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Nutrient Concentrations, Growth, and Yield of Tomato and Squash in Municipal Solid-waste-amended Soil

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***Abstract.* The effects of municipal solid waste (MSW) materials on growth, yield, and mineral element concentrations in tomato *(Lycopersicon esculentum* Mill.) (1991 and 1992) and squash *(Cucurbita maxima* Duch. Ex Lam.) (1992 and 1993) were evaluated. Agrisoil compost (composted trash), Eweson compost (co-composted trash and sewage sludge), or Daorganite sludge (chemically and heat-treated sewage sludge) were incorporated into calcareous limestone soil of southern Florida. The control had no MS W material added to the soil. The effect of MSW on crop growth, yield, and mineral element concentrations varied considerably between years for tomato and squash. In 1991, tomato plants grown in soil amended with Eweson or Daorganite had a greater canopy volume than plants in the control treatment. Tomato plants grown in Daorganite had greater total fruit weight (1991) than plants in Agrisoil and more marketable fruit (1992) than control plants. In both years, tomato plants in Agrisoil had higher root Zn concentrations than plants in the other treatments. In 1992, tomato plants in Eweson had lower root Mn concentrations than plants in the other treatments, whereas Mg concentrations in the roots were higher in the Daorganite treatment than in Eweson. Tomato plants in Agrisoil had higher Pb concentrations in the roots than plants in all other treatments. In 1991, leaves of tomato plants in Agrisoil had lower Ca concentrations than leaves of plants in the control treatment. In 1992, leaf Zn concentrations were greater for tomato and squash in Agrisoil than in the control or Daorganite. In 1992, canopy volume and yield of squash were greater for plants in Daorganite than for plants in the control and other MS W treatments. Although canopy volume and total squash fruit weight did not differ among treatments in 1993, plant height was greater for squash plants in the MSW treatments than for those in the control. In 1993, leaf Mg concentrations were greater for squash grown in Daorganite than for plants in the control or Agrisoil. In 1993, fruit Cd concentration was higher for plants with Eweson than for plants in the control or Agrisoil. However, the fruit Cd concentration in squash grown in Eweson compost (1.0 mg/kg dry weight) was far below a hazardous level for human consumption. Our results indicate that amending calcareous soils with MSW materials can increase growth and yield of tomato and squash with negligible increases in heavy metal concentrations in fruit.**

More than 180 million tons of municipal solid waste (MSW) materials are generated in the United States annually (Gillis, 1992). The greatest potential commercial use for this material is agricultural compost (Parr and Hot-nick, 1993).

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The effects of sewage sludge on growth and productivity of horticultural crops have been studied extensively. Amending soils with sewage sludge improved growth and yield of vegetable crops (Bryan and Lance, 199 1; Harrison and Staub, 1986; Sterret et al., 1982, 1983) and ornamental and landscape plants (Fitzpatrick and Carter, 1983; Fitzpatrick and Farrell, 1984). Only recently have MSW composts derived from household and yard trash become available on a large commercial scale. Thus, the effects of large-scale applications of trash-derived MSW materials on crop growth and yield are not well documented.

Vegetable crops in southern Florida are grown on soils of the Krome very gravely loam series (loamy-skeletal, carbonatic, hyperthermic Lithic Rendol) (Larson et al., 1991). These soils have an alkaline pH (7.2–7.6) (Larson et al., 1991) and are low in fertility and organic matter (Bryan and Lance, 199 1). Adding MSW material may improve soil water- and nutrient-holding capacities. Also, the nutrient content of the soil may be increased due to the presence of low concentrations of essential elements in MSW materials (Chancy et al., 1980)

MSW materials often contain metals such as Zn, Al, Cd, Pb, Fe, Cu, Mn, and Mo that may be phytotoxic or, if accumulated in the fruit, pose a health risk to humans (Chancy, 1980; Yuran and Harrison, 1986). In calcareous soils, such as those in southern Florida, heavy metals may not be available to the plant because they precipitate due to low volubility at the high pH of the soil (Street et al., 1978).

Our study was designed to determine the effects of MSW materials on nutrient concentration, growth, and yield of tomato and squash growing in calcareous soils of southern Florida.

Materials and Methods

In 1991 and 1992, tomato ('Sunny') and squash ('Dixie') were planted in a single-year rotation at the Univ. of Florida, Tropical Research and Education Center, Homestead. The cultivars planted represent the major commercial cultivars in Dade County, Fla.

Tomato. In Feb. 1991 and in Jan. 1992,3-week-old tomatoes grown from seed in flats were transplanted to polyethylene-covered beds, with 50 cm between plants and 1.8 m between rows. A different planting site was used each year. Insects and diseases were controlled following standard local practices.

In 1991, plants in all treatments were fertilized with 240 kg N/ha, of which 54% was applied in a granular form before planting and 46% was applied as a solution weekly during the growing period. Nitrogen was applied as NH_4NO_3 and KNO_3. Before planting, a 6.0N–5.3P–10.0K granular fertilizer was applied at 1800 $kg \cdot ha^{-1}$ in two bands 50 cm apart. The fertilizer was rototilled 10 cm into the bed, and two bands (12.5 cm apart) of 2.0N–13.2P–3.3K–2.4Mg at 900 $kg \cdot ha^{-1}$ were placed in the center of the bed. Beginning at flowering, liquid fertilizer was injected though a drip-irrigation system twice each week for 7 weeks at an average rate of 2.25 kg N/ha per day.

In 1992, cultural practices for tomato followed those of the 1991 tomato experiment with the following exceptions: all plants were fertilized with 225 kg N/ha, of which 68% was applied in a granular form before planting and 32% was applied as a solution weekly during the growing period. Before planting, an 8.0N–7.0P–13.3K granular fertilizer was applied at 1686 $kg \cdot ha^{-1}$ in two bands 50 cm apart, and after rototilling, a 2.0N-11.0P-3.3K-1.2Mg granular fertilizer was applied at 900 $kg \cdot ha^{-1}$ in two bands at the center of the bed. Liquid fertilizer was injected once each week for 5 weeks at an average rate of 2.05 kg N/ha per day, beginning at flowering.

Squash. To test residual effects of MSW in the soil on growth and yield of a second crop, squash was planted in Oct. 1992 and Nov. 1993 on the same beds used previously for the tomato crops. Squash plants were direct-seeded

Table 1. Concentration of mineral elements in three municipal solid waste (MSW) materials.

	MSW material		
Element	Agrisoil	Eweson	Daorganite
Concentration (% dry wt)			
N	0.48	1.18	3.19
P	0.14	0.98	1.72
K	0.28	0.64	0.11
Ca	0.12	1.55	14.95
Mg	0.003	0.009	0.006
Fe	0.002	2.71	0.95
S	0.022	0.11	1.37
Concentration (mg/kg dry wt)			
Cd	4.1	3.7	18.0
Cu	246.0	350.0	537.0
Ni	34.0	12.0	67.0
Pb	124.0	21,7	212.0
Zn	607.0	510.0	1180.0

in two rows on each bed. Plant spacing was 37.5 cm between rows and 37.5 cm between planting holes within rows. Each planting hole contained two plants. Between-bed spacing was 1.8 m. Insects and diseases were controlled following local standard agricultural practices.

All plants received 120 kg N/ha; 50% was applied in a granular form at planting, and 50% was applied as a solution during the growing period. Nitrogen was applied as NH_4NO_3 and KNO_3. At planting, a granular 8.0N-7.0P-13.3K fertilizer was applied at 750 $kg\cdot ha^{-1}$ in two bands 50 cm apart and rototilled 10 cm into the bed. Liquid fertilizer was injected though a drip-irrigation system once each week for 3 weeks at an average rate of 2.9 kg N/ha per day beginning at flowering.

MSW treatments. Treatments consisted of the following sources of MSW materials incorporated into the soil: 1) a control, with no MSW incorporated into the soil, 2) Agnsoil compost, composed of composted household and yard trash (Agripost, Miami) applied at 48 $Mg\cdot ha^{-1}$; 3) Eweson compost, composed of composted household trash and sewage sludge (Bedminster Bioconversions, Big Sandy, Texas) applied at 24 $Mg\cdot ha^{-1}$; and 4) Daorganite sludge, composed of chemically and heat-treated sewage (produced by Metro-Dade County, Fla. and distributed by the South Dade Soil and Water Conservation District, Homestead, Fla.) applied at 16 $Mg\cdot ha^{-1}$. Application rates for Daorganite were based on results from previous research (Bryan and Lance, 1991). Application rates of Eweson and Agrisoil composts were recommended by the producers, based on tests in growers' fields in southern Florida. Each MSW material was applied one time before planting in a 45-cm-wide strip with a steel belt distributor (Kennco Manufacturing, Ruskin, Fla.) and rototilled 10 cm into the bed. Producers provided mineral element concentrations in each of the MSW materials (Table 1).

The design was a randomized complete block. Plots were 18 m long and 60 cm wide, with 30 plants per plot for tomato and 60 plants per plot for squash. There were four single-plot replications for each treatment.

Data collection and analysis. The effects of MSW on crop growth, yield, and mineral element concentrations in plant organs were determined for each crop in each year. Plant height (from soil surface to the top of the canopy) and canopy width (at the widest point) were measured immediately before the first harvest. Canopy volume was determined by multiplying the plant height by the canopy width (within row) by canopy width (across row). Yield was recorded for all crops as total fruit weight and number per plant and per plot. Tomato fruit sizes (diameters) were large (>6.5 cm), medium (6.5–5.5 cm), and small (<5.5 cm). Large and medium tomato fruit were considered marketable. Plant height and canopy volume were recorded as means for $\geq$ 36 plants per treatment (nine plants per plot) and yields were recorded from all plants in each treatment.

For mineral analysis of plant tissues, 60 leaflets (from the three most recently fully expanded leaves on each plant) and 15 fruit were randomly collected from plants in each plot immediately before the first harvest; 30 root samples were collected from plants in each plot after the last harvest. Leaf, root, and fruit samples were washed in tap and then distilled water, dried at 60C, and ground to a powder with a cyclone grinder (UDY Corp., Fort Collins, Colo.). Nitrogen concentration was determined calorimetrically with a rapid flow analyzer (ALPKEM, Clackamas, Ore.) as described by Hanlon and DeVore (1989). Concentrations of P, K, Ca, Na, Mg, Al, Cu, Fe, Mn, Pb, Ni, Cd, and Zn were determined with an inductively coupled, argon plasma spectroscope (Model 9000; Jarrel-Ash, Waltham, Mass.).

Data were analyzed by analysis of variance and Duncan's multiple range tests.

Results and Discussion

There were significant interactions ($P \leq 0.05$) between year and MSW for many of the variables tested for each crop. Therefore, data for each crop were analyzed separately by year to determine the effects of MSW on plant growth, yield, and mineral element concentrations. Data are reported in tables only when there were significant ($P \leq 0.05$) MSW effects. For all other variables, there were no significant MSW effects.

In 1991, damage to some tomato plants, possibly due to contaminated fungicide, resulted in an uneven number of healthy plants per treatment. Therefore, yield was expressed as fruit fresh weight per plant. In 1992, tomato fruit yields were in the range of those obtained by growers for plants on the same soil.

Amending soil with Daorganite inconsistently increased growth and yield of tomato and squash, whereas Eweson and Agrisoil composts inconsistently increased growth but not yield (Table 2). In previous studies, amending southern Florida soil with Daorganite at a rate as low as 6.8 $Mg\cdot ha^{-1}$ resulted in increased yields of several vegetable crops (Bryan and Lance, 1991). In those studies, increased growth and yield for plants grown in Daorganite were attributed to the addition of N to the soil. Sewage sludge contains N in slowly available forms, which can enhance plant growth due to improved nutrition (Chancy et al., 1980). In our study, the MSW application rates were adjusted to add about the same amount of N in each MSW treatment. However, the mineralization rate of N from Daorganite may have been greater than that of Eweson and Agrisoil composts. Thus, the higher fruit yields in the Daorganite treatment may have been due to an effect of increased N availability. Although there were no significant differences in plant N concentrations among MSW treatments, the increased growth of plants in Daorganite may have resulted in a dilution of N (i.e., higher total N accumulation per plant in Daorganite), thus masking differences in N on a tissue dry weight basis among treatments.

Our fertilizer rates were similar to those used in standard commercial practice in southern Florida. In concurrent studies on Krome very gravelly loam soil, similar growth and yield responses were observed for tomato and squash on nonamended soil using one-third of the amount of inorganic fertilizer applied in this study (Ozores-Hampton et al., unpublished data). However, Krome very gravely loam soil is porous and has a poor nutrient-and water-holding capacity. Therefore, growers often apply large amounts of inorganic fertilizer to offset nutrient losses due to leaching during rainy periods. The lack of yield responses with Eweson and Agrisoil composts may have been due to suboptimal application rates of these composts or to optimum rates of inorganic fertilizer for all treatments, masking the effects of N from the compost. Although these composts have a lower N concentration than Daorganite, they have a higher organic matter content. Most benefits of composted household and yard trash applications to soil have been attributed to improved physical properties of the soil due to increased organic matter content (Gallardo-Lora and Nogales,

Table 2. Growth and yield of tomato (1991 and 1992) and squash (1992 and 1993) plants in soil amended with municipal solid waste (MSW) materials or a nonamended control.

	Tomato			Squash		
	1991		1992	1992		1993
MSW	Canopy vol (1000 cm^3)	Total fruit wt (g/plant)	No, fruit/ha[z]	Canopy vol (1000 cm^3)	Total fruit wt ($Mg\cdot ha^{-1}$)	Plant ht (cm)
None (control)	54.6 b[y]	110ab	393 b	3.19b	5.3 b	26.2 b
Agrisoil	73.1 ab	89 b	400 ab	3.38 ab	5.5 b	29.8 a
Eweson	93.2 a	121 ab	419 ab	3.42 b	6.0 ab	29.7 a
Daorganite	82.2 a	182 a	459 a	3,65 a	6.9 a	30.2 a

[z]Number of fruit per hectare × 1000.

[y]Mean separation among treatments by Duncan's multiple range test ($P \leq 0.05$).

1987) rather than to their value as fertilizers. Therefore, adding these materials to soils low in organic matter may increase water- and nutrient-holding capacity of the soil, thereby increasing crop productivity. However, the application rates possibly were too low to significantly increase soil water- and nutrient-holding capacity sufficiently to increase yield. This assumption is supported by the fact that adding these MSW materials to the soils did not increase concentrations of any macronutrient in the plants.

Although household trash and sewage sludge may contain substantial quantities of heavy metals (Chancy, 1980), adding some MSW materials to the soil only increased root Zn and Pb concentrations (Table 3), leaf Zn concentrations (Table 4), and fruit Cd concentrations (Fig. 1) compared to the control. In 1992, tomato plants grown in Eweson had lower Mn concentrations in roots than plants in the other treatments, and plants in Daorganite had higher Mg concentrations in roots than plants grown in Eweson (Table 3). In 1993, Mg concentrations in squash leaves were higher for plants in Daorganite than for plants in Agrisoil or the control (Table 4). Although there were significant differences in concentrations of some nutrients among MSW treatments, no symptoms of nutrient toxicity or deficiency were observed for either crop during either year. Also, the concentration of all mineral elements in the leaves were in the sufficiency ranges for tomato (Jones et al., 199 1) in 1991 and squash (Hochmuth et al., 1991) in 1992 and 1993. In 1992, concentrations of all elements in tomato leaves were in the sufficiency range except for Zn and Mn concentrations, which were slightly lower than the sufficiency range for plants in all treatments except Agrisoil (Jones et al., 1991). Similarly, in a study with corn *(Zea mays* L.), amending soil with sewage sludge resulted in heavy metal concentrations in the grain and ear leaf within ranges considered normal for healthy plants (Reed et al., 1991).

Of the heavy metals likely to accumulate in fruit, Cd traditionally has been considered the most serious risk to human health (Chancy, 1990). Chronic exposure to Cd has been linked to nervous disorders and hypertension (Schroeder, 1967), and the intake of high levels of Cd can lead to kidney damage (Ryan et al., 1982). In a recent review of public health issues related to MSW composts, Chancy (1991) asserted that increased Cd uptake due to MSW is too low to pose a serious health threat. We observed variability between crops and years for the effect of MSW on Cd concentration in the fruit; the MSW application increased fruit Cd concentration only for squash grown in 1993 (Fig. 1). This variability was not surprising because Yuran and Harrison (1986) found a great deal of genotypic variation in plant Cd uptake when 60 cultivars of noncrisphead lettuce were grown in sewage sludge. The 10-fold increase in Cd concentration in squash fruit in the Eweson treatment compared with the control was not high enough to pose a threat to human health if ingested (Chancy, 1980). The recommended, safe maximum, average daily dietary intake of Cd is 70 µg·day^{-1} (Chancy, 1990). Squash fruit is composed of ≈ 94% water (Lorenz and Maynard 1980); therefore, the 1 mg Cd/kg fruit dry weight for squash grown in Eweson compost (Fig. 1) is equivalent to ≈ 10.6 µg Cd/kg fruit fresh weight. Thus, it would be necessary to consume an unrealistic quantity (≈ 6.6 kg) of fresh fruit per day to pose a threat to human health. Similar to our observations, when other vegetable crops and tomato were grown in sewage sludge, Zn and Cd did not accumulate to levels high enough to be toxic to plants or hazardous for humans (Falahi-Ardakani et al., 1987a, 1987b). In a study using sewage sludge with a high metal content, the Cd concentrations in the edible portions of corn were low regardless of the source of compost in the transplant media (Street et al., 1978). In that study, volubility of Cd in the soil was dramatically reduced at pHs >7.25. The pH of southern Florida soil is 7.2 to 7.6 (Larson et al., 1991), and Cd is most likely precipitated due to low volubility at the high pH. In a glasshouse study with cucumber *(Cucumis sativus* L.) grown in sewage sludge in containers, Cd concentrations in fruit did not accumulate to levels hazardous to human health over a range

Table 3. Concentrations of Zn, Mn, Mg, and Pb in roots of tomato (1991 and 1992) grown in soil amended with municipal solid waste (MSW) materials or a nonamended control treatment.

	Tomato				
	1991	1992			
MSW	Zn (mg/kg dry wt)	Zn (mg/kg dry wt)	(mg/kg dry wt)	Mg (% dry wt)	Pb (mg/kg dry wt)
None (control)	31.8c[z]	43.0 c	58.3 a	0.200 ab	11.1 b
Agrisoil	59.7 a	69.7 a	57.4 a	0.200 ab	13.5 a
Eweson	40.2 b	55.4 b	45.7 b	0.218 b	10.0 b
Daorganite	44.2 b	55.6 b	55.8 a	0.220 a	11.1 b

[z]Mean separation among treatments by Duncan's multiple range test $(P \leq 0.05)$.

Table 4. Leaf Ca, Zn, and Mg concentrations in tomato (1991 and 1992) and squash (1992 and 1993) plants grown in soil amended with municipal solid waste (MSW) materials or a nonamended control treatment.

	Tomato		Squash	
	1991	1992	1992	1993
MSW	Ca (% dry wt)	Zn (mg/kg dry wt)	Zn (mg/kg dry wt)	Mg (% dry wt)
None (control)	4.0 a[z]	16.4 b	49,1 b	0.46 b
Agrisoil	3.5 b	25.7 a	56.7 a	0.46 b
Eweson	3.8 ab	19.3 ab	52.9 ab	0.50 ab
Daorganite	3.8 ab	16.6 b	50.9 b	0.51 a

[z]Mean separation among treatments by Duncan's multiple range test $(P \leq 0.05)$.

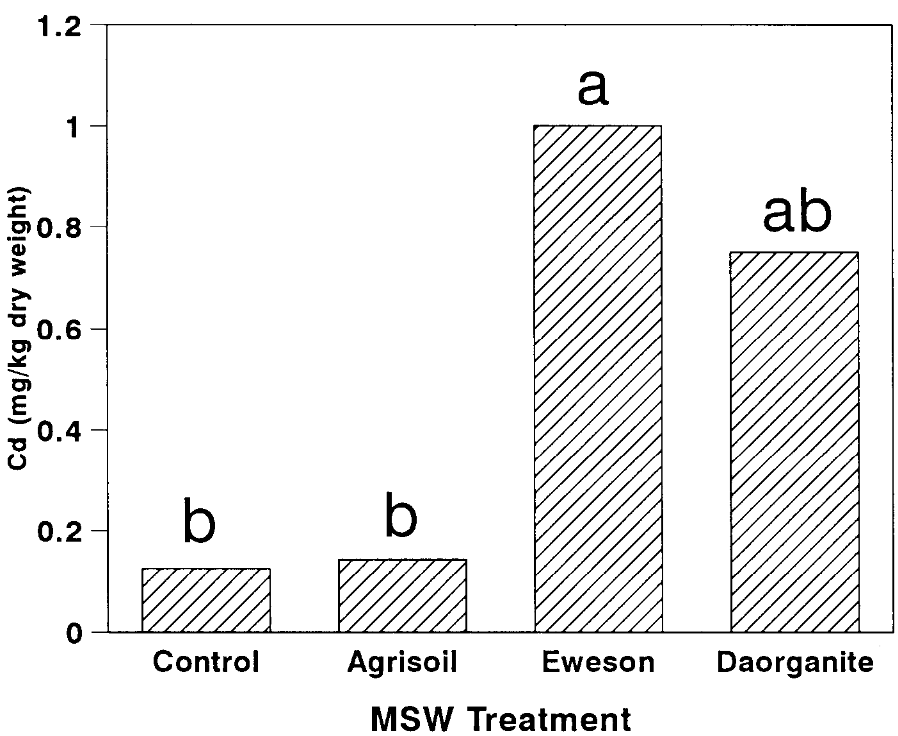

Fig. 1. Fruit Cd concentrations in squash plants grown in soil amended with municipal solid waste (MSW) materials or a nonamended control treatment (1993). Mean separation among treatments by Duncan's multiple range test $(P \leq 0.05)$.

of soil pH values (Falahi-Ardakani et al., 1988).

In 1991, tomato leaf Ca concentrations were higher in control plants than in plants grown in Agrisoil treatments (Table 4). Krome very gravelly loam soil is derived from limestone, and therefore, the Ca concentration is high (4-8 mg Ca/g dry weight soil) (Larson et al., 199 1). The addition of MS W may have diluted the Ca in the immediate vacinity of the roots.

Amending calcareous soils with MSW material can increase growth and yield of tomato and squash. In agreement with previous studies (Sterrett et al., 1982, 1983), amending soil with sewage sludge did not result in tissue heavy metal concentrations considerably higher than in plants in nonamended soil. Likewise, adding of composts produced from household and yard trash to Krome very gravelly loam soil did not result in plant heavy metal concentrations that were significantly higher than those of plants grown in nonamended soil. Therefore, in addition to sewage sludge, using MSW composts derived from household and yard trash for vegetable production appears to be a practical alternative to other disposal methods, such as incineration or burial in land fills. Fertilizer and water are not limited in the agricultural area of southern Florida and were not limited in this study. However, due to increasing urbanization and concerns about water quality and quantity, fertilization and irrigation are likely to be carefully regulated in the future. Therefore, the addition of MSW materials to southem Florida soil maybe beneficial for increasing water and nutrient holding capacity of the soil. Preliminary data with higher rates of Eweson (30 Mg dry weight/ha) indicate significant yield increases for tomato and squash compared to plants in nonamended soil (Schaffer and Bryan, unpublished data). Further studies using higher MSW application rates for several years on the same sites with different irrigation rates need to be conducted to test residual compost effects on growth, yield, and mineral element concentration of crops grown in calcareous soils as well as the persistence of these materials in the soil.

The limited crop growth and yield increases resulting from the MSW rates used under the conditions described in this study would not justify the additional expense to tomato and squash growers of purchasing and applying MSW materials. One solution to the potentially low cost : benefit ratio of MSW for growers may be for MSW manufacturers to obtain operating costs from disposal fees (commonly done at land fills) and to provide MSW to growers free of charge. Thus, if increases in crop production are not substantial enough to justify purchasing MSW, the use of these materials may still provide a viable waste disposal alternative.

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