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Effects of Long-term Organic Amendments and Soil Solarization on Pepper and Watermelon Growth, Yield, and Soil Fertility

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***Abstract*. Many vegetable growers rely on methyl bromide or other soil fumigants to manage soil pathogens, nematodes, and weeds. Nonchemical alternatives such as solarization and organic amendments are as yet largely unproven, but do offer promise of more sustainable solutions. The objective of this study was to evaluate the effects of long-term organic amendments and soil solarization on soil chemical and physical properties and on growth and yield of pepper (*Capsicum annuum* L.) and watermelon *(Citrullus lanatus* [Thunb.] Manst.). Main plots consisted of a yearly organic amendment or a nonamendment control. Four subplots of soil sanitation treatments consisted of solarization, methyl bromide, Telone, and nonfumigated. Each subplot was divided into two sub-subplots, one with weed control and one without weed control. Plant biomass was higher in plots with organic amendments than in nonamended plots. There were no differences in marketable pepper and watermelon yields between organic amended and nonamended plots during the 1998–99 and 1999–2000 seasons, respectively. However, higher pepper yields were produced from organic amended plots in the 1999–2000 season. Soil pH and Mehlich 1-extractable P, K, Ca, Mg, Zn, Mn, Fe, and Cu were higher in organic amended plots than in nonamended control plots. Soil organic matter concentration was 3-fold higher in amended soil than in nonamended soil. Effects of soil sanitation and weed management varied with crop and season. The methyl bromide and Telone treatments produced higher yields than soil solarization. In general, weed control did not affect plant biomass and yield for any of the crops and seasons. The results suggest that annual organic amendment applications to sandy soils can increase plant growth and produce higher or comparable yields with less inorganic nutrient input than standard fertilization programs.**

Methyl bromide is scheduled to be unavailable to U.S. vegetable growers in 2006. The ban of methyl bromide is projected to cost Florida fresh fruit and vegetable growers over $636 million in lost revenue (Spreen et al., 1995). Much of the loss is attributed to decreased acreage and production that would arise in the absence of methyl bromide as a soil fumigant. Tomato (*Lycopersicon esculentum* Mill.) acreage in Florida is expected to decrease by 50% and overall production by >60% (Spreen et al., 1995). Chemical alternatives such as the combination of fumigants Telone (1,3-dichloropropene) + chloropicrin with the herbicide Tillam (pebulate) are more expensive and may also be subject to future restrictions. Nonchemical alternatives such as solarization are as yet largely unproven but do offer promise of sustainable solutions. Solarization with clear plastic and UV-absorbing clear plastic can raise soil temperatures above the thermal death point for most weed seedlings to 45 °C (Horowitz, 1980). Soil moisture increases soil heat conductivity and sensitizes seeds to high temperatures. Clear plastic mulch decreased pigweed (*Amaranthus retroflexus* L.) populations within 2 weeks to <10% for 1 year (Horowitz et al., 1983), demonstrating the sensitivity of annual weeds to solarization. Solarization has also been demonstrated to be effective for yellow and purple nutsedge (*Cyperus esculentus* L. *and C. rotundus* L.), which are difficult to control with conventional methods (Chellemi, 1995).

Florida soils are generally sandy and low in organic matter, nutrients, and water-holding capacity, and therefore have inherently low fertility. The addition of organic matter has been shown to enhance their overall ability to retain both nutrients and water, and ultimately to improve plant growth and yields (Ozores-Hampton et al., 1998). In 1999, 23.8 × 10^6 t of solid waste was produced in Florida (4.3 kg daily per person), twice the national average (Glenn, 1999). Florida generates a variety of nonhazardous organic wastes, for which land application appears to be a viable option. These include biosolids, animal wastes, food wastes, yard trimming wastes, and municipal solid wastes (Smith, 1995). Many of these materials have use in agriculture.

Florida is a major vegetable-producing state, with 121,000 ha under cultivation each year (FASS, 2000). Minimizing fumigant and fertilizer leaching or runoff has become important due to potential negative environmental impacts. Soil amendments made from waste materials can also play a significant role in the development and maintenance of soil organic matter and increased water and nutrient holding capacity (Parr and Hornick, 1992). Additionally, some waste materials may be useful in weed management, since phytotoxic substances such as ammonia in biosolids can cause delayed seed germination, or weed seedling and plant death, and the heat and carbon dioxide released during decomposition of biosolids can cause weed stunting and chlorosis (Ozores-Hampton, 1998).

The objectives of this study were to evaluate the effects of soil solarization and long-term organic amendment application on pepper and watermelon growth and yield, and on soil chemical and physical properties.

Materials and Methods

The field experiments were conducted during 1998 and 1999 at the University of Florida's Southwest Florida Research and Education Center in Immokalee. The soil was Immokalee fine sand (sandy, siliceous, hyperthermic Arenic Haplaquods). The basic design of main plot organic amendments and subplot fumigation had been maintained since 1993 (Table 1). Different organic amendments

Table 1. History of organic amendments applied to the soil of field site in Immokalee, Fla., during 1993 to 1997 seasons.

Year	Organic amendments	Rate (Mg·ha^{-1})	Source in Florida
1993	Municipal solid waste compost	180	Broward County
1994	Biosolids	7.5	Tampa
1995	Yard trimmings/biosolids compost	22.5	Palm Beach
1996	Yard trimmings/biosolids compost	45	Palm Beach
1996	Cow manure	27	Palm Beach
1997	Yard trimmings/biosolids compost	45	Palm Beach

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were applied every year to simulate grower organic amendment availability throughout the long-term application. The present experiment used three levels of treatments in a split-split-split experimental design with four replications of each treatment combination. There were 1) two main plot treatments (amendments), consisting of one application of biosolids or an untreated control; 2) three (1998) or four (1999) subplot treatments (soil sanitation), consisting of methyl bromide and Telone located in the fumigated section of the subplots and solarization and nonsoil sanitation located in the nonfumigated section of the subplots; and 3) two sub-subplot treatments, with or without weed control.

Biological and chemical biosolids characteristics. Class B biosolids (anaerobic biological digestion and mechanical dewatered) were obtained from the Miami-Dade Water and Sewer Department, Miami, Fla. Three samples were taken two weeks before biosolids were field-applied, and analyzed for chemical and physical properties at the Soil and Water Science Department, Univ. of Florida, Gainesville. Moisture content was estimated by oven-drying 10 g (wet weight) at 105 °C for 24 h. Total N and C concentrations were measured in biosolids samples that were air-dried for 4 d, ground in a Spex 8000 mixer/mill, and combusted at 1010 °C in a Carlo-Erba NA-1500 C–N–S analyzer. The biosolids samples were acid-digested and analyzed by inductively coupled argon plasma spectroscopy (ICAP). Total nutrients and trace metals were analyzed according to EPA Method 3050 (USEPA, 1990). Electrical conductivity (EC) and pH were measured using a 2:1 (by volume) water-to-soil suspension.

Field experiments. Peppers ‘X 3R Aladdin’ (Peto Seed, Saticoy, Calif.) were grown in 1998–99 and 1999–2000 with watermelon ‘Summer flavor 800’ (Abbott and Cobb Inc., PA) as a second crop in the 1999–2000 season. No second crop was grown in the 1998–99 season. Solarization was performed on raised beds that were formed in the summer each year, beginning on 23 July 1998 and 1 June 1999, and continuing for 60 and 90 d, respectively, using clear high-density 0.75-mil polyethylene containing UV light inhibitors (Sonoco Products Co., Orlando, Fla.). Solarization was extended in the second year to allow better weed control for yellow and purple nutsedge. Biosolids were applied at bed formation (23 July 1998 and 1 June 1999 for solarization plots and 10 Sept. 1998 and 30 Aug. 1999 for the rest of the plots) at the rate of 37 and 48 Mg·ha^{-1} for each treatment for the 1998–99 and 1999–2000 season, respectively, based on crop nutrient requirements (Hochmuth et al., 1998). Higher rates of biosolids were applied during the second year to account for the watermelon crop. Soil fumigation treatments with methyl bromide and chloropicrin (98:2) were applied on 10 Sept. 1998 and 30 Aug. 1999. Methyl bromide was applied at the rate of 336 kg·ha^{-1}. Telone C35 (Dow AgroSciences), consisting of 61% dichloropropene and 35% chloropicrin, was applied at the rate of 327 kg·ha^{-1} on 30 Aug. 1999. Immediately after fumigation treatments were applied, all beds were covered with white-faced black polyethylene mulch, including beds that were covered previously with clear plastic for solarization.

Pepper plants were transplanted on 24 Sept. 1998 and 5 Oct. 1999. Plants were transplanted into raised beds 0.81 m wide, 0.1 m high, with 1.8 m between centers. Soil sanitation treatment subplots were 30 m long and weed control sub-subplot treatments were 15 m long. Pepper plant spacing was 25 cm in double rows separated by 45 cm, giving a plant population of 43,243 plants/ha. Yellow and green peppers were harvested three times during the 1998–99 season (28 Dec. 1998 and 2 Feb. and 20 Mar. 1999) and green pepper twice during the 1999–2000 season (11 Jan.and 7 Feb. 2000). On 28 Feb. 2000, watermelons were planted into the beds where the pepper crop had grown. Spacing was 1.8 m between plants giving a 3,136 plants/ha. Watermelons were harvest three times 22 May, 30 May, and 12 June 2000.

Plants were irrigated with a combination of drip irrigation and water table management or seepage irrigation. Drip irrigation tubing was a 0.25-mm biwall type with flow rates of 3.65 m^3·d^{-1} positioned in the center of the bed before the mulch application. Emission points were located on 30-cm spacing. Drip irrigation duration was 1 h, twice per day. Irrigation amounts were based on tensiometer readings to maintain soil-water potential greater than –15kPa. Tensiometers were located in the plant row at 30 and 60 cm depths in the organic amendment and nonorganic amendment plots and monitored twice per week.

Nitrogen was reduced by 50% during both season in the organic amendment plots to compensate for the N mineralized from the biosolids amendment. The Florida Department of Agriculture and Consumer Service interim best management practice (BMP) rule states that the contribution of plant-available N from organic materials shall be 50% of the total N concentration (FDACS, 1997). Additionally, mineralization studies of this type of biosolids concluded a 50% rate of mineralization per year (Obreza and Ozores-Hampton, 2000). Therefore, N contributions from biosolids applied at rates of 37 and 48 Mg·ha^{-1} for each treatment for the 1998–99 and 1999–2000 season, respectively, were 171 kg·ha^{-1} and 356 kg·ha^{-1}. Inorganic fertilizer was applied to the peppers by injection through the drip irrigation system at 428N–0P–178K and 377N–0P–157K kg·ha^{-1} for the nonbiosolids treatments and at 214N–0P–90K and 188N–0P–89K kg·ha^{-1} for the biosolids plots in the 1998–99 and 1999–2000 seasons, respectively. Fertilizer rates applied to the watermelon by injection though the drip irrigation system were 211N–0P–88K for the nonbiosolids and 106N–0P–44K for the biosolids plots in the 1999–2000 season. Under South Florida environmental conditions, a very low extractable amount of soil N is present in the soil; therefore we assume no N contribution from previous organic amendments application (Hochmuth et al., 1998). Plants were monitored for insects and diseases, and pesticides were applied as needed, according to Univ. of Florida Extension guidelines (Hochmuth et al., 1998).

Data collection. Two pepper shoots per plot were collected at 110 and 150 d after planting for the 1998–99 season and 30 and 60 d after planting for the 1999–2000 season and oven dried for 3 d at 65 °C to obtain dry weight per plant (fruit removed). One watermelon plant per plot was collected 30 d after planting for the 1999–2000 season for similar analysis. The yield of peppers was assessed according to USDA specifications of number and weight of extra-large, large, and medium fruit (USDA, 1997). Cull and colored pepper fruits were recorded. Total weight of the U.S. fancy, No.1, and No.2 marketable watermelon and culls per plot were used to assess watermelon yield for the 1999–2000 season (Powers, 1978). The area harvested from each sub-subplot was 15 m long every year.

Soil samples for nutrient analyses consisted of 10 composite soil cores 2.5 cm in diameter and 20 cm deep collected from each plot before the fall planting and after harvesting each crop in both years. Samples were oven-dried, passed through a 1-mm screen, and extracted with Mehlich-1 solution. The extract was analyzed for Ca, Mg, P, K, Cu, Mn, Fe, and Zn (Hanlon and DeVore, 1989). Soil pH was determined in a 1:2 dilution (v/v) with distilled water, and organic matter (OM) was determined by loss-on-ignition (Dellavalle, 1992). Fresh petiole sap concentrations for NO$_3$-N and K of the crops beginning at first flower buds and continuing until first harvest were assessed weekly using a Cardy ion meter (Spectrum Technologies, Inc., Plainfield, Ill.).

Data were subjected to analysis of variance (ANOVA) and mean separation using the Duncan’s multiple range test (SAS, 2000).

Results and Discussion

Biosolids analysis. Biosolids had an alkaline pH and moderate salt concentration, a C to N ratio <10, and contained from 4% to 6% N and 2% to 3% P (Table 2). The relatively low C to N ratios and high N concentration suggested that no soil N immobilization likely occurred after application and that 50% mineralization

Table 2. Chemical analysis of biosolids applied during 1998 and 1999 seasons.

Characteristics	1998	1999
Dry weight (%)		
C	32	36
N	4.4	5.7
P	2.2	2.7
K	0.10	0.14
Ca	6.4	6.0
Mg	0.64	0.83
Fe	1.06	1.32
Dry weight (mg·kg^{-1})		
Cd	7.5	7.2
Cu	492	627
Mn	45	40
Ni	44	153
Pb	118	98
Zn	1,051	1,395
Additional properties		
Moisture (%)	79	74
C to N ratio	7.3	6.4
PH	8.1	8.6
EC (DS·m^{-1})	12.9	14.5

Table 3. Influence of biosolid amendments on soild properties and nutrient levels.

Treatment	OM (%)	Nutrient level (mg·kg^{-1})								
		pH	P	K	Ca	Mg	Zn	Mn	Fe	Cu
June 1998										
Biosolids^{z}	2.8**	6.8**	351**	95*	4,782**	133**	NA^{y}	NA	NA	NA
Nonbiosolids	0.9	6.4	44	47	792	62	NA	NA	NA	NA
May 1999										
Biosolids	2.8**	6.3**	447**	37*	3,083**	91**	21.9**	28.6**	69.4**	15**
Nonbiosolids	0.8	5.7	50	26	338	31	2.5	5.9	17.2	6.7
October 1999										
Biosolids	2.5**	6.6	148**	21**	1,870**	26.4	29.6**	13.8**	67.9**	17.2*
Nonbiosolids	0.9	6.7*	52	11	321	26.9*	4.4	4.9	47.0	13.0
February 2000										
Biosolids	2.4**	6.5	162**	29	1,852**	135**	30**	10.1**	67.9**	15.7
Nonbiosolids^{x}	0.8	6.5	50	33	281	33	4.7	3.2	40.4	19.0
June 2000										
Biosolids	2.3**	6.6**	169**	24*	1,637**	115**	30**	9.1**	58.9*	5.9
Nonbiosolids	0.8	6.1	40	18	231	26	3.2	3.4	42.5	4.8

^{z}Biosolids = Class B biosolids (anaerobic biological digestion and mechanical dewatered) were obtained from the Miami-Dade Water and Sewer Department, Miami, Fla.

^{y}NA = not applicable.

^{x}Nonbiosolids = only inorganic fertilizer application.

^{NS**,*}Nonsignificant and significant at $P \leq 0.01$ or 0.05, respectively.

rates were expected in the first year (Obreza and Ozores-Hampton, 1999). The biosolids used in this study complied with the U.S. Environmental Protection Agency's criteria for land application for Class B (USEPA, 1999).

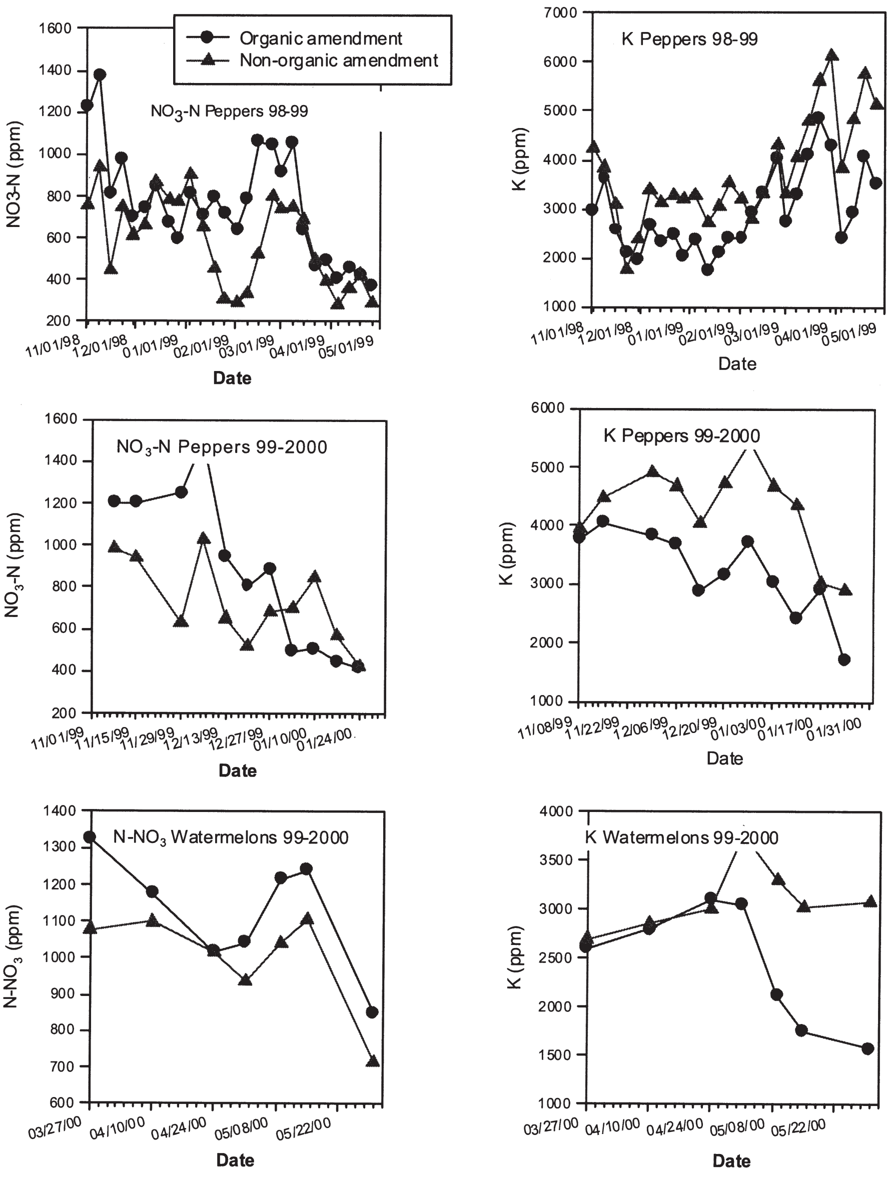
Soil analysis. Soil OM, pH, and Mehlich 1-extractable P, K, Ca, and Mg concentrations in 1998 and 1999, and Zn, Mn, Fe, and Cu in 1999 were higher in plots with organic amendments than in control plots (Table 3). Soil OM was 3-fold higher in biosolids plots than in nonamended plots, indicating the effects of long-term annual organic amendment application since 1993. Similar studies comparing traditional fertilizer application and compost only since 1990, composted plots were similar or higher in soil C, Ca, Mg, Cu, and Zn, although P and K were higher in traditional fertilizer plots (Warman, 2002; Warman, 1998; Warman and Havard, 1996).

Fresh petiole sap analysis. Measurements of pepper and watermelon sap nitrate were higher in the organic amendment plots than in nonamended plots, but lower than their sufficiency range for these crops (Fig. 1). Measurements of pepper and watermelon sap K were higher in the nonamended plots than in plots with biosolids, but above the sufficiency range for the crops (Fig. 1).

Plant growth. No interactions were observed among organic amendment, soil sanitation, and weed control treatments for any of the variables measured. Plant biomass was higher in the plots with organic amendments than without organic amendments for all crops and seasons (Table 4). Methyl bromide and nonfumigated plots produced a higher pepper biomass than solarized plots at 110 and 150 d after treatments (DAT) for the 1998–99 season. Nonfumigated plots produced the highest pepper biomass at 30 DAT for the 1999–2000 season. There were no differences in pepper biomass 60 DAT for the 1998–99 season and watermelon 30 DAT for the 1999–2000 season. Weed control did not affect plant biomass for any of the crops and seasons, except for pepper at 150 DAT for the 1998–99 season, when pepper plants were larger where weeds were removed.

Pepper yield. No interactions occurred either season among organic amendment, soil sanitation, and weed control treatments for

Fig. 1. Petiole SAP testing for pepper and watermelon seasons 1998–99 and 1999–2000.



any of the variables measured. No differences were found between organic amendment and nonamended plots during the1998–99 season, despite a 50% reduction of N and K application in amended plots during the crop season (Table 5). Soil fumigation with methyl bromide significantly improved yield over solarization in the 1998–99 season. Plants in nonfumigated or methyl bromide fumigated plots produced more marketable and extra-large peppers than solarized plots. Plants in nonfumigated plots yielded the most large size peppers. Highest yellow pepper yield was harvested from methyl bromide treated plots, followed by solarized and nonfumigated plots. Weed control did not affect plant yields during the 1998–99 season.

Table 4. Effect of biosolids amendments, soil sanitation treatment, and weed control on plant biomass during 1998 and 1999 seasons, on selected days after transplanting (DAT).

	Dry biomass (g)				
	Pepper 1998		Pepper 1999		Watermelon 1999
Treatment	110 DAT	150 DAT	30 DAT	60 DAT	30 DAT
Amendment					
Biosolids[z]	36.4**	42.3*	3.3**	19.7*	12.3**
Nonbiosolids[y]	24.3	31.2	1.0	10.5	4.0
Soil treatment					
Solarization	27.7b[x]	33.2b	1.7b	13.8	8.2
Nonfumigated	31.5a	39.5a	3.0a	16.6	9.2
Methyl bromide	33.4a	38.4a	1.8b	14.9	6.8
Telone	NA[w]	NA	1.9b	15.1	8.5
Significance	*	**	**	NS	NS
Weed control					
Yes	28.4	38.4**	2.2	14.9	NDA[v]
No	31.6	34.3	2.1	15.2	NDA

[z]Biosolids = Class B biosolids (anaerobic biological digestion and mechanical dewatered) were obtained from the Miami-Dade Water and Sewer Department, Miami, Fla.

[y]Nonbiosolids = only inorganic fertilizer application.

[x]Means in a columns with the same letter are not significantly different by Duncan's multiple range test ($P \leq 0.05$).

[w]NA = not applicable.

[v]No data available.

NS,**,*Nonsignificant and significant at $P \leq 0.01$ or 0.05, respectively.

Table 5. Effects of biosolids amendments, soil sanitation treatment, and weed control on pepper yields during 1998 and 1999 seasons.

	Total yield [(three harvests) Mg·ha^{-1}					
Treatment	Marketable yield	Extra-large	Large	Medium	Yellow	Culls
1998						
Amendment						
Biosolids	27.3	13.7	8.2	3.6	2.3	8.4
Nonbiosolids	22.3	10.6	7.1	2.3	1.7	7.4
Significance[y]	NS	NS	NS	NS	NS	NS
Soil treatment						
Solarization	21.5 b[z]	9.4 b	7.3 b	3.5	2.2 b	8.6
Nonfumigant	26.7 a	13.9 a	8.2 a	3.1	1.4 c	8.3
Methyl bromide	27.8 a	14.1 a	7.3 b	2.6	2.9 a	7.1
Significance	**	**	*	NS	**	NS
Weed control						
Yes	24.3	12.0	7.2	2.9	1.9	7.9
No	25.1	12.3	7.8	3.0	2.1	7.9
Significance	NS	NS	NS	NS	NS	NS
1999						
Amendment						
Biosolids[y]	27.1	12.3	8.5	6.2	NA[x]	3.9
Nonbiosolids[w]	17.3	7.6	5.9	3.8	NA	1.9
Significance	**	*	*	**	NA	NS
Soil treatment						
Solarization	20.5 b	8.6 b	6.9	4.9	NA	2.7
Nonfumigant	22.0 b	11.0 a	6.2	4.8	NA	3.1
Methyl bromide	22.0 b	8.8 b	8.9	4.3	NA	3.5
Telone	24.2 a	10.8 a	7.7	5.7	NA	2.5
Significance	**	*	NS	NS	NA	NS
Weed control						
Yes	23.1	10.8	7.2	5.1	NA	3.0
No	21.5	9.3	7.3	4.9	NA	2.8
Significance	**	**	NS	NS	NA	NS

[z]Means in a columns with the same letter are not significantly different by Duncan's multiple range test ($P \leq 0.05$)

[y]Biosolids = Class B biosolids (anaerobic biological digestion and mechanical dewatered) were obtained from the Miami-Dade Water and Sewer Department, Miami, Fla.

[x]NA = not applicable.

[w]Nonbiosolids = only inorganic fertilizer application.

NS,**,*Nonsignificant and significant at $P \leq 0.01$ or 0.05, respectively.

Yields of vegetable crops in Florida using soil solarization have been comparable to those obtained with methyl bromide in the first crop of the season, but not in the second crop due to insufficient control of root-knot nematodes (Chellemi, 1995, Chellemi et al., 1997a, 1997b). Therefore, these authors did not recommend soil solarization as a universal replacement for methyl bromide.

For the 1999–2000 season, pepper plants in plots receiving organic amendments yielded more marketable extra-large, large, and medium fruit than the nonamended control (Table 5). Similar studies with organic amendment (compost only) application compared with traditional fertilizer application in sandy soils for >3 years resulted in comparable or higher yields with organic amendment in cabbage, potato, sweet corn, tomato, and carrot (Warman, 1998; Warman and Havard, 1996). Highest marketable yields and most extra-large peppers were harvested from plants in plots treated with Telone C35 and nonfumigated plots than in solarized and methyl bromide plots. There were no differences among soil treatments in large, medium, and cull pepper production. Marketable yield and extra-large pepper yield were greatest from the plots where weeds were removed. Large, medium, and cull pepper yields were not affected by weed control.

Watermelon yield. No interactions or main effects occurred among organic amendment, soil sanitation, or weed control treatments for any of the variables measured (Table 6). No differences were found in organic amendment and nonamended plots during the 1999–2000 season, despite a 50% reduction in N and K application to amended plots during the crop season. Higher watermelon culls yields were harvested from plants in plots with organic amendments than in nonamended plots. There were no differences in cull yields among soil treatments or weed control.

Table 6. Effects of biosolids amendment, soil sanitation treatment, and weed control on marketable watermelon yields and culls during 1999–2000 season.

Parameter	Marketable yield [(three harvest) Mg·ha^{-1}]	Culls [(three harvest) Mg·ha^{-1}]
Amendment		
Biosolids[z]	68.5	1.5
Nonbiosolids[y]	69.5	0.8
Significance	NS	*
Soil treatment		
Solarization	65.4	0.7
Nonfumigant	66.3	0.7
Methyl bromide	72.3	1.9
Telone	72.0	1.3
Significance	NS	NS
Weed control		
Yes	72.7	1.2
No	65.3	1.1
Significance	NS	NS

[z]Biosolids = Class B biosolids (anaerobic biological digestion and mechanical dewatered) were obtained from the Miami-Dade Water and Sewer Department, Miami, Fla.

[y]Nonbiosolids = only inorganic fertilizer application.

NS,**,*Nonsignificant and significant at $P \leq 0.01$ or 0.05, respectively.

While effects of soil fumigation treatment and weed control varied with crop and season, soil sanitation treatments such as Methyl bromide and Telone fumigation produced higher yields than soil solarization. In general, weed control did not affect plant biomass and yield for any of the crops and seasons. Additionally, consistent benefits were obtained from the yearly applications of organic amendments. Soil organic matter and nutrient levels were increased in plots that had received long-term amendments. Pepper yield was either improved in amended plots (1999–2000 season) or showed no difference from nonamended plots (1998–99 season), despite the fact that amended plots received 50% less synthetic N and K application than nonamended plots. In this instance, organic amendments appeared to be viable substitutes for synthetic fertilizers, and provided long-term benefits to soil quality as well.

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