Table 1. The number of certified hot water treatment plants.

Country	1990	1991	1992	1993	1994
Venezuela	0	0	1	2	3
Nicaragua	0	0	0	0	1
Guatemala	0	0	0	1	2
Mexico	45	41	42	47	51
Brazil	1	2	3	3	4
Ecuador	0	1	1	1	2
Peru	0	2	4	4	4
Haiti	5	5	5	5	5

rity. Table 1 shows the situation of the hot water facilities in Latin America.

The mangos consumed in the United Sates are from Florida and Latin American countries (Table 2). In the last five years, mango imports provided about 85 percent of total U.S. mango supplies (1). Mexico is by far the major supplier, and its exports are expected to increase every year. The number of certified packing houses are also increasing (Table 1). Mangos from Mexico have a variable quality, as should be expected since there are so many treatment facilities in that country. Usually the quality is good; most treatment facilities are able to keep hot water damage to a minimum. The major quality problem observed at our packing house was due to advanced fruit maturity, which leaves the packer/shipper with a short time to get the product to the customer. Their major cultivar is Tommy Atkins, but they also ship significant amounts of 'Kent', 'Haden', and 'Keitt'.

Table 2. Volume of United States imports.

	Volume of Imports[1]				
Origin	1990	1991	1992	1993	1994
Venezuela	0	0	583,100	625,900	—
Nicaragua	0	0	0	0	38,497
Guatemala	0	0	0	150,000	448,500
Mexico	11,229,000	16,861,200	15,167,556	21,113,600	—
Brazil	37,000	228,200	377,200	697,300	—
Ecuador	0	25,000	59,000	70,000	—
Peru	0	481,000	669,800	606,300	—
Haiti	1,735,300	2,986,200	61,550	1,584,440	—
Florida	1,925,000	2,750,000	2,200,000	275,000	—

[1]Number of 4.5 Kg (10 Lb) boxes.

Table 3. Distribution of the mango supply throughout the year by country.

Origin	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Venezuela		—	—	—	—	—						
Nicaragua		—	—									
Guatemala			—	—	—	—						
Mexico			—	—	—	—	—	—	—			
Brazil	—									—	—	—
Ecuador										—	—	—
Peru	—											—
Haiti			—	—	—	—						
Florida						—	—	—				

Nicaragua and Guatemala are the most recent suppliers. The quality of the fruit from these countries is good, and hot water damage was minimal in the lots observed. The cultivars sent were 'Tommy Atkins' and 'Sensation'. Fruit from Venezuela are of variable quality. Hot water damage is a great problem with the fruit received in our packing house. The major cultivars received were 'Haden'. Brazil sends only 'Tommy Atkins' and in the beginning of the season hot water damage is a problem on the smaller fruits but for the most part fruit quality is good. Peru and Ecuador have good quality fruit. Hot water damage is a problem occasionally.

The volume of mangos entering the United States is bound to increase in the coming years. The limiting factor will be price. The market is reaching a point where a steady supply is available (Table 3), which will keep prices more stable, making mangos more popular among American consumers. Florida has a distinctive advantage over other suppliers. It is closer to the market and the fruits do not need to be submitted to any kind of treatment to be commercialized in most American states. Florida could also grow cultivars for specialty markets which do not take the hot water treatment well.

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EFFECTS OF MUNICIPAL SOLID WASTE COMPOST AND TRENCH DEPTH ON PAPAYA (*CARICA PAPAYA* L.) YIELD AND FRUIT QUALITY

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Abstract. **The effects of application rate of municipal solid waste (MSW) compost and trench depth on yield and fruit quality were determined for papaya *(Carica papaya L. cv.* Cariflora) grown in Krome very gravelly loam soil. Plants were cultivated in soil amended with Earthlife Compost (composted trash) at a rate of 0, 75, or 150 Mg · ha^{-1}, and trenched to a depth of 0,12.7, 25.4, or 38.1 cm. All plants were supplied with adequate fertilizer and irrigation. There was a significant interaction between MSW rate and trench depth only for average fruit weight. When MSW was applied at 75 Mg · ha^{-1}, average fruit weight was negatively correlated with trench depth. A similar trend was ob-**

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served when MSW was applied at 150 Mg · ha^{-1}, whereas for the 0 Mg · ha^{-1} (control) MSW treatment, there was no correlation between average fruit weight and trench depth. The percentage of plants with fruit maturing during the first 4 weeks of harvest (early maturing fruit) was positively correlated with MSW rate. Total fruit weight per plant was not affected by MSW rate or trench depth, but the total number of fruit per plant increased as application rate of MSW increased. Trench depth had no effect on total soluble solid concentration (brix), acidity, or firmness of the fruit. Total soluble solid concentration and acidity of the fruit were positively correlated with MSW rate. The results of this study indicate that, when fertilizer and irrigation rate are adequate, trench depth does not improve yield or fruit quality of 'Cariflora' papaya grown in Krome very gravelly loam soil. However, addition of MSW to the soil can affect yield, increase precocity, and improve fruit quality.

The use of municipal solid waste (MSW) materials as soil amendments and composts for agriculture has generated a great deal of interest during the past few years due to the increasing problems of solid waste disposal (Gillis, 1992). Continuous application of MSW to the soil can affect soil physical and chemical properties, thus improving water retention and cation exchange capacity (He, et al., 1992; Richard, 1992; Swietlik, 1993; Ozores-Hampton, et al., 1994). Additionally, some MSW materials, such as composted sewage sludge, can be a source of nutrients (Falahi-Ardakani, et al., 1987).

There are some concerns about amending agricultural soils with MSW materials, specifically the addition of heavy metals in the compost such as Zn, Cd, Pb, Cu, and Ni, which can be taken up by the plant and may be harmful to humans if ingested in sufficient quantities (Epstein, et al., 1992). Therefore, to reduce health risks, the United States Environmental Protection Agency (EPA) has set limits on the quantities of heavy metals from MSW that can be added to the soil over specified periods of time (Gouin, 1993). In alkaline soils, such as those of South Florida, heavy metals are often precipitated and are unavailable for plant uptake (Sterret, et al., 1982; Falahi-Ardakani, et al., 1988; Chaney and Ryan, 1993; Holmgren, et al., 1993; Ozores-Hampton, et al., 1994).

Recently, the effects of amending soil with sludge or MSW on growth and yield of vegetable crops has been studied (Harrison and Staub, 1986; Falahi-Ardakani, et al., 1988; Gouin, 1993; Ozores-Hampton, et al., 1994). However, there is little available information on effects of MSW composts on growth and yield of fruit crops. In preliminary studies in South Florida, papaya yield increased by the amending soil with composted sewage sludge (Bryan and Lance, 1991).

The primary soil type used for fruit production in South Florida is classified as Krome very gravelly loam (skeletal, carbonatic, hyperthermic udorthents) (M. E. Collins, unpublished data). This soil is extremely porous and contains very little organic matter (2%) (Larson, et al., 1991). The parent material of this soil is oolitic limestone (Leighty and Henderson, 1958; Larson, et al., 1991) and in its natural state it is very hard. In preparation for planting fruit crops, Krome very gravelly loam soil is generally rock-plowed to a depth of 10-17 cm and then trenched in two directions to a depth of about 45-60 cm. Trees are planted at the trench intersections (Colburn and Goldweber, 1961). However, for vegetable crops and fruit crops such as papaya, which have a relatively short crop cycle, the soil is generally only rock-plowed and bedded (beds are usually 10 cm high × 35-46 cm wide) (J. H. Crane, personal communication). For these crops, the soil is plowed to a depth of about 15 cm prior to planting. Although some growers believe that trenching may increase growth and yield of papaya, we are aware of no quantitative data to support this. Therefore, research is needed to quantify the effects of trenching and trench depth on growth and yield of papaya.

Currently in South Florida there are approximately 180 ha of papaya. This crop requires large quantities of water and nutrients. Incorporation of MSW materials (which generally have high organic matter contents) into the soil may increase water- and nutrient-holding capacities, thus reducing the amount of water and nutrients required for adequate growth and yield. Planting papaya in trenches may increase root depth and root surface area, thus increasing uptake of water and nutrients by the plant. The purpose of this study was to evaluate the effects of trenching and amending South Florida soil with MSW compost on growth, yield, and fruit quality of papaya.

Materials and Methods

Three-month-old papaya seedlings, grown in flats in a glasshouse, were transplanted to the field at the University of Florida, Tropical Research and Education Center in Homestead in Apr. 1993. Plants were placed in soil trenched at different depths (0, 12.7, 25.4, or 38.1 cm) and amended with different rates of Earthlife Compost (composted house and yard trash, distributed by Reuter, Inc., Pembroke Pines, FL). Compost was applied at 0 (control), 75, or 150 Mg · ha^{-1} and rototilled into the soil. Plants were arranged in a 3-row system with 1.52 m between plants in a row, 1.83 m between rows, and 3.35 m between triple rows. Rows were covered with plastic mulch. The experiment was a 4 × 3 factorial (4 trench depths and 3 rates of compost) in a completely randomized design. There were at least two replications per treatment with 6-11 female plants per replication. The variability in the number of female plants in each replication was due to the number of male plants remaining after plant thinning.

Before planting, 1790 kg/ha of 8-16-16 (N-P-K) granular fertilizer was applied. Plants were drip-irrigated and 38 g N per plant and 45 g K per plant as K_2O_5 was applied through the drip system. Due to difficulty in supplying sufficient water and fertilizer, the plastic mulch was removed in Sept. 1993 and drip irrigation was replaced with a sprinkler irrigation system. Plants were then fertilized monthly with 8-3-9 (N-P-K) granular fertilizer around the stems. Total N-P-K applied after initial transplanting until the end of the experiment was 269 g N per plant, 37 g P per plant as P_2O_5, and 260 g K per plant as K_20. Weeds, insects, and diseases were controlled using standard local practices.

In Aug. 1993, after initial fruit set, plant height from the ground to the lowest fruit (fruiting height) was determined. Beginning Oct. 1993 and until Apr. 1994, mature fruit were harvested at weekly intervals. Fruit were considered mature at color-break (when the skin began to turn yellow). During the first 2, 4, and 6 weeks of harvest, the percentage of plants with mature fruit was determined; this variable was considered an indicator of precosity. Total fruit number and weight, and average fruit weight were also determined. Fruit quality was evaluated by sampling 3 fruit per replication. Fruit firmness (with and without skin) was determined with a penetrometer (Ametex Equipment Systems, Landscale, PA) with a 6 mm^2 (1 mm × 6 mm) rectangular tip. Total soluble solids (TSS) in the fruit was determined with a hand-held refractometer (Fisher

Table 1. Effect of trench depth and municipal solid waste (MSW) compost rate on papaya fruiting height (height from soil to lowest fruit) and the percentage of plants with mature fruit during the first 6 weeks of harvest.

MSW rate (Mg·ha[-1])	Fruiting height (cm)	% plants with mature fruit weeks of harvest		
		2	4	6
0	64.70	6.0	37.80	89.90
75	64.20	14.30	53.70	91.50
150	63.50	19.40	60.30	96.90
Significance[z]				
Linear	NS	*	**	NS
Trench depth (cm)				
0	64.00	16.90	51.10	97.20
12.7	65.10	13.40	53.40	91.70
25.4	64.20	9.70	49.50	92.30
38.1	62.90	13.00	49.70	89.00
Significance				
Linear	NS	NS	NS	NS

[z]Linear models are non-significant (NS), significant at P≤0.05 (*) or P≤0.01 (**).

Table 2. Total number of fruits per plant and total fruit weight per plant of papaya grown in soil amended with different MSW compost rates and trenches at different depths.

MSW rate (Mg·ha[-1])	Number of fruit/plant	Kg fruit/plant
0	31	25.7
75	34	27.9
150	37	28.8
Significance[z]		
Linear	*	NS
Trench depth (cm)		
0	31	26.1
12.7	36	29.2
25.4	35	27.3
38.1	35	27.3
Significance		
Linear	NS	NS

[z]Linear models are non-significant (NS) or significant at P≤0.05 (*).

Scientific, Inc., Springfield, NJ), and acidity was determined by titration (A.O.A.C., 1990). Data were analyzed by regression analysis (SAS, 1985).

Results and Discussion

There was no significant interaction between trench depth and MSW rate or individual effects of either of these variables on fruiting height (plant height from the ground to the lowest fruit) (Table 1). Fruit height is a good indicator of plant precocity for papaya (Nakasone and Storey, 1955). Thus, plant precocity was not affected by soil trenching or by amending the soil with various rates of MSW.

There was a positive linear correlation between MSW rate and the percentage of plants that produced fruit early in the harvest season (Table 1). The percentage of plants in plots amended with 75 Mg · ha^{-1} of MSW that had mature fruit was 8.3% and 15.9% higher than the control plots during the second and fourth week of harvest, respectively. In soil amended with 150 Mg · ha^{-1} of MSW, the percentage of mature fruit during the second and fourth week of harvest was 13.4% and 22.5% higher than the control plots during the second and fourth week of harvest, respectively. During the sixth week of harvest, no differences in the percentage of plants with mature fruit were observed among MSW treatments. Trenching depth had no effect on the percentage of plants with mature fruit at any time during the harvest period (Table 1).

Trenching agricultural soils prior to planting fruit crops has been a common practice in southern Dade County. Trenching prior to planting can result in increased plant water- and nutrient-use efficiency by allowing greater root proliferation through the soil. Thus, trenching may result in higher yields compared to non-trenched plots (Colburn and Goldweber, 1961). However, we found that trench depth had no effect on fruit yield of papaya (Table 2).

There were no significant statistical interactions between trench depth and MSW application rate for the total number of fruit per plant or the total fruit weight per plant. There was a positive linear correlation between MSW rate and the total number of fruit per plant during the entire harvest period (Oct. 1993 through Apr. 1994) (Table 2). Amending soil with MSW increased the total number of fruit per plant. Plants in soil amended with 150 Mg · ha^{-1} of MSW compost had an average of 6 more fruit per plant than the control plots. Also, although not statistically significant, total fruit weight per plant tended to increase as MSW rate increased (Table 2). Plants in MSW-amended soil tended to have higher fruit numbers and weights than plants in the control plots during each harvest, except in Dec. and Jan. (probably due to lower temperatures) (data not shown). The differences in yields at the beginning of the harvest period may be related to the greater precocity of plant in the MSW-amended soil. However, the higher yields for plants in the MSW treatments compared to those in the control treatment from February through April suggests that MSW effects on yield were fairly consistent throughout the harvest period.

Amending agricultural soils in southern Dade County with composted waste material increased crop yields for papaya (Bryan and Lance, 1991), tomato, and squash (Ozores-Hampton, et al., 1994). However, previous studies with papaya focused on amending soil with sewage sludge rather than municipal trash and yard waste as used in this study. Sewage sludge has a relatively high nitrogen concentration compared to composted house and yard trash (Ozores-Hampton, et al., 1994). Thus, increases in papaya plant growth and yield resulting from sewage sludge application to the soil were attributed to increased nitrogen rates (Bryan and Lance, 1991). The increased total number and weight of fruit per plant in MSW-amended soil that we observed may have been due to increased soil water- and nutrient-holding capacity as a result of the MSW treatments.

There was a significant interaction between trench depth and MSW rate for the average fruit weight per plant (Table 3). In plots amended with 75 Mg · ha^{-1} of MSW, there was a negative linear correlation between average fruit weight per plant and trench depth. There was a similar trend for plots amended with 150 Mg · ha^{-1} of MSW (although not significant at $P \leq 0.05$). However, in the control plots trench depth had no effect on the average fruit weight per plant. These data suggest that additional expense of trenching prior to planting papaya in southern Dade County soil is not justified. In this study, irrigation and fertilization rates were not limiting. It is possible that under conditions of limited irrigation and/or

Table 3. Effects of municipal solid waste (MSW) compost rates on average fruit weight of papaya plants grown in soil trenched at different depths.

Trench depth	MSW rate		
	0 Mg·ha^{-1}	75 Mg·ha^{-1}	150 Mg·ha^{-1}
(cm)	Average fruit weight (g/fruit)		
0	773	875	833
12.7	769	851	790
25.4	839	783	723
38.1	818	739	737
Significance[z]			
Linear	NS	*	NS

[z]Linear models are non-significant (NS) or significant at P≤0.05 (*).

fertilization rates, trenching may improve papaya growth and yields by increasing the root surface area available for water and nutrient uptake.

There were no significant statistical interactions between trench depth and MSW rate for fruit firmness, TSS in the fruit, or fruit acid concentration. Fruit firmness (evaluated with and without the skin) was not affected by trench depth or MSW rate (Table 4). When 150 Mg · ha^{-1} of MSW were applied, TSS in the fruit was 10.4 brix. Conover, et al. (1986) observed the TSS content in 'Cariflora' papaya in South Florida to average 9.5-10.8 brix, depending on the year that TSS was measured. Thus, the TSS concentration observed for fruit in each MSW treatment was within the expected range. However, total soluble solid concentration in the fruit was linearly correlated with MSW rate, whereas trench depth had no effect on this variable (Table 4). There was a positive, linear correlation between MSW rate and acid content of the fruit (Table 4). There was no effect of trench depth on acidity of the fruit (Table 4).

Table 4. Effects of different municipal solid waste (MSW) compost rates and different trench depths on papaya fruit firmness, total soluble solids (TSS), and acidity.

MSW rate	Firmness (Kg pressure/6 mm^2)		TSS (brix)	Acidity (ml NaOH 0.1 N)
(Mg·ha^{-1})	With skin	Without skin		
0	1.64	0.47	9.6	1.6
75	1.63	0.42	9.8	1.7
150	1.60	0.45	10.4	1.8
Significance[z]				
Linear	NS	NS	*	*
Trench depth (cm)				
0	1.70	0.43	9.7	1.8
12.7	1.65	0.48	10.1	1.6
25.4	1.53	0.45	10.0	1.8
38.1	1.61	0.43	9.9	1.5
Significance				
Linear	NS	NS	NS	NS

[z]Linear models are non-significant (NS) or significant at P≤0.05 (*).

Although trenching did not improve fruit yield or quality, the addition of MSW to the soil increased both fruit yield and quality. Thus, amending South Florida soil with MSW compost may be a useful practice for improving production. However, the financial costs and benefits of MSW application must determined before recommending that growers use MSW for papaya production. Also, additional studies need to be conducted to determine the effects of repeated application of MSW to the soil on papaya production.

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