Fusarium Crown and Root Rot of Tomato in Greenhouse Rock Wool Systems: Sources of Inoculum and Disease Management with Benomyl

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ABSTRACT

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Fusarium oxysporum f. sp. *radicis-lycopersici* grew equally well on sterile rock wool growth substrate saturated with either sterile distilled water or plant growth solution but was completely suppressed by the addition of low concentrations of benomyl (0.023, 0.045, and 0.090 g a.i./L). In greenhouse studies using a hydroponic rock wool system, tomato plants that originated from infected transplants developed severe symptoms of Fusarium crown and root rot at the end of the season and had significantly lower yields than controls. Disease also developed in plants exposed to soil infested with *F. o.* f. sp. *radicis-lycopersici,* but little disease developed when a dilute conidial suspension of the pathogen was added to the rock wool system. Uninfected plants growing in the same rock wool production slab as infected plants did not develop substantial disease symptoms during any greenhouse test. Three-week-old seedlings treated with drenches of benomyl at dilutions ranging from 0.023 to 0.138 g a.i./L developed moderate to severe chlorosis. At the higher rates, phytotoxicity symptoms were more severe and often included stunting. Application of benomyl at 0.090 g a.i./L on a 21-day schedule to plants growing on rock wool production slabs resulted in optimal disease control. Our results suggest that production of disease-free transplants is of utmost importance for controlling Fusarium crown and root rot of tomato.

Fusarium crown and root rot (FCRR) of tomato (*Lycopersicon esculentum* Mill.), caused by *Fusarium oxysporum* Schlechtend.:Fr. f. sp. *radicis-lycopersici* Jarvis & Shoemaker, is characterized by extensive root rot and chocolate brown discoloration and decay of the interior of the lower stem. The disease was first described in 1975 (2,5) and is widespread throughout the Ohio greenhouse tomato industry as well as most production areas of the eastern United States and Canada. Infected plants with heavy fruit loads usually wilt on sunny days. Severely infected plants are often stunted and may eventually die after repeated wilting. Symptoms of FCRR differ from those of Fusarium wilt (caused by *F. oxysporum* f. sp. *lycopersici* (Sacc.) Snyder & Hans.) in that root and cortical rot is more severe and vascular discoloration extends no more than 15–30 cm above the soil line.

Considerable research has been directed toward development of control strategies for FCRR in soil-bed cultivation because of the devastating effects of this disease on production of greenhouse-grown tomatoes (5,9). A steamed soil-captafol drench procedure has proved effective in greenhouses equipped with buried steam tiles (8). Because many greenhouses are not equipped in this way and because captafol is no longer available, considerable research has also been directed toward developing commercially acceptable cultivars with resistance to *F. o.* f. sp. *radicis-lycopersici* (1,10).

In recent years, production of greenhouse tomatoes in the United States has begun to shift from ground-bed culture to various hydroponic systems, including rock wool. In this culture system, rectangular slabs (18 × 91 × 7.5 cm) of inert, expanded rock wool substrate enclosed in opaque white plastic sleeves are placed on a plastic-covered greenhouse floor. Tomato transplants grown in small cubes of rock wool (7.5 cm on each side) are placed on the surface of the slabs over holes cut in the plastic sleeve (typically two or three transplants per slab). Nutrient solution is provided at timed intervals through drip irrigation emitters placed at the base of each transplant (Fig. 1). Excess nutrient solution drains out through slits cut in the bottom of the plastic sleeves. The rock wool slab remains saturated with nutrient solution at all times. Roots grow throughout the slab, but many are concentrated on the lower surface against the plastic.

Although the basic biology of *F. o.* f. sp. *radicis-lycopersici* has been well studied in ground-bed production systems (2–5,7,9,11), little is known about FCRR in rock wool hydroponic systems. Recent outbreaks of the disease in rock wool have demonstrated the vulnerability of this system to FCRR. This study was initiated to investigate the potential for the introduction and spread of *F. o.* f. sp. *radicis-lycopersici* in rock wool substrate and to evaluate various control options. Our specific objectives were to determine the ability of *F. o.* f. sp. *radicis-lycopersici* to colonize rock wool substrate, with or without added plant nutrients; to determine whether the pathogen will spread from an infected plant to an uninfected plant growing in the same piece of rock wool substrate; to investigate the effects of introducing the pathogen into the rock wool system at various points in the production cycle; and to evaluate benomyl as a management tool for the disease. A preliminary report of this work has been published (6).

MATERIALS AND METHODS

Colonization of rock wool substrate. Dry rock wool substrate (Grodan; Grodania A/S, Hedehusene, Denmark) was cut into blocks measuring 7 × 7 × 1 cm, placed in sterile glass petri dishes, and autoclaved for 30 min. Each piece was then saturated with 40 ml of either sterile distilled water or a sterile solution of 20-20-20 (NPK) plant fertilizer (Peters Fertilizer Products; W. R. Grace & Co., Allentown, PA) at a concentration of 21.4 g/L. Sterile nutrient solutions were prepared by heating the dry material at 70 C for 60 hr and then dissolving it in sterile distilled water.

F. o. f. sp. *radicis-lycopersici* (isolate OSU-374) was grown on Difco potato-dextrose agar (PDA) for 7 days at 22–24 C under fluorescent lights set for a 12-hr photoperiod. A 1-cm^2 plug of mycelium with conidia taken from a PDA plate was used to inoculate 40 ml of potato-dextrose broth in a 250-ml flask. Broth cultures were incubated on a shaker table for 3 days at 25 C and then strained through one layer of sterile cheesecloth. Serial dilutions were made to attain a final spore suspension of approximately 200 cfu/ml. The center of each rock wool block was infested with 0.1 ml of this spore suspension, and the blocks were incubated at 20–24 C under fluorescent lights set for a 12-hr photoperiod.

One, 2, 4, 6, 8, and 10 days after infestation, 17 pieces of rock wool each 6 mm in diameter were aseptically removed from each block with a cork borer at 1-cm intervals in a cross pattern and

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placed onto acidified PDA (pH 3.5). Plates were incubated as above for 7 days, at which time each rock wool piece was visually evaluated for growth of *F. o.* f. sp. *radicis-lycopersici.* The point of detection farthest from the point of infestation was determined. These data were analyzed with a *t* test for each day. There were two replicate plates per treatment, and the experiment was conducted twice.

To test the effects of benomyl on the colonization of rock wool by *F. o.* f. sp. *radicis-lycopersici,* dry rock wool blocks were prepared and sterilized as before. Each block was saturated with 40 ml of either sterile distilled water or sterile benomyl (Benlate 50W) solutions at 0.023, 0.045, or 0.090 g a.i./L. A conidial suspension of *F. o.* f. sp. *radicis-lycopersici* (isolate OSU-471) was prepared as before and adjusted to 2.4×10^3 cfu/ml. The center of each rock wool block was infested with 0.1 ml of this spore suspension, and the blocks were incubated at 20–24 C under fluorescent lights set for a 12-hr photoperiod. There were four replicate plates per treatment. One, 3, 5, 7, and 9 days after infestation, 17 pieces 6 mm in diameter were removed aseptically from each block with a cork borer, incubated, and evaluated for growth of *F. o.* f. sp. *radicis-lycopersici* as previously described. The point of detection farthest from the point of infestation was determined. These data were analyzed for each day by analysis of variance and least significant difference means separation tests.

Greenhouse studies. Four greenhouse studies were conducted during 1987–1989 using the FCRR-susceptible tomato cultivar Caruso grown in a hydroponic rock wool system. In the first three studies, standard commercial Grodan rock wool production slabs ($18 \times 91 \times 7.5$ cm) in plastic sleeves were used. Each slab contained two tomato plants spaced about 50 cm apart. One plant in each slab was inoculated, while the other was kept as an uninoculated paired plant. Benomyl was applied to both plants. The experimental design was a split plot, with treatments as main plots and inoculation or lack of inoculation as subplots. The number of replications varied among studies. In the fourth study, individual treated plants were grown in rock wool slabs measuring $40 \times 14.5 \times 7.5$ cm in plastic sleeves, and the experimental design was a randomized complete block.

In all four studies, tomato seeds were germinated individually in rock wool "minicubes" measuring 3.7 cm on each side. After 2 wk, minicubes containing tomato seedlings were inserted into larger rock wool starter cubes measuring 7.5 cm on each side. Seedlings were grown for 8 wk in the greenhouse at 16–26 C with a 12-hr photoperiod. Transplants were then placed onto rock wool production slabs (Fig. 1).

Fig. 1. Tomato plant growing in a rock wool starter cube on a rock wool production slab covered by a plastic sleeve except for a hole cut under the transplant cube. Note drip irrigation emitter.

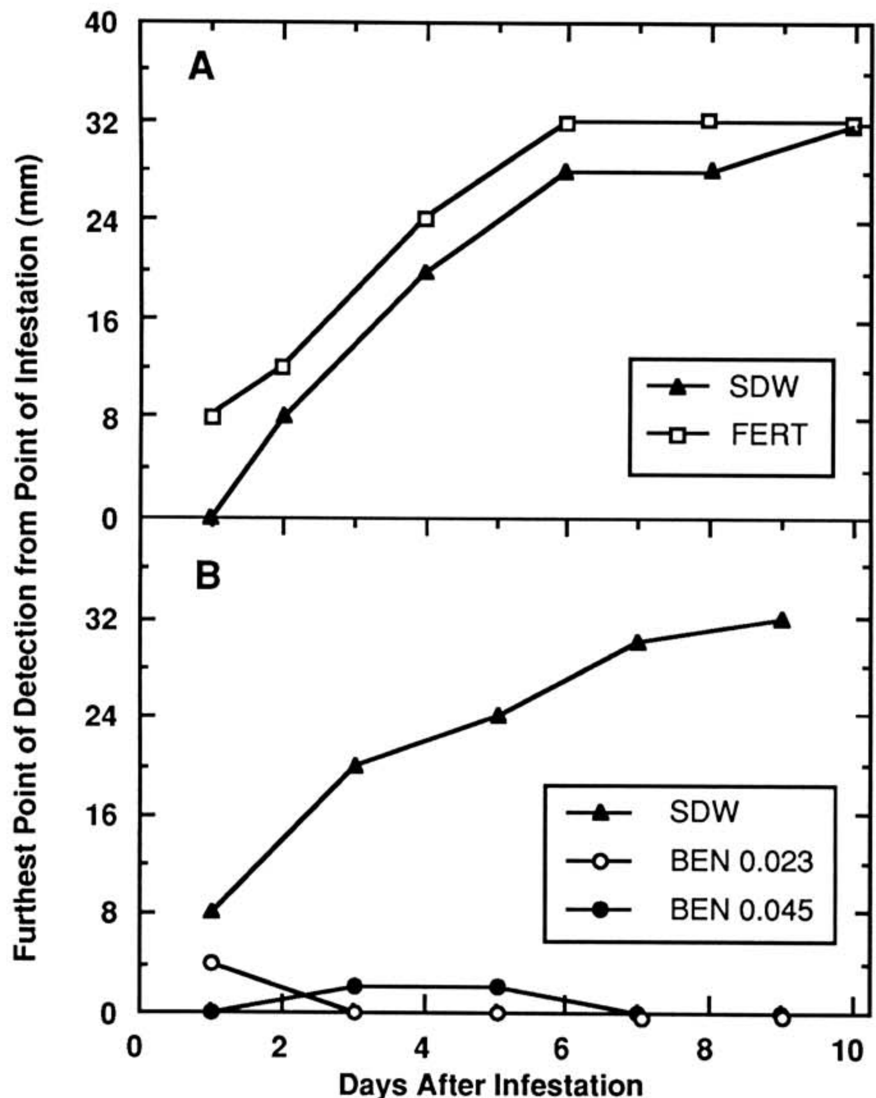

Fig. 2. Colonization of rock wool substrate by *Fusarium oxysporum* f. sp. *radicis-lycopersici.* **(A)** Substrate was saturated with either sterile distilled water (SDW) or a sterile solution of 20-20-20 (NPK) plant fertilizer (FERT). Each data point represents the mean of two replicate plates. Pairs of means do not differ significantly (P=0.05) at any time except day 1. **(B)** Substrate was saturated with either SDW or sterile benomyl (BEN) solutions at 0.023 or 0.045 g a.i./L. Each data point represents the mean of four replicate plates. Pairs of means of benomyl treatments do not differ significantly (P=0.05) at any time but do differ significantly from the SDW treatment at each respective time except day 1.

Plant height, disease development, and fruit yield were assessed weekly on both treated plants and untreated paired plants. In the first two studies, data on total yield were collected. In the later two studies, marketable yield was calculated by summing the weights of fruit graded U.S. #1 and #2.

At the end of each season (156–224 days after seeding), basal stems and taproots of each plant were sectioned and visually evaluated for symptoms of FCRR on a 0–3 scale, where 0 = symptomless; 1 = slight discoloration of vascular tissues in lower taproot; 2 = moderate discoloration of vascular tissues, not extending above soil line; 3 = extreme discoloration of vascular tissues extending well above soil line, or plant dead before final harvest.

Introduction of *F. o.* f. sp. *radicis-lycopersici* into rock wool systems (spring 1987). We used three techniques to simulate ways in which *F. o.* f. sp. *radicis-lycopersici* might be introduced into a rock wool production system. To evaluate infected transplants as a source of inoculum, we inoculated 4-wk-old seedlings grown in rock wool starter cubes by injecting 1 ml of a conidial suspension of the pathogen (isolate OSU-374) (3.9×10^6 cfu/ml) into the rock wool at four points 2–3 cm from each stem. Transplants were grown an additional 4 wk after inoculation and were then placed on rock wool production slabs.

Table 1. Phytotoxicity in 7-wk-old tomato plants grown in rock wool and treated with benomyl

Benomyl rate[x] (g a.i./L)	No. of plants with symptoms	Average phytotoxicity rating[y,z]	Average plant height[z] (cm)
0.000	0	1.0 a	20.4 a
0.023	0	1.0 a	16.0 b
0.045	4	1.8 ab	9.2 c
0.068	5	2.0 b	7.9 cd
0.090	4	2.2 b	7.0 de
0.113	5	3.2 c	4.7 f
0.138	5	3.2 c	5.4 ef

[x] Five 3-wk-old seedlings were each drenched with 250 ml of benomyl solution. Data presented are from one of three experiments.

[y] Phytotoxicity was evaluated visually on a scale of 1–5, where 1 = healthy appearance, normal color; 2 = slight interveinal chlorosis; 3 = moderate chlorosis; 4 = complete yellowing; and 5 = dead plant.

[z] Data within columns followed by a common letter do not differ significantly ($P = 0.05$) according to least significant difference values.

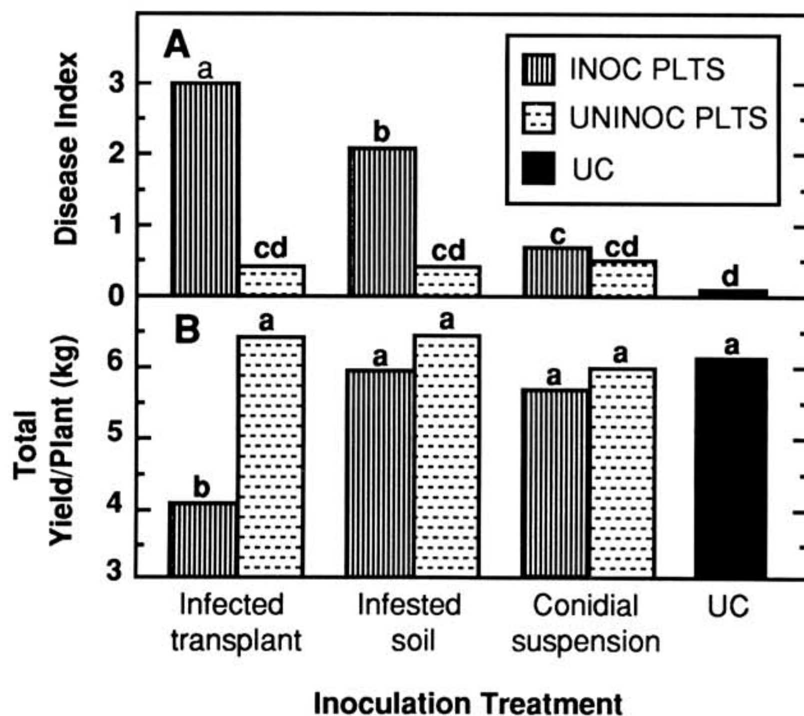

Fig. 3. Effect of three inoculation techniques on the severity of Fusarium crown and root rot at final harvest **(A)** and on total yield per plant **(B)** during the spring 1987 study. INOC PLTS = inoculated plants; UNINOC PLTS = uninoculated paired plants; UC = uninoculated control plants. Disease was rated on a scale from 0 (symptomless) to 3 (severely diseased). Each bar represents the mean of 10 replicate plants. In each graph, bars labeled with the same letter do not differ significantly (P=0.05) according to least significant difference values.

To simulate introduction of the pathogen in infested soil, we added 10 ml of a conidial suspension of *F. o.* f. sp. *radicis-lycopersici* (1.5×10^6 cfu/ml) to 200 cm^3 of moist, autoclaved soil. Infested soil was incubated at about 25 C for 2 wk and then air-dried in a greenhouse for 12 hr. This soil was then ground with a mortar and pestle and passed through sieves to obtain particles 1–2 mm in diameter. Infested soil (0.1 g) was placed on rock wool production slabs under the plastic at the edge of starter cubes containing 8-wk-old transplants just after they were placed on the slabs. In this position infested soil remained continuously moist.

To simulate introduction of the pathogen via the nutrient solution, we injected 1.0 ml of a dilute conidial suspension (3.6×10^2 cfu/ml) into rock wool starter cubes at a point adjacent to 8-wk-old transplants just under the drip irrigation emitters (Fig. 1) immediately after the cubes with transplants were placed onto the production slabs.

In all treatments, only one of the two plants in each rock wool slab was inoculated. In control treatments, neither plant was inoculated. There were 10 replicate plants per treatment. Plants were seeded 11 December 1986. Fruit harvest began 17 April 1987 and ended 12 June 1987. Average low and high greenhouse temperatures during this study were 16 and 29 C, respectively.

Effects of benomyl on *F. o.* f. sp. *radicis-lycopersici* in rock wool systems (fall 1987). A second study was designed to evaluate the efficacy of benomyl for control of FCRR in rock wool culture. An additional objective was to repeat some treatments from the previous study to obtain further data on the spread of *F. o.* f. sp. *radicis-lycopersici* in rock wool from points of introduction.

Before the study began, a preliminary benomyl rate experiment was conducted. Three-week-old seedlings were drenched with 250 ml of a benomyl solution at 0, 0.023, 0.045, 0.068, 0.090, 0.113, or 0.138 g a.i./L. After 3 wk, transplants were placed individually on rock wool slabs measuring 7 × 25 × 14.5 cm covered with two layers of 0.8-mil white plastic except for holes under the transplant blocks. Plants were maintained in a greenhouse at 20–27 C with a 12-hr photoperiod. Five replicate plants per treatment were arranged in a randomized complete block design. Height was measured and phytotoxicity was evaluated visually for each plant 3, 6, 11, 14, 21, 28, and 46 days after drenching. Phytotoxicity was rated on a 1–5 scale, where 1 = healthy appearance, normal color; 2 = slight chlorosis; 3 = moderate chlorosis; 4 = severe chlorosis; and 5 = dead plant. This experiment was done three times.

In the fall 1987 study, benomyl was applied to infected transplants and to

healthy transplants exposed to infested soil. Inoculation techniques were as previously described, except that inoculum was an equal mixture of *F. o.* f. sp. *radicis-lycopersici* isolates OSU-374 and OSU-471. Three benomyl treatments were tested. First, 2-wk-old seedlings growing in rock wool starter cubes were drenched once with 250 ml of a benomyl solution (0.110 g a.i./L). Second, this same benomyl treatment was applied to plants on rock wool slabs beginning when the transplants were placed on the slabs and at 20-day intervals thereafter throughout the season. The third treatment was a combination of the first two treatments. Controls included uninoculated plants without benomyl treatment, plants without benomyl treatment inoculated using both methods described above, inoculated plants given the benomyl starter cube drench only, and inoculated plants given the benomyl slab drench treatment only. There were seven replicate treated plants and untreated paired plants for each combination of benomyl treatment and inoculation technique. Plants were seeded 13 July 1987. Fruit harvest began 11 November 1987 and ended 16 December 1987. Average low and high temperatures in the greenhouse during this study were 17 and 26 C, respectively.

Timing of benomyl drenches for control of *F. o.* f. sp. *radicis-lycopersici* (spring 1988). Our third study examined further the timing of benomyl applications and movement of the pathogen from infected transplants to uninoculated plants growing in the same rock wool slabs. Infected transplants were produced as in previous studies. Two-week-old seedlings grown in rock wool starter cubes were drenched with 250 ml of a benomyl solution (0.090 g a.i./L). Four weeks after seeding, two-thirds of these plants were inoculated as previously described with 1 ml of a conidial suspension (4.5×10^6 cfu/ml) containing equal amounts of *F. o.* f. sp. *radicis-lycopersici* isolates OSU-374 and OSU-471. These same plants were placed on rock wool slabs at 8 wk of age and drenched at 10- or 20-day intervals with 250 ml per plant of a benomyl solution (0.090 g a.i./L). Uninoculated control plants were drenched with benomyl (0.090 g a.i./L) at 2 wk and then at 10-day intervals after being placed on rock wool slabs. Inoculated plants not treated with benomyl and untreated plants were used as additional controls. There were eight replicate plants per treatment. Plants were seeded 22 December 1987. Fruit harvest began 14 April 1988 and ended 23 June 1988. Average low and high temperatures in the greenhouse during this study were 17 and 25 C, respectively.

Effect of benomyl concentration on control of *F. o.* f. sp. *radicis-lycopersici* (spring 1989). Our fourth study evaluated various rates of benomyl for control of FCRR. Infected transplants were produced and inoculated as before. Two-week-old transplants were drenched with 250 ml of a benomyl solution at 0.023, 0.045, or 0.090 g a.i./L. Plants drenched with either 0.023 or 0.090 g a.i./L solution were then drenched with 250 ml per plant of a 0.090 g a.i./L solution at 21-day intervals beginning when they were placed on rock wool slabs. Plants originally drenched with the 0.045 g a.i./L solution were drenched with 250 ml of either a 0.045 or a 0.090 g a.i./L solution at the same intervals. In two additional treatments, plants were not drenched at 2 wk of age but were drenched with 250 ml of either a 0.045 or a 0.090 g a.i./L solution at 21-day intervals after being placed on rock wool slabs. All benomyl treatments were applied to infected transplants. Uninoculated and inoculated plants without benomyl were included as controls. There were 10 replicate plants per treatment. Plants were seeded on 23 November 1988. Fruit harvest began 29 March 1989 and ended 5 July 1989. Average low and high temperatures in the greenhouse during this study were 17 and 25 C, respectively.

RESULTS

F. o. f. sp. *radicis-lycopersici* grew equally well on rock wool substrate moistened with either sterile distilled water or nutrient solution (Fig. 2A). After 10 days, the fungus was recovered up to 32 mm from the point of infestation. When dilute benomyl solutions were added to the rock wool blocks, growth of the pathogen was strongly suppressed at 0.023 and 0.045 g a.i./L (Fig. 2B) and eliminated at 0.090 g a.i./L.

In the spring 1987 greenhouse study designed to investigate the introduction of *F. o.* f. sp. *radicis-lycopersici* into rock

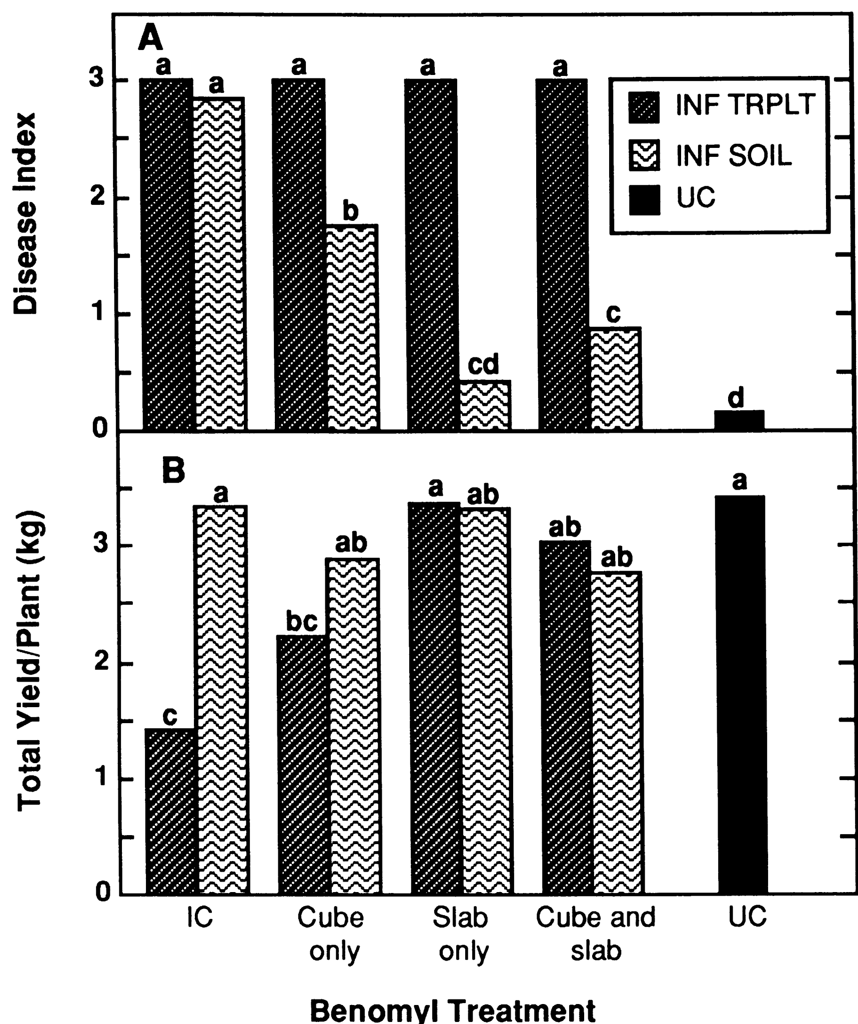

Fig. 4. Effect of benomyl drenches on the severity of Fusarium crown and root rot at final harvest **(A)** and on total yield per plant **(B)** during the fall 1987 study. Benomyl drenches (0.110 g a.i./L) were applied to 2-wk-old seedlings grown in rock wool starter cubes (cube only), to plants on rock wool production slabs at 20-day intervals (slab only), or both (cube and slab). INF TRPLT = infected transplant; INF SOIL = infested soil; UC = uninoculated control (without benomyl); IC = inoculated control (without benomyl). Disease was rated on a scale from 0 (symptomless) to 3 (severely diseased). Each bar represents the mean of seven replicate plants. In each graph, bars labeled with the same letter do not differ significantly (P=0.05) according to least significant difference values.

wool systems, the most severely diseased plants at the end of the season originated from infected transplants (Fig. 3A). Substantial disease also developed in plants contaminated with infested soil. Adding a dilute conidial suspension to the rock wool system resulted in very little disease by the end of the season. Regardless of inoculation treatment, little or no disease developed in the uninoculated paired plants growing in the same rock wool slabs with the inoculated plants.

Fruit yields were significantly lower only from plants that originated from infected transplants (Fig. 3B). The yield from plants exposed to infested soil was not significantly different from that of uninoculated control plants, even though some of the former became severely infected by the end of the season.

In the preliminary examination of benomyl rates conducted before the fall 1987 greenhouse study, results were similar all three times the test was done. Phytotoxicity symptoms ranging from slight interveinal chlorosis to general yellowing, especially of upper leaves, developed in tomato seedlings at all rates tested (Table 1). At higher rates, symptoms were more severe and often included stunting. Phytotoxicity first appeared 1 wk after benomyl application, with peak expression 3 wk later.

The fall 1987 greenhouse study was designed to evaluate the introduction of *F. o.* f. sp. *radicis-lycopersici* via infected transplants and infested soil and the use of benomyl in disease control. Transplants treated at 2 wk of age with benomyl (0.110 g a.i./L) developed some phytotoxicity and stunting symptoms 2 wk later. These symptoms were still visible at 8 wk when transplants were placed on rock wool slabs, but plants grew out of this condition within 3–4 wk. Infected transplants developed severe disease symptoms by the end of the season regardless of benomyl treatment (benomyl solutions applied only to the seedlings, applied to the rock wool slabs at 20-day intervals, or both) (Fig. 4A). Severe disease symptoms also developed in plants exposed to infested soil, but benomyl treatments, especially applications to the rock wool slab at 20-day intervals, significantly reduced disease severity at the end of the season (Fig. 4A). In all treatments, very little disease developed in the uninoculated paired plants grown in the same rock wool slabs with inoculated plants, as observed in the previous study. Uninoculated plants drenched with benomyl in the starter cubes or production slabs alone showed no evidence of disease and produced yields comparable to those of the uninoculated control.

Fruit yield from untreated infected transplants was reduced by at least 60% compared with that from uninfected control plants (Fig. 4B). Yield from infected transplants treated with benomyl on a 20-day schedule, however, was not significantly different from that of control plants, even though transplants initially showed phytotoxicity symptoms. Benomyl treatment of infected transplants as seedlings only did not prevent yield losses due to FCRR. Yield of plants exposed to infested soil did not differ significantly from that of untreated control plants (Fig. 4B).

In the spring 1988 tests evaluating the timing of benomyl applications, phytotoxicity and stunting were again observed on transplants treated with benomyl (0.090 g a.i./L) at 2 wk of age but, as before, plants grew out of this condition within 3–4 wk after being placed on the rock wool slabs. As in previous studies, plants growing from infected transplants developed severe disease symptoms by the end of the season regardless of benomyl treatment (Fig. 5A). Again, very little disease developed in uninoculated paired plants growing in the same rock wool slabs as inoculated plants, regardless of treatment. Uninoculated plants drenched with benomyl at 10-day intervals had negligible evidence of disease and produced yields comparable to that of the untreated control.

Marketable yields from plants grown from infected transplants not treated with benomyl were only 30% of those from untreated control plants (Fig. 5B). Plants treated with benomyl, even at the reduced rates, yielded normally. Yields with the 10- and 20-day benomyl application schedules did not differ significantly.

In the last greenhouse benomyl rate study (spring 1989), phytotoxicity symptoms were again observed in trans-

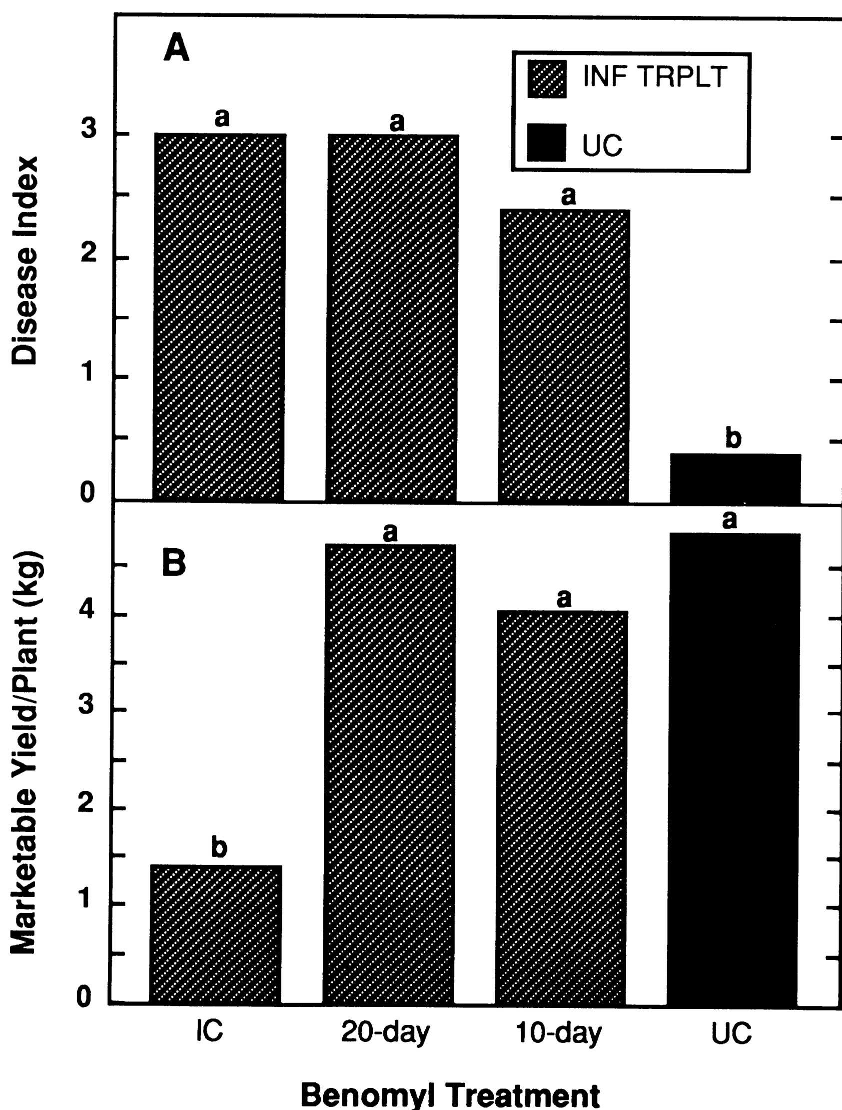

Fig. 5. Effect of 10- and 20-day intervals between benomyl drenches on the severity of Fusarium crown and root rot at final harvest **(A)** and on marketable yield per plant **(B)** during the spring 1988 study. Benomyl drenches (0.090 g a.i./L) were applied to 2-wk-old seedlings grown in rock wool starter cubes and then to plants on rock wool production slabs on either a 10- or 20-day schedule. INF TRPLT = infected transplant; UC = uninoculated control (without benomyl); IC = inoculated control (without benomyl). Disease was rated on a scale from 0 (symptomless) to 3 (severely diseased). Each bar represents the mean of eight replicate plants. In each graph, bars labeled with the same letter do not differ significantly (P=0.05) according to least significant difference values.

plants drenched at 2 wk of age with benomyl at either 0.045 or 0.090 g a.i./L. Plants drenched with 0.045 g a.i./L grew out of this condition within 3-4 wk of being placed on the rock wool slabs. Plants drenched with 0.090 g a.i./L at 2 wk, however, were significantly shorter than untreated control plants at 18 wk of age. Nevertheless, these two treatments did not differ significantly in yield. As in all previous greenhouse studies, plants growing from infected transplants developed severe disease symptoms by the end of the season, regardless of benomyl treatment (Fig. 6A).

Marketable yields of plants grown from infected transplants that were not treated with benomyl were less than 10% of those from any other treatment (Fig. 6B). Yields from inoculated plants treated with benomyl at 0.090 g a.i./L either in the rock wool slab alone or in the starter cube plus slab combination did not differ significantly from those of untreated control plants. Yields of plants from the other four benomyl treatments were lower than yields from untreated control plants but were still considerably higher than those from infected transplants not treated with benomyl.

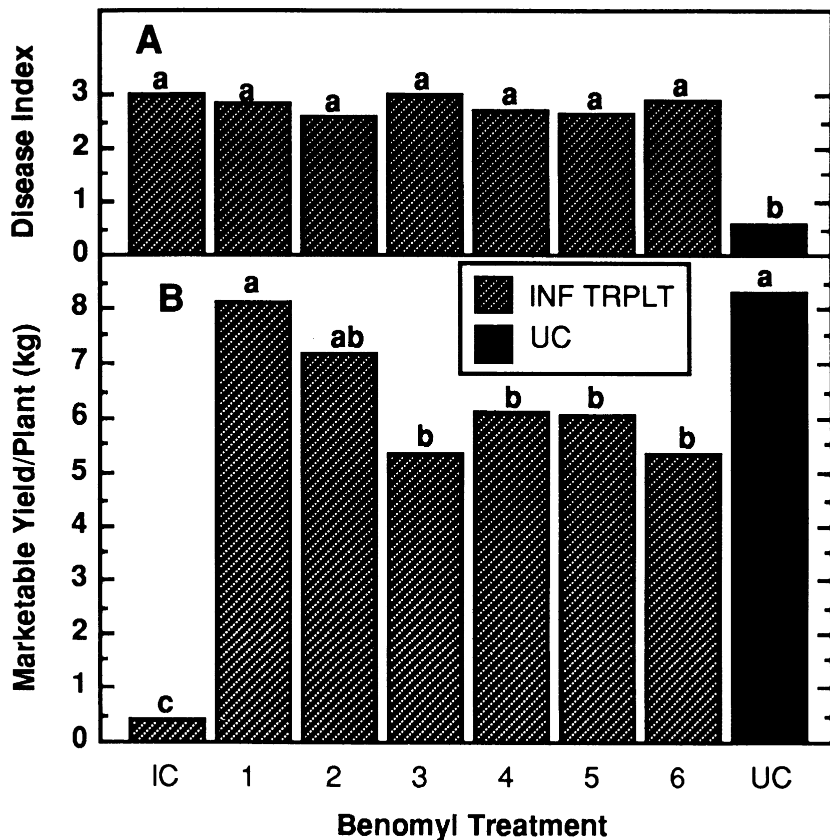

Fig. 6. Effect of benomyl drench treatments on the severity of Fusarium crown and root rot at final harvest (**A**) and on marketable yield per plant (**B**) during the spring 1989 study. Inoculated control (IC) and uninoculated control (UC) plants received no benomyl. Benomyl treatments were slab drench (0.090 g a.i./L) only (1), cube and slab drenches (0.090 g a.i./L) (2), slab drench (0.045 g a.i./L) only (3), cube and slab drenches (0.045 g a.i./L) (4), cube drench (0.023 g a.i./L) and slab drench (0.090 g a.i./L) (5), and cube drench (0.045 g a.i./L) and slab drench (0.090 g a.i./L) (6). Cube drenches were applied to 2-wk-old transplants. Slab drenches were applied on a 21-day schedule beginning when transplants were placed on production slabs. INF TRPLT = infected transplant. Each bar represents the mean of 10 replicate plants. In each graph, bars labeled with the same letter do not differ significantly (P=0.05) according to least significant difference values.

DISCUSSION

F. o. f. sp. *radicis-lycopersici* readily colonized sterile rock wool substrate in petri dish tests with or without added plant nutrients. In spite of this result, uninfected plants growing in the same rock wool production slabs as infected plants did not develop substantial disease symptoms during any full-season greenhouse test in this study. This result was contrary to our initial expectations and indicates that rock wool systems may be less vulnerable to rapid spread of FCRR than was originally thought.

Evaluation of potential modes of contamination of rock wool systems with *F. o.* f. sp. *radicis-lycopersici* was a primary objective of this study. Our results indicate that the use of infected transplants to establish crops on rock wool is likely to result in serious losses of fruit yield by the end of the season. Disease-free transplants grown to maturity in rock wool slabs contaminated with small amounts of infested soil also developed disease symptoms by the end of the season that were similar to those on plants grown from infected transplants. However, these plants gave normal fruit yields, presumably because of delayed initiation of disease. Contamination of transplants with a conidial suspension of *F. o.* f. sp. *radicis-lycopersici* injected under the irrigation emitters when the transplants were placed on the rock wool slabs resulted in no significant disease at harvest.

Our results indicate that production of disease-free transplants is of the utmost importance in control of this disease. Introduction of the pathogen to the rock wool production system itself is much less significant, provided the transplants are not initially infected. This observation may also explain why spread of the pathogen from infected plants to adjacent uninfected plants did not result in substantial disease or reduced yields in the adjacent plants; even though the fungus may have been able to grow through the rock wool medium to an adjacent plant, infection would have occurred past the time when substantial damage would result.

Benomyl was effective in preventing yield losses from FCRR throughout these studies. Growth of and colonization by *F. o.* f. sp. *radicis-lycopersici* in sterile rock wool substrate in vitro were greatly restricted by the addition of benomyl at concentrations as low as 0.023 g a.i./L. Treatment of rock wool production slabs with benomyl proved useful even with infected transplants. Although root systems of these plants became heavily infected with *F. o.* f. sp. *radicis-lycopersici* by the end of the season, benomyl slowed disease development enough during the season to permit normal yields.

Phytotoxicity symptoms from benomyl applications were observed only in seedlings treated at 2–3 wk of age. Of the several rates and timings for benomyl application tested, 0.090 g a.i./L applied at 21-day intervals to plants growing on rock wool slabs gave the best disease control. Drenching 2-wk-old seedlings with benomyl does not seem advisable because of associated phytotoxicity. Seedling drenches resulted in no additional yield or disease control compared with applications during production.

Although benomyl may provide acceptable control of FCRR at present, widespread or intensive use of this fungicide may result in the selection of benomyl-tolerant strains of the pathogen. Long-term control of this disease depends on the development of disease-resistant tomato cultivars with acceptable horticultural characteristics.

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LITERATURE CITED

1. Berry, S. Z., and Oakes, G. L. 1987. Inheritance of resistance to Fusarium crown and root rot in tomato. HortScience 22:110-111.
2. Farley, J., Oakes, G., and Jaberg, C. 1975. A new greenhouse tomato root rot disease caused by *Fusarium oxysporum:* A preliminary report. Pages 27-29 in: Greenhouse vegetable research—1975. Ohio Agric. Res. Dev. Cent. Res. Summ. 82.
3. Jarvis, W. R. 1989. Fusarium crown and root rot of tomatoes. Phytoprotection 69:49-64.
4. Jarvis, W. R., Dirks, V. A., Johnson, P. W., and Thorpe, H. J. 1977. No interaction between root knot nematode and Fusarium foot and root rot of greenhouse tomato. Plant Dis. Rep. 61:251-254.
5. Jarvis, W. R., Thorpe, H. J., and MacNeill, B. H. 1975. A foot and root rot disease of tomato caused by *Fusarium oxysporum.* Can. Plant Dis. Surv. 55:25-26.
6. Mihuta-Grimm, L., and Rowe, R. C. 1989. Sources of inoculum and control of Fusarium crown and root rot of tomatoes in greenhouse rockwool systems. (Abstr.) Phytopathology 79:1162.
7. Nutter, F. W., Warren, C. G., Wells, O. S., and MacHardy, W. E. 1978. Fusarium foot and root rot of tomato in New Hampshire. Plant Dis. Rep. 62:976-978.
8. Rowe, R. C., and Farley, J. D. 1978. Control of Fusarium crown and root rot of greenhouse tomatoes by inhibiting recolonization of steam-disinfested soil with a captafol drench. Phytopathology 68:1221-1224.
9. Rowe, R. C., Farley, J. D., and Coplin, D. L. 1977. Airborne spore dispersal and recolonization of steamed soil by *Fusarium oxysporum* in tomato greenhouses. Phytopathology 67:1513-1517.
10. Scott, J. W., and Farley, J. D. 1983. 'Ohio CR-6' tomato. HortScience 18:114-115.
11. Sonoda, R. M. 1976. The occurrence of a Fusarium root rot of tomatoes in south Florida. Plant Dis. Rep. 60:271-274.