Chemical Control of *Phytophthora cinnamomi* on Avocado Rootstocks

M. D. COFFEY, Professor, H. D. OHR, Extension Plant Pathologist, S. D. CAMPBELL, Staff Research Associate, and F. B. GUILLEMET, Staff Research Associate, Department of Plant Pathology, University of California, Riverside 92521

ABSTRACT

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Good control of *Phytophthora cinnamomi* was achieved with 2-yr-old Hass avocado nursery trees grafted on Duke 7 clonal rootstocks by using fosetyl-Al as a 3-L preplant application (500 μg a.i./ml) 48 hr before planting and as a postplant soil treatment at either 70 or 35 g a.i./m^2, two or four times per year, respectively. Similar disease control was obtained using a mixture of metalaxyl and etridiazole (ethazol) in which the preplant dosages were 25 and 200 μg a.i./ml and the postplant rates, applied twice per year, were 2 and 10 g a.i./m^2 of metalaxyl and etridiazole, respectively. Twenty-year-old Fuerte avocados on *Phytophthora*-susceptible rootstocks severely infected with *P. cinnamomi* were pruned back to their scaffold limbs and treated with either metalaxyl or fosetyl-Al. Both fungicides restored fruit production within 2 yr. The most cost-effective treatment was a foliar spray (3 g a.i./L) of fosetyl-Al applied three to five times per year.

The fungicides etridiazole (ethazol) fosetyl-Al, and metalaxyl have high biological activity against soilborne *Phytophthora* diseases (1–3,5–7,9,10, 12–15), particularly where they are used with container-grown ornamental plants. Use of chemical control on field-grown trees has only recently become a reality (4,6,9). In a part of this study, the ability to replant avocado (*Persea americana* Mill.) using the Duke 7 rootstock, which possesses moderate resistance to *Phytophthora cinnamomi* Rands (15,16), was investigated in an integrated control approach in which soil fungicides were employed to increase the level of resistance.

Control of avocado root rot on mature fruit-bearing trees established on *Phytophthora*-susceptible rootstocks is even more difficult. About 20–25% of the 20,000–24,000 bearing hectares in California are affected by avocado root rot (11). The feasibility of the use of the systemic fungicides metalaxyl and fosetyl-Al in a curative role to restore economic levels of fruit production in bearing avocado trees is explored in this study.

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MATERIALS AND METHODS

Integrated control with replant nursery trees. Two field trials were established in May 1982 to test the efficacy in a replant situation of metalaxyl (Ridomil), fosetyl-Al (Aliette), and etridiazole (Terrazole) in controlling avocado root rot on 2-yr-old nursery trees planted in ground naturally infested with *P. cinnamomi*. The avocado trees were Hass scions grafted on Duke 7 clonal rootstocks, which possess moderate resistance to *P. cinnamomi* (15,16). The soil was a sandy loam (pH 7.2, 79% sand, 13% silt, and 8% clay). The level of natural infestation with *P. cinnamomi* at planting was three or four propagules per gram (ppg) of soil. With most treatments, 0.5 L of the same soil amended with 200–300 ppg of *P. cinnamomi* produced on millet seed was incorporated with the soil used for planting each avocado tree. Inoculum density was determined using a soil-dilution plating technique in conjunction with a PARPH selective medium (8).

Fungicide treatments consisted of a single preplant preventative application and a postplant treatment consisting of either two (mixture experiment) or four (sequential experiment) applications. For the preplant treatment, the tree container was drenched 48 hr before planting with a 3-L solution of one or more fungicides, each used at rates of 500 μg a.i./ml of fosetyl-Al 80WP, 25 μg a.i/ml of metalaxyl 2E, and 200 μg a.i./ml of etridiazole 4E.

Two field experiments with replant nursery trees were organized into separate randomized blocks, each with a spacing of 6 m between rows and between trees. In two separate experiments, postplant applications of the three fungicides were made either sequentially or in mixtures.

Mixture experiment with replant trees. In this experiment, treatments were replicated nine times. Fungicides were used either singly or in mixtures of two products, for both the preplant and two postplant applications. Rates of postplant applications were 70 g a.i./m^2 of fosetyl-Al 80WP, 2 g a.i./m^2 of metalaxyl 5G, and 10 g a.i./m^2 of etridiazole 5G.

Sequential experiment with replant trees. Ten replicates were used for each treatment. Preplant treatments consisted of either fosetyl-Al, metalaxyl, or etridiazole, and the first of the four postplant applications consisted of the same fungicide. Subsequent applications involved an alternative fungicide. For postplant treatment with fungicides, application rates were 35 g a.i./m^2 of fosetyl-Al, 1 g a.i./m^2 of metalaxyl, and 5 g a.i./m^2 of etridiazole. Fungicides were applied to 1 m^2 of ground, then irrigated in.

Control of *P. cinnamomi* on mature trees. An experiment was initiated using 20-yr-old avocado trees (cultivar Fuerte) grown on rootstocks susceptible to *P. cinnamomi*. These trees were infected with avocado root rot caused by *P. cinnamomi* and had an average decline rating of 3.1 on a scale of 0–5, where 5 = permanent wilting and death. In May 1980, the trees were cut back to their scaffold limbs and fungicide treatment was begun in January 1981 after some regrowth of new foliage. There were six replicates per fungicide treatment. Metalaxyl 5G was used four times as a soil treatment at 2.5 g a.i./m^2 per application in 1981 and twice at 2 g a.i./m^2 per application in 1982 and 1983 (Table 1). Fosetyl-Al 80WP was used four times as a soil treatment at 8.5 g

a.i./m^2 per application in 1981 and twice at the same rate in 1982 and 1983. All soil treatments involved a ground area of about 16 m^2 and the fungicide formulations were irrigated in. Fosetyl-Al was also applied as a trunk and foliar spray using a 3-g a.i./L aqueous solution, each tree receiving about 20 L per application with a hydraulic pump sprayer. In 1981, there were five applications of fosetyl-Al used as a foliar spray, and in 1982 and 1983, there were three applications per year. A third treatment with fosetyl-Al involved a combination of both soil and foliar applications using the same dosages and frequencies.

Disease assessment procedures. Foliage health was rated for the degree of stress caused by root rot on a scale of 0–5, where 0 = no visible symptoms and 5 = permanent wilting of the leaves. In replant experiments, the increase in stem girth was measured at 15 cm above the soil level using a Bernier caliper exactly 1 yr later, in May 1983. With the experiment with mature trees, the various treatments were measured for the total weight of fruit and the number of fruit produced per tree in January and November 1983.

RESULTS

Integrated control with replant nursery trees. Five months after planting, in the experiment with mixtures of fungicides, fosetyl-Al alone was as good as any combination of products (Table 2). The combinations of either etridiazole or metalaxyl with fosetyl-Al did not give superior control of avocado root rot (Table 2). Metalaxyl or etridiazole used alone gave poor control of avocado root rot; however, a combination of metalaxyl plus etridiazole gave disease control equivalent to fosetyl-Al used alone (Table 2). Five to 12 mo after planting, fosetyl-Al still gave very good control, as did the combination of etridiazole and metalaxyl (Table 2). At 12 mo, neither metalaxyl nor etridiazole used alone gave any control of root rot (Table 2).

Addition of inoculum to the planting hole intensified disease severity of plants not protected with fungicide compared with similar plants planted in naturally infested soil with no additional inoculum (Table 2). However, the fungicide treatment with fosetyl-Al plus metalaxyl, used in both situations, gave equivalent disease control (Table 2).

Fosetyl-Al applied either two or four times per year but using the same total amount of product gave good control of avocado root rot (Table 2). Fosetyl-Al alternated with either etridiazole or metalaxyl gave effective though ultimately poorer control of root rot. None of the other fungicide treatments in the sequential experiment gave control of root rot. When fosetyl-Al was applied as the second and fourth postplant treatment in a sequence where either etridiazole or metalaxyl was the first treatment, there was no control of root rot (Table 2).

Control of *P. cinnamomi* on mature trees. Mature avocado trees with an average disease severity value of 3.1, pruned in May 1980 to scaffold limbs, regenerated new growth of foliage. Fungicides applied from January 1981 gave effective control of root rot, as evaluated by the lack of visual stress on

Table 1. Effect of the fungicides metalaxyl and fosetyl-Al on control of foliar symptoms caused by *Phytophthora cinnamomi* on 20-yr-old avocado trees (cultivar Fuerte)

Fungicide treatment[x]	Disease severity[y] (months after initial fungicide treatment)				
	8 Mo	13 Mo	21 Mo	30 Mo	35 Mo
Fosetyl-Al spray treatment	0.1 a[z]	0.4 ab	0.2 a	0.6 a	0.8 a
Fosetyl-Al soil treatment	0.1 a	0.2 a	0.3 a	0.8 a	0.8 a
Fosetyl-Al spray + soil treatment	0.2 a	0.0 a	0.2 a	0.8 a	1.2 a
Metalaxyl	0.3 a	0.6 ab	0.8 a	2.3 b	2.8 b
Control	1.4 b	1.6 b	2.4 b	3.3 b	3.4 b

[x] Metalaxyl was applied in January, April, August, and December 1981; June and October 1982; and May and July 1983. Fosetyl-Al (foliar spray) was used in January, May, July, September, and November 1981; June, October, and December 1982; and May, July, and September 1983. Fosetyl-Al (soil treatment) was applied in January, May, July, and October 1981; June and October 1982; and May and July 1983.

[y] Visual ratings of foliar symptoms on a scale of 0–5, where 0 = no disease and 5 = permanent wilting.

[z] Mean values are based on six replicates (five replicates for fosetyl-Al [spray + soil treatment]). Values with the same letter are not significantly different ($P = 0.05$) according to Duncan's multiple range test.

Table 2. Effects of the fungicides metalaxyl, fosetyl-Al, and etridiazole used alone or in combination on avocado root rot as reflected in disease severity and trunk girth increase of 2-yr-old avocado trees on Duke 7 rootstocks

Fungicide treatment	Disease severity[u] (days after planting)			Increase in trunk girth (%)[v]
	90 Days	160 Days	230 Days	365 Days
Mixture experiment[w]				
Fosetyl-Al	0.0 a[x]	0.1 a	0.6 a	33.1 a
Fosetyl-Al + metalaxyl	0.0 a	0.0 a	0.3 a	30.2 ab
Fosetyl-Al + etridiazole	0.1 a	0.4 a	0.5 a	29.1 ab
Metalaxyl + etridiazole	0.2 a	0.4 a	0.5 a	29.0 ab
Etridiazole	0.3 a	1.8 a	2.1 b	18.1 bc
Metalaxyl	0.1 a	1.9 b	2.4 b	12.3 c
Control	2.5 c	3.4 c	3.1 b	12.0 c
Fosetyl-Al + metalaxyl[y] (no additional inoculum)	0.0 a	0.3 a	0.6 a	30.2 ab
Control[y] (no additional inoculum)	0.9 b	2.1 b	2.3 b	21.9 abc
Sequential experiment[z]				
Fosetyl-Al	0.0 a	0.2 a	0.6 a	35.0 a
Fosetyl-Al/etridiazole	0.1 a	0.5 a	0.7 a	26.8 ab
Fosetyl-Al/metalaxyl	0.0 a	0.7 a	1.3 a	24.7 b
Metalaxyl/etridiazole	0.6 a	2.0 bc	2.4 b	17.9 bc
Metalaxyl	0.2 ab	2.0 bc	2.3 b	11.3 c
Etridiazole/fosetyl-Al	0.2 ab	1.6 b	2.7 bc	11.9 c
Metalaxyl/fosetyl-Al	0.3 ab	2.5 c	3.1 bc	11.3 c
Etridiazole/metalaxyl	0.1 a	1.7 bc	2.8 bc	9.9 c
Etridiazole	0.3 ab	1.9 bc	2.9 bc	10.5 c
Control	1.9 c	3.5 d	3.6 c	11.9 c

[u] Visual ratings of foliar symptoms on a scale of 0–5, where 0 = no visible symptoms and 5 = permanent wilting.

[v] Percentage increase in trunk diameter calculated from ([new diameter]/[initial diameter]) × 100, 1 yr after planting.

[w] In the experiment with mixtures of fungicides, compounds were applied either singly or in mixtures of two products. There was a single preplant treatment (May 1982) and two postplant treatments (May and August 1982).

[x] Values with the same letters are not significantly different ($P = 0.05$) according to Duncan's multiple range test.

[y] These treatments did not receive additional inoculum of *Phytophthora cinnamomi* at planting.

[z] In the experiment with sequences of fungicides, compounds were applied alternately. The compound named first was the one used for both the preplant and first postplant treatment. There were four postplant treatments (May, August, October, and December 1982).

Table 3. Fruit production on 20-yr-old avocado trees (cultivar Fuerte) as influenced by fungicide treatments

Fungicide treatment	Yield 24 mo after first fungicide treatment		Yield 34 mo after first fungicide treatment[y]	
	No. of fruit per tree	Fruit wt per tree (kg)	No. of fruit per tree	Fruit wt per tree (kg)
Fosetyl-Al spray treatment	7 a[z]	1.8 a	75 a	17.2 a
Fosetyl-Al soil treatment	78 ab	11.4 ab	119 a	28.4 a
Fosetyl-Al spray + soil treatment	34 ab	6.3 ab	132 a	29.2 a
Metalaxyl	94 b	16.4 b	74 a	14.2 a
Control	14 a	2.0 a	8 a	1.3 a

[y] Fruit were harvested in November 1983, about 2 mo before the normal maturity date.
[z] Values with the same letter are not significantly different ($P = 0.05$) according to Duncan's multiple range test.

their foliage (Table 1). Metalaxyl soil application or fosetyl-Al applied either as spray to the trunk and foliage, as a soil treatment, or as a combination spray plus soil treatment gave effective root rot control for 2 yr (Table 1). In January 1983, a quantitative evaluation of the restoration of fruit yield showed that the metalaxyl treatment was superior to the fosetyl-Al spray treatment (Table 3).

During 1983, the visual rating of trees treated with metalaxyl increased and by December was not significantly different ($P = 0.05$) from that of trees in the control treatment (Table 1). Trees treated with a soil application of fosetyl-Al had twice the fruit production obtained with metalaxyl (Table 3), but these differences were not significantly different ($P = 0.05$).

DISCUSSION

The high efficacy of fosetyl-Al compared with either metalaxyl or etridiazole, under the severe disease pressure that developed in the two replant experiments, was not an unexpected finding. The rates of fosetyl-Al used as a postplant treatment, either 35 or 70 g a.i./m^2 per application, were in excess of those demonstrated to give good control of *P. cinnamomi* in greenhouse pot experiments (7,15,17). In contrast, the poor control given by metalaxyl was unexpected, because the rates used provided adequate control of avocado root rot in the greenhouse (15–17). However, the severe disease pressure that resulted from adding extra inoculum of the pathogen to the planting hole was probably atypical of many field situations. The good control achieved by a mixture of metalaxyl and etridiazole was similar to that resulting from fosetyl-Al alone. Experiments are in progress with mixtures of metalaxyl and etridiazole to determine whether there is any synergistic interaction between the two fungicides.

Recently, fosetyl-Al was registered for use on ornamentals in the United States. A comparison of fungicide costs demonstrated that the combination of metalaxyl and etridiazole gave equivalent control of root rot for about one-third of the cost of fosetyl-Al, which was used in the replant experiments. Clearly, more research is required to establish the critical minimal levels of fosetyl-Al that would give effective root rot control. In the experiment with mature trees, fosetyl-Al applied at a rate of only 8.5 g a.i./m^2 gave effective control compared with 35-g/m^2 used in a replant experiment. Cost-effective control of avocado root rot in replant situations would appear feasible using fosetyl-Al.

The concept of bringing severely diseased avocado trees back into useful economic production is one which has long been a challenge (16). The results obtained by combining the cultural practice of severe pruning of diseased trees with use of metalaxyl and fosetyl-Al were encouraging. Initially, metalaxyl treatment led to the fastest recovery of fruit production. A foliar application of fosetyl-Al was less effective. However, in the subsequent year, metalaxyl was less effective in controlling avocado root rot and tree vigor declined significantly. Whether this was due to an inadequate level of fungicide usage or to some other factor is under investigation. Ultimately, the most cost-effective control of root rot on mature trees was achieved with foliar applications of fosetyl-Al.

More research is required with mature trees on more cost-effective methods of application of systemic fungicides, such as trunk injection (4), in order to reduce the quantities of chemical needed to control avocado root rot. With replant trees, the beneficial effects achievable through the use of mixtures or sequential applications of different fungicides such as metalaxyl, fosetyl-Al, and etridiazole require critical investigation.

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