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EFFECTS OF SOIL FUMIGATION, COMPOST, AND NON-FUMIGATION ON THE YIELD, FRUIT QUALITY, DISEASE INCIDENCE, AND OTHER VARIABLES OF TOMATO CULTIVARS

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Abstract. **The effects of soil fumigation, compost, and non-fumigation on the yield, fruit quality, root weight, plant height, and other variables were studied in the spring 1995, fall 1995, and fall 1996. Tomatoes grown in fumigated soils had significantly greater marketable fruit yield ($P < 0.0001$), greater medium size fruit yields ($P < 0.0001$), greater number of marketable fruits per plant ($P < 0.001$), taller plants ($P < 0.001$), heavier root weights ($P < 0.04$), and lower root-knot nematode infestation ($P < 0.0001$), than tomatoes grown in non-fumigated soils. No significant differences were found in the 1996 test between tomatoes grown in fumigated soils and those grown in compost treated soils for the variables total marketable yield, large fruit yield, nematode infestation, and root weight. These results, however, contrasted with the results of the 1995 spring test, that indicated compost significantly reduced tomato yields, and root weights, and failed to reduce the nematode infestation, as compared with the fumigation treatment. The different responses of tomatoes in the fall 1996 and spring 1995 were attributed to the poor quality of the compost applied in the spring. Whereas the height of tomato plants was significantly reduced in the non-fumigated soils, no differences were found in the height of the tomato plants grown in fumigated and compost treated soils. Nevertheless, tomatoes grown in compost treated plots had higher infections of *Alternaria solani* (Ell. & G. Martin) Sor. and *Phoma destructiva* Plowr. than those grown in fumigated or non-fumigated soils ($P < 0.05$). There was significant variability among tomato cultivars in the variables marketable yield, and large fruit yield. There was no significant interaction between cultivars and treatments.**

Introduction

The use of soil fumigants beneath polyethylene has provided useful control of nematodes, soilborne fungi, and weeds in tomato (*Lycopersicon esculentum* Mill.) for over 30 years in Florida. Fumigation of the soils is important especially where crop rotations can not be employed to control populations of harmful organisms. Currently the Florida tomato industry is largely dependent on methyl bromide-containing fumigants. The Federal Clean Air Act requires that the use of methyl bromide be phased out by 2001, consequently alternatives would be urgently considered. Preliminary studies of compost treatments suggested some beneficial effects of the compost on the physical properties of soils, soil microflora, and suppressive action on some soil pathogens. This research was undertaken to: (1) find alternatives to the soil fumigation by methyl bromide, (2) to determine the effects of municipal solid waste (MSW) compost on the growth and development of tomato, and (3) to determine the performance of some tomato cultivars and advanced breeding lines grown under south Florida conditions.

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Materials and Methods

Experiments were conducted during three consecutive years in Krome very gravely loam soil (Rockdale) in Homestead, Florida. Methyl bromide-chloropicrin (MC 75-25) at the rate of 168 kg·ha^{-1} (150 lb. per acre) fumigant was applied to the soil. In the 1995 fall experiment the compost type used was Co-Compost from Bedminster Corporation (Bedminster Bioconversions, McMinnville, Tennessee). In the fall 1996 experiment, MSW compost from Clean Organic Waste (UF, TREC, Homestead, FL) MSW was incorporated into the soil at the rate of 29.6 t·ha^{-1} (dry weight) into soil beds 91.4 cm wide and 15.24 cm high, that were covered with polyethylene mulch. Chemical and physical compositions of the MSW compost were recently reported by Ozores-Hampton et al. (1994). Seeds were sown in Pro-Mix (Premier Brands, Inc., Redhill, PA) and the seedlings were transplanted on polyethylene mulched beds in single row beds 91.4 cm wide and 15.24 cm high, that were spaced on 1.8 m (6 ft) centers. T-Tape (T-Systems International Inc., San Diego, CA) drip irrigation tubing was placed 2 cm deep and 15 cm from bed centerS. The plants were transplanted 38 cm (15 in.) apart within rows, with iron bar stakes and strings to support the plants. Fertilizer 6-2.62-9.96-1.21 (N-P-K-Mg) plus minor elements was applied at the rate of 1120.8 kg·ha^{-1} (1000 lb. per acre) in dry bands 33 cm (13 in) from the bed center and rototilled 10.2 cm (4 in) deep. Liquid fertilizer 4-0-6.64 N-P-K was applied twice per week in the drip irrigation with an average of 280.5 l·ha^{-1} (30 gal. per acre) per week beginning at fruit set. These are equivalents to 13.49 kg·ha^{-1} of N and 22.39 kg·ha^{-1} of K weekly for about 8 weeks. (12 lbs N and 24 lbs K_2O per acre). A total of 11 to 15 tomato commercial cultivars and breeding lines were tested. In addition to yields, data were collected for root weight, and incidence of bacterial leaf spot and nematodes for each cultivar included in the test. A split-plot design was used in all the experiments with treatments as main plots and cultivars as subplots. Root weight was determined from random samples of three roots dug from each plot. Bacterial leaf spot and stem canker caused by *Alternaria solani* and Phoma destructiva evaluations were based on the observation of all plants of each plot, and rated using a scale from 1 = free of symptoms; 5 = severe. The root-knot infestation was determined from three random samples of roots dug from each plot and using a scale

Table 1. Comparison of the effects of treatments of soil fumigation and non-fumigation on yields, number of fruit, fruit weight, and root weight. Fall 1995.

	Marketable fruits			Large fruits		Medium fruits		Cull fruits	Bacterial
Treatment	Yield t·ha^{-1}	Number × 1000	Fruit wt. (g)	Yield t·ha^{-1}	Number × 1000	Yield t·ha^{-1}	Number × 1000	Yield t·ha^{-1}	spot rating[y]
Fumigated	39.7 a[z]	263 a	276 a	27.5 a	160 a	12.2 a	104 a	6.5 a	2.60 a
Non-fumigated	33.4 b	231 b	266 b	22.9 b	140 b	10.4 b	915 b	5.1 b	2.76 a
Treatment P > F	0.0001	0.0001	0.0318	0.0001	0.0001	0.0042	0.0157	0.0114	0.5153
cv × treat P > F	0.2308	0.1730	0.2493	0.2389	0.0573	0.6128	0.8099	0.6185	0.5386

[z]Duncan's multiple range test. Means of the same column followed by the same letter are not significantly different (P < 0.05).
[y]Bacteria leaf spot rating 1 = none, 5 = severe.

from 1 to 8, where 1 = free of nematodes; 8 = severe infestation. Tomato was harvested three times for each growing season in fall and spring 1955, and fall 1966.

Results and Discussion

Results of the fall 1995 experiment are in Tables 1 and 2. These included only fumigation and non fumigation treatments, as the compost was not available. Significant differences were found between fumigation and non-fumigation treatments in all categories including total, large and medium size marketable fruits, total average fruit weights and medium fruit weights (Table 1). No significant differences were found in the fruit weights (fruit sizes) between fumigated and non-fumigated plots (Table 1). There was significant variability among tomato cultivars (Table 2). Marketable yields ranged from 43.3, 43.1, and 40.3 t·ha^{-1} for 'Sunny', 'Florida 7578', and 'Solimar', respectively to only 28.4 for 'Florida 7658'. There was significant variability in fresh weight of roots among cultivars (Table 2). Root fresh weights ranged from 45, 39, 39, 38, 37 g·plant^{1} for 'Bonita', 'Merced', 'Equinox', 'Agriset 761', and 'Solimar' to 23, 25 and 25 for 'NC 45241', 'Fla. 7514' and 'NC 95244', respectively. Because cultivar × treatment interactions were not significant for any of the variables studied (Table 1), data from fumigated and non-fumigated were pooled in Table 2.

Results of the spring 1995 experiment are in Tables 3 and 4. Treatments included fumigation, non-fumigation and compost treatments. Fumigated plots had more marketable yield that non-fumigated or compost treated plots (Table 3); however, no differences were found in the marketable number of fruits. There was no significant variability in the fruit size (g·fruit^{-1}) of marketable fruits among the treatments of fumigation, non-fumigation and control (Table 3). The root-knot nematode infestation was significantly higher in the non-fumigated treatments, medium in the compost treatments, and lower in the fumigated plots. Root weights were significantly heavier in the fumigated and non-fumigated treatments than in the compost (Table 3). There was no interaction between cultivars and treatments for any of the variables studied, including marketable yields, fruit weights, root weights or root-knot nematode infestation (Table 3).

There was significant variability in the yields among tomato cultivars (Table 4). Because cultivars × treatments interaction was not significant (Table 3), data from fumigated, non-fumigated and compost for tomato cultivars were pooled in Table 4. The marketable yields ranged from 13.8, 13.8, 13 t·ha^{-1} for 'Solar Set', 'Florida 7658' and 'Florida 7579' to 8.8 and 5.6 t·ha^{-1} for 'Sunny' and 'Bonita', respectively (Table 4). The average fruit weight ranged from 159, 150 and 146 g·fruit^{1} for 'Merced', 'Sunbeam' and 'Solar Set' to 127 and 130 g in 'Equinox' and 'Sunny', respectively (Table 4). Yields were characteristically lower in the spring planting than in fall planting.

Results of the fall 1996 test are in Tables 5 and 6. Soil fumigation, non-fumigation, and compost were treatments. Tomatoes grown in fumigated soil had significantly larger marketable fruit yield (P < 0.01), larger medium size fruit

Table 2. Comparison of the performance of 12 tomato cultivars. Data from fumigated and non- fumigated plots were pooled because cultivar × treatment interactions were not significant statistically. Fall 1995.

	Marketable fruits		Large fruits	Medium fruits	Cull		
Cultivar	Yield t·ha^{-1}	fruit wt. (g)	Yield t·ha^{-1}	Yield t·ha^{-1}	Yield t·ha^{-1}	Root fresh wt. (g) per plant	Bacterial leaf spot rating[y] 1 to 5
Agriset 761	36.2 bc[z]	145 de	24.4 c-e	107.5 ab	25.5 a	38 ab	2.43
Sunny	43.3 a	140 de	30.0 ab	119.0 a	5.7 ab	32 ab	2.37
Equinox	38.3 a-c	149 b-e	26.0 a-d	104.7 ab	6.9 ab	39 ab	2.62
Fla. 7514	31.8 cd	146 c-e	19.8 e	102.0 ab	4.4 b	25 b	2.62
Fla. 7578	43.1 a	148 b-e	30.5 a	105.0 ab	5.3 ab	30 ab	2.50
Fla. 7658	28.4 cd	157 a-c	20.1 e	65.3 c	6.0 ab	34 ab	3.12
Merced	35.1 bc	159 ab	25.1 a-d	84.6 a-c	6.9 ab	39 ab	2.50
Bonita	35.0 bc	143 de	21.5 de	112.1 a	7.9 a	45 a	2.87
Solimar	40.2 ab	154 b-d	28.4 ab	94.5 a-c	6.5 ab	37 ab	2.43
Sunbeam	36.4 bc	167 a	27.2 a-c	74.7 bc	5.9 ab	34 ab	2.75
NC 95241	35.7 bc	153 b-d	25.1 a-d	89.7 a-c	4.1 b	23 b	2.87
NC 95244	36.5 bc	154 b-d	25.1 a-d	91.5 a-c	4.2 b	25 b	3.00
Cultivar P > F	0.0001	0.0062	0.0002	0.0102	0.0134	0.6179	

[z]Duncan's multiple range test. Means of the same column followed by the same letter are not significantly different (P < 0.05).
[y]Bacteria leaf spot rating 1 = none, 5 = severe.

Table 3. Tomato experiment of the 1995 spring. Comparison of the effects of treatments of fumigation, non-fumigation and compost on tomato yields, fruit weight, root weight and nematode infestation.

Treatment	Marketable yield t·ha-1	Total yield t·ha-1	Marketable Large fruits t·ha-1	Marketable fruit size (g)	Marketable number of fruits	nematode rating[y] 1 to 8	Root fresh wt g·plant-1
Fumigants	14.6 a[z]	16.1 a	4.5	145.35	181 b	2.0 a	30.5 a
Non-fumigated	14.2 a	16.0 a	3.2	145.71	178 b	5.7 c	29.4 a
Compost	4.7 b	5.4 b	1.13	126.35	299 a	5.7 b	23.9 b
Treatment P > F	0.0001	0.0001	0.0001	0.4531	0.0001	4.1	0.0343
Cult × Treat P > F	0.0698	0.0435	0.0165	0.8972	0.5291	0.4537	—

[z]Duncan's multiple range test. Means in the same column followed by the same letter are not significantly different (P < 0.05).
[y]Nematode rating 1 = none, 8 = severe.

Table 4. Comparison of 11 tomato cultivars. Data from non-fumigated, fumigated and compost treatment were pooled for the split-plot analysis. Spring 1995.

Cultivar	Marketable yield t·ha-1	Total yield t·ha-1	Marketable large fruit t·ha-1	Marketable fruit size (g)	Marketable number of fruits	Nematode rating[y] 1 to 8	Root fresh wt g·plant-1
Solar set	14.9 a[z]	14.6 ab	3.44 b	146 a-c	951	3.8 a	22.7 a
Florida 7658	14.8 a	14.8 ab	3.0 b-d	135 bc	558	4.1 a	26.6 a
Florida 7579	13.4 a	14.4 ab	3.8 b	141 a-c	933	4.3 a	24.0 a
Florida 7578	13.4 a	15.1 ab	4.09 a	143 a-c	951	3.4 a	29.4 a
Florida 7514	12.6 ab	14.0 ab	3.10 bc	137 bc	915	4.1 a	30.1 a
Merced	12.5 ab	16.0 a	5.20 a	159 a	771	4.1 a	32.0 a
Sunbeam	10.9 a-c	12.5 a-c	2.95 b-d	150 ab	736	4.1 a	29.1 a
Equinox	9.8 bc	10.3 cd	2.00 c-e	127 c	753	3.9 a	25.2 a
Agriset	9.2 bc	11.6 b-d	1.71 de	136 bc	682	3.7 a	28.9 a
Sunny	8.8 cd	9.97 cd	1.38 e	130 c	682	3.7 a	30.1 a
Bonita	5.7 d	8.10 d	1.18 e	131 bc	413	4.4 a	29.1 a
P > F	0.0001	0.0001	0.0001	0.067	0.455	0.0001	0.0001
cv	32.3	30.7	49.65	14.58	38.93	4.7	44.6

[z]Duncan Multiple range test. Means in the same column followed by the same letter are not significantly different (P < 0.05).
[y]Nematode rating 1 = none, 8 = severe.

yield (P < 0.001), greater plant height (P < 0.001), greater root weight (P < 0.04), and lower root-knot nematode infestation (P < 0.001) than tomatoes grown in non-fumigated soils (Table 5). Remarkably, no differences were found between tomatoes grown in fumigated soils and those grown in compost amended soils in marketable yield, large or medium fruit yields, number of marketable fruits per plant, average marketable fruit weight, plant height or root weight (Table 5). These results however, contrasted with results of the 1995 spring test which indicated that compost treatments reduced tomato yields, and root weights, and failed to reduce the nematode infestation. as compared with the fumigation treatment. The different responses of tomatoes in spring1995 and fall 1996, with the negative effect of compost amendment to the soil in the spring 1995 experiments, were attributed to the poor quality of the compost. No significant differences were found in marketable yields, and large fruit yields of tomatoes planted in fumigated soils and compost amendment solids (Table 5). Nevertheless, tomatoes grown in compost treated plots had a more severe infection (about 10%) of stem cankers caused by *Alternaria solani* (Ell. & G. Martin) Sor. and *Phoma destructiva* Plowr., than tomatoes grown in fumigated or non-fumigated soils (P > 0.05).

There was significant variability among tomato cultivars in the total marketable yields, large fruit yields and number of fruits. Because cultivar × treatment interaction was not signif-

Table 5. Comparison of the effects of treatments of soil fumigation, compost and non fumigation on yields, number of fruit, fruit size, plant height, root weight, root nematode infestation and incidence of the stem cankers caused by *Alternaria solani* and *Phoma destructiva*. Fall 1996.

	Marketable			Large	Medium	Cull	*Alternaria*, *Phoma*		Root	
Treatment	Yield t·ha-1	Number × 1000	fruit wt. (g)	Yield t·ha-1	Yield t·ha-1	Yield t·ha-1	rating 1 to 5	Root-knot Plant height (cm)	nematode rating[y] (1 to 8)	dry wt. (g)
Fumigated	85.6 a[z]	554 a	159 b	65.9 a	19.8 a	4.2	3.64 b	92 a	1.21 c	5.55 a
Non-fumigated	71.9 b	441 b	167 a	56.9 b	15.0 b	4.6	3.77 b	88 b	3.33 a	4.96 b
Compost	82.6 a	533 a	158 b	63.2 a	19.2 a	4.1	4.03 a	92 a	2.57 b	5.27 a
Treatment P > F	0.0001	0.0001	0.0181	0.0217	0.0001	0.6136	0.0473	0.0002	0.0001	0.037
Cult × Treat	0.9984	0.8808	0.8954	1.0000	0.0710	0.6643	0.1574	0.183	0.2065	0.3918

[z]Split plot statistic analysis. Duncan's Multiple Range Test. Means of the same column followed by the same letter are not significantly different (P < 0.05).
[y]Nematode rating 1 = none, 8 = severe.

Table 6. Comparison of the performance of 15 tomato cultivars and breeding lines. Data from fumigated, non-fumigated, and compost plots were pooled because cultivars × treatment interactions were not significant statistically. Fall 1996.

Treatment	Marketable Yield $t \cdot ha^{-1}$	Marketable fruit wt. (g)	Large Yield $t \cdot ha^{-1}$	Medium Yield $t \cdot ha^{-1}$	Cull Yield $t \cdot ha^{-1}$	*Alternaria Phoma* rating 1 to 5	Plant height cm	Root-knot nematode rating[y] 1 to 8	Root dry wt. (g)
Agriset	82.5	163 b-d[z]	64.1 a-c	18.4 b-d	4.7	3.50 b-d	91 a-c	2.33	
Bonita	83.0	164 b-d	64.6 a-c	18.5 b-d	3.3	3.11 cd	88 bc	2.52	5.16 bc
Merced	72.7	198 a	64.4 a-c	8.3	5.1	3.50 b-d	88 bc	2.52	5.37 a-c
Solar Set	70.0	166 bc	65.0 a-c	15.0 c-f	4.2	3.72 a-d	88 bc	2.04	4.80 bc
Equinox	84.6	170 b	67.6 ab	17.1 b-e	4.9	3.72 a-d	92 a-c	2.56	5.23 bc
Fla 7658	79.8	161 b-d	64.3 a-c	15.4 b-f	4.2	4.44 ab	92 a-c	2.59	5.81 ab
Fla 7713	79.1	167 bc	66.7 ab	12.2 e-g	2.6	4.00 a-c	93 ab	2.37	5.56 a-c
Fla 7578	83.9	158 b-d	63.7 a-c	20.1 bc	4.4	3.56 b-d	92 a-c	2.93	n.d[x]
Fla 7514	78.9	151 d	58.8 b-d	20.0 bc	3.5	3.72 a-d	90 a-c	2.29	4.88 bc
Sanibel	87.0	160 b-d	73.5 a	13.6 d-f	4.4	4.67 a	95 a	2.00	6.18 ab
Leading Lady	71.9	155 cd	52.8 c-e	18.9 bc	4.78	4.22 ab	93 ab	2.37	n.d.
Flora Dade	78.8	137 e	48.2 de	30.4 a	3.5	2.94 d	86 c	2.33	6.63 a
HMX 3800	76.8	130 e	45.2 e	31.6 a	3.18	3.72 a-d	92 ab	2.26	4.19 c
HMX 2824	78.8	188 a	68.0 ab	10.8 fg	5.3	4.33 ab	93 ab	2.15	n.d.
HMX 3799	82.6	155 cd	62.2 a-c	20.5 b	5.7	4.06 a-c	90 a-c	2.25	4.78 bc
Cultivar P > F	NS	0.0001	0.0155	0.0001	NS	0.0002	0.0261	0.4338	0.001

[z]Duncan's Multiple Range Test. Means followed by the same letter are not significantly different ($P < 0.05$).
[y]Nematode rating 1 = none, 8 = severe.
[x]n.d. = no data.

icant for any of the variables studied (Table 5), data of each cultivar from fumigated, non-fumigated and compost were pooled in Table 6. High marketable fruit yields were recorded for all 15 tomato cultivars, and there was not significant variability among them (Table 6). Marketable fruit yields in $t \cdot ha^{-1}$ ranged from 87.0, 84.6, 82.9, 82.6, and 82.5 for 'Sanibel', 'Equinox', 'Bonita', 'HMX 3799' and 'Agriset 761' to 72.7 and 71.9 for 'Merced', and 'Leading Lady', respectively (Table 6). There was also significant variability among cultivars in marketable large fruits. The marketable large fruits ranged from 73.4, 67.9, and 67.6 $t \cdot ha^{-1}$ for 'Sanibel', 'HMX 2824' and 'Equinox' to 48.2 and 45.2 for 'Flora-Dade' and 'HMX 3800', respectively. There was also significant variability among cultivars in marketable medium size fruits. The marketable medium size yields ranged 31.6 $t \cdot ha^{-1}$ for 'HMX 3800' and 30.4 for 'Flora-Dade' to only 10.8 for 'HMX' and 6.6 for 'Merced' (Table 6). Finally, there was significant variability among cultivars in the marketable fruit size (g/fruit). Fruit weight in grams ranged from 219, 212, 197, 190 and 190 grams for the cultivars 'Merced', 'HMX 2824', 'Equinox', 'Agriset 761' and 'Solar Set' to 161 for 'HMX 2824'.

The effects of soil additives on the plant height and root weight were also studied. There was significant variability among cultivars for plant height ($P < 0.03$). The plant height ranged from 95.3 cm, 93.4 cm, 92.7 cm, and 92.6 cm for 'Sanibel', 'Florida 7713', 'HMX 2824' and 'Leading Lady', respectively. There was significant variability among cultivars for root weights. The root dry weights ranged from 6.63, 6.2 and 5.8 g for 'Flora-Dade', 'Sanibel' and 'Florida 7658', to 4.19 g for 'HMX 3800', respectively (Table 6).

The response of tomato cultivars to some diseases and nematodes was also studied. The stem canker caused by *Alternaria solani* and *Phoma destrictiva* was very severe at the end of the season. There was a significant variability among cultivars in the susceptibility to this disease ($P < 0.001$). The disease rated (1 = free; 5 = severe) from 2.9, 3.1 and 3.5 for 'Flora-Dade', 'Bonita' and 'Agriset 761' to 4.7, 4.4, 4.3 and 4.2 for 'Sanibel', 'Florida 7658', 'HMX 2824' and 'Leading Lady', respectively (Table 6). There was no significant variability among cultivars in the root-knot nematode ratings. The root-knot ratings (1 = free; 8 = severe) ranged from 2.9 and 2.6 for 'Florida 7578' and 'Florida 7658', respectively to 2.0 and 2.2 rating in 'Sanibel' and 'HMX 2824'. Soils amended with MSW had increased yields of tomatoes (Maynard, 1993) and other vegetables (Bryan and Lance, 1993).

The experiments reported here indicated that when good quality amendments of compost were added to the soil, beneficial effects were evident. Most of the beneficial effects of MSW compost applications to soil have been attributed to improved physical properties of the soil due to increases of organic matter content rather than to their value as nutrient source (Gallardo-Lora and Nogales, 1987). The reduction of soilborne plant disease damage by incorporation of compost to the soils, as well as the beneficial effects of compost on the microflora of the soil have been mentioned (Ozores-Hampton and Bryan, 1993; Ozores-Hampton et al., 1994; Ozores-Hampton, 1997).

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