Control of Apple Replant Disease with Formaldehyde in Washington

R. P. COVEY, Plant Pathologist, B. L. KOCH, Associate Horticulturist and Soil Scientist, and H. J. LARSEN, Assistant Plant Pathologist, Tree Fruit Research Center, Washington State University, Wenatchee 98801; and W. A. HAGLUND, Plant Pathologist, Northwestern Washington Research and Extension Unit, Mount Vernon 98273

ABSTRACT

Covey, R. P., Koch, B. L., Larsen, H. J., and Haglund, W. A. 1984. Control of apple replant disease with formaldehyde in Washington. Plant Disease 68:981-983.

In greenhouse studies, formaldehyde was as effective as chloropicrin or methyl bromide in alleviating growth suppression indicative of an apple replant disease (ARD) that occurs commonly in apple orchard soil in Washington State. The effective range of formaldehyde was 0.06–0.43 mg/kg in most soils tested. Metalaxyl and a fungicide mixture containing fenaminosulf were not effective. Soil application of formaldehyde in spring but not autumn alleviated ARD in a field test.

Additional key words: specific apple replant disease

An apple replant disease (ARD) has been reported previously in the state of Washington (3,5,11). The disease appears similar to the specific apple replant disease (SARD) reported in other fruit-growing regions of the world (4,7,8,17), but in Washington, the situation is complicated by the high arsenic content of many orchard soils (2). The causal agent is unknown although various fungi, bacteria, and possibly nematodes have been implicated (1,4,15,17,18). In some regions, nematodes are involved in a nonspecific apple replant disease (NSARD) (12). The major problem in elucidating the relationship between these diseases and the etiology of SARD is the lack of diagnostic symptoms (8,17). It is possible that several distinct diseases with similar symptoms occur. Until the etiology of this disease is understood, it will be necessary to repeat control studies in each apple-growing region.

Although fumigants such as dichloropropene (1,3-D) have generally alleviated NSARD, only general biocides such as methyl bromide (MB) or chloropicrin (CP) have given practical control of SARD (3,5,7,8,12,18). Results with fungicides and fungicide mixtures have generally been disappointing (3,7), but formalin has been reported effective (7,18) or moderately effective (7) for control of SARD. Sewell et al found that formalin compared favorably with CP in overcoming SARD in England (16,18).

The following studies were made to determine if formaldehyde would control ARD in Washington. Other pesticides were also tested in an attempt to characterize the possible causal agents.

Scientific paper 6087, College of Agriculture Research Center, Washington State University, Pullman 99164. Project 0177. This research was supported in part by a research grant from the Washington Tree Fruit Research Commission.

Accepted for publication 2 May 1984.

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.

MATERIALS AND METHODS

Soils used in greenhouse studies were collected from four orchard sites where ARD was known or suspected to occur. Each site was cropped to apples. A composite soil sample from 20 to 76 cm deep was taken from the center of the alley between rows of trees. The soil was mixed thoroughly and divided into 12-kg subsamples before pesticide treatment. The arsenic content of the soil was determined by the Soil Testing Laboratory of Washington State University. Arsenic contents of soils 1 and 3 were 45 and 136 μg/g, respectively, whereas soils 2 and 4 contained only trace amounts. Soils 1, 3, and 4 had previously been planted to commercial orchards, whereas soil 2 came from a nursery where four crops of apple trees had been grown during a 16-yr period.

Pesticide treatments (Table 1) were applied to the 12-kg samples in 4-mil plastic bags that were sealed either before treatment with CP and MB or immediately after treatment with the other pesticides. Formaldehyde was added as a 37% formalin solution (40 g of formaldehyde per liter) and the rate expressed as milligrams of formaldehyde per kilogram of dry soil. A range of formaldehyde concentration (0.06–0.43 mg/kg) was compared. All treatments except MB and CP were applied in 100 ml of water and mixed thoroughly with the soil. The same amount of water was added to the MB and CP treatments before sealing the bag. MB and CP were injected as liquid into the bags at one point per bag. The fungicide mixture treatment consisted of 3 mg of quintozene (Terrachlor 75WP), 0.83 mg of fenaminosulf (Dexon 70WP), 2.87 mg of benomyl (Benlate 50WP), and 0.21 mg of oxytetracycline (Terramycin 17WP) per kilogram of soil. Treated and untreated soil was kept in the sealed bags for 6–8 days, then exposed to air for 3–4 wk. Soil 3 was aired for only 2 wk before planting.

After aeration, soil was placed in 1.4-L round pots (12 × 12 cm). A 3-wk-old apple seedling that had been grown aseptically was planted in each pot. These seedlings were selected for uniform size and vigor. Plants were maintained on a greenhouse bench and watered as needed. Each pot was fertilized every 2 wk with 50 ml of NH_4NO_3 (2.65 g/L) solution and each month with 50 ml of a solution (5.3 g/L) of 23-19-7 (NPK) plus micronutrients (RA-PID-GRO Corp., Dansville, NY). Aphids were controlled with permethrin EC (12 g/L, 0.92 ml/L) or endosulfan 50WP (1.2 g/L), and powdery mildew was controlled with oxythioquinox 25WP (0.45 g/L) as needed. Tests on soils 1–3 were made during the spring and early summer without supplemental lighting. Soil 4 was tested in the autumn and winter, with the photoperiod increased to 14 hr by sodium halide lighting.

All treatments were assayed at harvest for nematodes by a modified centrifugal flotation technique. Fifty cubic centimeters of soil was placed in 500 ml of water, agitated, allowed to settle for 10 sec, and decanted. The residual soil was resuspended by agitation and the process repeated. The 1 L of liquid and particulate suspension was concentrated to 25 ml by gravity and vacuum decanting. A sugar solution was added and the suspension centrifuged as described by Jenkins (9). After centrifugation, the supernatant was decanted and the residue resuspended in 1 L of water, allowed to settle for a minimum of 4 hr, vacuum-decanted to 2 ml of liquid, and observed for type and number of nematodes.

Shoots of the apple seedlings were harvested about 10 wk after planting, and samples were dried (about 50 C) to a constant weight. Each treatment was replicated 10 times and growth data were analyzed by analysis of variance and Duncan's multiple range test (SAS) (6) at $P \geqslant 0.05$.

Field control of ARD by formaldehyde was tested in a pear orchard at Wenatchee, WA. Pear trees, including stumps, were removed in September 1981, the holes backfilled with soil from the same orchard, and the rows tilled and leveled. Treatments consisted of an untreated check, an autumn fumigation, and autumn and spring formaldehyde drenches. A randomized block design with 10 replicates was used. MB at 454 g/planting site was applied with a modified O'Bannon and Bistine probe (14) following Washington State University recommendations for fumigation of soil in tree fruit orchards (10). Formaldehyde was applied as a 37% formalin solution at 1 L/site followed by 2 L of water to aid in leaching the formaldehyde into the soil. Runoff was prevented by pouring the solution into a 30-cm plastic ring that had been pressed slightly into the soft soil. Application dates for the formaldehyde treatments were 20 October 1981 and 22 March 1982. Apple trees of the cultivar Delicious on seedling rootstocks were planted on 15 April 1982 within the previous rows at about equal distances from previous pear tree locations. Trunk circumference was measured 15 cm above the ground line immediately after planting and after the first season's growth. A narrow line was painted on the trunk at the point of measurement as a guide for later measurements. Growth was evaluated as increased trunk circumference and difference evaluated using a standard *t* test at $P \geqslant 0.05$.

RESULTS

Shoot weight of apple seedlings grown in each of the four soils was increased by soil fumigation with CP, MB, and formaldehyde (0.22 mg/kg soil) (Table 1). Formaldehyde fumigation of soil 2 resulted in larger seedlings than fumigation with either CP or MB, whereas in soil 1, both CP and formaldehyde were more effective than MB. There was no significant difference in seedling size when these three treatments were compared in soils 3 and 4. Except for soil 1, formaldehyde was effective over the entire range (0.06–0.43 mg/kg) tested. The minimal effective concentration in soil 1 was 0.11 mg of formaldehyde per kilogram of soil. Regression analysis indicated that plant growth response to formaldehyde dosage varied among the four soils.

Soil fumigation with carbon disulfide increased the weight of seedlings grown in soil 4 but had no effect on seedlings grown in the other soils. Soil treatments with metalaxyl, the fungicide mixture, and fenamiphos (Nemacur) did not result in increased seedling weight. In soil 1, metalaxyl appeared phytotoxic.

With the exception of soil 4, very low populations of plant-parasitic nematodes were recovered. Fewer than three plant-parasitic nematodes were recovered from 50 cc of soil in the check treatments of soils 1–3; these were in the genera *Pratylenchus*, *Paratylenchus*, *Trichodorus*, *Criconemoides*, and *Gracilicus*. Plant-parasitic nematodes were recovered from soil 1 treated with carbon bisulfide, the fungicide mixture, and the check. No plant-parasitic nematodes were recovered from soil 2. Parasitic types were recovered from soil 3 treated with formaldehyde (at 0.05 and 0.10 g/kg), metalaxyl, the fungicide mixture, and the check.

The predominant nematode recovered from soil 4 was *Paratylenchus* spp., of which the highest population, 327/50 cc, occurred in soil treated with carbon bisulfide. Populations of 102–154/50 cc were recovered from the control and from soils treated with formaldehyde (0.05 g/kg), fungicide mixture, and fenamiphos. Nematodes were not detected in the methyl bromide treatment and fewer than 16/50 cc were found in soil treated with chloropicrin or the higher rates of formaldehyde (0.43, 0.22, and 0.11 g/kg).

Both the MB and spring formaldehyde treatments significantly increased growth of apple trees planted in a former pear orchard. Increases in trunk circumferences at the end of the first growing season were 1.35, 1.95, 1.43, and 2.15 cm for the check, MB, autumn formaldehyde, and spring formaldehyde treatments, respectively.

Samples for nematode assay were taken from the check and from soils treated with MB and the spring application of formaldehyde in the pear orchard about 1 yr after planting. The sod alley between the rows was also sampled. Fewer than 60 of any given species of plant-parasitic nematode per 50 cc of soil were present. Genera found in association with the check treatment included *Paratylenchus, Criconemoides, Meloidogyne*, and *Xipinema*. In addition to these genera, *Helicotylenchus, Trichodorus*, and *Tylencorhynchus* were found in the sod strip. Only *Paratylenchus* sp., and *Cricomenoides* sp. were found in the MB-treated soils. A few (two per 50 cc) *Pratylenchus* sp. were the only nematodes recovered from the formaldehyde-treated soil.

Table 1. Effects of various pesticides on the shoot weight of apple seedlings grown for 10 wk in four soils previously cropped to apples

Treatment	Rate (mg a.i./kg soil)	Dry weight (g)[y] Soil 1	Soil 2	Soil 3	Soil 4
Chloropicrin	0.430	2.98 a	1.84 b	3.72 a	1.40 b
Formaldehyde 37%	0.220	2.41 ab	2.45 a	2.99 ab	1.58 a
Methyl bromide	20.960	2.09 bc	1.75 b	2.95 ab	1.48 a
Carbon disulfide	2.450	1.92 bcd	0.98 c	1.78 c	1.01 b
Metalaxyl 240 g/L	0.005	1.01 e	0.75 c	2.09 bc	—
Fungicide mixture	...[z]	1.59 cde	1.02 c	2.23 bc	0.58 c
Fenamiphos	0.280	1.23 de	1.03 c	1.87 bc	0.71 bc
Check		1.22 d	0.78 c	1.68 c	0.45 c

[y] Means in the same column followed by the same letter are not significantly different ($P = 0.05$) according to Duncan's multiple range test.

[z] Fenaminosulf 70WP (0.83 mg/kg soil), quintozene 75WP (3 mg/kg soil), oxytetracycline 17WP (0.21 mg/kg soil), and benomyl 50WP (2.78 mg/kg soil).

DISCUSSION

Poor growth in apple replant situations is the major symptom of ARD and it is customary to consider the alleviation of growth suppression as control of ARD (7,8,16). As in previous studies in Washington (3), CP controlled ARD as well or better than did MB. The Washington recommendation for use of MB rather than CP for control of this disease is based more on ease of application in interplant situations than on difference in efficacy between these fumigants.

In both greenhouse and orchard tests, formaldehyde was as effective a fumigant as MB for stimulating apple growth. An apple growth-suppressing factor in pear orchard soil that may be elevated with CP fumigation has been reported previously from Washington (11). Other authors have included closely related species when defining the limits of specific apple replant disease. On the basis of our current knowledge, we consider the factor in pear orchard soil to be the same as that causing ARD in the state.

Our data indicate formaldehyde may be a practical alternative to MB. Spring fumigation with MB has produced several instances of phytotoxicity. Growers frequently have difficulty preparing an orchard for autumn fumigation before the soil is too cool for an effective treatment.

On the basis of data presented, we assume that nematodes were not responsible for the poor growth in soils 1–3. Growth responses were noted in soil 2 as a result of CP, MB, and formaldehyde treatments, whereas no parasitic nematodes were detected in any of the treatments. Fenamiphos eliminated the nematode population in soils 1 and 3 but no growth responses were noted from this treatment. In soil 4, *Paratylenchus* may have contributed to the restricted seedling growth in some treatments. The carbon disulfide treatment, however, resulted in improved plant growth over the check treatment even though almost twice the number of nematodes were recovered. Mai and Abawi (13) have pointed out the need for further studies on the effect of *Paratylenchus* spp. on growth of pome and stone fruits.

The distribution pattern of ARD within any given orchard in the Columbia River drainage is quite uniform. The disease is specific in that pome fruits are affected and stone fruits are not (3). Mai and Abawi (13), in a recent review on replant diseases of pome and stone fruits, pointed out that these are characteristics of specific replant diseases. Although the nonspecific nematode-associated replant diseases appear to be most important in the northeastern United States (12,13), a specific replant disease of apple of unknown etiology has been noted (8). Although our conclusions might be modified by root assay for nematodes, we believe the ARD in Washington is of specific nature and nematodes are of minor importance.

The results with formaldehyde treatment confirm the findings of Sewell et al (16,18) that formaldehyde is as effective as CP in overcoming SARD. As in Sewell's (16,17) studies, metalaxyl was not effective against the apple replant disease. These results point to a similar etiological agent of the apple replant disease in England and Washington.

LITERATURE CITED

1. Barclay, G. A. 1968. Studies on florescent *Pseudomonas* spp. associated with the leaf and root surfaces of fruit plants. Ph.D. thesis, Univ. Lond., London, England. 134 pp.
2. Benson, N. R. 1976. Retardation of apple tree growth by soil arsenic residue. J. Am. Soc. Hortic. Sci. 101:251-253.
3. Benson, N. R., Covey, R. P., Jr., and Haglund, W. A. 1978. The apple replant problem in Washington state. J. Am. Soc. Hortic. Sci. 103:156-158.
4. Bunt, J. A., and Mulder, D. 1973. The possible role of bacteria in relation to the apple replant disease. Meded. Fac. Landbouwwet. Rijksuniv. Gent 38:1381-1385.
5. Covey, R. P., Jr., Benson, N. R., and Haglund, W. A. 1979. Effect of soil fumigation on the apple replant disease in Washington. Phytopathology 69:684-686.
6. Helwig, J. T., and Council, K. A., eds. 1979. SAS Users Guide. SAS Institute, Raleigh, NC. 494 pp.
7. Hoestra, H. 1968. Replant disease of apple in the Netherlands. Meded. Landbouwhogesch. Wageningen 68:13.
8. Jaffee, B. A., Abawi, G. S., and Mai, W. F. 1982. Role of soil microflora and *Pratylenchus penetrans* in an apple replant disease. Phytopathology 72:247-251.
9. Jenkins, W. R. 1964. A rapid centrifugal flotation technique for separating nematodes from soil. Plant Dis. Rep. 48:692.
10. Koch, B. L., and Covey, R. P. 1980. Recommendations for soil fumigation in apple orchards. Wash. State Univ. Coop. Ext. Serv. EM 3830. 2 pp.
11. Koch, B. L, Covey, R. P., Jr., and Haglund, W. A. 1980. Growth response of apple and pear seedlings to pear soil fumigation with chloropicrin. HortScience 15:598-600.
12. Mai, W. F., and Abawi, G. S. 1978. Determining the cause and extent of apple, cherry and pear replant disease under controlled conditions. Phytopathology 68:1540-1544.
13. Mai, W. F., and Abawi, G. S. 1981. Controlling replant diseases of pome and stone fruits in northeastern United States by replant fumigation. Plant Dis. 65:859-864.
14. O'Bannon, J. H., and Bistine, F. W. 1969. A simple device for injecting methyl bromide into a replant site. Plant Dis. Rep. 53:799-802.
15. Otto, G., and Winkler, H. 1977. Untersuchungen über die Ursache der Bodenmüdigkeit bei Obstgehölzen. VI. Nachweis von Aktinomyzeten in Faserwurzeln von Apfelsämlingen in Böden mit verschiedenen Müdigkeitsgraden. Zentralbl. Bakteriol. Parasitenk. Infektionsk. Hyg. Abt. 2.132:593-606.
16. Sewell, G. W. F. 1978. Potential soil treatments for the control of the 'specific replant disease' of apple. Pages 97-99 in: Rep. East Malling Res. Stn. 1977.
17. Sewell, G. W. F. 1981. Effect of *Pythium* species on the growth of apple and their possible causal role in apple replant disease. Ann. Appl. Biol. 97:31-42.
18. Sewell, G. W. F., and White, G. C. 1979. The effects of formalin and other soil treatments on the replant disease of apple. J. Hortic. Sci. 54:333-335.