Effect of Annual Soil Fumigation and Preharvest Vine Burning on Verticillium Wilt of Potato

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ABSTRACT

Annual spring fumigation for 5 successive years reduced populations of *Verticillium albo-atrum* in field soils, delayed infection and wilt symptoms, and increased yields of potatoes. Annual preharvest burning of potato vines to destroy the microsclerotia in stem tissue increased yields when used for 2 successive years, but did not reduce either soil populations of *V. albo-atrum* or infection, nor did it delay wilt symptoms unless applied for 3 consecutive years. Results of annual combination treatments of soil fumigation and vine burning were similar to those for soil fumigation alone.

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Yields of *Solanum tuberosum* L. 'Russet Burbank' are decreasing in most production areas of the Columbia Basin Project in Washington owing to *Verticillium albo-atrum* Reinke & Berth.

(microsclerotial type). One fumigation application to soils infested with *V. albo-atrum* increased yields of potatoes 1 or more years after treatment (1, 6, 9, 12, 14, 16, 20). Effects of consecutive annual soil fumigations have not yet been reported. Flaming of diseased mint stubble (7) and burning potato stems (15) in the field reduced the Verticillium wilt organism in the stems of the current crop in proportion to the speed (miles per hour) at which the burner was operated. Data on yield of either mint oil or potatoes after flaming or burning have not yet been presented.

In 1966, we initiated field experiments to measure the effects of annual soil fumigation, annual burning of vines, and a combination of these treatments on populations of *Verticillium* in the soil, infection, wilt symptom expression, and yield of potatoes. Through application of these treatments, we sought to determine if potatoes could be successfully grown in continuous monoculture on infested soil.

MATERIALS AND METHODS.—The field used was cropped to dryland wheat until 1962, then planted to alfalfa under irrigation until 1965. The Shano silt loam soil was initially infested with *V. albo-atrum* (microsclerotial type) in 1965 by planting seed pieces of Russet Burbank potato dipped in a suspension of mycelia, conidia, and microsclerotia of the organism. Russet Burbank potatoes were grown in the experimental field from 1966 to 1970 without further intentional infestation of the soil.

Two fumigation treatments were used: (i) Telone (1,3-dichloropropene and related hydrocarbons) + Picfume (chloropicrin); and (ii) DD (1,3-dichloropropene, 1,2-dichloropropane, 3,3-dichloropropene, 2,3-dichloropropene, and related C_3 chlorinated hydrocarbons) + Picfume. Both treatments were applied at rates of 13.05 Telone or DD + 3.26 Picfume liters/hectare, respectively, by fumigation-spring shanks, 22.9 cm in depth and spaced 22.9 cm apart to the same plots each spring from 1966 to 1970, except that in 1966, Telone PBC (Telone, propargyl bromide, and Picfume) at 19.58 liters/hectare was applied rather than DD + Picfume.

For the years 1966 through 1970, respectively, soil temperatures were 10.0, 7.2, 8.9, 7.8, and 7.8 C, and soil moistures, on an oven-dry basis, were 11.0, 12.0, 9.7, 16.2, and 12.3%. Each fall from 1966 through 1969, potato vines killed by frost were either beaten with a vine beater or burned by propane gas at 80 psi with a field burner traveling at less than 1.6 km/hr. All of the leaves and only about 8 cm of the aboveground portion of the stems remained after burning. A nonfumigated, vine-not-burned (vines beaten) treatment was the control. Vines are normally left unbeaten on the soil surface; however, vine-beating reduces the possibility of equipment dragging vines from plot to plot and thereby contaminating the vine-burned plots. All treatments were randomly replicated 6 times in plots 7.3 m wide (8 rows) by 15.2 m long. Each year, tubers from one row were harvested for yield data. The remaining tubers were left to freeze on the soil surface in the field.

We determined infection by *V. albo-atrum* in 1968-1970 by plating sections of potato stems on streptomycin-ethanol agar (13). Numbers of plants with symptoms typical of Verticillium wilt were recorded during this interval. Populations of *Verticillium* in the soil were determined from 1968 to 1970 by the method previously described (2). Soil samples, each consisting of cores, 1.7 cm in diam X 25.4 cm in depth, were collected at random from each treatment plot and mixed to provide a composite sample. Propagule counts were determined by preparing three separate 1:50 soil-water dilutions for each composite soil sample and three assay plates for each dilution. Data for each treatment were recorded as counts of *Verticillium* colonies on 54 assay plates.

RESULTS.—Fumigation each spring from 1966 to 1970 reduced the number of *Verticillium* propagules in the soil when compared to those determined for the nonfumigated treatments, but the propagule number increased again by fall each year (Table 1). Burning of vines before harvest in the fall, either with or without fumigation, generally reduced the

TABLE 1. Effect of annual soil fumigation and preharvest vine treatment on populations of *Verticillium* in infested soil

		Verticillium propagules/g oven-dry soil[c]														
		1968			1969					1970						
Fumigants[a]	Vine treatment[b]	Mar. 14	Apr. 10	Oct. 18	Apr. 7	May 2	June 18	July 29	Aug. 26	Mar. 10	Apr. 22	June 18	July 22	Aug. 19	Sept. 14	Dec. 18
Telone + Picfume	Beating	172	138	1,222	0	0	17	48	214	440	3	7	14	219	210	254
Telone + Picfume	Burning	86	9	4,245	0	3	0	31	251	270	0	6	0	12	18	27
DD + Picfume	Beating	243	330	1,632	0	18	64	192	204	348	0	17	34	32	57	440
DD + Picfume	Burning	101	0	996	0	7	31	29	2,687	219	0	3	0	0	10	10
Not fumigated	Beating	631	1,066	959	11	495	253	278	537	381	163	129	252	277	384	741
Not fumigated	Burning	1,801	1,684	1,355	0	17	159	357	608	245	16	73	32	158	197	54

[a]Fumigants applied at 13.05 + 3.26 liters/hectare on 25 Mar. 1968; 9 Apr. 1969; and 1 Apr. 1970.
[b]Treatments applied to potato vines before harvest each fall in 1967, 1968, and 1969.
[c]Average number of propagules as determined by counts made on 54 assay plates/treatment.

population of *Verticillium* in the soil by spring.

Soil fumigation and preharvest vine burning reduced the number of stems infected with *Verticillium* (Table 2). The combination treatment, soil fumigation plus preharvest vine burning, reduced the percentage of infected stems more than did soil fumigation alone.

The number of plants with Verticillium wilt symptoms was reduced significantly each year following spring fumigation of infested soil (Table 3). Annual preharvest burning of infected vines as the only treatment did not significantly reduce the number of plants with symptoms until after 3 and 4 years of treatment (1969 and 1970).

Fumigation with Telone-Picfume plus vine-burning increased yields significantly each year, except in 1966, compared to those for plots that were neither fumigated nor given a vine-burning treatment (Table 4). Yields were increased significantly by the preharvest vine-burning treatment alone in 1968-1970, but not in 1967. Only in 1969 did the combination treatment of soil fumigation and preharvest vine burning produce a significant yield increase over fumigation without vine burning (i.e., DD + Picfume, 888 quintal/hectare).

DISCUSSION.—Propagules of *Verticillium* increased by fall in the fumigated and vine-burned plots (Table 1). Experimental design (completely randomized block) probably led to interplot spread of pathogen propagules via irrigation water (G. D. Easton, *unpublished data*), and dust particles from frequent wind storms (2).

We have not yet determined the type of propagules in soil giving rise to *Verticillium* colonies, but no doubt all forms (microsclerotia, conidia, and mycelia fragments) are present at one time or another during each year. Since mycelia and conidia of *V. albo-atrum* are short-lived (5, 11), they are not usually considered important as overwintering propagules, and hence have little significance as inoculum in soil (5). An opposite point of view (19) is that they do act as infective propagules in soil. Populations of microsclerotia remain relatively stable in soil (5, 11, 17).

TABLE 2. Effect of annual soil fumigation and preharvest vine treatment on infection by *Verticillium albo-atrum* (microsclerotial type)

		Percentage of infected stems[c,d]							
		1968	1969			1970			
Fumigants[a]	Vine treatment[b]	Sept. 10	June 19	July 23	Aug. 26	June 30	July 22	Aug. 10	Sept. 9
Telone + Picfume	Beating	74 c	1 a	3 a	46 bc	0 a	3 a	0 a	15 b
Telone + Picfume	Burning	19 a	0 a	2 a	4 a	0 a	1 a	0 a	3 a
DD + Picfume	Beating	62 c	0 a	5 a	33 b	0 a	0 a	1 a	13 b
DD + Picfume	Burning	23 a	0 a	0 a	6 a	0 a	1 a	1 a	2 a
Not fumigated	Beating	33 ab	16 b	40 c	75 d	35 c	23 c	14 c	30 c
Not fumigated	Burning	53 bc	2 a	25 b	66 cd	4 b	5 b	4 bc	12 b

[a]Fumigants applied at 13.05 + 3.26 liters/hectare on 25 Mar. 1968; 9 Apr. 1969; and 1 Apr. 1970.
[b]Treatments applied to potato vines before harvest each fall in 1967, 1968, and 1969.
[c]100 stems were collected randomly from the six replications of each treatment.
[d]Means followed by the same letter are not significantly different at the 5% level according to Duncan's multiple range test.

TABLE 3. Effect of annual soil fumigation and preharvest vine treatment on incidence of potato plants with Verticillium wilt

		Number of plants with symptoms[c,d]				
Fumigants[a]	Vine treatment[b]	12 Sept. 1966	7 Sept. 1967	10 Sept. 1968	3 Sept. 1969	3 Sept. 1970
Telone + Picfume	Beating	0 b	0 b	15 b	1 c	1 c
Telone + Picfume	Burning	0 b	0 b	4 c	.3 c	0 c
DD + Picfume	Beating	0 b	0 b	9 b	2 c	0 c
DD + Picfume	Burning	0 b	0 b	2 c	0 c	0 c
Not fumigated	Beating	6 a	21 a	34 a	30 a	27 a
Not fumigated	Burning	5 a	13 a	32 a	23 b	15 b

[a]Fumigants applied at 13.05 + 3.26 liters/hectare each spring in 1966, 1967, 1968, 1969, and 1970.
[b]Treatment applied to potato vines before harvest each fall in 1966, 1967, 1968, and 1969.
[c]Value given is based on an examination of about 34 plants/treatment.
[d]Means followed by the same letter are not significantly different at the 5% level according to Duncan's multiple range test.

TABLE 4. Effect of annual soil fumigation and preharvested vine treatment on yields of potatoes grown in *Verticillium*-infested soil

Fumigants[a]	Vine treatment[b]	Yield (quintal/hectare)[c]				
		1966	1967	1968	1969	1970
Telone + Picfume	Beating	716 a	705 a	775 a	823 ab	672 ab
Telone + Picfume	Burning	644 bc	650 a	796 a	840 ab	731 ab
DD + Picfume	Beating	716 a[d]	624 ab	823 a	791 b	682 ab
DD + Picfume	Burning	666 ab[d]	678 a	840 a	888 a	699 ab
Not fumigated	Beating	611 c	504 c	585 c	422 d	520 c
Not fumigated	Burning	611 c	546 bc	678 b	601 c	634 b

[a]Fumigants applied at 13.05 + 3.26 liters/hectare each spring in 1966, 1967, 1968, 1969, and 1970.
[b]Treatment applied to potato vines before harvest each fall in 1966, 1967, 1968, and 1969.
[c]Means followed by the same letter are not significantly different at the 5% level according to Duncan's multiple range test.
[d]Telone PBC (19.58 liters/hectare) substituted for DD + Picfume.

Fluctuations in numbers of propagules of *Verticillium* in the soil from season to season probably result from air-drying of soil by wind and sun when the plant canopy is absent (11), leaching by irrigation water (3), irrigation (remoistening) of soils (4, 11), exhausting of indigenous nutrient resources (3), and presence of root exudates from susceptible plant species (18). According to Isaac (8) and Lockwood (10), saprophytic growth of *V. albo-atrum* does not occur.

After the winter of 1968-1969, propagules of *Verticillium* were recovered only from soils in plots that were neither fumigated nor burned on 7 April 1969 (Table 1). This was probably due to the effect on propagules of the much lower than usual temperatures during the previous winter. Average air temperatures within 0.4 km of the experimental field for the winters (December, January, and February) of 1966-1967, 1967-1968, 1968-1969, and 1969-1970 were +2.9 C, +1.3 C, −5.2 C, and +0.5 C, respectively, indicating that the winter of 1968-1969 was much colder than previous or subsequent winters (Climatology Data, U.S. Dep. Commerce, Supt. Documents, Gov. Printing Office, Wash., D.C., 1966-1970). Total precipitation during the four winters varied but slightly, and was, therefore, probably not a factor affecting *Verticillium*.

Preharvest vine burning alone in heavily infested fields may not be effective, since the initial soil population of *Verticillium* may be too great. Under such circumstances, it would be necessary also to fumigate for one or two seasons before preharvest vine burning alone will provide adequate control.

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