Effect of Soil Solarization and Fungicide Soil Drenches on Crater Disease of Wheat

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ABSTRACT

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The development and yield of wheat growing in crater disease soil was enhanced significantly by tarping with clear polyethylene and by fumigation with methyl bromide. Soil drenching with copper oxychloride, fenarimol, and benomyl also controlled crater disease significantly but to a lesser degree than solarization and methyl bromide. *Bipolaris sorokiniana, Fusarium culmorum, F. equiseti, Rhizoctonia solani,* and *Sclerotium rolfsii* were associated with the wheat roots, but only *B. sorokiniana* was suppressed by some of the treatments, ie, solarization, methyl bromide, and procymidone. Application of the latter fungicide, however, did not result in enhanced plant growth.

Cultivation of wheat (*Triticum aestivum* L.) in dryland fields on the Springbok Flats, Republic of South Africa, is seriously threatened by a condition referred to as crater disease. The disease is characterized by patches of chlorotic, stunted plants that appear about 4 wk after planting. Affected plants usually die in the seedling stage, though some remain alive but dwarfed until tillering. Yield reduction caused by crater disease can be as high as 35% (21). Two fungal species are implicated as causal organisms of this disease, ie, *Periconia macrospinosa* Levebvre & Johnson and *Rhizoctonia solani* Kühn, possibly in synergistic association with another (20,21). However, it has also been hypothesized that phytotoxic aromatic nitroso compounds could be involved (23).

No work has been done on the chemical control of *P. macrospinosa*. Information on the chemical control of *R. solani* is voluminous, but reports on the application of fungicides to control this pathogen on wheat are limited (6,18,29). Thus far, little attention has been given to the control of crater disease by chemical means. In this paper we report on the effect of soil drenching with various fungicides on the disease and the effect of soil solarization, a technique known to control many soilborne pathogens (7).

MATERIALS AND METHODS

The following fungicides were applied as soil drenches (3.75 L/m^2) in a randomized field experiment in a crater patch on the Springbok Flats (values in parentheses represent g a.i./L applied): anilazine (0.20), benodanil (0.67), benomyl (0.67), captafol (1.10), copper oxychloride (0.91), fenarimol (1.00), iprodione (0.6), pencycuron (0.40), procymidone (0.40), quintozene (1.00), thiabendazole (0.60), and tolclofos-methyl (0.40). In addition, formaldehyde (15 g/L) was applied in a similar way, whereas methyl bromide was evaluated as a fumigant at the rate of 85 g/m^2. Soil was also covered for 4 wk with 200-μm-thick clear polyethylene sheets. The maximum temperature recorded under the polyethylene at a depth of 15 cm was 48 C, whereas the maximum temperature recorded in uncovered soil was 36 C. Five replicates were used per treatment and plot size was 2 × 4 m. Control plots received 3.75 L/m^2 of water.

Four weeks after application of the various chemicals and directly after solarization, a soil sample was taken from each plot at a depth of 0–20 cm. The fungi present in the samples were determined by plating out serial dilutions of the soil on dextrose-peptone-yeast extract medium (17). After incubation for 5–7 days at 27 C, colonies that developed were counted and the fungi were isolated and identified. The propagule concentration of *R. solani* in the various soil samples was determined according to the beet seed technique (15,16), using 20 seeds per 50 g of soil per plot. After incubation for 72 hr at 27 C, the recovered, washed, and blot-dried seeds were plated out on a medium selective for *R. solani* (10). The number of seeds yielding *R. solani* after incubation at 27 C for 48 hr was recorded.

Wheat (cultivar Inia) was planted mechanically in the various plots. Five weeks after planting, 10 plants were selected randomly and removed from each plot. The roots were excised, washed in tap water, and cut into segments about 1 cm long. All root segments from each plot were pooled, sterilized superficially for 1 min with 3% sodium hypochlorite, rinsed in sterile water, and blot-dried aseptically. Fifty randomly selected root segments from each pooled sample were plated out on 1.5% water agar supplemented with 125 mg/L chloramphenicol and incubated at 27 C. The plates were examined daily for 5 days and again after 5 wk. Fungi that developed from the segments were isolated and identified. Shoots were dried at 70 C and weighed. At maturity, the wheat was harvested and grain yield and 1,000-kernel weight were determined.

RESULTS

None of the chemicals applied as soil drenches significantly reduced the number of fungal propagules in the soil; however, solarization and fumigation with methyl bromide resulted in a significant decrease in the incidence of fungi (Table 1). Fungi representing 25 different taxa were isolated from the variously treated plots. Of these, *R. solani, Fusarium culmorum* (W. G. Sm.) Sacc., and *F. equiseti* (Corda) Sacc. are recognized as wheat root pathogens (5,27). None of the treatments resulted in a significant reduction in the propagule concentration of any of these pathogens in the soil. On the contrary, drenching with benomyl significantly increased the number of propagules of *R. solani*. *Trichoderma* spp. (mainly *T. viride*) Pers. ex Gray) occurred in significantly greater numbers in soil treated with formaldehyde than in the soil of the control treatment.

Five recognized root and crown pathogens of wheat occurred in the roots of the plants 5 wk after planting, ie, *R. solani, F. culmorum, F. equiseti, Sclerotium rolfsii* Sacc. (9), and *Bipolaris sorokiniana* (Sacc.) Shoem. (27). *P. macrospinosa* did not develop from any of the root segments plated out, even after incubation for 5 wk. *B. sorokiniana* had the highest incidence in the roots, followed by *F. equiseti*, whereas the number of root segments yielding *F. culmorum, S. rolfsii*, and *R. solani* was relatively low (Table 2). Solarization, fumigation with methyl bromide, and drenching with procymidone significantly reduced the incidence of *B. sorokiniana* in the roots. The other four pathogens were not affected significantly by any of the treatments.

Five weeks after planting, the dry shoot weight of the wheat plants growing in solarized soil was 3.4 times higher than

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that of the plants growing in the control soil, whereas 2.1-, 1.8-, 1.6-, and 1.5-fold increases in weight over the control were evident in the case of fumigation with methyl bromide and drenching with copper oxychloride, fenarimol, and benomyl, respectively. These increases were all statistically significant (Table 3). Solarization, fumigation with methyl bromide, and drenching with copper oxychloride resulted in significant increases in grain yield. The 4.8-fold increase over the control observed in the case of solarization was significantly higher than the 2.6-fold increase caused by methyl bromide, which in turn was significantly higher than the 1.9-fold increase brought about by copper oxychloride. The 1,000-kernel weight was increased significantly by solarization, as well as by drenching with copper oxychloride.

DISCUSSION

This paper constitutes the first report on the control of crater disease of wheat by soil solarization and by fumigation with methyl bromide. Although no published information is available on the use of solarization for control of related diseases of wheat, the alleviating effect on crater disease achieved with this technique is in accordance with reports on other crops (7). Methyl bromide, of course, is commonly used as a soil disinfectant and is known to reduce the incidence of pathogens like *R. solani* on wheat roots (26).

Solarization and fumigation with methyl bromide, as well as drenching with procymidone, reduced infection of the roots by *B. sorokiniana* significantly. The effectiveness of procymidone against *B. sorokiniana* is in accordance with previous findings (28). However, application of the latter fungicide did not result in enhanced plant growth, thus indicating that the better growth observed after solarization and fumigation with methyl bromide was not due to the inhibition of *B. sorokiniana*. Because procymidone is not phytotoxic toward wheat (22), the possibility of a masking phytotoxic effect can be ruled out. The noninvolvement of *B. sorokiniana* in the disease syndrome is further endorsed by the fact that benomyl, which significantly controlled crater disease during the initial stages of plant growth, is ineffective against this pathogen (2).

Contrary to a previous report (21), *P. macrospinosa* was not found associated with crater disease, whereas the incidence of the other fungus implicated in the disease, ie, *R. solani* (20), was extremely low compared with the figures reported for barley stunt disorder (15), a condition related to crater disease. Of the other pathogens encountered, *S. rolfsii* is known to occur on the Springbok Flats, but *F. culmorum* and *F. equiseti* have not previously been found associated with wheat in this area (11). Because none of these pathogens were inhibited significantly by any of the treatments that enhanced plant growth, their respective roles in the disease remain uncertain.

It is known that solarization and fumigation with methyl bromide increase the availability of certain nutrients in the soil and hence enhance plant growth (4,12,19). However, in a subsequent experiment on the Springbok Flats (*unpublished*), neither solarization nor fumigation with methyl bromide significantly improved the development of wheat plants growing in healthy soil. Therefore, the considerably better growth achieved in diseased soil by solarization and fumigation with methyl bromide indicates that the cause of crater disease is an actively invading entity. Furthermore, the alleviating effects obtained with copper oxychloride, benomyl, and fenarimol indicate that a fungus is involved in the disease syndrome. All three of these fungicides are active against a wide spectrum of fungi (2,3,28). The fact that the fungicides did not perform as well as solarization could possibly be ascribed to the adsorption of the chemicals by the upper soil layers. It is known that fungicides applied as soil drenches are often rendered less inhibitory this way, especially in soils with a high clay content (1,8) like the vertisols-pellusterts of the Springbok Flats (24). Obviously, soil mixing with fungicides should be investigated.

Two other aspects of interest that evolved from this investigation are the enhanced incidence of *R. solani* in soil treated with benomyl, which is in accordance with previous reports (6,18), and the significantly higher numbers of *Trichoderma* spp. in soil treated with

Table 1. Effect of soil solarization and chemical treatments on the incidence of fungi in crater disease soil

	Propagules per gram of soil				
Treatment	**Total ($\times10^2$)**	***Fusarium culmorum*** **($\times10^2$)**	***Fusarium equiseti*** **($\times10^2$)**	***Trichoderma*** **($\times10^2$)**	***Rhizoctonia solani*** **(% beet seed colonized)**
Solarization	39 a[z]	0 a	15 a	0 b	0.0 b
Methyl bromide	72 ab	2 a	0 a	0 b	0.0 b
Copper oxychloride	310 cde	18 a	0 a	10 b	0.0 b
Fenarimol	360 ef	30 a	12 a	4 b	1.2 ab
Benomyl	342 ef	25 a	0 a	18 b	2.4 a
Tolclofos-methyl	246 abcde	0 a	22 a	0 b	0.4 b
Captafol	274 bcde	0 a	0 a	2 b	0.0 b
Thiabendazole	188 abcde	6 a	0 a	0 b	0.4 b
Anilazine	354 ef	0 a	11 a	0 b	1.2 ab
Iprodione	188 abcde	2 a	2 a	16 b	1.2 ab
Quintozene	160 abcde	0 a	6 a	14 b	0.4 b
Pencycuron	292 cde	15 a	5 a	0 b	0.0 b
Formaldehyde	120 abc	8 a	0 a	95 a	0.4 b
Benodanil	138 abcd	2 a	0 a	26 b	0.0 b
Procymidone	180 abcde	20 a	0 a	2 b	1.6 ab
Control	300 cde	8 a	2 a	38 b	0.0 b

[z] In each column, values followed by the same letter do not differ significantly ($P=0.05$) according to Duncan's multiple range test.

Table 2. Effect of soil solarization and chemical treatments on the incidence of wheat root pathogens in the roots of 5-wk-old wheat plants growing in crater disease soil

	Percentage incidence				
Treatment	***Bipolaris sorokiniana***	***Fusarium culmorum***	***Fusarium equiseti***	***Sclerotium rolfsii***	***Rhizoctonia solani***
Solarization	13 c[z]	3.0 ab	18 ab	0.0 b	0.0 a
Methyl bromide	14 c	2.0 b	18 ab	0.8 ab	0.4 a
Copper oxychloride	59 ab	2.0 ab	18 ab	0.0 b	0.4 a
Fenarimol	38 abc	4.0 a	20 ab	0.0 b	0.0 a
Benomyl	49 ab	1.0 b	6 b	0.0 b	0.0 a
Tolclofos-methyl	41 abc	2.0 b	20 ab	0.0 b	0.0 a
Captafol	66 a	1.0 b	17 ab	0.4 ab	0.0 a
Thiabendazole	50 ab	2.0 b	9 ab	0.0 b	0.0 a
Anilazine	60 ab	2.0 b	19 ab	0.0 b	0.0 a
Iprodione	36 abc	2.0 b	28 a	0.0 b	0.0 a
Quintozene	43 abc	3.0 ab	12 ab	0.0 b	0.0 a
Pencycuron	46 abc	3.0 ab	7 ab	0.4 ab	0.0 a
Formaldehyde	33 abc	3.0 ab	20 ab	0.0 b	0.0 a
Benodanil	30 bc	2.0 b	4 b	0.0 b	0.0 a
Procymidone	13 c	0.5 b	25 ab	0.0 b	0.0 a
Control	60 ab	3.0 ab	11 ab	0.0 b	0.0 a

[z] In each column, values followed by the same letter do not differ significantly ($P=0.05$) according to Duncan's multiple range test.

Table 3. Effect of soil solarization and chemical treatments on the development and yield of wheat plants in crater disease soil

Treatment	Dry shoot weight 5 wk after planting (mg)	Grain yield (g/m^2)	1,000-Kernel weight (g)
Solarization	212 a[z]	147.6 a	39.8 a
Methyl bromide	173 b	110.4 b	37.2 bc
Copper oxychloride	116 c	58.8 c	37.8 ab
Fenarimol	101 cd	28.8 d	35.1 cde
Benomyl	96 cde	32.1 d	34.1 de
Tolclofos-methyl	91 cdef	30.7 d	35.0 cde
Captafol	89 cdef	30.8 d	35.1 cde
Thiabendazole	85 defg	22.5 d	33.3 de
Anilazine	78 defgh	28.4 d	32.8 e
Iprodione	73 defgh	28.6 d	35.8 bcd
Quintozene	73 defgh	33.0 d	34.5 cde
Pencycuron	70 efgh	30.5 d	33.7 de
Formaldehyde	67 fgh	27.8 d	34.8 cde
Benodanil	61 gh	22.1 d	35.3 cde
Procymidone	55 gh	36.2 d	34.5 cde
Control	63 fgh	31.1 d	35.5 cde

[z] In each column, values followed by the same letter do not differ significantly ($P = 0.05$) according to Duncan's multiple range test.

formaldehyde. It is known that *Trichoderma* spp. are capable of rapidly colonizing disinfected soil (13,25). In this investigation, this phenomenon occurred only in the soil treated with formaldehyde and not in the soil fumigated with methyl bromide.

The costs involved render solarization and fumigation with methyl bromide unsuitable for control of crater disease on a large scale. Furthermore, because the effectiveness of solarization and fumigation with methyl bromide depends on the presence of sufficient moisture in the soil (7,14), adequate rain before treatment would be a prerequisite for using these techniques commercially under dryland conditions. Nevertheless, should either of the treatments have a lasting effect, a cost-effect analysis might prove them economically feasible.

LITERATURE CITED

1. Bateman, G. L., and Nicholls, P. H. 1982. Experiments on soil drenching with fungicides against take-all in wheat. Ann. Appl. Biol. 100:297-303.
2. Bollen, G. J., and Fuchs, A. 1970. On the specificity of the in vitro and in vivo antifungal activity of benomyl. Neth. J. Plant Pathol. 76:299-312.
3. Buchenauer, H. 1979. Comparative studies on the antifungal activity of triadimefon, triadimenol, fenarimol, nuarimol, imazalil and fluotrimazole in vitro. J. Plant Dis. Prot. 86:341-354.
4. Chen, Y., and Katan, J. 1980. Effect of solar heating of soils by transparent polyethylene mulching on their chemical properties. Soil Sci. 130:271-277.
5. Giha, O. H. 1978. The pathogenicity of fungi associated with foot- and root-rot diseases of irrigated wheat in Nigeria. Pest Artic. News Summ. 24:306-312.
6. Jenkyn, J. F., and Prew, R. D. 1973. Activity of six fungicides against cereal foliage and root diseases. Ann. Appl. Biol. 75:241-252.
7. Katan, J. 1980. Solar pasteurization of soils for disease control: Status and prospects. Plant Dis. 64:450-454.
8. Kataria, H. R., and Grover, R. K. 1976. Some factors affecting the control of *Rhizoctonia solani* by systemic and non-systemic fungicides. Ann. Appl. Biol. 82:267-278.
9. Kilpatrick, R. A., and Merkle, O. G. 1967. Seedling disease of wheat caused by *Sclerotium rolfsii*. Phytopathology 57:538-540.
10. Ko, W., and Hora, F. K. 1971. A selective medium for the quantitative determination of *Rhizoctonia solani* in soil. Phytopathology 61:707-710.
11. Maas, E. M. C., and Kotzé, J. M. 1981. Fungi associated with root diseases of wheat in South Africa. Phytophylactica 13:155-156.
12. Millhouse, D. E., and Munnecke, D. E. 1979. Increased growth of *Nicotiana glutinosa* as partially related to accumulation of ammonium-nitrogen in soil fumigated with methyl bromide. Phytopathology 69:793-797.
13. Mughogho, L. K. 1968. The fungus flora of fumigated soils. Trans. Br. Mycol. Soc. 51:441-459.
14. Munnecke, D. E., Moore, B. J., and Abu-El-Hay, F. 1971. Soil moisture effects on control of *Pythium ultimum* or *Rhizoctonia solani* with methyl bromide. Phytopathology 61:194-197.
15. Murray, D. I. L. 1981. *Rhizoctonia solani* causing barley stunt disorder. Trans. Br. Mycol. Soc. 76:383-395.
16. Papavizas, G. C., Adams, P. B., Lumsden, R. D., Lewis, J. A., Dow, R. L., Ayers, W. A., and Kantzes, J. G. 1975. Ecology and epidemiology of *Rhizoctonia solani* in field soil. Phytopathology 65:871-877.
17. Papavizas, G. C., and Davey, C. G. 1959. Evaluation of various media and antimicrobial agents for isolation of soil fungi. Soil Sci. 88:112-117.
18. Prew, R. D., and McIntosh, A. H. 1975. Effects of benomyl and other fungicides on take-all, eyespot and sharp eyespot disease of winter wheat. Plant Pathol. 24:67-71.
19. Rovira, A. D. 1976. Studies on soil fumigation. I. Effects on ammonium, nitrate and phosphate in soil and on the growth, nutrition, and yield of wheat. Soil Biol. Biochem. 8:241-247.
20. Scott, D. B. 1980. Foot and root diseases in wheat: Dryland rot. Farming S. Afr. G.2.4 (Division Agricultural Information, Pretoria). 7 pp.
21. Scott, D. B., Visser, C. P. N., and Rufenacht, E. M. C. 1979. Crater disease of summer wheat in African drylands. Plant Dis. Rep. 63:836-840.
22. Smith, E. M. 1983. Chemical and physical control of wheat root diseases. M.Sc. thesis, University of Pretoria, Pretoria, Republic of South Africa. 88 pp.
23. Van der Merwe, A. J., and Volsteedt, F. du R. 1980. The effect of nitrate growth inhibitors on the growth of wheat seedlings. Agrochemophysica 12:27-32.
24. Van der Merwe, C. R. 1962. Soil groups and subgroups of South Africa. Sci. Bull. Dep. Agric. S. Afr. 356. 355 pp.
25. Warcup, J. H. 1951. Effect of partial sterilization by steam or formalin on the fungus flora on an old forest nursery soil. Trans. Br. Mycol. Soc. 34:519-532.
26. Warcup, J. H. 1976. Studies on soil fumigation. IV. Effects on fungi. Soil Biol. Biochem. 8:261-266.
27. Wiese, M. V. 1977. Compendium of Wheat Diseases. American Phytopathological Society, St. Paul, MN. 106 pp.
28. Worthing, C. R., ed. 1979. The Pesticide Manual. British Crop Protection Council, Croydon. 655 pp.
29. Wu, W. S. 1976. Increasing the effectiveness of seed-treated fungicides by the pelleting method. Bot. Bull. Acad. Sin. 17:151-160.