.4
24 Oct. 1988	35.1	19.1	28.4
19 Apr. 1989	33.9	20.9	32.6
Control group	28.8	16.5	33.5

[z]Mean number of fruit in northeast quarter of canopy of each treated tree.

Whether the PFD pathogen survives when blossoms are unavailable has not yet been determined. Further studies are needed to determine if the persistent calyxes are significant factors in the survival of the pathogen between bloom periods. If calyxes are of survival value to the fungus, the effect of removal of calyxes on disease development will have to be evaluated.

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PHYTOPHTHORA FEEDER ROOT ROT OF BEARING CITRUS: FUNGICIDE EFFECTS ON SOIL POPULATIONS OF *PHYTOPHTHORA PARASITICA* AND CITRUS TREE PRODUCTIVITY

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Abstract. **Fungicide treatments for control of feeder root rot of mature citrus caused by *Phytophthora parasitica* were made for 4 yr in 4 Florida orchards. Foliar applications of fosetyl-Al at high (FOS-H) and low (FOS-L) frequency and soil applications of metalaxyl (MET) were compared to untreated controls. When propagule densities of *P. parasitica* were expressed on a soil volume basis, MET treatments usually reduced fungal populations, but when propagule densities were expressed on a root weight basis, all treatments reduced fungal populations in most locations. The FOS-H, FOS-L, and MET treatments increased feeder root densities by averages of 26.8, 9.4, and 47.8%, respectively, above the untreated controls in the 4 orchards over all 4 yr. Feeder root loss in citrus due to infection by *P. parasitica* appears to be substantial and is corrected by applications of fosetyl-Al or metalaxyl. Tree appearance was improved by fungicide treatments in 3 of the 4 orchards. Average fruit weight was increased by all treatments in the grapefruit orchard, but not by any treatment in the 3 orange orchards. The percent juice in the fruit was consistently increased by fungicide treatments, but the sugar-acid ratio was affected only occasionally by fungicide applications. Total fruit and juice yields were increased by the FOS-H and MET treatments in one orchard and by the MET treatment in another orchard. Since large, consistent tree responses to treatment were not observed, orchards to be treated should be selected carefully.**

Phytophthora diseases of citrus are major problems in citrus orchards worldwide (12, 13). Foot rot, which occurs when *Phytophthora* spp. infect the base of the tree, is a commonly observed problem of citrus in Florida. The disease occurs primarily on young trees and occasionally losses can be severe. Foot rot can be controlled effectively by proper orchard management and use of fungicides (2, 3, 9, 11, 15). Feeder root rot, caused by *Phytophthora* spp., is a com-

Florida Agricultural Experiment Station Journal Series No. N-00057.
This research was supported in part by a grant from Rhone-Poulenc, Inc., Research Triangle Park, NC 27709 with additional financial support from Ciba-Geigy Corp., Greensboro, NC 27419. We wish to thank The Collier Company/Grove Division of Immokalee, Riverland Groves and River Country Citrus of Indiantown, Platts Groves, Inc. of Fort Pierce, and Saxon Fruit Company of Winter Haven for use of their orchards and cooperation in the study. The authors gratefully acknowledge the technical assistance of N. L. Berger, J. Cordy, and R. R. Pelosi.

mon problem in citrus nurseries (5, 13, 17), but its importance in bearing orchards is uncertain. The commonly used rootstocks, such as sour orange, trifoliate orange, Cleopatra mandarin, Carrizo citrange, and Swingle citrumelo, are tolerant to nearly immune to Phytophthora foot rot and scaffold root rot (13, 16). However, when they are overwatered in infested nurseries or inoculated as young seedlings in screening tests for resistance, most of these species and cultivars suffer serious root rot (1, 4). Applications of metalaxyl and fosetyl-Al have proven highly effective for control of feeder root rot problems in nurseries (2, 3).

Little is known about the incidence and importance of feeder root rot on bearing citrus trees. Even though many rootstocks are resistant to bark infection, they could be susceptible to feeder root infection. Some rootstocks might tolerate root rot by rapid regeneration of new roots, but Carpenter and Furr (1) found little evidence of differences between varieties and species in root regenerating ability. Prior to the development of fosetyl-Al and metalaxyl, no chemical means were available to control root rot and thus determine its impact on tree performance and fruit yield. Recent reports from California (7, 8) indicated that feeder root loss from infection by *Phytophthora* spp. could be reduced by fungicide applications and fruit yields increased on the highly susceptible sweet orange rootstock.

This study was designed to determine the effect of fosetyl-Al and metalaxyl applications on soil populations of *P. parasitica* and on the feeder root densities, tree condition, and fruit yield of citrus trees on different rootstocks.

Materials and Methods

Locations. The 4 orchards selected for tests were at least 15 yr old and all showed signs of mild decline, which could have been attributable to feeder root loss since all had moderate to high populations of *P. parasitica.* The citrus nematode, *Tylenchulus semipenetrans* Cobb, was found in high populations in one orchard, but that orchard was treated with aldicarb to reduce possible decline due to nematodes.

The sites chosen were: i) a Pineapple sweet orange [*Citrus sinensis* (L.) Osb.] orchard on Cleopatra mandarin (*C. reshni* Hort. ex Tan.) rootstock planted on a spacing of 7.6 x 4.6 m (25 x 15 ft) on an Oldsmar fine sand near Immokalee (Pineapple/Cleo); ii) a Ruby Red grapefruit (*C. paradisi* Macf.) orchard on sweet orange rootstock planted on a spacing of 9.1 x 6.7 m (30 x 22 ft) on a Winder sand near Ft. Pierce (grapefruit/sweet); iii) a Hamlin sweet orange orchard on sour orange (*C. aurantium* L.) rootstock planted on a spacing of 8.2 x 6.1 m (27 x 20 ft) on Pineda sand near Ft. Pierce (Hamlin/sour); iv) a Hamlin sweet orange orchard on sweet orange rootstock planted on a spacing of 8.2 x 8.2 m (27 x 27 ft) on a Tavares fine sand near Lakeland (Hamlin/sweet).

Treatments. The 4 fungicide treatments were: i) foliar applications of fosetyl-Al (Aliette 80 WP, Rhone-Poulenc, Inc., Research Triangle Park, NC 27709) at high frequency (FOS-H); ii) foliar applications of fosetyl-Al at low frequency (FOS-L); iii) soil applications of metalaxyl (Ridomil 2E, Ciba-Geigy Corp., Greensboro, NC 27419) (MET); and iv) a nontreated control.

In the Pineapple/Cleo, grapefruit/sweet, and Hamlin/sour orchards, fosetyl-Al applications were made with concentrate speed sprayers that applied from 1.1 to 2.5 hl spray mix/ha (130-300 gal/acre) depending on the type of sprayer. In the Hamlin/sweet orchard, fosetyl-Al was applied with a handgun sprayer, using about 11.3 hl spray mix/ha (1350 gal/acre) and only the FOS-H treatment was used. At all 4 locations, fosetyl-Al was applied at 5.61 kg of Aliette 80WP/ha (5.0 lb/acre). In the Pineapple/Cleo, grapefruit/sweet, and Hamlin/sour orchards, metalaxyl applications were made as soil surface sprays of Ridomil 2E using 4.61 liters/ha (0.5 gal/acre) of treated surface area. Applications were made using 1.4 to 2.7 hl of spray material per hectare (1700-3200 gal/acre) of treated surface area depending on the tree spacing and approximately 50% of the orchard soil surface area was treated. In the Hamlin/sweet orchard, metalaxyl was applied as a soil drench in basins formed around the dripline of each tree using 24.5 liters of Ridomil 2E per hectare (2.9 gal/acre) applied in about 71 hl of water/ha (8500 gal/acre). Fungicide application dates were in spring (March-April), early summer (May-June), late summer (July-August), and fall (September-October). The FOS-H applications were made on all dates in 1985 and in 1986 and in spring, early summer, and late summer in 1987 and 1988. The FOS-L applications were made in early and late summer in 1985 and 1986 and in spring, early, and late summer in 1987 and 1988. The MET applications were made in spring, late summer, and fall in 1985; in early summer, late summer, and fall in 1986; and in early and late summer in 1987 and 1988.

Each fungicide treatment in the Pineapple/Cleo, grapefruit/sweet, and Hamlin/sour orchard was replicated 5 times on 4-tree plots arranged in a randomized complete block design. Each plot consisted of 4 trees in a row with a single buffer tree between the plots. An untreated buffer row was left between the treated rows. In the Hamlin/sweet orchard, affected trees were scattered throughout the orchard, and 30 trees in mild decline and 30 in moderate decline were selected for the test. Blocks of 12 trees, each containing 6 trees in mild decline and 6 trees in moderate decline, were chosen and the FOS-H, MET, and control treatments randomly assigned to 2 trees in mild decline and 2 trees in moderate decline. Five replicate blocks were used.

Data collection. For determination of propagule densities of *P. parasitica* and root densities, sample collection and handling methods developed previously were used (14). Soil cores were collected with a standard auger at the dripline of the trees and passed through a screen with 3-mm openings to separate roots from soils. Feeder roots, defined as those with less than 2 mm diameter, were dried to a constant weight at 60°C, and root density was expressed as mg dry weight/cm^3 of soil. Soil was moistened and incubated at room temperature (21-23° C) for 1 to 5 days. A 10 cm^3 subsample was suspended in 90 ml of 0.25% water agar and one ml plated on each of 5 plates of PAR media (6, 14). Plates were incubated at 28°C for 3 days, washed, and the colonies counted.

Propagule densities were calculated per cubic centimeter of soil volume and per milligram of root. Propagule and root densities were determined for a composite sample of 4 to 6 cores taken within each replicate plot of each treatment on each sample date.

Canopy condition considering primarily the foliage density and leaf size was rated on a scale of 0 = healthy to 3 = severe decline in the fall of the year at each site.

Trees were harvested and the fruit yield of each plot was determined annually after maturity had been reached for each cultivar. Hamlin oranges were harvested in December-January, Pineapple oranges in February-March, and grapefruit in April-May. A sample of at least 40 fruit was collected at random within each plot and the average fruit weight was determined. The juice was extracted and the percent juice, total soluble solids, percent acid, and other juice characteristics were determined by a computerized citrus juice analyzer (Toledo Scales, Toledo, OH). The total soluble solids produced per hectare was calculated from the fruit yield, juice percentage, and the percent soluble solids in the juice.

Results

Over the 4-yr test period, the number of propagules per cm^3 of soil in the MET treatment was significantly lower than in the controls in 3 of the 4 locations (Table 1). The number of propagules/cm^3 of soil in the FOS-H and the FOS-L treatments was significantly lower than in the controls only in the Hamlin/sour orchard. Feeder root densities in the FOS-H and MET treatments were significantly higher than in the controls at all 4 sites tested. Feeder root densities in the FOS-L were significantly greater than the controls only in the Pineapple/Cleo orchard. When propagule densities were expressed on the basis of root weight, rather than soil volume, the propagule densities in the fungicide treated plots were significantly lower than in the controls in almost every case (Table 1).

Canopy decline ratings were consistently lower in the MET treatments and often lower in the FOS-H and FOS-L treatments than in the controls (Table 2). Thus, when considered across all 4 yr, fungicide treatments generally brought about slight, but significant improvements in tree condition.

The average fruit yield per tree was greater in the FOS-H and the MET treatments than in the controls in the Pineapple/Cleo orchard, and yield was greater in the MET treatments than in controls in the Hamlin/sour orchard (Table 2). At the other locations, the yield of the treated trees was occasionally significantly higher than the untreated controls in an individual year, but was not significantly greater over all years collectively. All 3 fungicide treatments resulted in significantly greater average fruit weight of grapefruit compared to the controls at one site, but the weight of oranges at the other 3 locations, except for the MET treatment in the Pineapple/Cleo orchard, did not differ between treatments (Table 3).

The percent juice in fruit was slightly but consistently increased by fungicide application especially the FOS-H and MET treatments (Table 3). The sugar-to-acid ratio was not consistently affected, but occasional increases due to treatment were noted (Table 3). When total soluble solids per hectare were taken into consideration, results were similar to overall yields with the MET and FOS-H treatments having higher yields than the controls in the Pineapple/Cleo orchard and MET treatments having higher yields in the Hamlin/sour orchard. In addition, the FOS-H treatment increased yields of soluble solids in the grapefruit and Hamlin orchards on sweet orange rootstock.

Table 1. Effect of fungicide application programs on populations of *Phytophthora parasitica* and root density of citrus averaged across 5 sampling dates per year and across all 4 seasons from 1985-88.

Fungicide program[z]	Propagules/cm^3 soil			
	Pineapple/[y] Cleo	Hamlin/[y] Sour	Grapefruit/[y] Sweet	Hamlin/[y] Sweet
FOS-H	25.4	15.0*	11.7	19.6
FOS-L	26.2	16.5*	12.1	—
MET	17.5*[x]	11.4*	10.4	14.6*
Control	27.9	25.1	10.8	21.0
$LSD_{0.05}$	5.4	2.9	3.5	2.7

Fungicide program	Root density (mg dry wt/cm^3 soil)			
	Pineapple/ Cleo	Hamlin/ Sour	Grapefruit/ Sweet	Hamlin/ Sweet
FOS-H	0.55*	0.56*	0.88*	0.66*
FOS-L	0.54*	0.51	0.71	—
MET	0.66*	0.72*	0.87*	0.80*
Control	0.47	0.49	0.65	0.47
$LSD_{0.05}$	0.03	0.03	0.06	0.07

Fungicide program	Population density (propagule/mg dry root tissue)			
	Pineapple/ Cleo	Hamlin/ Sour	Grapefruit/ Sweet	Hamlin/ Sweet
FOS-H	45.7*	27.3*	12.4*	28.2*
FOS-L	46.9*	30.5*	16.3	—
MET	25.9*	15.4*	12.0*	18.8*
Control	61.9	51.5	17.2	42.4
$LSD_{0.05}$	9.9	5.5	4.8	5.3

[z]FOS-H = fosetyl-Al, applied as Aliette 80 WP, 4 times per year in 1985 and 1986 and 3 times per year in 1987 and 1988; FOS-L = fosetyl-Al, applied twice a year in 1985 and 1986 and 3 times per year in 1987 and 1988; MET = metalaxyl, applied as Ridomil 2E, 3 times per year in 1985 and 1986 and twice per year in 1987 and 1988.
[y]Pineapple = Pineapple sweet orange; Hamlin = Hamlin sweet orange; Grapefruit = Ruby Red grapefruit; Cleo = Cleopatra mandarin; Sour = sour orange; sweet = sweet orange rootstock.
[x]Significantly different from the control at $P \leq 0.05$.

Discussion

Fosetyl-Al, when applied as a foliar spray, is translocated downward to the roots and prevents infection (2), but it probably has no direct effect on fungal propagules in the soil. This product presumably increased feeder root densities by reducing root rot. Where fosetyl-Al treatments prevented increases in soil populations of *P. parasitica* in these tests, they probably did so by limiting the multiplication of the fungus on treated roots. Thus, differences in propagule densities on fosetyl-Al-treated trees seemed more substantial when densities were expressed on the basis of root weight than on the basis of soil volume.

In contrast to fosetyl-Al, metalaxyl directly kills the fungus in the soil (2, 3) and thus reduces the number of propagules per unit volume of soil. By reducing infection, it also increases feeder root densities. When propagule densities are expressed on a root weight basis, the effect of metalaxyl also appeared more substantial. Since fungicide

Table 2. Effect of fungicide application programs on the canopy decline *rating and yield* of citrus averaged across all 4 seasons from 1985-88.

Fungicide program[z]	Decline rating[y] Pineapple/ Cleo[x]	Hamlin/ Sour[x]	Grapefruit/ Sweet[x]	Hamlin/ Sweet[x]
FOS-H	0.81*[w]	0.96*	1.45	1.46
FOS-L	0.85*	1.05	1.38*	—
MET	0.53*	0.75*	1.22*	1.21*
Control	1.10	1.14	1.52	1.32
$LSD_{0.05}$	0.11	0.11	0.12	0.10

Fungicide program	Yield (boxes/tree) Pineapple/ Cleo	Hamlin/ Sour	Grapefruit/ Sweet	Hamlin/ Sweet
FOS-H	3.2*	2.9	4.7	7.6
FOS-L	2.7	2.7	4.5	—
MET	3.5*	3.3*	4.3	8.1
Control	2.6	2.9	4.2	8.2
$LSD_{0.05}$	0.22	0.15	0.43	0.34

[z]See Table 1 for description of fungicide programs.
[y]Based on a scale from 0 = healthy to 3 = severely diseased.
[x]See Table 1 for description.
[w]Significantly different from control at $P \leq 0.05$.

treatments increase feeder root densities, and consequently, the amount of substrate available for multiplication of the fungus, expression of densities on a soil volume basis minimizes the apparent disease control. Thus, expression of densities on a root weight basis seems more appropriate when comparing fungicide treatments.

The FOS-H, FOS-L, and MET treatments increased feeder root density over that of the untreated controls by an average of 26.8, 9.4, and 47.8%, respectively, when considered across all orchard sites and across all 4 yr. However, the increase in feeder roots was not accompanied by a corresponding increase in total fruit yield in all cases. When citrus is grown primarily for juice, the yield in total soluble solids per hectare is of primary importance. Small significant effects of fungicide treatment on the percent juice and occasionally on the sugar-to-acid ratio were noted. When fruit quality as well as quantity were taken into consideration, yield was affected by the FOS-H treatments at 3 of 4 sites and by the MET treatment at 2 of the 4 sites. Fruit size is an important characteristic for producers of fresh market fruit. In these tests, all fungicide treatments produced small, but consistent, increases in average weight of grapefruit at 1 site, but generally did not affect orange sizes at the other 3 sites.

The lack of an increase in productivity of citrus trees at some sites in response to the increased feeder root densities brought about by fungicide treatment is difficult to explain. In the Pineapple/Cleo orchard, where yields were increased, the improvement in feeder root densities was no greater than at the other sites (Table 1). Cleopatra mandarin rootstock is considered more tolerant to diseases induced by *Phytophthora* spp. than sweet orange rootstock (13), which was the rootstock used at 2 other sites where no yield response was found.

Table 3. Effect of fungicide application programs on fruit and juice characteristics averaged across all 4 seasons from 1985-88.

Fungicide program[z]	Average fruit weight (g/fruit) Pineapple/[y] Cleo	Hamlin/[y] Sour	Grapefruit/[y] Sweet	Hamlin/[y] Sweet
FOS-H	162	145	362*	141
FOS-L	161	146	359*	—
MET	163*[x]	146	372*	144
Control	159	143	342	147
$LSD_{0.05}$	3.1	3.1	8.3	2.9

Fungicide program	Percent juice Pineapple/ Cleo	Hamlin/ Sour	Grapefruit/ Sweet	Hamlin/ Sweet
FOS-H	58.6*	59.2*	62.1*	56.9
FOS-L	56.3	59.0*	60.8	—
MET	58.3*	59.1*	61.5*	57.8*
Control	56.4	58.3	60.4	56.7
$LSD_{0.05}$	0.56	0.36	0.59	0.39

Fungicide program	Sugar-acid ratio Pineapple/ Cleo	Hamlin/ Sour	Grapefruit/ Sweet	Hamlin/ Sweet
FOS-H	17.5	16.7	12.0*	14.4
FOS-L	18.0*	16.6	11.8*	—
MET	17.6	16.9	11.7	15.0*
Control	16.8	16.9	11.5	14.7
$LSD_{0.05}$	0.92	0.19	0.26	0.18

Fungicide program	Soluble solids (kg/ha) Pineapple/ Cleo	Hamlin/ Sour	Grapefruit/ Sweet	Hamlin/ Sweet
FOS-H	3287*	1923	2567*	3284*
FOS-L	2776	1790	2431	—
MET	3558*	2198*	2301	3500
Control	2666	1924	2297	3510
$LSD_{0.05}$	206	101	231	135

[z]See Table 1 for description of fungicide programs.
[y]See Table 1 for description.
[x]Significantly different from the control at $P \leq 0.05$.

Some fungicide treatments significantly reduced populations of *P. parasitica* and increased root densities compared to the untreated controls, but the benefits of treatment were not great in many cases. Thus, a general recommendation for treatment of orchards where feeder root rot occurs cannot be made. We and others have suggested that propagule densities may be used as a guide in decisions on whether or not to initiate treatment programs, and that the threshold for treatment should be approximately 10 to 15 propagules per cm^3 of soil (8, 10, 12). Given that the relationships between fungal populations, feeder root densities, and yields are not straight-forward, establishment of a firm threshold level may not be possible.

More research is needed on the dynamics of populations of *P. parasitica*, feeder root turnover, and citrus tree health and productivity before sound recommendations can be made.

Many benefits of fungicide treatment were noted over the 4 yr of applications tested in this project. It was obvious, however, from these studies, that occasional applications of fosetyl-Al or metalaxyl will do little or nothing to control feeder root rot and give no benefits whatsoever. Few effects of treatments were noted after the first year (10) and benefits accrued only after a sustained program of fungicide applications. Thus, the treatment program needs to be sustained for a sufficient period to allow trees to recover and regain full production.

If a juice price of $1.40 per pound of solids, which has been common in recent years, is assumed, then the gross return above the controls in the Pineapple/Cleo orchard would have been over $1000 per acre per year with the FOS-H and MET treatment. Even after subtracting product, application, and interest costs, profit to the grower would have been substantial. However, in the Hamlin/sweet orchard, no increase in yield was observed and a net loss would have been incurred by the producer. In the Hamlin/sour and grapefruit/sweet orchards, significant increases in soluble solids were observed with certain treatments. In these cases, gross returns above the controls of $300 to $700 per year would probably have paid for treatment costs, but would have returned minimal profits. Decisions on orchards to be treated should be based on a knowledge of the orchard condition and history, populations of *P. parasitica*, susceptibility of the rootstock as well as anticipated fruit and juice prices and ultimately must be the responsibility of individual grove managers.

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