Aerial Versus Ground Application of Fungicides to Control Brown Rot of Citrus Fruit

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ABSTRACT

Solel, Z. 1983. Aerial versus ground application of fungicides to control brown rot of citrus fruit. Plant Disease 67:878-880.

The performance of copper fungicides to control brown rot of *Citrus* spp., caused by *Phytophthora citrophthora*, by a single aerial application was inferior to a standard single ground application. Yet in most experiments, the degree of control achieved by spraying from a helicopter was acceptable. The advantages of a single ground application with a supplementary aerial treatment are discussed. When applied from the ground, copper hydroxide (Kocide 101) at 4.6 kg/ha was less effective than a Bordeaux mixture at 20 kg/ha of pentahydrated copper sulfate.

Brown rot of citrus (*Citrus* spp.) fruit incited by *Phytophthora citrophthora* (R. E. Sm. & E. H. Sm.) Leonian is a common disease in citrus orchards in Israel (7,8) as well as in the United States (2,3,10). Inoculum production on the soil surface or on decayed fruit and subsequent splashing and blowing of sporangia onto fruit to cause infection require heavy rains (2). The disease is routinely prevented by spraying the lower fruits (within 1 m of the ground) and the soil underneath the trees with a copper fungicide once in autumn before the rainy season (5). In rainy winters, a supplementary treatment is recommended in late winter (4).

Fungicides are generally applied with a tractor-drawn sprayer driven between the rows. If effective disease control could be achieved by spraying with a helicopter, the application could be made under any soil conditions and topography to the whole orchard and at the optimal time. Furthermore, there would be no damage to, or drop of, fruit in a dense canopy. Bordeaux mixture usually is the preferred fungicide because of its long-lasting properties and lower cost compared with other copper-containing fungicides. Its disadvantages, especially for aerial application, are inconvenience of preparation and corrosiveness to the spraying equipment. In this study, aerial application and copper hydroxide were evaluated as optional treatments to the ground application of Bordeaux mixture.

Contribution from the Agricultural Research Organization, Volcani Center, Bet Dagan, Israel No. 549-E, 1982 series.

Accepted for publication 19 January 1983.

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MATERIALS AND METHODS

Fungicides. Bordeaux mixture was prepared by dissolving the required dose of pentahydrated copper sulfate (25.5% Cu) in the amount of water adjusted to the spraying type and adding 0.7 kg hydrated lime to each kilogram. Application rates were based on the copper-containing component (Table 1). For copper hydroxide (cupric hydroxide, 65.3% Cu), I used Kocide 101 (WP 77% a.i.).

Application methods. Ground sprays applied at the rate of 2,000 L/ha were aimed toward the lower canopy of the

trees, up to 1 m above soil level, as well as to the soil underneath and between the trees. The aerial spray was applied from a helicopter with a 15-m boom at the rate of 150 L/ha.

Experimental layout. Six experiments were conducted in four orchards of Valencia oranges (*Citrus sinensis* (L.) Osbeck) and in two orchards of Marsh Seedless grapefruit (*Citrus paradisi* Macf.) in six different locations. The spacing of the trees was 6 × 4 m with 28–44 trees per row. Ground sprays were applied to four rows, of which the central two were evaluated for disease rate. For aerial treatments, five rows were sprayed in two passes and the two rows adjacent to the overlapping zone were evaluated. The experiments were designed in randomized blocks of four replicates per orchard. The treatments (Table 1) were applied once, in November.

Evaluation of brown rot infection. Counts of infected fruit were made 7–10 days after each rain cycle, according to the temperature, so that incubation would be complete and fruits infected while on the tree would have just dropped. At each date, dropped fruits were collected from the ground beneath the trees and the brown rot-infected ones counted. Counting was discontinued at the end of winter, after a few weeks without substantial rainfall.

The statistical analysis was performed on the cumulative number of infected fruit at the end of the season. Because the variability between the replicates was approximately proportional to the treatment mean, the analysis of variance was performed on the logarithms of the observed values and the standard errors were obtained as percentages of the means.

RESULTS

Examination of fruit from the lower canopy as well as of papers placed underneath the trees revealed sparse spray droplets after helicopter spraying, compared with dense deposits after ground applications. The incidence and pattern of accumulation of *P. citrophthora* infected fruit in the various orchards throughout the season in both check and treated rows are plotted in Figure 1. The first heavy rains occurred in the various locations between mid-December and mid-January, and observations of infection started thereafter. The increase in number of infected fruits during the winter was gradual and without extreme increments, especially in the treated rows. The relative performance of the treatments was consistent during the season; however, comparisons between treatments were clearest when total seasonal infection was considered.

When applied from the ground, the fungicides performed better than when applied by air; thus, ground application resulted in fewer infected fruit (Fig. 1A–D). Both aerial and ground treatments varied in efficiency in the different orchards. In experiment A, both fungicides performed well by aerial application, although results were better by ground spraying than by helicopter application (1,010 and 2,060 infected fruit per hectare after treatment with Bordeaux mixture by ground and aerial spraying and 1,150 and 2,160 infected fruit per hectare for copper hydroxide, respectively) (Fig. 1A). Aerial treatments strongly reduced *P. citrophthora* infection in experiments E and F (Fig. 1E,F) (60 and 87% control, respectively). In experiments B and D (Fig. 1B,D), the aerial application of copper hydroxide gave only poor control of brown rot (45

Table 1. Details of treatments in experiments to control brown rot of citrus in Israel

Experiment	Location	Crop	Fungicide[a]	Application rate (kg a.i./ha) Air	Application rate (kg a.i./ha) Ground	Amount of seasonal rainfall (mm)	No. of rainy days
A	Regba	Grapefruit	BM	20.0	20.0	523	49
			CH	7.7	4.6		
B	Gedera N	Orange	BM	···	20.0	272	25
			CH	7.7	4.6		
C	Benaya	Orange	BM	10.0	20.0	636	44
			CH	7.7	4.6		
D	Lod	Orange	BM	···	20.0	662	50
			CH	7.7	4.6		
			CH	4.6	4.6		
E	Yagur	Grapefruit	CH	7.7	···	331	35
F	Gedera S	Orange	CH	7.7	···	272	25

[a] BM = Bordeaux mixture, CH = copper hydroxide.

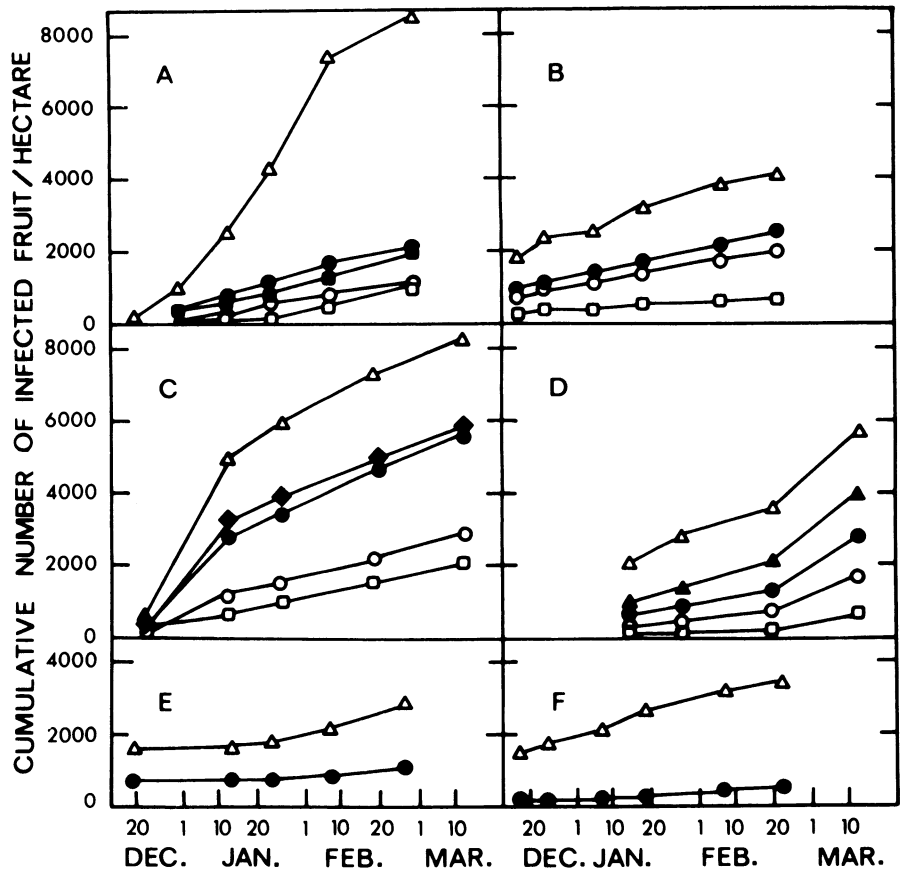

Fig. 1. Effect of ground and aerial treatments with Bordeaux mixture (BM) and copper hydroxide (CH) on the incidence of *Phytophthora citrophthora* infection of citrus fruit. The total infection rates for the treatments in each experiment differed significantly ($P = 0.05$) from each other, except those indicated in parentheses: **(A)** experiment A, grapefruit (no significant difference between fungicide applied with the same mode); **(B)** experiment B, oranges (no significant difference between application modes of copper hydroxide); **(C)** experiment C, oranges (no significant difference between fungicides applied from the air); **(D)** experiment D (oranges, aerial application of copper hydroxide 4.6 kg/ha did not differ either from the corresponding higher dose nor from the control); **(E)** experiment E, grapefruit; and **(F)** experiment F, oranges. ◆ = BM 10.0 kg/ha, aerial; □ = BM 20.0 kg/ha, ground; ■ = BM 20.0 kg/ha, aerial; o = CH 4.6 kg/ha, ground; ● = CH 7.7 kg/ha, aerial; ▲ = CH 4.6 kg/ha, aerial; and Δ = check.

and 51%, respectively). If related to the corresponding ground treatment, however, the efficiency of the 7.7-kg dose was 88 and 73%, respectively. In experiment C (Fig. 1C), aerial treatments with both fungicides were unsatisfactory; note should be taken of the half-strength (10 kg/ha) Bordeaux mixture applied from the air. When applied from the ground, copper hydroxide was often less effective than Bordeaux mixture (experiments B–D) except for experiment A, where both fungicides performed similarly and well.

DISCUSSION

The conventional approach to brown rot control is based on application of a copper fungicide to two complementary targets (3). The fruit is covered with a protective deposit and the ground underneath the trees is treated to inhibit inoculum production over it. When a high-volume spray is applied to the lower canopy of the trees, a part of it lands on the soil indirectly as a result of runoff. Klotz et al (4–6) and Pappo et al (8) evaluated fungicides and application procedures by collecting fruits from a treated plot and inoculating them in the laboratory. With such an evaluation procedure, the part played by the fungicide reaching the ground is overlooked. In this study, evaluation of fungicide performance was conducted in the field so that the combined effect of both treated targets was assayed.

The fruit examined after aerial spraying revealed sparse fungicide deposits, whereas most of the toxicant was deposited on the upper canopy of the trees and to a limited extent on the ground. We may surmise that rain gradually washed the fungicide from the canopy onto the fruit in the lower canopy and onto the ground. The efficiency of redistribution of fungicides by rainfall to control citrus melanose and scab was demonstrated by Yamada (11). Fungicides deposited on the upper surfaces of the leaves at the tops of the trees could be found on leaves in inner parts of the trees. The value of soil coverage with copper fungicides in preventing brown rot is common knowledge. Recently, it has been demonstrated in field trials that when Bordeaux mixture was applied by under-canopy sprinkler irrigation, effective control of brown rot was obtained although there was little protective fungicide deposit on the fruit (7).

Our trials as well as those from California (4,5) suggest that usually, if the operation of a ground sprayer is feasible, it would be preferable to a helicopter. Still, aerial application may provide an acceptable degree of control when treatment is required immediately after a rainy period, especially as a supplementary treatment in late winter. Aerial treatment may be preferred in orchards with a dense canopy, where the operation of a ground sprayer would cause considerable damage. Bordeaux mixture is a more reliable fungicide than copper hydroxide, but the latter has the technical advantages of being easier to prepare and spray is less corrosive than Bordeaux mixture. In addition, in plots where copper phytotoxicity is anticipated (1,9), ground spraying with copper hydroxide at the recommended dose (4.6 kg/ha) will add less copper into the orchard.

ACKNOWLEDGMENTS

I thank M. Kovacs, Y. Oren, E. Israeli, and Rachel Messinger for their valuable help.

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