Effect of *Phytophthora megasperma* var. *sojae* on Yield of *Asparagus officinalis*

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ABSTRACT

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Field plots of the asparagus cultivar U.C. 157 established in Yolo loam at Davis in 1978 were inoculated in 1982 with field soil containing *Phytophthora megasperma* var. *sojae* and regularly (3-to 5-mo intervals) sprayed with metalaxyl at 1.12 kg a.i./ha to control Phytophthora rot. In 1983, metalaxyl treatment was discontinued on half of the plots that had been sprayed previously, and in 1984, treatment was begun on half of the plots that had not been sprayed previously. Sprayed plots yielded between 38 and 118% more than unsprayed plots and had higher yields with larger-diameter spears in 1983. Control of Phytophthora rot with metalaxyl also resulted in earlier production in 1983 but did not affect survival of plants or vigor of summer fern growth. A significant amount of spear and/or crown rot occurred below the soil surface in unsprayed plots. Losses caused by Phytophthora rot were higher during wet seasons than during dry seasons and were higher during the early part of each season when soil conditions were cool and wet. Two consecutive years of severe Phytophthora rot in unsprayed plots may induce a long-lasting and possibly permanent decrease of productivity of established asparagus.

Additional key words: asparagus decline, asparagus viruses, *Fusarium* spp.

An unidentified *Phytophthora* sp. that attacked asparagus spears before harvest and during shipment was first reported in California in 1938 (2). This condition, known to growers as "slime" because of the water-soaked, slightly sunken, soft lesions that developed on the spears (2,9), is common in early spring, especially during wet weather.

In 1974, Boesewinkel (3) isolated *P. megasperma* var. *sojae* (*P.m. sojae*) Hildebrand from spears in New Zealand and reported that it killed plants in commercial crops. However, no data were reported on the long-term effect of Phytophthora rot on asparagus production in established fields.

Metalaxyl is an acylalanine fungicide with activity restricted to several fungi in the order Peronosporales, including *Pythium, Phytophthora, Peronospora, Pseudoperonospora, Plasmopara, Bremia, Sclerospora, Peronosclerospora, Sclerophthora,* and *Albugo* (15). Of these, only *Phytophthora* has been reported as a pathogen of asparagus (2,3,6,9,10). Hence it is possible to use metalaxyl as a diagnostic tool to separate the effect on production of *Phytophthora* and related fungi from that of other soilborne pathogens of asparagus, especially *Fusarium oxysporum* f. sp. *asparagi* Cohen & Heald (11) and *F. moniliforme* Sheldon (4,12).

This paper reports the results of a 3-yr study to determine the effect of *P.m. sojae* on yield of established asparagus. Two preliminary reports of this work have been published (7,9).

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MATERIALS AND METHODS

Plots of the cultivar U.C. 157 were established at Davis in Yolo loam as seedling transplants in spring 1978. Each two-row plot was 14.3 m long with rows 1.8 m apart and plants spaced 0.3 m apart in the row.

Soil samples were taken from the trial site in December 1981 and January 1982, and an attempt was made to isolate *Phytophthora* spp. from the soil with a seedling baiting technique (6). Because *Phytophthora* spp. could not be isolated, all plots were inoculated on 13 February 1982 with soil from a field known to contain *P.m. sojae*. Soil was collected from various sites in the field and thoroughly mixed, then about 4 L was evenly spread over the center of each 14.3-m-long row. To minimize contamination between neighboring plots, dams were made at the end of each plot by filling the furrows between the beds with soil.

On 20 February 1982, metalaxyl (Ridomil 2E) was applied at the rate of 1.12 kg a.i./ha in about 720 L/ha of water with a compressed CO_2 sprayer. A band 3.6 m wide was sprayed on half of the plots. To completely control *Phytophthora* rot when free water either from summer irrigation or winter rains was on the plots, the same treatment was applied to the same plots at 3- to 5-mo intervals on 29 May and 27 October 1982 and 10 January and 21 May 1983. The remaining plots were not sprayed. The treatments were arranged in a randomized complete block design with eight replicates.

Plots were harvested for 73 days in 1982 starting on 10 March and ending on 22 May and for 84 days in 1983 starting on 24 February and ending on 18 May. After each harvest, unless otherwise stated, the number of diseased and healthy spears was recorded. Healthy spears were trimmed to 225 mm long, graded into marketable (basal diameter $\geq$5 mm) and unmarketable (basal diameter $<$5 mm, deformed or open bracts), and weighed. During the last 2 wk of harvest in 1983, marketable spears were graded into three grades—small ($\geq$5 mm but $<$13 mm basal diameter), medium (13–19 mm basal diameter), and large ($>$19 mm basal diameter)—to determine the effect on quality where Phytophthora rot had or had not been controlled. A count of plants and senescent ferns in each plot was taken at the end of summer in 1982 and 1983. At the same times, plots were evaluated for vigor of fern growth.

To determine if the effect of applying metalaxyl lasted more than one season, applications to half of the plots that had previously been regularly sprayed since February 1982 were discontinued after the end of the 1983 harvest season (+/−M). On half of the plots that had not been previously sprayed, metalaxyl was applied at 1.12 kg a.i./ha on 20 February 1984 (−/+M). This was to determine if, after two seasons of severe disease, yield could be increased to equal that of plots in which Phytophthora rot had previously been controlled. Half of the remaining plots were sprayed on 28 July, 26 September, and 16 December 1983 and 20 February and 20 November 1984 (+M); the rest were not sprayed (−M). The four treatments were replicated four times in a randomized complete block design.

In 1984, plots were harvested for 91 days starting on 16 February and ending on 16 May. During the sixth week and the last 3 wk of harvest, marketable spears were graded into small, medium, and large. Because of the relatively low rainfall during the harvest season in 1984, additional water was applied to the trial area by sprinkler irrigation at the rate of about 2.5 mm/hr on 6 March (25 mm), 9 March (25 mm), 28 March (9 mm), and 8

April (25 mm).

To determine whether the response to metalaxyl application was a result of controlling only *Phytophthora* spp., four 103-mm-diameter soil cores were taken at random from the furrows between the rows to a depth of about 220 mm from each +M and −M plot on 1 June and 29 November 1984. Roots were washed from the soil, rinsed in running tap water for several hours, blotted dry, and weighed before being surface-sterilized for 5–10 min in 1% sodium hypochlorite and plated onto antibiotic potato-dextrose agar (6).

Pathogenicity of all fungal isolates was determined on asparagus seedlings, cultivar U.C. 157. Twelve seeds were sown in pots filled with a 50:50 (v/v) mixture of U.C. mix (13) and river sand. Inoculum was prepared by grinding pure cultures of each fungus in 86-mm-diameter petri plates poured with 20 ml of 20% V-8 juice agar (200 ml of V-8 juice mixed with 3 g of calcium carbonate, and 20 g of Difco-Bacto agar in 800 ml of distilled water) for 8 days in an incubator (20 C) under fluorescent lights (18-hr photoperiod). Each plate was flooded with 20 ml of autoclaved fresh pond water for 6 days before being homogenized at high speed for 30 sec in 500 ml of fresh pond water in a Waring Blendor. Nineteen days after seeding, the pots were placed in a water bath held at 15 ± 1 C and the seedlings were flooded with tap water

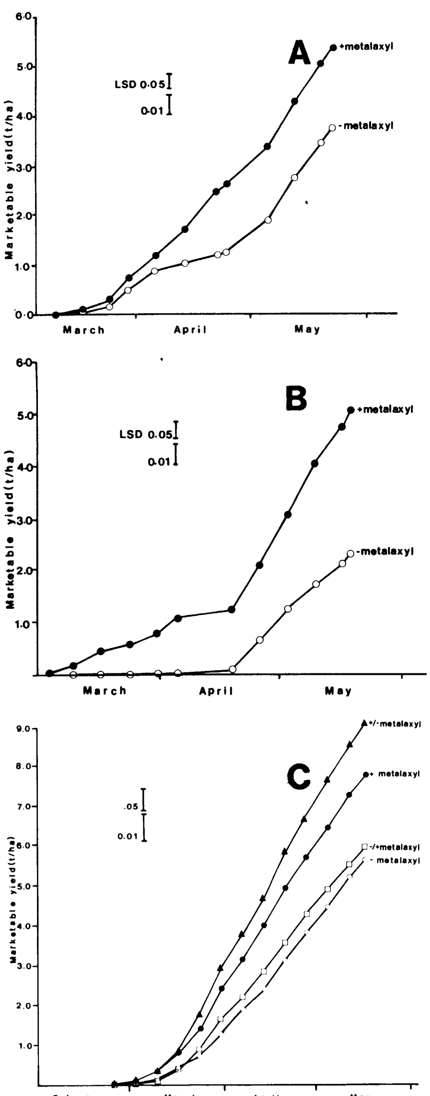

Fig. 1. Effect of metalaxyl on cumulative market yield of asparagus spears in **(A)** 1982, **(B)** 1983, and **(C)** 1984. +metalaxyl = Plots sprayed at 1.12 kg a.i./ha at 3- to 5-mo intervals since 20 February 1982, +/−metalaxyl = plots sprayed at 3- to 5-mo intervals from February 1982 to May 1983, −/+metalaxyl = not sprayed until February 1984, and −metalaxyl = not sprayed.

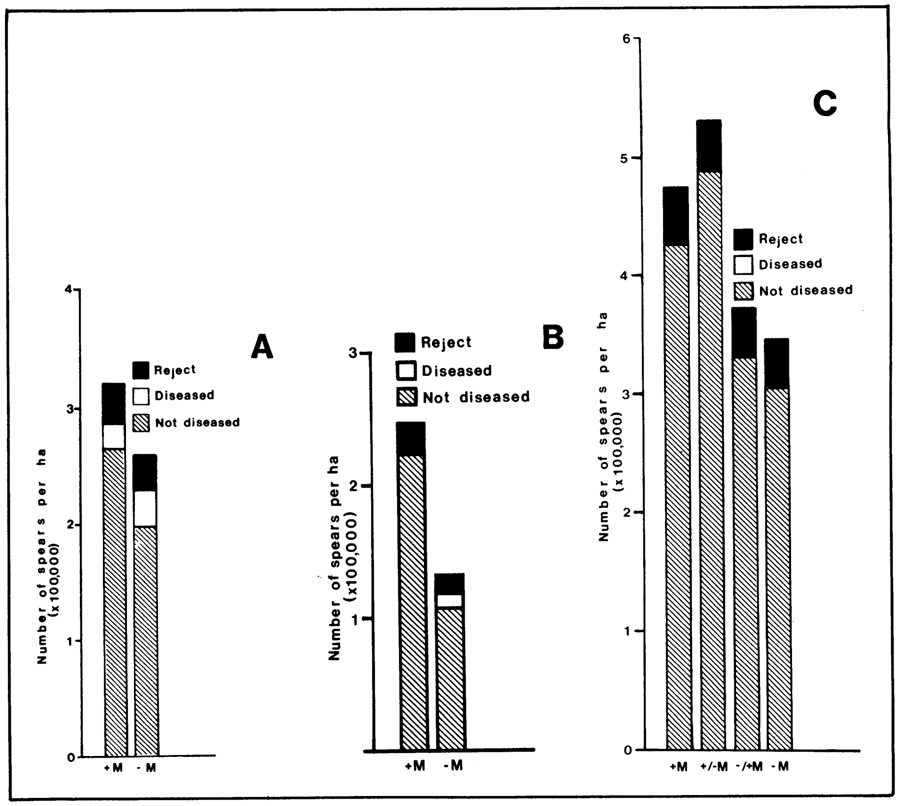

Fig. 2. Effect of metalaxyl on number of diseased, marketable, and reject asparagus spears in **(A)** 1982, **(B)** 1983, and **(C)** 1984. +M = plots sprayed at 1.12 kg a.i./ha at 3- to 5-mo intervals since 20 February 1982, +/−M = plots sprayed at 3- to 5-mo intervals from February 1982 to May 1983, −/+M = not sprayed until February 1984, and −M = not sprayed.

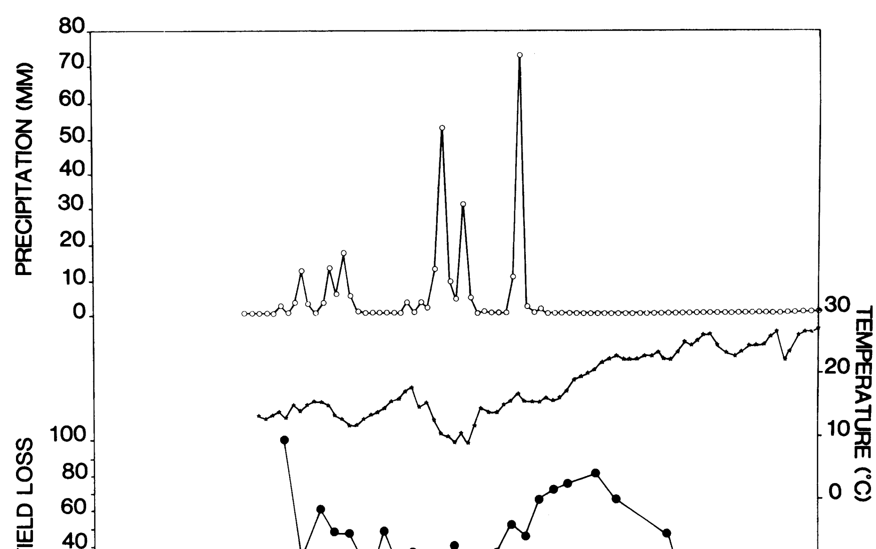

Fig. 3. •——• = Percentage total yield losses in 1982 caused by Phytophthora rot in asparagus not treated with metalaxyl, o——o = rainfall, and ★——★ = soil temperature at 100 mm.

before being inoculated by pouring 100 ml of inoculum over the surface of the U.C. mix/sand. The controls received only fresh V-8 juice agar homogenized in pond water. After 2 days, the pots were drained and 3 days later were flooded for 24 hr with tap water and again 4 days later. The seedlings were evaluated for root rot 12 days after inoculation by the method described in an earlier paper (6).

Climatological data. Rainfall and soil temperatures (at 100 mm deep) were collected from the University of California, Davis Climatic Benchmark Station, about 0.5 km from the trial.

Data from the trial were subjected to analysis of variance, and differences between treatment means were determined using a least significant difference test.

RESULTS

In 1982, plots treated with metalaxyl had significantly higher yields from 5 April to the end of the season (Fig. 1A). Plots treated with metalaxyl produced 33% more marketable spears and fewer diseased spears than plots that were not sprayed (Fig. 2A). There was no significant difference between treatments in the number of reject spears. Treatment with metalaxyl resulted in 22% more spears (diseased + marketable + reject). This indicates that some spear rot and/or crown rot probably occurred below the soil surface and therefore was not detected. Thus, to estimate the total losses in untreated plots and to determine the time during the season at which the major losses occurred, the percent total losses were calculated at each harvest using the following equation: percent total losses = 1 − (total no. of healthy spears in untreated plots/total no. of spears in treated plots) × 100. The highest losses occurred in the early part of the harvest season, when soil temperatures were between 9 and 24 C, especially after periods of heavy rainfall in late March and early April that resulted in surface-flooding of the plots (Fig. 3).

In 1983, plots treated with metalaxyl yielded 118% more than untreated plots (Fig. 1B). In addition, the harvest season started about 11 days earlier in sprayed plots than in plots that were not sprayed. Application of metalaxyl resulted in significantly (P = 0.01) higher yields during the last 2 wk of harvest of spears in all three size categories (Table 1). There was a 67, 101, and 164% yield increase of small, medium, and large spears, respectively, in treated plots.

In 1983, treatment with metalaxyl gave almost complete control of Phytophthora spear rot (Fig. 2B). The total number of spears (diseased + marketable + reject) that emerged above the soil surface was 84% higher in treated plots than in untreated plots. Highest losses in untreated plots occurred in the early part of the harvest season after periods of wet weather when soil temperatures were between 10 and 16 C (Fig. 4). Although significant quantities of rain fell in late April and early May, losses were lower during May, when the soil was drier and warmer. There were no significant differences between treatments in the number of plants per plot, number of senescent ferns per plot, or vigor of summer fern growth in 1982 or 1983.

In 1984, there was no significant difference (P = 0.01) in yield of marketable spears between plots that had been regularly treated with metalaxyl during the previous 3 yr and those that were not sprayed after May 1983 or between plots that had never been sprayed and plots that were sprayed only once before harvest in 1984 (Fig. 1C). The harvest, which started in late February in all plots, was 1–2 wk earlier than in the previous two seasons. Plots that had never been sprayed with metalaxyl had significantly

Table 1. Effect of metalaxyl on yield of asparagus spears during the last 2 wk of harvest in 1983

	Yield (t/ha)			
Treatment[a]	**Small**[b]	**Medium**[b]	**Large**[b]	**Total**
+ M	0.725	1.170	0.136	2.031
− M	0.435	0.583	0.052	1.070
LSD 0.05	0.081	0.158	0.033	0.095
0.01	0.120	0.234	0.049	0.140

[a] + M = plots sprayed at 1.12 kg a.i./ha at 3- to 5-mo intervals from 20 February 1982, − M = not sprayed.

[b] Small = basal diameter ≥5 but <13 mm, medium = basal diameter 13–19 mm, and large = basal diameter >19 mm.

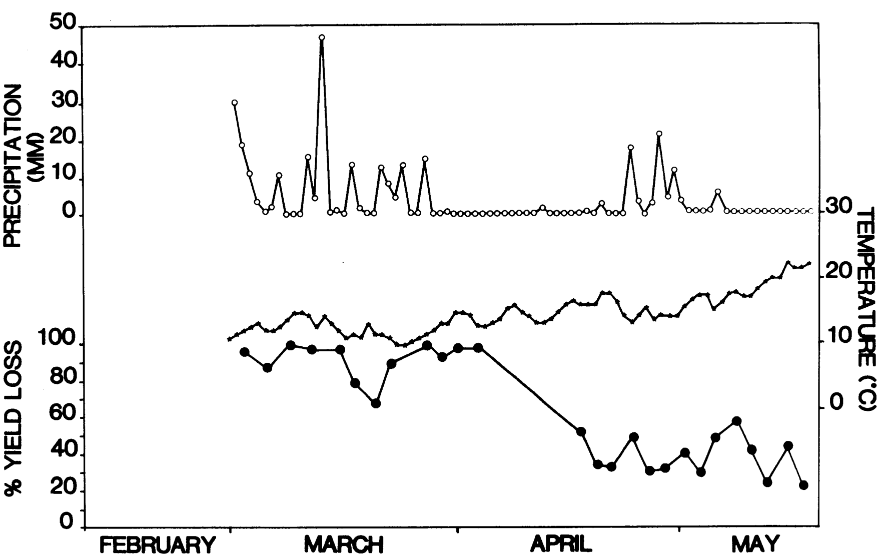

Fig. 4. •——• = Percentage total yield losses in 1983 caused by Phytophthora rot in asparagus not treated with metalaxyl, o——o = rainfall, and ★——★ = soil temperature at 100 mm.

Table 2. Yield of asparagus spears during the sixth week (28 March to 4 April) and the last 3 wk (27 April to 16 May) of harvest in 1984

		Yield (t/ha)			
Dates	**Treatments**[a]	**Small**[b]	**Medium**[b]	**Large**[b]	**Total**
28 Mar.–4 Apr.	+M	0.256	0.705	0.194	1.155
	+/−M	0.229	0.811	0.166	1.206
	−/+M	0.190	0.474	0.164	0.828
	−M	0.156	0.497	0.171	0.824
LSD 0.05		0.078	0.124	NS	0.135
0.01		0.111	0.178	···	0.194
27 Apr.–16 May	+M	1.168	0.980	0.056	2.204
	+/−M	1.325	1.057	0.105	2.487
	−/+M	0.902	0.890	0.041	1.833
	−M	1.012	0.880	0.087	1.979
LSD 0.05		0.294	NS	NS	0.470
0.01		0.423	···	···	0.676

[a] +M = sprayed at 3- to 5-mo intervals from February 1982, +/−M = sprayed at 3- to 5-mo intervals from February 1982 to May 1983, −/+M = not sprayed until February 1984, and −M = not sprayed.

[b] Small = basal diameter ≥5 but <13 mm, medium = basal diameter 13–19 mm, and large = basal diameter >19 mm.

($P = 0.01$) more diseased spears than any other treatments (Fig. 2C). The +M and +/−M treatments resulted in significantly ($P = 0.01$) more marketable spears than the −/+M or −M treatments. The +M and +/−M treatments also resulted in higher yields of medium spears during the sixth week of harvest and slightly higher yields of small spears during the last 3 wk of harvest (Table 2). There was no significant ($P = 0.01$) difference between treatments in yield of small or large spears during the sixth week or of medium or large spears during the last 3 wk.

Although the total amount of water applied to the plots (rainfall + irrigation) was lower in 1984 than in the two previous years, losses in unsprayed plots were relatively high throughout the entire season, even under the dry and warm soil conditions in May (Fig. 5).

The mean fresh weight of roots per plot (total from four cores) was significantly ($P = 0.05$) higher in the +M treatments (28.03 g) than in the −M treatments (20.27 g) on 29 November 1984. Fresh weight of roots was not recorded on 1 June 1984. *Pythium* and *Mortierella* spp. were isolated from both +M and −M treatments in June, but *P.m. sojae*, *Pythium*, and *Mortierella* spp. were isolated from −M treatments in November. None of these three fungi were isolated from roots from plots sprayed with metalaxyl. None of the isolates of *Pythium* or *Mortierella* spp. was pathogenic on asparagus seedlings, whereas all isolates of *P.m. sojae* caused severe root rot that resulted in death of the seedlings.

DISCUSSION

Regular treatment of plots with metalaxyl resulted in fewer spears infected by *Phytophthora*, and yield was increased between 38 and 118%. Similar yield increases from the use of metalaxyl in established asparagus have been shown in other trials at Davis in 1983 and 1984 (10; Falloon et al, *unpublished*), in two trials on peat soils in the Sacramento-San Joaquin Delta in 1982 and 1983 (9,10), in one trial in coastal southern California in 1983 (A. O. Paulus, *personal communication*), and in one trial in New Zealand (14). Because neither *Mortierella* nor *Pythium* spp. were pathogenic on asparagus seedlings, it seems probable that the yield reduction in plots that were not sprayed with metalaxyl was caused mainly by *P.m. sojae*.

During the 1983 season, harvesting of plots in which Phytophthora rot had been controlled with metalaxyl started earlier and resulted in higher yields of better quality spears at the end of the harvest season. Both responses are of value to California asparagus growers, who receive higher prices for asparagus produced early in the season and for medium and large spears.

A low level of diseased spears was found in 1982 and 1983 in plots that were treated with metalaxyl. During both years, infection followed periods of heavy rainfall, which caused surface-flooding of the plots and probably resulted in contamination of plots treated with metalaxyl from those that were not treated.

Yield increases from the control of *P.m. sojae* with metalaxyl were higher during wet seasons (1982 and 1983) than in the relatively dry 1984 season. This also was found in other trials at Davis (Falloon et al, *unpublished*). Yield losses from Phytophthora rot were higher in the early part of all three harvest seasons when field conditions were cool and wet. The optimum temperature for disease development when asparagus seedlings were inoculated with *P.m. sojae* was about 15 C (P. G. Falloon, *unpublished*). At 27 C or higher, no root rot occurred. Because soil temperatures during harvest in this trial seldom exceeded 24 C, low soil moisture was the most likely limitation to disease development during the latter part of each harvest season.

If metalaxyl was withheld for 1 yr after regular applications in the two previous years, yields were not reduced significantly nor were the number of diseased spears increased (Figs. 1C and 2C). Metalaxyl has a typical half-life under field conditions of between 30 and 125 days, and repeated applications have not resulted in a buildup in the soil (1). The significantly fewer diseased spears in the +/−M treatment than in the −M treatment in 1984 may therefore be a result of reduced inoculum concentration after 2 yr of frequent metalaxyl applications rather than the result of metalaxyl residues in the soil or plants.

Differences between total spear counts in sprayed and unsprayed plots showed that a significant amount of Phytophthora rot of spears and/or crowns probably occurred below the soil surface and was therefore not detected (9). Phytophthora has been recognized as a pathogen of asparagus in California since 1938 (2); thus it seems likely that the effect of *Phytophthora* spp. on asparagus production in California has been underestimated for many years, especially during wet harvest seasons.

Although losses from Phytophthora rot were relatively high in 1982 after heavy rains in March and April, disease losses in May were insignificant, probably because no rain had fallen since mid-April. In 1984, however, despite relatively little rain throughout the season and none after mid-April, disease losses in unsprayed plots remained high compared with plots in which Phytophthora rot had been controlled during the two previous years. In addition, the fresh weight of roots was lower in plots where Phytophthora rot had not been controlled. Despite the marked yield increases in all three seasons from the control of Phytophthora rot, there was no detectable difference between treatments in survival of plants or vigor of summer fern growth after 2 yr of severe disease. It therefore appears that *P.m. sojae* has relatively little effect on survival of established asparagus plants in comparison with its effect on spring spear production but that Phytophthora rot may result in a gradual weakening of the plants. Because application of metalaxyl in 1984 to plots that had not previously been sprayed and which had encountered two consecutive years of severe disease did not significantly increase yield, it appears that 2 yr of severe infection by *P.m. sojae* may have a long-lasting, possibly permanent effect on productivity of established asparagus. Asparagus decline is defined as a reduction in the size and number of spears to the point where the planting is unprofitable (11) and has been attributed to various causes including *F. oxysporum* f.sp. *asparagi* (11) and *F. moniliforme* (4,12). Asparagus virus II (AV II) was

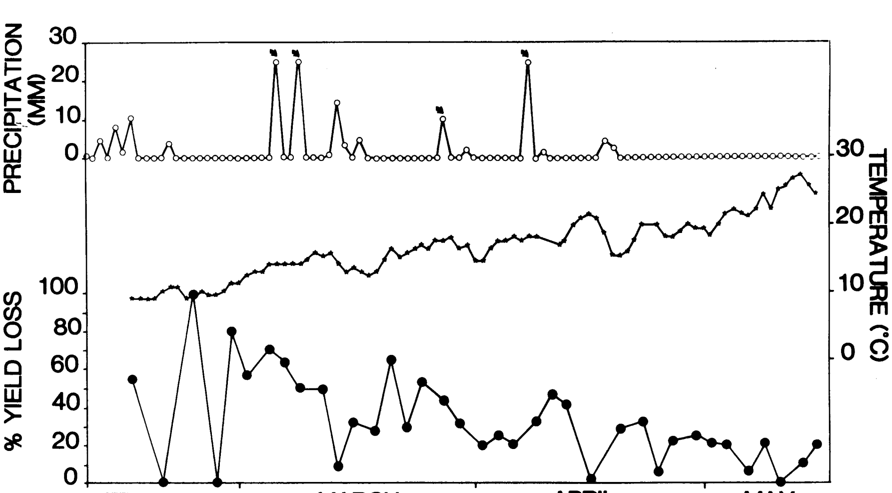

Fig. 5. •——• = Percentage total yield losses in 1984 caused by Phytophthora rot in asparagus not sprayed with metalaxyl, ★——★ = soil temperature at 100 mm, and o——o = rainfall and irrigation. Arrows indicate time of irrigation.

recently found in asparagus in California (8). Asparagus seedlings infected with AV II are more susceptable to *F. oxysporum* f. sp. *asparagi* and *F. moniliforme* than seedlings free of AV II (5). We conclude, therefore, that asparagus decline in California is the result of an interaction among various pathogens including *Fusarium, Phytophthora,* and asparagus viruses as well as adverse management practices (4) and that the relative importance of each is likely to vary from season to season.

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