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SOIL FUMIGANTS FOR CONTROL OF NEMATODES, FUSARIUM WILT, AND FUSARIUM CROWN ROT ON TOMATO[1]

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Abstract. **Methyl isothiocyanate 20%/chlorinated C_3 hydrocarbons, including dichloropropenes, dichloropropane and related chlorinated hydrocarbons 80% (MS/DD) (Vorlex) at 30 gal/acre, methyl isothiocyanate 17%/chlorinated C_3 hydrocarbons, including dichloropropenes, dichloropropanes and related chlorinated hydrocarbons 68%/chloropicrin 15% (MS/DD/C) (Vorlex 201) at 20 or 25 gal/acre, methyl bromide 67%/chloropicrin 32% (MB/C33) (Terr-o-gas) at 350 lb./acre, and methyl bromide 99.5%/chloropicrin 0.5% (MB/C 0.5) (Brom-o-gas) at 400 lb./acre were evaluated in the fall 1983 and MS/DD at 25 or 35 gal/acre, MS/DD/C or methyl isothiocyanate 40% (MS) (Trapex 40) at 25 gal/acre, and (MB/C 0.5) at 400 lb./acre were evaluated in the spring 1984 for crop yield response and control of nematodes, Fusarium wilt (**Fusarium oxysporum **Schlecht. f. sp.** lycopersici **(Sacc.) Snyder & Hansen race 3) or Fusarium crown rot (**Fusarium oxysporum **Schlecht. f. sp.** radicis-lycopersici **Jarvis & Shoemaker) of tomato. All treatments increased tomato fruit yield and reduced populations of the sting (**Belonolaimus longicaudatus **Rau), stunt (**Tylenchorhynchus **spp.), and awl (**Dolichodorus heterocephalus **Cobb) nematodes. Root-knot [**Meloidogyne incognita **(Kofoid & White) Chitwood] nematodes were suppressed by all treatments. All treatments reduced Fusarium wilt race 3 and Fusarium crown rot. A greater number of plants showed symptoms of wilt at pH 5.5-6.0 than at pH 7.0-7.5; soil pH had no effect on incidence of crown rot.**

Soil fumigation is a common practice in sandy soils repeatedly planted to tomato in Florida. Methyl bromide/chloropicrin mixtures are most frequently used (8) in soil pest management programs which include full-bed mulch (6), adjustment of soil reaction (3, 5), and use of host resistance (9) to protect crops from Fusarium wilt race 2, Verticillium wilt (*Verticillium albo-atrum* Reinke & Berth), nematodes, and weed infestations.

The advent of Fusarium wilt race 3, the increase in importance of Fusarium crown rot in commercial tomato fields, and the critical review being given methyl bromide as an agricultural pesticide by the Environmental Protection Agency emphasized the need for re-evaluation of available broad-spectrum soil fumigants. Previous research (3, 4, 6, 7, 9) demonstrated the efficacy of certain fumigants for control of Fusarium wilt race 2, Verticillium wilt and nematodes. Five available materials were selected from this inventory of chemicals for evaluation of their efficacy against

[1]Florida Agricultural Experiment Stations Journal Series No. 5954. Trade names are included for the benefit of the reader and do not infer any endorsement or recommendation by the author.

nematodes, Fusarium wilt race 3 and crown rot at 2 pH levels.

Materials and Methods

Four fumigation trials were performed: 2 tests in the fall 1983, and 2 in the spring 1984. In each test a split plot design was established on Eau Gallie fine sand (Aeric haplaquod, sandy, siliceous, hyperthermic) with natural infestations of nematodes with soil pH levels as the whole plots, fumigants as subplots. The soil was cultivated and amended (5) with elemental sulfur or hydrated lime [$Ca(OH)_2$] to establish 4 replicates in each test at levels of pH 5.5-6.0 or pH 7.0-7.5.

Beds were constructed 8 inches high, 30 inches wide on 54-inch centers. In both seasons one field was inoculated with the Fusarium wilt race 3 fungus, the other field with the Fusarium crown rot fungus by burying the incubated inoculum/nutrient/vermiculite substrate 4 inches deep in the center of the bed. Fertilizer (1800 lb./acre 18-0-21) was banded on the shoulder of the bed (12 inches off center); a mix of 500 lb./acre superphosphate + 20 lb./acre FN 503 + 300 lb./acre 18-0-21 was broadcast over the bed.

On August 5, 1983 with soil temperature 84°F at a 4-inch depth, both inoculated fields received the following treatments (rates calculated on an acre broadcast basis; rates in parentheses represent rates per 1000 linear bed ft): 1) nontreated control; 2) MS/DD/C at 20(0.92) and 25(1.15) gal; 3) MS/DD at 30(1.38) gal; 4) MB/C33 at 350(18.5) lb.; and MB/C0.5 at 400(21.1) lb. On March 2, 1984, treatments in both fields were as follows: 1) nontreated control; 2) MS/DD at 25(1.15) gal; 3) MS/DD/C at 25(1.15) gal; and 4) MS at 25(1.15) gal; 5) MS/DD/C 35 (1.61) gal; and 6) MB/C0.5 400(21.1) lb.

Three streams of each chemical were injected 6 inches deep on 8-inch centers into 25 ft single bed plots. White/black laminated plastic film (1.25 mil) was sealed over the bed as each plot was treated. Soil moisture (0-6 inches deep) at time of treatment in the fall and spring was 10.5% on a dry weight basis. This was roughly field capacity and was maintained with a constant water table 18 inches below the bed surface.

Two weeks after treatment in each season plots were planted with 5-week-old containerized transplants of tomato (*Lycopersicon esculentum* Mill.) cv. Sunny spaced 1 ft apart. All plants were pruned, staked, and tied 3 times. Commercial pesticides were applied weekly for foliage disease and insect control.

Plants were examined routinely for symptoms of wilt. Soil samples were collected at last harvest for nematode population assay (1) and roots of the plants were indexed (2) for severity of galling caused by the root-knot nematode. Tomato fruit yields were recorded for 3 harvests in the fall test on race 3, for 2 harvests in the other 3 tests. All data were submitted to statistical analysis.

Results and Discussion

Crop response. In the fall 1983 tests, soil pH had no effect on total tomato yield. In the spring 1984 tests, 61% more size 5 x 6 fruit were picked during the first harvest from plants grown in soil infested with race 3 at pH 7.5-8.0 (1.13 ton/1000 row ft) than at pH 5.5-6.0 (0.71 ton/1000 row ft). Also in the spring, on soil infested with crown rot, the high pH produced 27% greater yield (2.21 vs. 1.74 ton/1000 row ft) of all grades of tomato. This difference was the result of a greater number of 5 x 6 fruit in both harvests and a greater number of 6 x 6 in the second harvest.

All fumigation treatments in all 4 tests (2 seasons on 2 fields) improved total tomato yield (Table 1). MB/C0.5 in both seasons, followed closely by MB/C33 and the high rate of MS/DD/C in the fall, excelled in each harvest of plots infested with race 3. All treatments were equally beneficial in both seasons for the plots infested with crown rot. Increases in race 3 yield were due to production of size 5 x 6 and/or 6 x 6 fruit (Tables 2, 3).

Table 1. Yield response of tomato to soil fumigants applied to Eau Gallie fine sand which was inoculated prior to treatment with Fusarium wilt (*F. oxysporum* f. sp. *lycopersici* race3) or Fusarium crown rot (*F. oxysporum* f. sp. *radicis-lycopersici*) organisms.

		Yield (tons/1000 row ft)						
		Fusarium wilt				Fusarium crown rot		
		Harvest				Harvest		
Treatment	Rate/acre[z]	1	2	3	Total	1	2	Total
Fall 1983								
Control	—	1.20 b[y]	1.24 b	0.47 b	2.91 c	0.96 c	1.62 b	2.58 b
MS/DD/C[x]	20 gal	1.49 b	1.85 a	0.85 a	4.19 b	1.85 ab	2.62 a	4.47 a
MS/DD/C	25 gal	1.53 b	2.38 a	0.88 a	4.79 ab	1.55 b	2.34 a	3.89 a
MS/DD	30 gal	1.24 b	1.98 a	0.92 a	4.14 b	1.44 b	2.60 a	4.04 a
MB/C33	350 lb.	1.69 ab	2.21 a	0.89 a	4.79 ab	1.64 ab	2.39 a	4.03 a
MB/C0.5	400 lb.	2.33 a	2.08 a	0.92 a	5.33 a	2.04 a	2.63 a	4.67 a
Spring 1984								
Control	—	1.66 c	0.46 d	—	2.12 c	2.06 b	0.66 b	2.72 b
MS/DD	25 gal	2.92 ab	1.07 c	—	3.99 b	3.43 a	0.90 ab	4.33 a
MS/DD/C	25 gal	2.70 b	1.66 a	—	4.36 b	3.00 ab	1.20 a	4.20 a
MS	25 gal	3.03 ab	1.13 bc	—	4.16 b	3.00 ab	0.97 a	3.97 a
MS/DD	35 gal	2.94 ab	1.44 abc	—	4.38 b	3.41 a	1.10 a	4.51 a
MB/C0.5	400 lb.	3.59 a	1.50 ab	—	5.09 a	3.66 a	1.06 a	4.72 a

[z]Three streams/bed.
[y]Mean separation within columns by Duncan's multiple range test, 5% level.
[x]MS/DD/C = methyl isothiocyanate 17%/chlorinated C_3 hydrocarbons, including dichloropropenes, dichloropropane and related chlorinated hydrocarbons 68% (Vorlex 201).
MS/DD = methyl isothiocyanate 20%/chlorinated C_3 hydrocarbons, including dichloropropenes, dichloropropane and related chlorinated hydrocarbons 80% (Vorlex).
MB/C33 = methyl bromide 67%/chloropicrin 33% (Terr-o-gas).
MB/C0.5 = methyl bromide 99.5%/chloropicrin 0.5% (Brom-o-gas).
MS = methyl isothiocyanate 40% (Trapex 40).

Table 2. Effect of soil fumigants on percent increase in weight of large size (5 x 6, 6 x 6) tomato fruit produced on soil naturally infested with nematodes and introduced inoculum of Fusarium wilt race 3 in the fall 1983 as compared to nontreated plots.

Treatment	Rate/acre[z]	Yield increase (%) Size 5 x 6	Size 6 x 6
MS/DD/C[x]	20 gal	39.8 bc[y]	42.6 a
MS/DD/C	25 gal	66.7 ab	56.7 a
MS/DD	30 gal	23.9 c	43.3 a
MB/C33	350 lb.	75.8 ab	66.2 a
MB/C0.5	400 lb.	89.2 a	70.0 a

[z]Three streams/bed.
[y]Mean separation within columns by Duncan's multiple range test, 5% level. All treatments yielded more than the nontreated control.
[x]See Table 1 for key to fumigant treatments.

A greater response of fruit grade to soil fumigants was obtained in soil inoculated with race 3 in the spring than in the fall. Increases in size 5 x 6 fruit in the fall ranged from a low of 24% with MS/DD at 30 gal/acre to 89% with MB/C0.5 (Table 2), whereas in the spring increases ranged as high as 213% above the nontreated control (Table 3).

Disease response. In both seasons (Tables 4 & 5), less Fusarium wilt developed under the high pH regime; crown rot was apparently not affected by soil pH. At the low pH (5.5-6.0) all soil treatments were equally effective in reducing the symptoms of wilt. At pH 7.0-7.5 also, all treatments were better than the nontreated control. However, in the spring test, MB/C0.5, MS/DD/C and MS/DD at 35 gal/acre excelled. Crown rot was active both seasons. Although there was no effect due to soil pH, fumigants reduced the disease. In the fall 76% of the plants in the control were infected. Infection in better treated plots ranged from 43 to 46% and the low rate of MS/DD/C was no different (56%) from the control. In the spring MS/DD (35 gal/acre) gave better control (26% infection vs. 82% for the nontreated plots) than MS/DD (61%) or MS at 25 gal/acre (54%). Other treatments were intermediate.

Nematode control. Five genera of plant parasitic nematodes were recognized in the 4 tests. Common to all seasons were the stubby-root (*Trichodorus christiei* Allen), the stunt, root-knot, and awl nematodes. Additionaly, exclusive to the area inoculated with crown rot was a population of the sting nematode. All genera except the stubby-root nematodes responded strongly to soil fumigation (Table 6). In the fall tests, no differences were found with treatment and stubby-root populations; in the spring race 3 plots, statistical reductions in numbers were measured with all treatments except MS/DD at the lower rate. However, in the spring, crown rot-plot populations were higher than the control in all treatments except MS, where no differences from the control occurred.

Root-knot galling was more severe in the race 3 area. All treatments gave equally excellent control of root galling in the fall. Although fumigants reduced galling in the spring, MB/C0.5 and the higher rate of MS/DD gave best results. Excellent control of the stunt and sting nematodes was obtained in all tests. The awl nematode appeared to be more active in the fall than spring crops, but again, fumigation was successful in suppressing populations.

Conclusions

All treatments were successful in increasing tomato yield. Control of wilt symptoms was uniformly excellent except in the high pH areas of the spring test where some separa-

Table 3. Effect of soil fumigants on percent increase in weight of large size (5 x 6, 6 x 6) tomato fruit produced on soil naturally infested with nematodes and introduced inoculum of Fusarium wilt race 3 or Fusarium crown rot in spring 1984 as compared to nontreated plots.

Treatment	Rate/acre[z]	Yield increase (%): Fusarium wilt race 3, Size 5 x 6	Fusarium wilt race 3, Size 6 x 6	Fusarium crown rot, Size 5 x 6	Fusarium crown rot, Size 6 x 6
MS/DD[x]	25 gal	108.6 b[y]	114.9 b	121.5 a	110.7 a
MS/DD/C	25 gal	114.0 b	124.4 b	109.9 a	83.9 a
MS	25 gal	144.1 b	132.8 ab	112.4 a	77.7 a
MS/DD	35 gal	109.7 b	116.9 b	136.1 a	91.7 a
MB/C0.05	400 lb.	213.0 a	170.7 a	171.2 a	114.0 a

[z]Three streams/bed.
[y]Mean separation within columns by Duncan's multiple range test, 5% level. All treatments yielded more than the nontreated control base.
[x]See Table 1 for key to fumigant treatments.

Table 4. Percentage of the tomato plant stand exhibiting wilt symptoms at several stages of growth in the fall 1983 soil fumigation trials at 2 pH levels.

		% of plants affected											
		Fusarium wilt race 3										Fusarium crown rot	
		6 wk		7 wk		8 wk		10 wk		13 wk		15 wk	
Fumigant	Rate/acre[z]	Lo[x]	Hi	Lo	Hi	Lo	Hi	Lo	Hi	Lo	Hi	Lo	Hi
Control	—	28 b[y]	16 b	45 c	23 b	55 c	33 b	68 c	36 b	78 c	55 b	83	70
MS/DD/C[w]	20 gal	0 a	0 a	0 a	0 a	1 a	0 a	0 a	1 a	4 a	8 a	60	52
MS/DD/C	25 gal	0 a	1 a	0 a	4 a	0 a	4 a	0 a	4 a	0 a	5 a	60	30
MS/DD	30 gal	0 a	4 a	0 a	4 a	0 a	8 a	1 a	10 a	1 a	14 a	48	43
MB/C33	350 lb.	1 a	0 a	3 a	0 a	3 a	0 a	3 a	3 a	3 a	3 a	49	38
MB/C0.5	400 lb.	3 a	0 a	9 a	0 a	9 a	0 a	11 a	0 a	6 a	0 a	60 N.S.	33 N.S.

[z]Three streams/bed.
[y]Mean separation within weeks by Duncan's multiple range test, 5% level.
[x]Lo = pH 5.5-6.0; Hi = pH 7.0-7.5.
[w]See Table 1 for key to fumigant treatments.

Table 5. Percentage of the tomato plant stand exhibiting wilt symptoms at several stages of growth in the spring 1984 soil fumigation trials at 2 pH levels.

		% of plants affected											
		Fusarium wilt race 3										Fusarium crown rot	
		4 wk		5 wk		6 wk		7 wk		8 wk		13 wk	
Fumigant	Rate/acre[z]	Lo[x]	Hi	Lo	Hi	Lo	Hi	Lo	Hi	Lo	Hi	Lo	Hi
Control	—	14 b[y]	3 a	30 c	13 b	54 d	29 c	68 d	38 c	74 d	53 c	83	80
MS/DD[w]	25 gal	0 a	4 a	3 a	9 a	3 a	13 bc	6 a	19 b	9 a	23 b	65	58
MS/DD/C	25 gal	0 a	0 a	0 a	0 a	1 a	1 a	1 a	5 a	4 a	5 a	58	30
MS	25 gal	0 a	1 a	0 a	9 a	3 a	14 b	3 a	18 b	8 a	29 b	63	45
MS/DD	35 gal	1 a	0 a	1 a	4 a	5 a	4 bc	5 a	4 a	8 a	6 a	33	25
MB/C0.5	400 lb.	0 a	0 a	0 a	0 a	0 a	0 a	1 a	0 a	6 a	1 a	53 N.S.	28 N.S.

[z]Three streams/bed.
[y]Mean separation within single weeks by Duncan's multiple range test ($P < .05$).
[x]Lo = pH 5.5-6.0; Hi = pH 7.0-7.5.
[w]See Table 1 for key to fumigant treatments.

Table 6. Soil nematode population estimates at harvest of tomatoes grown on fumigated Eau Gallie fine sand with natural nematode infestation and inoculated with the Fusarium wilt race 3 or Fusarium crown rot fungus.

	Rate/	Fusarium wilt race 3					Fusarium crown rot					
Treatments	acre[z]	T[y]	Tyl	Mel	Doli	Rt. index[x]	T	Tyl	Mel	Doli	B	Rt. index
Fall 1983												
Control	—	111	472 b[w]	1214 d	707 c	3.4 b	401	560 b	684 b	679 b	217 b	1.8 b
MS/DD/C[v]	20 gal	257	4 a	866 c	110 b	0.9 a	545	1 a	542 b	54 a	1 a	0.5 a
MS/DD/C	25 gal	225	7 a	113 ab	30 a	0.4 a	397	4 a	133 a	70 a	4 a	0.4 a
MS/DD	30 gal	328	9 a	158 ab	46 a	0.4 a	324	1 a	53 a	43 a	5 a	0.3 a
MB/C33	350 lb.	142	1 a	294 b	7 a	0.8 a	293	1 a	696 b	0 a	2 a	0.3 a
MB/C0.5	400 lb.	283 N.S.	1 a	11 a	3 a	0.5 a	340 N.S.	1 a	198 a	26 a	2 a	0.6 a
Spring 1984												
Control	—	838 b	12	254 b	8	4.4 d	588 a	30	1238 b	187 b	143 b	2.7 b
MS/DD	25 gal	718 b	1	64 a	0	3.0 c	1054 c	3	122 a	1 a	17 a	1.5 b
MS/DD/C	25 gal	388 a	0	13 a	0	2.0 b	1000 bc	1	80 a	3 a	10 a	0.3 a
MS	25 gal	333 a	0	21 a	0	2.2 c	715 a	1	9 a	8 a	16 a	0.7 a
MS/DD	35 gal	200 a	0	0 a	0	0.8 a	918 b	0	0 a	1 a	0 a	0.2 a
MB/C0.5	400 lb.	364 a	0 N.S.	0 a	0 N.S.	0.7 a	1112 c	0 N.S.	6 a	0 a	0 a	0.2 a

[z]Three streams/bed.
[y]Nematoda genera: T = *Trichodorus* (stubby root); Tyl = *Tylenchorhynchus* (stunt); Mel = *Meloidogyne* (larvae) (root-knot); Doli = *Dolichodorus* (awl); and B = *Belonolaimus* (sting). Nematodes/100 cm^3 soil.
[x]Rt. index: 0 = no root galling; 5 = severe root galling.
[w]Mean separation within columns by Duncan's multiple range test, 5% level.
[v]See table 1 for key to fumigant treatments.

tion was apparent as plots treated with MS and the low rate of MS/DD developed significantly more disease than other treated plots. Although incidence of crown rot was higher than the incidence of wilt following fumigation, the same relationship existed relative to control by MS and the low rate of MS/DD when pH levels were pooled in the spring.

Since no resistance to either Fusarium pathogen examined in this work is available in commercially acceptable tomato cultivars adapted to Florida conditions, infested fields should be fumigated prior to planting tomato. Generally, MB/C0.5 (400 lb./acre), MB/C33 (350 lb./acre), and MS/DD (35 gal/acre) produced the highest yields in response to control of nematodes as well as soil-borne disease organisms.

Although genetic resistance to Fusarium wilt race 3, crown rot, and root-knot nematodes may be incorporated into commercially acceptable tomato cultivars adapted to Florida in the near future, such host resistance can merely be incremental in improving tomato production in the state. The soil pest community is so diverse, plant response so complex, and the need for maximum fruit yield per production unit so intense, that some means of soil fumigation will be needed for some time. However, available fumigants are far from the perfect solution to soil pest problems and a crop management system making concerted use of cultural, genetic, and chemical means of pest management must become routine for Florida growers.

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