Control of *Verticillium dahliae* by Metam-Sodium in Loessial Soil and Effect on Potato Tuber Yields

Y. BEN-YEPHET, Division of Plant Pathology, Agricultural Research Organization, Volcani Center, Bet Dagan, Israel, E. SITI, Extension Service, Israel Ministry of Agriculture, Beer Sheva, Israel, and Z. FRANK, Division of Plant Pathology, Agricultural Research Organization, Volcani Center

ABSTRACT

Ben-Yephet, Y., Siti, E., and Frank, Z. 1983. Control of *Verticillium dahliae* by metam-sodium in loessial soil and effect on potato tuber yields. Plant Disease 67:1223-1225.

Penetration of metam-sodium applied with irrigation water into loessial soil in the field was studied by measuring viability of *Verticillium dahliae* microsclerotia placed 2, 10, 20, 30, and 40 cm deep in the soil. Equal quantities of metam-sodium were applied as concentrated solution, dilute solution, or concentrated solution followed by dilute solution. The dilute application was inferior to both the concentrated and the combined ones. More chemical was required to kill microsclerotia by the combined than by the concentrated application. With the concentrated application, penetration of the chemical was maximal when the dose was dissolved in the first 5–10% of the irrigation water. Metam-sodium applied to commercial fields with each of the methods at a dose of 800 or 1,000 L/ha reduced disease incidence and significantly increased potato yields compared with controls irrigated with water only or with plots treated with 300 L/ha of metam-sodium. The highest increase in yield was obtained with concentrated application of 800 L/ha of metam-sodium; in two fields of the cultivar Desiree, yields were 7.5 and 10 t/ha over those of controls.

Verticillium dahliae Kleb. is a prevalent soilborne pathogen in the Negev region of Israel. Potato, an important crop in the area, suffers a considerable decrease in yields from attacks by *V. dahliae*. In addition to the use of potato cultivars tolerant to *V. dahliae*, treatment of soil with metam-sodium (Vapam) was found to improve potato yields (7). This fungicide is being used against *V. dahliae* because of its effectiveness, low cost, and ease of application to soil via the sprinkler irrigation system. For use in loessial soil, Gerstl et al (5) recommended applying the fungicide in water through the irrigation system at a constant concentration to the desired depth of treatment. In a previous laboratory study of columns filled with contaminated soil, however, application of first a concentrated, then a dilute solution of metam-sodium (combined mode) was superior to either application alone and killed all microsclerotia throughout the 40-cm-deep layer tested (2).

Contribution No. 550-E, 1982 series, from the Agricultural Research Organization, Volcani Center, Bet Dagan, Israel.

Accepted for publication 9 May 1983.

The publication costs of this article were defrayed in part by page charge payment. This article must therefore be hereby marked "*advertisement*" in accordance with 18 U.S.C. § 1734 solely to indicate this fact.

The persistent structures of the fungus are microslcerotia widespread in the soil profile of the upper 40 cm. Even a very low population of microsclerotia can cause an epidemic, so for efficient control, all microsclerotia throughout this soil profile should be killed. The purpose of our study was to compare the effects of the three modes of metam-sodium application under field conditions on the viability of *V. dahliae* microsclerotia to a depth of 40 cm in loessial soil and on disease incidence and yield in potato.

MATERIALS AND METHODS

Microsclerotia were separated from potato stems as described previously (4), and those smaller than 250 μm in diameter were mixed with air-dried loessial loam, 10,000/g of soil. Aliquots (0.5–1 g) of the mixture were placed in 20-μm mesh nylon bags, and the bags were tied along a string 2, 10, 20, 30, and 40 cm from a zero point, then buried at those depths from soil level. Ten to 14 days later, soil samples from fungicide and control plots were suspended in 50 ml of sterile distilled water, poured onto filter paper, and rinsed three times with sterile distilled water. Fifty microsclerotia from each sample were plated on a synthetic medium containing pentachloronitrobenzene and sucrose (1). To observe germination, a single microsclerotium was lifted with a botanical needle under a low-power dissecting microscope and plated on the synthetic medium. An 80–100% reduction in inoculum viability in a soil layer was regarded as successful control of the fungus, and soil depths to which this level of kill occurred were considered.

Microplot and field experiments were done in the Negev region of Israel in silty loam loessial soil (20% clay, field capacity 20%, pH 8.4). Technical grade metam-sodium, 32.7% a.i. in an aqueous solution (pH 9.1), was used.

Microplot study. Microplots were established in fields previously cropped with wheat or pea. Microsclerotia inserted to a depth of 40 cm in the middle of 1-m^2 microplots were treated with the fungicide by each of the three modes of application using a watering can. Treatments were replicated in randomized blocks at least three times in each of the two experiments. The irrigation volume necessary to reach field capacity of the soil down to 40 cm was 80 L/m^2. For the dilute application, the fungicide was diluted in the total water volume. For the concentrated application, the fungicide was diluted in 10 L and applied to the soil, followed by irrigation with 70 L. In the combined application, the fungicide dose was split into two portions and applied first as a concentrated solution, then as a dilute solution.

In the first experiment, the effect of the fungicide was tested at 60, 80, 100, and 120 ml/m^2 in dilute and combined applications. In the combined application, the fungicide dose was split into equal portions. In the second experiment, 60, 70, 80, and 90 ml/m^2 were tested with all three modes of application. In the combined application, fungicide doses were split 60 + 10, 60 + 20, and 60 + 30 ml/m^2.

Field study. The fungicide solution was applied through the sprinkler irrigation system. In fields infested with both *V. dahliae* and the nematode *Pratylenchus thornei*, the common practice is to use a nematicidal dose of metam-sodium (300 L/ha) in a dilute application. This treatment was included in some field trials for comparison with fungicidal doses. In July, metam-sodium was applied through the sprinkler irrigation system at four naturally infested locations in the Negev region, and 21 days later the fields were planted with potatoes. Randomized-block plots were at least 400 m^2. Each treatment was replicated at least three times. Three strings with microsclerotia were inserted in the soil before treatment in each replicate. Microsclerotia viability was used to indicate the depth of efficient fungicide penetration.

In autumn 1980, the potato cultivar Spunta was planted in a field treated with 1,000 L/ha of metam-sodium by dilute and combined (650 + 350 L) applications. In another field, soil was treated with 1,200 L/ha in either dilute or combined (800 + 400 L) applications. In autumn 1981, two additional fields were treated with 800 L/ha; the fungicide was applied by the concentrated mode in one field and by all three modes in the second field. In the second field, concentrated doses were diluted in 200,000–250,000 L/ha. In both fields, the potato cultivar Desiree was planted.

Disease incidence in potato plants was rated by sowing segments of stems on the synthetic agar medium (1) several times from 70 days after planting until the end of the growing season. Tuber yields were determined by manual harvest of five replicate rows, each 6 m long.

RESULTS

Microplot study. Microslcerotia were killed throughout a deeper soil profile in the combined than in the dilute application, and the percent kill was enhanced as the fungicide dose per irrigation volume increased. Microsclerotia were killed to a depth of 20 cm by dilute and combined applications of 60 ml/m^2 of metam-sodium and to depths of 20 and 40 cm, respectively, by dilute and combined applications of 120 ml/m^2. When fungicide doses were tested by all three modes of application, dilute application of all doses killed microsclerotia to a depth of 20 cm, whereas concentrated and combined applications of all doses killed microsclerotia to a depth of 40 cm. The results indicated that concentrated application of 60 ml/m^2 was sufficient to kill microsclerotia throughout the top 40-cm layer.

Equal doses (60 ml/m^2) of metam-sodium diluted in different volumes of water (2, 4, 8, 16, 32, 64, and 80 L) were applied and supplemented with water to a total of 80 L/m^2. Increasing the dilution of the primary drench reduced metam-sodium efficacy, but the effect was not linear. The depth to which microsclerotia were killed was greatest (40 cm) with

Table 1. Effect of metam-sodium on *Verticillium dahliae* microsclerotia control, disease incidence in potato plants, and autumn tuber yield

Field/cultivar	Metam-sodium dose (L/ha) and application mode[x]	Depth to which 80–100% of microsclerotia killed (cm)	Infected plants[y] (%) I	Infected plants[y] (%) II	Potato tuber yield[z] (t/ha)
A/no plants	800 concentrated + 400 dilute	40	...	...	...
	1,200 dilute	20	...	...	...
	None	0	...	...	...
B/Spunta	650 concentrated + 350 dilute	35	52	60	28.1 a
	1,000 dilute	20	89	92	27.0 a
	300 dilute	...	98	98	24.1 b
	None	0	98	98	24.2 b
C/Desiree	800 concentrated	35	35	45	37.5 a
	300 dilute	15	98	98	27.1 b
D/Desiree	800 concentrated	...	65	80	31.6 a
	700 concentrated + 100 dilute	...	83	98	27.1 b
	800 dilute	...	84	98	28.1 b
	None	...	100	100	23.9 c

[x] Dilute = fungicide dose diluted in 800,000 L/ha. Concentrated = fungicide dose diluted in 80,000–100,000 L/ha, except for field D, where it was diluted in 200,000–250,000 L/ha, and followed by irrigation with water to make 800,000 L/ha. Combined application = first dose applied as concentrate and second dose as dilute solution. When 300 L/ha applied, fungicide dose diluted in 600,000 and 400,000 L/ha in fields B and C, respectively.

[y] I = disease incidence measured 70 days after planting for both Spunta and Desiree; II = disease incidence measured 90 days after planting for Spunta and 115 days after planting for Desiree.

[z] Data followed by the same letter do not differ significantly according to Newman-Keuls and *Q* methods. Field B = $P \leq 0.05$ between mean of combined and dilute treatments at 1,000 L/ha and mean of dilute application at 300 L/ha and control. Fields C and D = $P \leq 0.01$ and $P \leq 0.05$, respectively.

water volumes of 2, 4, and 8 L. Increasing the dilution from 16 to 32 L reduced the depth of microsclerotia kill by 12 cm; dilution up to 64 L reduced the depth by only another 4 cm.

Field study. Combined application through the sprinkler irrigation system of 1,000 and 1,200 L/ha of metam-sodium killed microsclerotia to a depth of 35 and 40 cm, respectively. Dilute application of the same doses killed microsclerotia to a depth of 20 cm (Table 1, fields A and B). In another experiment, concentrated application of 800 L/ha of metam-sodium killed microsclerotia to a depth of 35 cm. Dilute application of 300 L/ha killed microsclerotia to 15 cm (Table 1, field C).

Disease incidence in Spunta potato plants 90 days after planting was 60% in plots treated with metam-sodium applied in the combined mode, compared with almost 100% in the other treatments (Table 1, field B). In Desiree plants, disease incidence 115 days after planting was 45% in plots treated by concentrated application of 800 L/ha, compared with almost 100% in plots treated by dilute application of 300 L/ha (Table 1, field C). In the experiment where the three modes of application were compared using 800 L/ha of metam-sodium, the concentrated application resulted in 80% disease incidence and the other modes, almost 100% (Table 1, field D).

The tuber yields of Spunta plants were significantly higher (4 and 3 t/ha) after combined and dilute applications of 1,000 L/ha of metam-sodium than after no treatment or the 300 L/ha dilute treatment (Table 1, field B). The Desiree tuber yield after concentrated application of 800 L/ha was increased by 10 t/ha over the yield after the 300 L/ha dilute treatment (Table 1, field C). In the field treated with 800 L/ha, the increase in yield of Desiree over that of the control was 7.5 t/ha after concentrated application and 4 t/ha after either combined or dilute application (Table 1, field D).

DISCUSSION

Of the three modes of applying metam-sodium to kill *V. dahliae* microsclerotia to a depth of 40 cm in loessial soil, concentrated or combined application was more effective than dilute application. Under field conditions, concentrated application required a smaller dose of metam-sodium to kill microsclerotia than combined application did.

Results of the dilute and combined applications are in good agreement with those reported from a laboratory study (2), but results of laboratory studies with concentrated application in soil columns could not be verified in the field. In columns of sieved soil, concentrated application of fungicide killed microsclerotia in the lower layer but not in the upper layer, possibly because of an almost complete piston effect. Because soil structure and percolation are better in the field, the piston effect exists only partially, resulting in a lower rate of displacement of the biocide from the upper layer. Under field conditions, therefore, concentrated application killed microsclerotia throughout a profile down to 40 cm. Also, the high temperature in the upper layer (8) decreases microsclerotia viability (6) and increases toxicity of the chemical to microsclerotia (2; Ben-Yephet, *unpublished*).

It has been suggested that the fungicidal activity of metam-sodium is exerted through conversion to methyl isothiocyanate (MIT) molecules and that an increase in clay or peat content of the soil decreases the amount of MIT release (9,10). A previous study (2) confirmed that a larger fungicide dose was required to kill microsclerotia in a sieved heavy soil (54% clay) than in a loessial soil (20% clay). In fact, to predict the amount of MIT required to kill microsclerotia, the concentrations of the fungicide applied during the treatment must be considered. The limited penetration of metam-sodium in dilute application into loessial loam as indicated by microsclerotia viability may be due to the poor soil structure slowing down water percolation. Contact of the solution with the upper soil layer is thereby extended and the proportion of the fungicide molecules being adsorbed to the clay fraction (20% of the loess) is increased. Current tests (Ben-Yephet and Frank, *unpublished*) with alluvial soil (54% clay) of naturally good structure and percolation capacity and with the same soil finely sieved (<250 μm) indicate that microsclerotia are killed to a deeper layer in clodded than in finely sieved soil with dilute application of the fungicide.

Krikun and Orion (7) reported an increase in potato yields when a dose as low as 300 L/ha of metam-sodium was applied. The increase was explained by decreases in the population of *P. thornei*, the nematode enhancing disease caused by *V. dahliae* in potato plants. In our study, however, potato yields were increased only in the 1,000 and 800 L/ha treatments compared with no treatment or the 300 L/ha treatment. This disagreement in results is probably due to high inoculum levels of microsclerotia in our trials, owing to previous Verticillium wilt of potatoes in the study fields. The largest increase in yield was obtained with the concentrated fungicide solution, which controlled microsclerotia to the greatest depth. The lesser effectiveness of the fungicide in field D (Table 1), as reflected by the small decrease in disease incidence, was probably due to the greater dilution of the metam-sodium dose. The increase in fungicide dilution reduced microsclerotia control in the lower soil layer.

Metam-sodium application at fungicidal doses reduced disease incidence for part of the growing season, although differences in disease incidence were smaller by the end of the season. Another possible effect of the treatment, not yet tested, could be on colonization density of the fungus in plant tissues. Both aspects—incidence and colonization density—may account for the marked yield differences among treatments. It should be noted that established decreases in inoculum levels of other soil pathogens, namely, *Rhizoctonia, Sclerotinia, Fusarium*, and pathogenic bacteria, also may have improved plant growth and tuber yield.

In loessial soil with a poor structure, concentrated application of metam-sodium was superior to dilute application and more economical than a split dose in combined application. The metam-sodium treatment cost subtracted from the value of the yields from the two Desiree fields, 31.6 and 37.5 t/ha, respectively, leaves a surplus of 4.3 and 6.8 t/ha, respectively, as a net profit.

Autumn incorporation of potato residues greatly increases the microsclerotia population in soil (3). If this practice continues, the need for application of fungicides through the sprinkler irrigation system will become even greater.

ACKNOWLEDGMENTS

We wish to thank A. Gnizi, Division of Statistics and Experimental Design, and Z. Gerstl, Division of Soil Residues Chemistry, for their advice; Y. Szmulewich for technical assistance; and Agan Chemical Co., Ashdod, Israel, for supplying metam-sodium.

LITERATURE CITED

1. Ausher, R., Katan, J., and Ovadia, S. 1975. An improved selective medium for the isolation of *Verticillium dahliae*. Phytoparasitica 3:133-137.
2. Ben-Yephet, Y. 1979. Penetration of metham and mylone into soil columns as measured by their effect on viability of microsclerotia of *Verticillium dahliae*. Plant Soil 53:341-349.
3. Ben-Yephet, Y., Evans, G., and Sappir, D. 1981. Reducing *Verticillium dahliae* microsclerotia production on potato and tomato stems by chemical spray applications. Phytoparasitica 9:226-227.
4. Ben-Yephet, Y., and Frank, Z. 1978. Toxicity of metham towards *Verticillium dahliae* microsclerotia. Plant Dis. Rep. 62:119-121.
5. Gerstl, Z., Mingelgrin, U., Krikun, J., and Yaron, B. 1977. Behavior and effectiveness of Vapam applied to soil in irrigation water. Proc. Isr.-Fr. Symp. Behav. Pestic. Soil 1975. Spec. Publ. Agric. Res. Organ., Bet Dagan, Israel. 82:42-50.
6. Katan, J. 1981. Solar heating (solarization) of soil for control of soilborne pests. Annu. Rev. Phytopathol. 19:211-236.
7. Krikun, J., and Orion, D. 1979. Verticillium wilt of potato: Importance and control. Phytoparasitica 7:107-116.
8. Mahrer, I. 1979. Prediction of soil temperature of a soil mulched with transparent polyethylene. J. Appl. Meteorol. 18:1263-1267.
9. Munnecke, D. E., Domsch, K. H., and Eckert, J. W. 1962. Fungicidal activity of air passed through columns of soil treated with fungicides. Phytopathology 52:1298-1306.
10. Munnecke, D. E., and Martin, J. P. 1964. Release of methylisothiocyanate from soil treated with mylone (3,5-dimethyl-tetrahydro 1,3,5 2H-thiadiazine-2-thione). Phytopathology 54:941-945.