EFFECT OF FUMIGANTS AND OTHER CHEMICALS ON YIELD OF POTATOES ON VERTICILLIUM WILT INFESTED SOILS[1/]

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REVIEW OF PREVIOUS WORK

Fumigation

Since 1948, various soil fumigants have been tested for the control of Verticillium wilt in infested soils. Nielson (11) of Idaho found chloropicrin to delay wilt of potatoes and increase production. Young (15) of Oregon in 1956 reported that Vapam®[2/] delayed wilt; however, Guthrie (5) of Idaho did not obtain a yield response when he applied Vapam®. Menzies and Nelson (10) of Washington reported no response in yield of potatoes when he treated severely infested Yakima Valley soils with ethylene dibromide. Powelson and Carter (12), between 1961 and 1964, found DD®, ethylene dibromide, chloropicrin, Telone®, Vapam®, Vidden D®, and Vorlex® to give very high yield responses on wilt infested soils near Klamath Falls, Oregon. Kunkel and Weller (9) found in experiments conducted in the Columbia Basin from 1958-1963 that chloropicrin, Telone®, Vapam®, Vorlex® and a mixture of Telone® and Picfume® increased yields signigicantly compared to the control. Both Kunkel and Weller (9) and Powelson and Carter (12) reported significantly higher yields in fumigated soils than non-fumigated soils 1, 2, and even 3 years after treatment.

Easton (1, 2, 4) in 1963, 1964 and 1965 also obtained yield responses from fumigation mixtures in experiments near Prosser and Othello, Washington. DD® + chloropicrin, M-2467 (propargyl bromide + Vidden D®), M-2467 + chloropicrin, Telone PBC® (Telone® + propargyl bromide + chloropicrin) as well as Telone® + chloropicrin significantly increased yields. Fumigation with DD® or Telone® alone without chloropicrin did not produce significant yield responses. Plots of Verticillium wilt infested soil fertilized at rates of 100, 150, 200 and 300 lbs of N per acre (Ammonium nitrate form) and fumigated with Telone® + chloropicrin produced higher yields and greater numbers of tubers than plots receiving only the fertilizer treatments.

1/ This investigation was made possible through grants supplied by the Washington State Potato Commission, Dow Chemical Company, Chemagro Corporation, Diamond Alkali Company, and Niagara Chemical Division.

2/ The trade names of chemicals are used to define specifically the products worked with in this paper. Use of the trade name does not constitute a guarantee or warrantee of the product by Washington State University or that the behavior of similar products would be the same of different from the ones used.

Work at Prosser and Othello in 1964 and 1965 showed that there was no significant yield response beyond the first year after fumigation (4). This information is in contrast to that of Powelson and Carter (12) and Kunkel and Weller (9).

Systemic Insecticides

Hoyman (6) reported that the progress of Verticillium wilt in 1963 was less rapid and the yield and per cent of U.S. No. 1 tubers were greater in a 25 ft. row banded with 3 lbs. active Di-Syston® per acre, than in a non-treated row. This Di-Syston® treatment yielded 180 cwt. /A more than the untreated control (8). Later laboratory tests showed Di-Syston to be the least effective of 6 insecticides tested in depressing _Verticillium albo-atrum_ Reinke and Berthold, the fungus which causes Verticillium wilt (6).

Hoyman (6, 7) further reported that Di-Syston® granules (3lbs. active per acre) and Bay 37289 granules (3lbs, active per acre) banded at planting in 1964 significantly increased yield over that of the untreated control on wilt infested soil. Foliar spray applications of Di-Syston® (9.72 lbs. active per acre) and Systox (3.18 lbs. active per acre) also were reported produce significant yield increases. These 4 systemic insecticide treatments (Di-Syston® granules, Bay, 37289 granules, Di-Syston® spray, and Systox® spray) yielded 241, 238, 203 and 160 cwt. /A more than the control, respectively.

Hoyman (8) reported in 1965 that Di-Syston® banded at planting (3lbs. active per acre), sidedressed (3 lbs. active per acre) and both banded at planting and sidedressed later produced significantly higher yields than the non-treated controls. He also reported Temik[R], a new systemic insecticide, to yield 300 cwt. /A more than the control when applied by both banding at planting (1.5 lbs. active per acre) and later sidedressed (1.5 lbs. active per acre).

Schultz (13) of New York applied Di-Syston® as a liquid concentrate through spray nozzles at time of planting at the rate of 5 gals. per acre. Under the conditions of this trial, Di-Syston[R] was ineffective in controlling Verticillium wilt or increasing yield.

Easton (3, 4) in 1965 at the Research Farm near Othello applied Di-Syston® to Verticillium infested soil as a preplant broadcast treatment. Di-Syston® at rates of 3 and 9 lbs. active per acre failed to delay Verticillium wilt symptoms or increase production compared to the control. In this same experiment, Lanstan® granules at the rate of 60 lbs. active per acre significantly increased the yield 123 cwt. /A over that of the control.

REASON FOR FURTHER EXPERIMENTATION

Because of the preliminary evidence that Di-Syston® might increase yield on Verticillium wilt infested soil, it was decided to test Di-Syston® extensively in 1966 and also to compare it with Temik®, Lanstan®, other experimental chemicals, and 3 fumigation treatments. Two experiments were conducted at the H. P. Singleton Headquarters near Prosser and 3 experiments were conducted at the Othello Research Farm near Othello. Di-Syston® applications included broadcast before planting, banding at planting, sidedressing after planting, and a combination of banding and sidedress treatments.

HISTORY OF VERTICILLIUM INFESTATION OF SOIL

Prosser, 1966 (Tables 1, 3, 4)

The plot area utilized in the 1966 experiments at the H.P. Singleton Headquarters near Prosser, Washington had never grown potatoes prior to 1966; however, commercial potatoes had been raised to the west of this field approximately 10 years earlier. It was assumed that the soil would be infested with Verticillium wilt organism by wind blown inoculum from the commercial field to the west.

Othello, 1966 (Tables 2, 3, 5 and 6)

Soil at the Othello Research Farm near Othello, Washington was infested in 1965 with the Verticillium wilt organism by planting infested potato seed pieces. These seed pieces had been dipped into a suspension of conidia and microsclerotia of the organism. Symptoms of the disease were seen by the fall of that year. Plant debris was plowed under to increase the soil inoculum.

The seed pieces planted at the H. P. Singleton Headquarters and the Othello Research Farm in 1966 were not reinfested with the Verticillium wilt organism.

METHODS AND MATERIALS

Othello and Prosser, 1966 (Tables 1-6)

The fields were chisel plowed prior to fumigation 13-15 in. deep both lengthwise and crosswise and plowed 11-12 in, deep to loosen the soil for diffusion of fumigants. The three fumigation treatments of Telone®, Telone® + Picfume®, and Telone PBC® were applied as preplant treatments with injection chisels 9 in. deep and 9 in. apart. A roller packed the soil immediately after injection.

Othello and Prosser, (Tables 4-6)

Broadcast preplant treatments of DACONIL 2787, Di-Syston®, Lanstan®, Terraclor®, and Tide® were spread on the surface of the chiseled and plowed soil and mixed to a depth of 4-5 in. with a garden rototiller.

After fumigation or application of the broadcast treatments, the soil was packed, ditched, irrigated, disced, and repacked.

Othello and Prosser, 1966 (Tables 1-5)

Di-Syston®, Lanstan®, and Temik® were banded at planting with an applicator for granular chemicals attached to the potato planter. Di-Syston® and Temik® were banded to each side of the row through the fertilizer tubes along with the fertilizer. Lanstan was applied in a similar manner except two other tubes applied a 6-8 in. wide band of granule in front of the planter opening shoe. Lanstan® is not a systemic but a volatile soil fungicide; it was felt that the opening shoe and closing discs would serve to mix and distribute the chemical in the soil.

The sidedressed treatments of Di-Syston®, Lanstan®, and Temik® were applied in one band at the side of each row by means of equipment attached to the front potato cultivator designed for application of granular chemicals. These chemicals were applied about 1 inch deeper than the potato seed pieces and at distances sufficient from the seed pieces to avoid contact with the lateral roots. The distances from the seed piece for the first, second, third and fourth sidedressing dates were about 3, 4, 5 and 7 inches, respectively.

Prosser and Othello, 1966 (Table 3)

One hundred stems were collected at random from 6 untreated plot starting 6 weeks after planting at Prosser and starting 8 weeks after planting at Othello. The sampling hereafter was at 3 week intervals at both locations. Presence of the Verticillium wilt organism from each stem (approximately 1 inch above ground level) was determined by growth on streptomycin-alcohol agar. 4/

Prosser and Othello, 1966 (Tables 1-2, 4-6)

Verticillium wilt reading were taken by recording the number of wilted plants in one row of each 20 ft. treatment plot.

4/ Phytopathology 49:527-528, 1959.

EXPERIMENTAL DESIGN

Each experimental field plot was at least 4 rows of potatoes (12 ft.) and 20 ft. in length. Ten foot alleys at the beginning and end of each 20 ft. plot served as buffers for the treated plots. All data shown are the means of 6 replications. Treatments were randomly located in each replication.

STATISTICAL ANALYSIS

All data except those in Table 5 were statistically analyzed by acceptable procedures (14). Analysis of variance was used to determine if any group of data were significant. Duncan's Multiple Range Test was utilized to compare means. Means associated with the same letter of the alphabet are not significantly different at the 5% level.

RESULTS

Neither yield nor the per cent of U. S. No. 1 grade tubers was significantly increased by Di-Syston® treatments in the 1966 experiments at Prosser and Othello (Tables 1 and 2) regardless of the rate, the method of application, or the date of application. Samplings of stems for the Verticillium wilt organism (Table 3) revealed 55% infection at Prosser on September 1 and 86% infection at Othello on September 16. The wilt organism was present in stem tissue just above ground level about 7 or 8 weeks after planting and the first plant wilt symptoms appeared 12 to 14 weeks after planting. Verticillium wilt plant readings showed that 18 out of 23 plants (78%) were showing wilt in the untreated plots at Prosser on August 23 (Table1) and 10 out of 23 plants (43%) were showing wilt in the untreated plots at Othello on September 12 (Table 2). In only one treatment-sidedressing on July 5 at Othello with 6 lbs. active Di-Syston®, was the incidence of Verticillium wilt significantly lower than the control.

Di-Syston®, applied as a band, sidedress, and combination treatment, was also compared with Temik®, Lanstan® and 3 fumigants at Prosser and Othello (Tables 4 and 5). Neither Di-Syston®, Temik®, Lanstan®, or Telone® significantly increased yield compared to the control at either location. Fumigation with Telone PBC® (30 gals. /A) and Telone® + Picfume® (20 + 5 gals, /A) significantly increased yield at both Prosser and Othello. Telone PBC® yield 574 cwt. /A at Prosser and 639 cwt. /A at Othello, or 104 cwt. /A and 178 cwt. /A more than the control, respectively. Telone + Picfume yielded 617 cwt. /A at Prosser and 639 cwt. /A at Othello or 147 cwt. /A and 178 cwt. /A more than the control, respectively. At Prosser (Table 4), (the highest yield cwt. /A) for each chemical was 457 for Di-Syston®, 523 for Temik®, 515 for Lanstan®, and 515 for Telone®, or 13 less, 53 more, 45 more, and 45 more than the control (470 cwt. /A), respectively. At Othello (Table 5), the greatest yield (cwt./A) for each chemical was 515 for Di-Syston®, 537 for Temik®, 566 for Lanstan® and 537 for Telone® or 54, 76, 105 and 76 more than the control (461 cwt./A) respectively. Temik® applied as a sidedress treatment produced the same yield as Telone (30 gals./A) which has never shown a significant yield response in 3 years of experimentation. At Othello (Table 5), Lanstan® applied at 15 and 30 lbs. active/A at planting produced 84 and 105 cwt./A more than the control. Possibly this represents an increased yield response; however, this response could also be due to field variations in fertilization or Verticillium wilt infestation in the Lanstan® treated plots. At Prosser phytotoxicity was severe at plant emergence in the plots treated with Lanstan® at 30 lbs. active per A. and less severe in plots treated at 15 lbs. active per A at planting; however, only yields from plots sidedressed at a rate of 15 lbs. active/A were significantly reduced (Table 4). The reason for this reduced yield cannot be explained.

Some of the treatments with Di-Syston®, Temik® and Lanstan®, and fumigation with Telone PBC® and Telone® + Picfume® significantly reduced Verticillium wilt on September 12 at Othello (Table 5). Telone PBC® and Telone® + Picfume® also significantly reduced the percent of tubers with Rhizoctonia black scurf at harvest.

Di-Syston® bradcast at a rate of 6 lbs. active/A and rototilled into the soil along with other experimental chemicals did not give a significant yield response (Table 6).

DISCUSSION

Hoyman's results at Prosser (6, 7 and 8) with Di-Syston® in 1963, 1964, and 1965 showed yield increases of 180 to 241 cwt. per acre over the control in Verticillium wilt infested soils. My results in 1966 at Prosser and Othello show no yield response from Di-Syston® on infested soil.

Possibly, these differences in results with Di-Syston® can be explained by differences between the plot areas in cropping sequence or contamination by other potato parasites. Hoyman's experiments were conducted on a field near Prosser that had grown irrigated crops since 1919 and had been cropped continously to potatoes since 1958 (6). The soil was heavily infested with abundant microsclerotia of the Verticillium wilt organism formed on and within the vines of susceptible potato selections and varieties during the 5 years from 1958-1963. It also had become contaminated with root knot nematode, Meloidogyne hapla Chitwood, and nematode-gall tubers were present (8).

My experiments concerned with Di-Syston® treatments in 1966 (Tables 1-6) were conducted on infested soils which had either never raised potatoes or had raised potatoes only 1 year previously. No root knot nematode galls were found on any of the tubers from any of these experiments. The experiments were conducted in infested fields near Prosser and Othello and were not on the same field two years in a row.

Yield increases from Di-Syston® might occur in fields subjected to continuous cropping to potatoes and consequently having infestations of Verticillium, root knot nematode or other pathogens in the soil. A few fields in Washington or elsewhere with similar cropping histories may benefit from application of Di-Syston®. It should be noted that even the most effective fumigants may not produce significant yield increases when applied to soils not heavily or not uniformly infested with the Verticillium organism (2, 4).

The reasons yield increases occur when certain fumigation treatments are applied to Verticillium wilt infested soils are not known. Symptoms of Verticillium wilt are only delayed by fumigation. With a long growing season, the wilted plants are killed by the organism before frost and the microsclerotial overwintering stage forms in the stems. Thus far, methods have not been developed to determine if fumigation reduces the Verticillium wilt organism in the soil.

Nielson (11) reported that yield can be increased by nitrogen fertilizer in Verticillium infested soils. Easton (4) found yields and the number of tubers to be significantly increased in plots treated witl 100 to 300 lbs. of available N per acre in the form of Ammonium nitrate compared to untreated plots in a Verticillium infested field near Othello. Fumigation with Telone® + chloropicrin produced significantly greater number of tubers and higher yields than the plots receiving only 100-300 lbs. of available N per acre.

Fumigation of soils with a low infestation of the Verticillium wilt organism did not show a yield response. (4).

RECOMMENDATIONS FOR CONTROL OR DELAY OF VERTICILLIUM WILT

Washington State University does not recommend Di-Syston® for control of Verticillium wilt for potatoes. Chemogro Corporation has registered Di-Syston® on potatoes for the control of insect pests only.

Washington State University at this time does not recommend any fumigation treatment for control or delay of Verticillium wilt. None of the fumigants tested which produced significant yield increases on Verticillium wilt infested soil are registered for use on potatoes. Commerical fields in Washington in general appear still to have low levels of wilt infestation and have not shown a yield response to fumigation. However, if potato growing areas in Washington become more heavily infested, fumigation may provide a satisfactory method for delaying Verticillium wilt and maintaining high production.

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Table 1. Rate and method of applying Di-Syston® for Verticillium wilt delay near Prosser, Washington in 1966.

Fertilizer: 200 N, 10 Zn

Planted: April 28, 1966

Harvested: Sept 27, 1966

Lbs. Active/A at date of application	Mean Vert. wilt [3/] [4/] August 23	Mean % U.S. No. 1[3/]	Mean yield cwt. /A.[3/]
3P[1/]	17	69	464
3S[2/] June 1	19	69	399
3S June 10	16	60	464
3S June 21	16	62	471
3S July 1	18	66	464
6P	16	64	428
6S June 1	14	63	421
6S June 10	17	59	421
6S June 21	16	63	421
6S July 1	20	63	421
3P + 3S June 1	16	67	428
3P _ 3S June 10	17	63	370
3P + 3S June 21	15	63	486
3P + 3S July 1	13	63	493
Control	18	64	435

1/ Di-Syston® applied at planting.

2/ Di-Syston® sidedressed at date indicated.

3/ Data not significant according to F test at the 5% level.

4/ Number of plants out of approximately 23 showing Verticillium wilt symptoms

Table 2. Rate and method of applying Di-Syston® for Verticillium wilt delay near Othello, Washington 1966.

Fertilizer : 300 N. 150 P, 150 K, 10 Zn Planted: May 16, 1966

Harvested: October 15, 1966

Lbs. active/A. at date of application	Mean Vert. wilt 4/ 5/ Sept. 12	Mean % U. S. No. 1 4/	Mean yield cwt./A. 4/
3P 1/	7 abc	83	479
3S 2/ June 13	6 ab	81	566
3S June 22	7 abc	77	537
3S July 5	7 abc	84	545
6P	10 bc	82	479
6S June 13	9 abc	78	530
6S June 22	7 abc	82	566
6S July 5	4 a 3/	83	603
3P + 3S June 13	10 bc	84	508
3P + 3S June 22	7 ab	85	545
3P + 3S July 5	9 abc	81	486
Control	10 bc	84	537

1/ Di-Syston® applied at planting.

2/ Di-Syston® sidedressed at date indicated.

3/ Values significantly different from control according to Duncan's Multiple Range Test at the 5% level.

4/ Data not significant according to F test at the 5% level.

5/ Number of plants out of approximately 23 showing Verticillium wilt symptoms.

Table 3. Progress of the Verticillium wilt organism in potato stems during 1966.

H. P. Singleton Headquarters - Prosser Planted : April 28, 1966

Date of sampling stems	Weeks after planting	Stems per 100 sampled with Vert. organism 1/
June 7	6	0
June 30	9	12
July 21	12	28
(Appearance of first Verticillium wilt plant symptoms)		
August 11	15	45
September 1	18	55

Othello Research Farm - Othello, Wash. Planted: May 16, 1966

Date of sampling stems	Weeks after planting	Stems per 100 sampled with Vert. organism 1/
July 15	8	4
August 5	11	32
(Appearance of first Verticillium wilt plant symptoms)		
August 26	14	57
September 16	17	86

1/ A total of 100 stems were collected at random from 6 replicates from untreated plots. Growth of the Verticillium organism was determined by culturing of Streptomycin-alcohol agar.

Table 4. Fumigation versus experimental chemicals for Verticillium wilt delay near Prosser, Washington in 1966.

Fertilizer: 200 N, 10 Zn   Planted: April 26   Harvested: Sept. 27

Chemicals	Active chemical per acre[1/]	Mean Vert. wilt[2/] August 23	Mean yield cwt./A.
Di-Syston®	3 lb. P	18	457 cd
Di-Syston®	3 lb. S	18	457 cd
Di-Syston®	6 lb. P	14	450 cd
Di-Syston®	6 lb. S	18	457 cd
Temik®	3 lb. P	13	523 abc
Temik®	3 lb. S	14	486 bcd
Temik®	6 lb. P	15	479 bcd
Temik®	6 lb. S	12	479 bcd
Lanstan®	15 lb. P	16	515 abcd
Lanstan®	15 lb. S	17	436 d[3/]
Lanstan®	30 lb. P	14	472 cd
Lanstan®	60 lb. B	16	486 bcd
Telone®	30 gal. PP	10	515 abcd
Telone PBC®	30 gal. PP	8	574 ab[3/]
Telone® + Picfume®	20 + 5 gal. PP	7	617 a[3/]
Control	None	15	470 cd

[1/] P = chemicals applied at planting

S = chemicals side-dressed on June 16

B = chemicals broadcast on April 8

PP = chemicals applied as preplant treatment on March 28

[2/] Numbers of plants out of approximately 23 showing Verticillium wilt symptoms.

[3/] Values significantly different from the control according to Duncan's Multiple Range Test at the 5% level.

Table 5. Fumigation versus experimental chemicals for Verticillium wilt delay near Othello, Washington in 1966.

Fertilizer: 300 N, 150 P, 150 K, 10 Zn   Planted: May 10   Harvested: Oct. 14

Chemicals	Active chemical per acre[1]	Mean Vert. wilt[2] Sept. 12	Mean % tubers with Rhiz. black scurf (weight)	Mean yield cwt./A.
Di-Syston®	3 lb. P	9 bcd[3]	77 ef	508 bc
Di-Syston®	3 lb. S	16 ef	75 ef	479 bc
Di-Syston®	3 lb. P+3 lb. S	11 bcdef	41 bc	515 b
Di-Syston®	6 lb. P	9 bcd[3]	69 def	508 bc
Di-Syston®	6 lb. S	9 bcd[3]	64 cdef	515 b
Temik®	3 lb. P	10 bcde	80 ef	479 bc
Temik®	3 lb. S	12 cdef	77 ef	537 ab
Temik®	3 lb. P+3 lb. S	12 cdef	87 f	515 b
Temik®	6 lb. P	6 ab[3]	67 cdef	523 b
Temik®	6 lb. S	13 cdef	75 ef	501 bc
Lanstan®	15 lb. P	9 bcd[3]	68 cdef	545 ab
Lanstan®	15 lb. S	12 cdef	67 cdef	508 bc
Lanstan®	15 lb. P+15 lb. S	8 bc[3]	64 cdef	508 bc
Lanstan®	30 lb. P	7 bc[3]	58 cde	566 ab
Lanstan®	60 lb. B	13 cdef	79 ef	494 bc
Telone®	30 gal. PP	17 f	47 bcd	537 ab
Telone PBC®	30 gal. PP	1 a[3]	15 a[3]	639 a[3]
Telone® + Picfume®	20 + 5 gal. PP	1 a[3]	30 ab[3]	639 a[3]
Control	None	16 ef	66 cdef	461 bc

1/ P = chemicals applied at planting

S = chemicals side-dressed on July 5

B = chemicals broadcast on April 15

PP = chemicals applied as preplant treatment on March 30

3/ Number of plants out of approximately 23 showing Verticillium wilt symptoms.

2/ Values significantly different from the control according to Duncan's Multiple Range Test at the 5% level.

ble 6. Chemical screening test for Verticillium wilt and Rhizoctonia control near Othello, Washington in 1966.

rtilizer: 300 N, 150 P, 150 K, 10 Zn   Planted: May 20, 1966

emicals applied: May 6, 1966   Harvested: October 20, 1966

Chemicals	Active chemical per acre (lbs.)	Mean Vert. wilt plants 1/2/	Mean % non-infested stems (no Rhiz. lesions)	Mean % tubers with black scurf (weight)	Mean % U.S. No.1 tubers 1/ (weight)	Mean yield (cwt./A.)
CONIL 2787, 75% WP	40	13	11 ab	53 d	77	414
CONIL 2787, 75% WP	60	11	9 b	51 cd	75	472
-Syston®, 10% G	6	7	11 ab	42 bcd	77	494
nstan®, 20% G	60	10	5 b	43 bcd	75	479
rraclor®, 2 E.C.	30	9	24 a 3/	20 a 3/	80	457
de®, powder	50 (actual)	9	6 b	40 bcd	74	501
de®, powder	150 (actual)	14	4 b	32 abc	79	501
ontrol	--	8	5 b	27 ab	77	486

/ Data not significant according to F test at the 5% level.
/ Number of plants out of approximately 23 showing Verticillium wilt symptoms.
/ Values significantly different from the control according to Duncan's Multiple Range Test at the 5% level.