Interactions Between Foliar Sprays and Soil Fumigation In the Yield Response of Potatoes

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ABSTRACT

Yield increases in potatoes (*Solanum tuberosum*) from control (by foliar spray) of *Alternaria solani* were greater in fumigated than nonfumigated soils. In some instances, significant yield increases from the early blight control occurred only in fumigated plots; in others, significant yield increases over those of nonsprayed controls occurred in both nonfumigated and fumigated soils. The interaction between Verticillium wilt and early blight is suggested as a critical factor in data interpretation.

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The effect of early blight caused by *Alternaria solani* (Ell. & Martin) L. R. Jones & Grout on the yield of potatoes (*Solanum tuberosum* L.) in the western United States has never been established. Significant yield responses to early blight control have been obtained in Colorado only in occasional seasons, irrespective of disease severity and the degree of control achieved (8, 9, 10). Harrison and Venette (10) suggested that Verticillium wilt might be involved in reducing yield benefits in potatoes following early blight control.

The research reported in this paper was initiated to test the hypothesis that *Verticillium albo-atrum* Reinke & Berth. (Microsclerotial form) and possibly other soil-borne pathogens were responsible for nullifying yield increases expected when field control of potato early blight was achieved.

MATERIALS AND METHODS.—Field trials were conducted in the San Luis Valley at Center, Colorado (mountainous southcentral Colorado, elevation 2,317 m = ca 7,600 ft) and in the Fort Morgan, Colorado, area (northeastern Colorado plains, elevation 1,316 m = ca 4,318 ft). Experiments at Center were conducted in 1969 and 1971, using Russet Burbank as the test cultivar in soil in which Russet Burbank potatoes had been grown continuously since 1962. Tests at Fort Morgan were conducted in 1971 using the Norchip cultivar. Plots at Center were row irrigated; those at Fort Morgan were irrigated by an overhead sprinkler. A randomized block design was used in all studies in 1971 with four replications per treatment. In 1969 only two replications were used due to lack of available space. All of the plots were located in fields with histories of severe Verticillium wilt. *Rhizoctonia solani* Kuhn was also present at each location but other soil-borne pathogens were not known to be present.

In each experiment, 4-row plots were fumigated during the last week in April and potatoes were planted between 13 May and 30 May. In 1969, fumigated plots were treated with 227.1 liters (60 gal) per acre of Vorlex (Methyl isothiocyanate + dichloropropenes + dichloropropanes) injected 20.3-25.4 cm deep with a Morton Soil Fumigator II. The 1971 plots were treated with 121.1 liters (32 gal) per acre of Telone C (1, 3 dichloropropene + chloropicrin) injected 25.4-30.5 cm (ca 10-12 in) deep with commercial fumigation equipment. Both of these chemicals had been shown to be effective in reducing Verticillium wilt severity in Colorado (Harrison, M.D., *unpublished*) and elsewhere (4, 5, 17). Control plots were left untreated.

Foliar sprays were applied to one-half of all plots. Manzate D (Manganese ethylenebisdithiocarbamate + zinc) at rates of 453.6 gm (= ca 1.0 lb) of formulated chemical per acre in 1969 and 680.4 gm (= ca 1.5 lb) in 1971 was applied four or five times at 14-day intervals each season. Applications were begun on 23 June to 26 July and continued until plant maturity.

Disease evaluations were made periodically during the growing season. Early blight severity was measured by estimating the amount of infected foliage at at least five locations in each plot using the Horsfall-Barratt rating scale (11).

The effect of soil fumigation on Verticillium wilt severity was measured in several ways at each location. *Verticillium* inoculum densities were estimated in each plot prior to fumigation and again after fumigation (just before planting) using a technique previously described (7). The amount of root infection by *Verticillium* was measured by collecting roots from five plants per plot 6-8 wk after plant emergence. The roots were composited and washed in running water for 24 h then 0.25 gm of tissue was cut into sections approximately 4-5 mm long, distributed in three sterile petri dishes and covered with melted cooled alcohol agar (16) modified by the addition of 1.0 g/liter of polygalacturonic acid. The plates were incubated for 7-10 days at 20-25 C then the number of *Verticillium* colonies originating from the root tissue was counted. Laboratory isolations were also made from 40 potato stems per treatment in 1971 to determine the extent of *Verticillium* infection. No isolations were made in 1969. Periodic measurements of disease severity were made in each plot by estimating the amount of plant defoliation (1969) or the amount of wilted foliage (1971) at five or six locations in each plot using the Horsfall-Barratt rating scale (11). The individual ratings were averaged to give a disease index for each plot which was then converted to percent disease.

The severity of Rhizoctonia stem girdling was measured at each location by digging ten hills in each plot in mid-July and estimating the severity of infection on the basal portion of each stem (40-50 stems/plot) using the Horsfall-Barratt rating scale (11). The individual ratings were averaged to give a disease severity index for each plot. Tubers were harvested from measured sections in each plot and immediately weighed and graded.

RESULTS.—Although early blight severity varied from year to year, and between locations, the effectiveness of foliar sprays as determined by foliage disease ratings was essentially the same in both fumigated or nonfumigated plots (Table 1). Early blight severity in control (nonsprayed) plots was also essentially the same on fumigated and nonfumigated soil. Soil fumigation had no effect on early blight as estimated by foliage disease ratings.

Blight severity at Center was greatest in 1969, producing the most severe epidemic in a 10-yr period. The disease progressed much slower at Center in 1971, a condition more normal for that area.

Soil fumigation reduced the severity of Verticillium wilt in all of the tests (Table 2). The data show that relatively high amounts of *Verticillium* inoculum (75-110 propagules/g soil) were present in the soil at all locations and that fumigation reduced the populations to some extent in every case. *Verticillium* infection was reduced in all of the fumigated plots as shown by the reduced amount of root infection, the reduced number of plants from which *Verticillium* could be isolated and the reduced wilt severity based on foliar disease readings during the season in the fumigated plots when compared to the nonfumigated ones. The occurrence of hail at Center in 1971 made late season wilt readings impossible but the higher readings in the nonfumigated plots in early August plus the marked reduction in plant infection detected by laboratory isolations suggest that Verticillium wilt was effectively reduced by the fumigation treatments.

Rhizoctonia infection (Table 2) was not significantly affected by fumigation in any of the plots. No other soil

TABLE 1. Potato early blight (*Alternaria solani*) severity in sprayed and nonsprayed plots in fumigated and nonfumigated soil

Treatment[c]	Plot location and disease rating[a,b]					
	Fort Morgan 1971		Center 1969		Center 1971	
	5 Aug	17 Aug	7 Aug	21 Aug	4 Aug	19 Aug
Fumigated control	1.5	4.8	9.8	11.0	1.0	4.7
Fumigated and sprayed	0.1	1.1	4.0	5.7	0.6	2.2
Nonfumigated control	1.6	5.0	10.6	11.0	1.2	4.5
Nonfumigated and sprayed	0.1	1.5	3.9	6.4	0.8	2.1

[a]Horsfall-Barratt rating scale, 0-11.
[b]Fort Morgan, Colorado, is located in northeastern Colorado at 1,316 m (ca 4,318 ft) elevation and Center, Colorado, is in southcentral Colorado at 2,317 m (ca 7,600 ft) elevation.
[c]Fumigated plots treated with Vorlex (227.1 liters/A) in 1969 and Telone C (121.1 liters/A) in 1971. Sprayed plots received Manzate D at rates of 453.6 g/A (ca 1.0 lb/A) formulated chemical in 1969 and 680.4 g/A (ca 1.5 lb/A) in 1971.

borne diseases were observed in any of the plots.

Yield increases due to early blight control were usually greater on fumigated than on nonfumigated soil (Fig. 1).

At Center, Colorado, only in the year of severe blight (1969) did foliar sprays increase potato yields significantly in all U.S. grades except U.S. No. 1 > 283.5 gm (10 oz) regardless of whether or not the plot was fumigated. Otherwise potato yield increases were, with the exception of the U.S. No. 1 > 283.5 gm (10 oz), always greater in fumigated than nonfumigated plots. Yield increases from foliar sprays on fumigated soil over those on nonfumigated soil, ranged from 2,100 kg/ha [= 8.5 cwt (hundredweight)/*A*] (marketable yield) to 9,910 kg/ha (= 40.1 cwt/A) (total yield). In 1971, foliar sprays on nonfumigated plots did not increase potato yields significantly in any U.S. grade. In fumigated plots, on the other hand, foliar sprays increased yields significantly in all U.S. grade categories except U.S. No. 1 > 283.5 gm (= 10 oz). Even in this category, however, 3,110 kg/ha (= 12.6 cwt/A) more potatoes were produced in fumigated than in nonfumigated plots.

At Fort Morgan, Colorado, early blight control increased the yield of Norchip potatoes significantly in both fumigated and nonfumigated plots (Fig. 1). However, total yield increase (2,920 kg/ha = 11.8 cwt/A) and increase in larger tubers was significantly greater in fumigated ($P = 0.01$) than in nonfumigated ($P = 0.05$) plots. The total increase of U.S. No. 1 potatoes was not greatly affected by fumigation, but the proportion of the U.S. No. 1 tubers in the larger size category; i.e., > 7.6 cm (= 3 in) diam was markedly greater on the fumigated soil. In fact, a significant increase in yield above nonsprayed control plots was obtained only in the fumigated plots. Proportionally fewer U.S. No. 1 potatoes in the smaller size range (5.1-7.6 cm = 2-3 in diam) were produced in the fumigated plots.

DISCUSSION.—The data show that greater yield increases attributable to early blight control can be expected on fumigated than on nonfumigated soil. This effect was most striking at Center, Colorado, in 1969 and 1971, when yield increases in all tuber grades (except U.S. No. 1 > 10 oz in 1969) were greater in fumigated than in nonfumigated plots. Infection by *A. solani* appeared early in the season (about 1 July, approximately 3-4 wk earlier than usual) in 1969 at Center, and reached epidemic proportions by late July. Under these severe disease conditions significant yield increases were demonstrated on both fumigated and nonfumigated soil.

TABLE 2. The effect of soil fumigation on Verticillium wilt (*Verticillium albo-atrum*) and Rhizoctonia stem girdling (*Rhizoctonia solani*)

Location and treament	Inoculum density propagules/g		Root infection (colonies/g)	Plants infected[c] (%)	Wilt[a] (%)		Rhizoctonia severity
	Before fumigation	After fumigation					
Center, 1969					Aug. 21	Sept. 4	
Control	110	100	28	...	46.0	96.0	5.2
Fumigated[d]	85	45	10	...	23.5	83.0	4.8
Center, 1971					Aug. 4	Aug. 19[b]	
Control	75	68	5	53.8	0.6	...	4.6
Fumigated	85	68	4	33.8	0.4	..	4.2
Ft. Morgan, 1971					Aug. 5	Aug. 12	
Control	75	60	36	60.0	17.0	38.5	2.2
Fumigated	105	55	10	42.5	4.0	7.5	2.2

[a]Percent wilt = percent defoliation (1969) or percent wilted foliage (1971).
[b]No foliar readings were made 19 Aug. due to hail injury which occurred on 4 Aug. making accurate readings impossible.
[c]Based on laboratory isolations from 40 stems per treatment.
[d]Plots fumigated with 60 GPA of Vorlex in 1969 and 32 GPA of Telone C in 1971.

In 1971, a more normal disease development occurred in the Center, Colorado, area. Early blight infection appeared relatively late in the season (late July to early August); the disease progressed more slowly and became severe only near the end of the growing season. The most dramatic effect of soil fumigation was seen in 1971 and significant yield increases were found in the fumigated, but not in the nonfumigated, plots.

Similar results were observed at Fort Morgan where total yield and yield of large tubers [> 7.6 cm (= 3 in) diam] were increased more when early blight was controlled on fumigated than nonfumigated soils. Early blight in the Fort Morgan area (1,316 m elevation = ca 4,318 ft) usually develops earlier and becomes more severe than in the Center area (2,317 m elevation = 7,600 ft) due to higher temp and the use of overhead sprinklers. The data suggest that the confounding effects of root pathogens may result in erroneous conclusions regarding the benefit of certain control measures, particularly when the effects are measured in terms of crop yield.

In some cases, such as the Center, Colorado, area where early blight infection is usually mild until late in the season, yield reductions may be small and soil-borne pathogens may mask the benefits from early blight control. In other areas (or seasons) where early blight is more severe and develops earlier, significant yield increases due to blight control may occur in spite of soil-borne diseases. Even under these conditions, greater yield increases may be expected in fumigated than in nonfumigated plots.

Differential control of early blight by foliar sprays in fumigated and nonfumigated plots is probably not responsible for the observed effect. Table 1 shows that control of early blight in fumigated and nonfumigated plots was essentially equal in each experiment.

Increased plant vigor following soil fumigation even in the absence of known pathogens has been observed repeatedly (1, 2, 3, 12, 14, 15). This phenomenon could in itself render potato plants more tolerant of early blight infection and partially explain the results of this study. Early blight is known to attack old or weakened plants (18) and factors which increase plant vigor or delay plant maturity should reduce early blight severity. Altman and Tsue (3) suggested that soil fumigation results in increased nitrogen availability. This could affect early blight development by delaying plant maturity. One would expect that these effects would result in at least some reduction in the amount of early blight observed on the foliage, but this was not apparent in the study (Table 1).

Wilhelm et al. (20) reported that nutrient deficiency symptoms in cotton which were corrected by Zn applications were sometimes induced by fumigating soils with chloropicrin-methyl bromide mixtures. If similar deficiencies were induced in potatoes by fumigation, at least some of the increased yield response due to early blight control on plants grown in fumigated soils might be attributed to the Zn present in the foliar spray (Manzate D). In these studies, however, no abnormal symptoms indicating nutrient dificiency were observed in any of the plots. In fact, the plants in fumigated plots were invariably larger, greener, and more vigorous than those grown in nonfumigated soil. To the knowledge of the

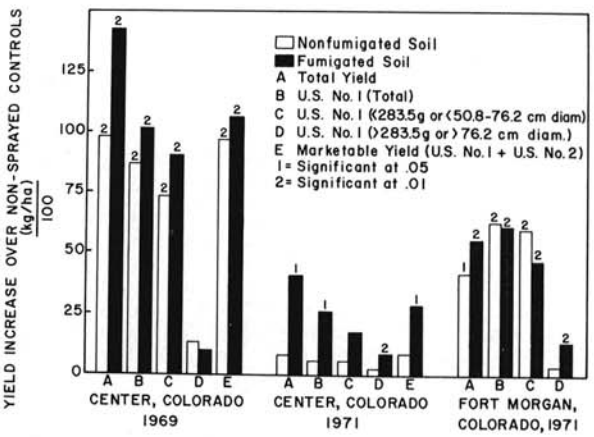

Fig. 1. Potato yield increases due to early blight control by foliar sprays on fumigated and nonfumigated soil. [Statistical comparisons were made between sprayed and nonsprayed plots on the same (i.e. fumigated or nonfumigated) soil type for each grade class].

author, no fumigation-induced nutrient deficiencies have ever been reported in potatoes, even though considerable experimental and commercial fumigation has been done. Studies by Soltanpour (19) on the same farm at Center, Colorado, where these experiments were made showed that no significant response occurred when Zn was applied, indicating that adequate quantities were present in the soil. While the correction of nutritional deficiencies cannot be entirely eliminated as a partial explanation for the greater yield response on fumigated than on nonfumigated soils when foliar sprays were applied, this possibility seems remote.

It seems more reasonable, however, that the reduction of Verticillium wilt by soil fumigation could explain the increased effectiveness of early blight control (as measured by potato yield response) on fumigated soil. Verticillium wilt is known to reduce plant vigor and to cause premature senescence and death of potato plants (6). In areas like the San Luis Valley of Colorado (Center) where early blight normally becomes severe late in the season, Verticillium wilt may adversely affect the plants in nonfumigated plots before severe early blight develops, thus the plants are killed or weakened before the time when maximum benefit would be obtained from blight control. In fumigated plots, in which wilt severity is reduced, the plants remain active longer, and early blight infection can reach its maximum severity and exert a measurable effect on potato yield. Under these conditions, foliar sprays apparently result in yield increases. This agrees with previous observations by the author which suggested that yield response from foliar sprays might be measured only in seasons when Verticillium wilt was not severe (10). This phenomenon may explain why significant yield increases occur more consistently in other areas (13) than in Colorado. In regions where early blight appears earlier and/or develops more rapidly, it may induce considerable yield loss even before Verticillium wilt appears, resulting in significant yield losses which could be reduced by foliar sprays. In these areas, as in the case of the Center,

Colorado, area in 1969 and Fort Morgan in 1971, soil fumigation would probably still increase the magnitude of yield response to early blight control but significant increases would likely be shown in both fumigated and nonfumigated soil.

These results emphasize that in order to avoid drawing erroneous conclusions when studying specific control measures, a knowledge of disease interactions and possible confounding effects of other pathogens is important.

LITERATURE CITED

1. ALTMAN, J. 1965. Plant growth studies. Pages 35-40. *in* Proc. 11th Conference on control of soil fungi, Reno, Nevada.
2. ALTMAN, J. 1966. Side effects associated with the use of nematocides, Pages 39-44. *in* Symposium on nematode control, University of Hawaii.
3. ALTMAN, J., and K. M. TSUE. 1965. Changes in plant growth with chemicals used as soil fumigants. Plant Dis. Rep. 49:600-602.
4. EASTON, G. D. 1964. The results of fumigating Verticillium and Rhizoctonia infested potato soils in Washington. Am. Potato J. 41:296 (Abstr.).
5. EASTON, G. D., M. E. NAGLE, and D. L. BAILEY. 1971. Effect of annual fumigation and annual preharvest vine burning on control of Verticillium. Pages 9-11. *in* Proc. 10th Annual Wash. State Potato Conference.
6. GUTHRIE, J. W. 1960. Early dying (Verticillium wilt) of potatoes in Idaho. Idaho Agric. Exp. Stn. Res. Bull. 45.
7. HARRISON, M. D., and C. H. LIVINGSTON. 1966. A method for isolating Verticillium from field soil. Plant Dis. Rep. 50:897-899.
8. HARRISON, M. D., C. H. LIVINGSTON, and N. OSHIMA. 1965. Control of potato early blight in Colorado. I. Fungicidal spray schedules in relation to the Epidemiology of the disease. Am. Potato J. 42:319-327.
9. HARRISON, M. D., C. H. LIVINGSTON, and N. OSHIMA. 1965. Control of potato early blight in Colorado. II. Spore traps as a guide for initiating applications of fungicides. Am. Potato J. 42:333-340.
10. HARRISON, M. D., and J. R. VENETTE. 1970. Chemical control of potato early blight and its effect on potato yield. Am. Potato J. 47:81-86.
11. HORSFALL, J. G., and R. W. BARRATT. 1945. An improved system for measuring plant diseases. Phytopathology 35:655 (Abstr.).
12. IYATOMI, K., and T. NISHIZAWA. 1970. Growth response of rice to soil fumigation. Pages 226-228. *in* T. A. Toussoun, R. V. Bega, and P. E. Nelson, eds. Root diseases and soil borne pathogens. University of California Press, Berkeley. 252 p.
13. JACK, R. W. 1916. Does it pay to spray potatoes in Rhodesia? Rhodesia Agric. J. 13:354-360.
14. KREUTZER, W. A., and J. T. W. MONTAGUE. 1950. Chlorobromopropene, a potential fungicidal soil fumigant. Phytopathology 40:16 (Abstr.).
15. MARTIN, J. P., D. G. ALDRICH, W. S. MURPHY, and G. R. BRADFORD. 1953. Effect of soil fumigation on growth and chemical composition of citrus plants. Soil Sci. 75:137-151.
16. NADAKAVUKAREN, M. J., and C. E. HORNER. 1959. An alcohol agar medium selective for determining Verticillium microsclerotia in soil. Phytopathology 49:527-528.
17. POWELSON, R. L. 1964. Efficacy of soil fumigation for control of Verticillium wilt of potatoes. Am. Potato J. 41:302-303 (Abstr.).
18. ROWELL, J. B. 1953. Leaf blight of tomato and potato plants. Factors affecting the degree of injury incited by Alternaria davci f. solani. R. I. Agric. Exp. Stn. Bull. 320. 29 p.
19. SOLTANPOUR, P. N. 1969. Effect of N, P, and Zn on yield and composition of potatoes. Agron. J. 61:288-289.
20. WILHELM, S., A. GEORGE, and W. PENDERY. 1967. Zinc deficiency in cotton induced by chloropicrin-methyl bromide soil fumigation to control Verticillium wilt. Phytopathology 57:103 (Abstr.).