Field Evaluation of Soil Fumigation and Fungicide Drenches for Control of *Phytophthora fragariae* in Red Gauntlet Strawberries

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ABSTRACT

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Soil fumigation and fungicide drenches were compared for control of strawberry red stele (*Phytophthora fragariae*). In naturally infested soil, red stele was controlled either by fumigating with a mixture of chloropicrin and methyl bromide (2:1) at 450 kg/ha or by preplant dipping and drenching the soil at planting with an aqueous suspension of either 500 mg/L benomyl plus 500 mg/L metalaxyl or 500 mg/L iprodione plus 500 mg/L metalaxyl applied at 100 ml/plant. In untreated areas, as many as 58% of the plants died and those that survived were severely stunted with red steles in 37% of their roots. In fumigated or fungicide-drenched areas, the number of dead plants rarely exceeded 5% and red stele roots were either not detected or their incidence was less than 1%.

Between 30 and 50% of Red Gauntlet strawberry plants wilted and collapsed on many commercial strawberry plantings in the Adelaide Hills of the Mt. Lofty Ranges in early summer of 1980. The collapsed plants and associated root rotting indicated that the problem was soilborne and that soil fumigation and fungicide drenches could possibly be used for control. Because the disease was seriously affecting the livelihood of many South Australian growers, experiments to evaluate methods of control were initiated before the causal organism was identified.

Soil fumigation is widely used to control soilborne diseases of strawberries (5,15), but apart from work by Meagher and Jenkins (4) on root-knot and Verticillium wilt, there has been no evaluation of soil fumigation for control of strawberry root rots in Australia. Fungicides applied to soil at planting or as foliar sprays have been used in the United Kingdom and United States to control some soilborne diseases of strawberries (3,7–9) but none have been evaluated on strawberries in Australia.

Experiments to evaluate both soil fumigation and fungicides were undertaken, and while the work was in progress, *Phytophthora fragariae* (Hickman) was isolated from diseased plants (12). This indicated that *P. fragariae* was associated with the root rotting. Although the fungus has not been isolated from other strawberry-growing areas of Australia, the presence of red stele symptoms in these areas indicates that the fungus could also be causing problems in other states. This paper reports the studies undertaken to evaluate and compare soil fumigation and fungicide drenches to control red stele in South Australia.

MATERIALS AND METHODS

Experiments were conducted on two properties where commercial plantings of

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strawberries had wilted and collapsed during the previous season. The sites were at Carey Gully and Summertown, which are about 2 km apart in the central Adelaide Hills area of the Mt. Lofty Ranges. Soil at both sites was a friable clay loam with moderate crumb structure.

At each site, two blocks each of four beds 40–60 cm wide × 21 m long and 1.4 m apart at the center were laid out. One block was untreated and the other was fumigated with a mixture of chloropicrin and methyl bromide (2:1) at 450 kg/ha, using a commercial fumigation rig to inject the fumigant through two tynes set 15 cm apart and 8 cm below the soil surface. The planting bed was covered with black plastic immediately after fumigation. Nonfumigated rows were covered with plastic. Soil between the rows was not fumigated or covered with plastic.

Red Gauntlet runners certified "virus-free" were divided into three equal batches. One batch was immersed in a 15-L mixture containing 500 mg active ingredient (a.i.) benomyl (Benlate 50WP)/L, 500 mg a.i. metalaxyl (Ridomil 25WP)/L, and 2 ml/L Citowet (BASF Australia Ltd.), a wetting agent. Another batch was immersed in a mixture of 500 mg a.i. iprodione (Rovral 50WP)/L, 500 mg a.i. metalaxyl/L, and 2 ml/L Citowet. The remaining batch was immersed in a solution containing 2 ml/L Citowet.

Previous isolations from certified runners had shown *Botrytis cinerea* and occasionally *Phytophthora cactorum* present in some samples of runners. Benomyl or iprodione were used to control *B. cinerea* and metalaxyl to control *P. cactorum* if either was present on the runners used in these experiments.

The runners were immersed for 1 hr and drained and planted the next day (9 July 1981). Runners from each treatment were planted separately in double-row plots 3.5 m long. There were 24 plants per plot. At planting, 100 ml of either a benomyl plus metalaxyl or iprodione plus metalaxyl mixture at the rate used before was poured around the base of each plant. Treatments were arranged in a randomized block so that each was replicated twice in each row of the fumigated and nonfumigated blocks, giving a total of eight replicates per treatment in each block.

At each site, the grower watered the plants regularly and controlled weeds by hand-hoeing or with herbicides. Dead plants in each plot were counted three times during the growing season.

In late November, two plants were removed from the center of each plot, and 10 primary roots selected at random from each plant were rated for rotted roots. The presence of red steles in these roots was also scored after slicing the length of each root (9).

Rotted root data were analyzed using a log-linear model that assumed that the error distribution approximated the Poisson distribution. The analysis produces a likelihood ratio statistic that is asymptotically χ^2 distributed (1).

Isolation of fungi. Fungi were isolated from roots of strawberry plants before planting, before and after immersion in either benomyl plus metalaxyl or iprodione plus metalaxyl mixtures, and 3 and 4 mo after planting in October and November.

Five plants were picked at random from the untreated and fungicide-treated batches before they were planted. Plants were first washed with tap water and roots with lesions were then removed from the plants and immersed in a 1% sodium hypochlorite solution for 2 min. Pieces of root were dissected from the margins of lesions, dried on blotting tissue paper, and placed on water agar or potato-dextrose agar, both of which contained 50 mg/L of streptomycin sulfate. The plates were incubated for 2 to 3 wk at 25 C. Fungal growth originating from the root pieces was identified.

Two plants from opposite ends of each plot were removed in October from a minimum of four fungicide-treated plots in both the fumigated and nonfumigated blocks at Carey Gully and Summertown. The method described earlier was used to isolate fungi from root lesions on these plants as well as from those on the plants removed in November to rate root rotting and the incidence of red stele.

RESULTS

Dead plants were first noted 12 wk after planting (early October) in the nonfumigated, nondrenched plots at both sites. Bulked data showed that incidence of dead plants steadily increased, and by mid-January, 58% of the plants in these plots were dead at Carey Gully and 27.5% at Summertown (Table 1).

Few dead plants were found in the fumigated or fungicide-drenched plots at any time. At both sites, the numbers of dead plants in these treatments rarely exceeded 5%.

Incidence of root rot and red stele are shown in Table 2. Rotted roots were present in all treatments and the highest number (100% at Carey Gully and 95% at Summertown) occurred in the untreated areas. At Summertown, differences in incidence of root rotting between treatments were not great, although lower numbers occurred in fumigated soil. At Carey Gully, the lowest number of rotted roots occurred in soil treated with benomyl plus metalaxyl in both fumigated and nonfumigated soil.

Analysis of data showed that for the hypothesis of no association between fumigation and the number of rotted roots, the likelihood ratio statistic, G^2, was 17.4 on 4 degrees of freedom (df) and 20.46 on 4 df for Carey Gully and Summertown, respectively. The hypothesis is rejected; fumigation and the number of rotted roots are associated.

For the hypothesis of no association between fungicide drench and the number of rotted roots the G^2 statistic was 79.1 on 8 df for Carey Gully and 3.92 on 8 df for Summertown. Thus, at Carey Gully, drenching had a significant ($P < 0.001$) effect on the incidence of rotted roots, whereas at Summertown, this effect was not significant.

Red stele symptoms occurred predominantly in the untreated plots. At Carey Gully, 37% and at Summertown, 12% of the roots in this treatment had red steles. Of the other treatments, only the iprodione plus metalaxyl treatment in the nonfumigated soil and the control in the fumigated treatment showed 0.6 and 0.7% red stele symptoms, respectively.

Fungal isolations. Some of the fungi and their frequency of isolation from root lesions on plants taken from various treatments are shown in Tables 3 and 4. *Fusarium*, *Pythium*, and *Rhizoctonia* are discussed in detail because these fungi are known to be pathogenic to strawberries. Other fungi isolated were species of *Alternaria*, *Botrytis*, *Candida*,

Table 1. Percentage of dead plants after soil fumigation or application of fungicide drenches at planting

Soil treatment Fungicide[a]	No. dead plants[b] at various days after planting					
	Carey Gully			Summertown		
	97	114	188	97	114	188
Fumigated[c]						
Benomyl (1 g/L) + metalaxyl (2 g/L)	0	0	0	0	0.6	0.6
Iprodione (1 g/L) + metalaxyl (2 g/L)	0	0	0	0	0.7	2.0
Control (no fungicide)	0	0.5	4.0	0	0.7	6.0
Nonfumigated						
Benomyl (1 g/L) + metalaxyl (2 g/L)	0	0	0	0	0.2	5.0
Iprodione (1 g/L) + metalaxyl (2 g/L)	0	0	0	0	0.2	5.5
Control (no fungicide)	23.0	37.0	58.0	0.5	9.0	27.5

[a] Fungicide suspensions of 100 ml/plant applied at planting.
[b] Calculated from 192 plants per treatment.
[c] Chloropicrin plus methyl bromide (2:1) at 450 kg/ha.

Cladosporium, *Cylindrocarpon*, *Mortierella*, *Penicillium*, *Phoma*, *Rhizopus*, *Trichoderma*, *Ulocladium*, and *Varicosporum*, which are considered saprophytic or weakly parasitic.

Before planting. *Fusarium* spp. and *Pythium* spp. grew from 20 and 18%, respectively, of isolations from roots of untreated plants (Table 3). Immersing the plants in either fungicide mixture inhibited isolation of *Pythium* but not *Fusarium*. *Rhizoctonia* was isolated from lesions on the roots of untreated plants but not from plants dipped in fungicides. A *Botrytis* sp. was isolated from plants immersed in the iprodione plus metalaxyl mixture.

After planting. Because the range of fungi and their frequency of isolation from Carey Gully and Summertown were similar at both sampling times, data for these samplings have been combined in Table 4.

In nonfumigated soil, *Phythium* spp. were isolated from 11% of the untreated plants but not from plants drenched with either fungicide mixture. *Pythium* spp. were also isolated from 5.5% of the untreated plants and from 1% of plants drenched in benomyl plus metalaxyl in the fumigated soil. *Fusarium* spp. and *Rhizoctonia* sp. were isolated frequently from most treatments in both fumigated and nonfumigated soil. Neither fungicide mixture reduced the frequency of isolation of *Fusarium* or *Rhizoctonia* when compared with the control.

DISCUSSION

In these experiments, red stele (*Phytophthora fragariae*) was controlled by immersing strawberry runners in a fungicide mixture containing metalaxyl and applying the same fungicide mixture to the soil at planting. The control achieved with the fungicide treatments was as good as or better than that obtained by fumigating the soil with a mixture of chloropicrin and methyl bromide.

Although the soil drench treatments consisted of a mixture of either benomyl or iprodione plus metalaxyl, it is unlikely that benomyl or iprodione had a major effect on *P. fragariae* because Montgomerie and Kennedy (6,7) reported that neither thiabendazole (TBZ), a benzimidazole fungicide similar to benomyl, nor iprodione controlled red stele. The effect of immersing strawberry runners in fungicides before planting was not tested alone, but experiments elsewhere (8) have shown this treatment to be ineffective in controlling red stele. My experiments showed that one's ability to isolate *Pythium* was reduced in runners immersed in fungicides when compared with untreated runners. Because the treatment is relatively inexpensive and easy to apply, it might be a useful practice for minimizing the risk of introducing pathogens into fumigated soil.

These results confirm other reports on the effectiveness of metalaxyl for red stele control; however, my technique differed slightly from that of McIntyre and Walton (3), who applied metalaxyl as a soil drench at transplanting, as a spray soon after budbreak, and again before dormancy began. It seems that a single transplant fungicide treatment is sufficient to control red stele in annual strawberry plantings, but further work in Australia is necessary to determine if multiple fungicide treatments are necessary in plantings grown for more than 1 yr.

In the untreated plots of these experiments, the large number of dead plants and the stunted plants with red steles in the main roots and the lack of rootlets were typical of severe *P. fragariae* infection (13). Because soil fumigation and metalaxyl control both *Pythium* spp. and *P. fragariae* (2,3,10,14), it was not possible to determine if *Pythium* was affecting plants in these experiments. The large number of dead plants in the untreated areas, however, indicates that *P. fragariae* was mainly involved because *Pythium* attacks feeder rootlets, causing poor plant growth and stunting rather than plant death (11,14). The involvement

Table 2. Incidence of root rotting and red stele in Red Gauntlet strawberry plants drenched with fungicides at planting and grown in fumigated or nonfumigated soil

Soil treatment Fungicide[a]	Roots rotted (%)[b] Carey Gully	 Summertown	Roots with red stele (%)[b] Carey Gully	 Summertown
Fumigated[c]				
Benomyl (1 g/L) + metalaxyl (2 g/L)	29	68	0	0
Iprodione (1 g/L) + metalaxyl (2 g/L)	62	79	0	0
Control (no fungicide)	36	73	0.7	0
Nonfumigated				
Benomyl (1 g/L) + metalaxyl (2 g/L)	33	87	0	0
Iprodione (1 g/L) + metalaxyl (2 g/L)	59	93	0.6	0
Control (no fungicide)	100	95	37	12
Fumigation × root rot interaction	$G_4^2 = 17.4$ ($P = 0.001$)	$G_4^2 = 20.46$ ($P = 0.001$)		
Drench × root rot interaction	$G_8^2 = 79.1$ ($P = 0.001$)	$G_8^2 = 3.92$ (Not significant)		

[a] Fungicide suspensions of 100 ml/plant applied at planting.
[b] Rotted roots and red stele were assessed on 10 roots on each of two plants per plot, with a total of 160 roots assessed for each treatment.
[c] Chloropicrin plus methyl bromide (2:1) at 450 kg/ha.

Table 3. Fungi isolated from roots of Red Gauntlet strawberry runners immersed in fungicides

Fungi	Isolation frequency (%) No fungicide	 Benomyl + metalaxyl[a]	 Iprodione + metalaxyl[b]
Fusarium spp.	20.0	41.5	33.3
Pythium spp.	18.3	0.0	3.3
Rhizoctonia sp.	1.6	0.0	0.0
Total isolations (no.)	61	53	60

[a] Benomyl (1 g/L) plus metalaxyl (2 g/L).
[b] Iprodione (1 g/L) plus metalaxyl (2 g/L).

Table 4. Fungi isolated from the roots of Red Gauntlet strawberry plants grown in fumigated or unfumigated soil and drenched with fungicides at planting

	Isolation frequency (%)					
	Fumigated[a]			Nonfumigated		
Fungi	No drench	Benomyl + metalaxyl drench[b]	Iprodione + metalaxyl drench[c]	No drench	Benomyl + metalaxyl drench[b]	Iprodione + metalaxyl drench[c]
Fusarium spp.	16.6	17.4	22.0	5.50	6.7	47.2
Pythium spp.	5.5	1.1	0.0	11.10	0.0	0.0
Rhizoctonia sp.	4.1	11.6	11.1	0.09	12.1	8.3
Total isolations (no.)	72	86	36	108	74	36

[a] Chloropicrin plus methyl bromide (2:1) at 450 kg/ha.
[b] Benomyl (1 g/L) plus metalaxyl (2 g/L).
[c] Iprodione (1 g/L) plus metalaxyl (2 g/L).

of either *Fusarium* or *Rhizoctonia* is also unlikely because these fungi were isolated from both the treated and untreated areas. Furthermore, the absence of vascular staining in the petioles of stunted and collapsed plants and the failure to isolate *Verticillium* from affected plants also indicate that this fungus had not killed plants.

These experiments have demonstrated that preplant dipping combined with fungicide drenches could be readily adopted by strawberry growers because the treatments require no specialized equipment and are inexpensive compared with soil fumigation. There are, however, two main disadvantages of using this technique to control red stele. First, the fungicide treatments are unlikely to control other common soilborne pathogens of strawberry such as *Verticillium*, *Rhizoctonia*, and *Fusarium* that are controlled by soil fumigants. Second, as observed in this trial, weeds occurred more frequently in the drenched rows than in fumigated rows. Thus, the growth of weeds such as blackberries (*Rubus* spp.) that are normally controlled by fumigation could create management problems in plantings treated only with fungicides.

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