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Utilization of Organic Waste Composts in Vegetable Crop Production Systems

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Abstract

Composts derived from various organic wastes, including municipal solid waste (MSW), were evaluated for N fertilizer substitution potential, capacity to control weeds in vegetable row alleyways, as an alternative to polyethylene mulch on beds, and as a soil amendment in intensive crop production systems. When compared to plots without compost, bell pepper (Capsicum annuum) yields from plots amended with composts were higher at 0 and were similar at 50 or 100% inorganic fertilizer rates (100% equalled growers' fertilizer regimes). Cucumber (Cucumis sativus), seeded after the final bell pepper harvest, produced higher yields on plots with residual compost. Tomato (Lycopersicon esculentum) grown on plots amended with sugarcane filtercake compost produced higher marketable yields and larger fruit size at 0, 50, or 100% inorganic fertilizer rates (growers' fertilizer regime) than when grown on unamended plots with the same inorganic fertilizer treatments. Plots mulched with compost, with bed sides stabilized by living mulches, had higher bell pepper stands (losses attributed to Phytophthora capsici) than plots of beds covered with polyethylene mulch (the conventional material). However, polyethylene mulched plots resulted in higher marketable bell pepper yields than compost mulched plots. Winter squash (Cucurbita pepo), seeded on the compost plots after bell pepper harvest, had higher plant stands and yields similar to squash seeded on the polyethylene mulched plots. MSW compost, particularly immature compost, spread on bed alleyways provided weed control similar to or better than that from herbicides. Concentrations of NO_3-N and NH_4-N in the leachates from one of five composts peaked at 246 and 29 mg/l, respectively, after applying 300 to 400 ml of water. Applications of 1500 ml water (equivalent to a 34 cm rain) leached 3.3 to 15.8% of the total N in the composts. Under field conditions, the N mineralization rate of the five composts ranged from -2.1 (attributed to N immobilization by immature compost) to 9.1%. These investigations suggest that composts can play important roles in vegetable cropping systems.

The number of landfills in the USA has declined from 8000 in 1988 to 3197 in 1995, whereas composting facilities for yard trimmings have increased from 750 in 1988 to 3316 in 1995 (Steuteville, 1996). Municipal solid waste (MSW) compost production is becoming an integral part of solid waste management schemes throughout the USA and other parts of the world. Eggerth (1996) reported an increase from two MSW composting facilities in the United States in 1984 to 18 in 1994. However, in 1993, only 3.1% of the MSW waste generated in the United States was composted, 18.6 % was recycled, 15.9% incinerated, and 62.3% was land filled (Eggerth, 1996). Of the 20.3 million t of MSW produced in Florida in 1992, nearly 60% were biodegradable organics (Florida DEP, 1993; Smith, 1994). MSW compost facilities and compost production rates should dramatically increase in the future because new state and/or local regulations are designed to reduce disposal of biodegradable materials into landfills, cost effective compost facilities have been developed by the private and public sectors to produce high quality end products, and acceptance of compost by commercial agricultural has increased.

Rynk (1992) has defined composting as "a biological process in which microorganisms convert organic materials such as manure, sludge, leaves, paper, and food waste into a soil-like material called compost". Compost feedstock compositions can consist of mixtures of yard trimmings, wood chips, paper, food wastes, and sewage sludge (biosolids). Production methods vary from inexpensive and simply managed static piles to very expensive, highly technical, and computerized in-vessel operations as described by Rynk (1992) and Hughes (1980). Feedstock materials, composition, method of production, and size and time of production can affect the chemical, biological, and physical quality characteristics of compost. He et al. (1995) reported differences in physical and chemical properties of 10 composts collected from production facilities throughout the United States. Compost application to commercial vegetable cropping systems is relatively new in the USA. Research has suggested that composts can serve as soil amendments to improve soil water and nutrient holding capacity, particularly in sandy soils, increase soil organic matter, and, ultimately, improve plant growth and yields. Compost can be utilized as an alternative to polyethylene mulches, serve as an alternative weed control material, and increase soil fertility in vegetable crop production systems. The purpose of this paper is to present information on MSW composts evaluated as mulches and soil amendments in vegetable production systems in Florida.

Compost as an Alternative to Polyethylene Mulch

Polyethylene is utilized as a mulch in many commercial vegetable crop production systems in Florida. It is used as a cover on raised beds to increase or decrease soil temperatures, conserve soil moisture, block weed growth, and reduce inorganic nutrient leaching, particularly from heavy rainfall (>100 cm/year) that occurs in subtropical and tropical production areas, and it serves as a vapor barrier for soil fumigants such as methyl bromide. In Florida alone, more than 9.5 million kg of polyethylene were used for agricultural production (Servis, 1992). Disposal of plastic in landfills or by direct burning with propane is costly for growers. Therefore, we investigated the potential use of MSW compost in combination with living mulches as an alternative to polyethylene mulch in an intensive vegetable crop production system of southern Florida.

Traditional raised beds for bell pepper production in southern Florida were established (Hochmuth, 1988) with drip irrigation installed in the center of each bed. Beds were covered with polyethylene mulch (control) or 224 t/ha of either woodchips, a MSW compost, or a compost from sewage sludge (biosolids) and yard trimmings. Three cover species were compared for stabilizing effects on bedsides. Vertical bedsides were sodded with Saint Augustine grass (*Stenotaphrum secundatum*), planted with perennial peanuts (*Arachis glabrata*) seedlings, or sown with forage peanuts (*Arachis* sp.) prior to transplanting. Bell peppers "PR-3002" were transplanted, yield and fruit size data collected, plants removed, and a subsequent winter (butternut) squash (*Cucurbita pepo* cv "Waltham") was sown to evaluate residual effects from the compost. Experimental methods and compost chemical and nutrient characteristics were reported by Roe et al. (1994).

As expected, the sewage sludge/yard trimmings waste compost had higher concentrations of N, P, and K and other macro and micronutrients than the MSW compost (Roe et al., 1994). *Phytophthora capsici* caused a greater plant stand reduction in polyethylene mulched plots than in organic mulched plots (Table 1). However, total pepper yields were highest and fruit size was larger in the polyethylene mulch plots than in the organic cover plots. Bed sides were stabilized by each living mulch, but bell pepper yields did not differ

Table 1. Bell pepper and squash plant stand percentages and yields as influenced by polyethylene or organic mulches and vertical bed sides stabilized by living mulches. Squash was planted on beds after bell pepper harvest

Mulch	Bell pepper							Squash			
	Stand DAT[1]		Shoot	Marketable fruit yield		Early[2] fruit	Size	Stand 28 DAS	Marketable fruit yield		Size
	101	107									
	------ % ------		g	t/ha	g/plant[3]	%	g/fruit	%	t/ha	g/plant	g/fruit
Polyethylene (PL)	18	2	28.1	6.99	329	98	206	62	9.51	973	436
Living mulch (LM)											
Floratam grass	73	54	10.2	2.86	116	62 b[4]	174	56 a[4]	8.95	871 a	556
Jade grass	72	50	11.2	3.23	136	67 ab	179	56 a	9.56	943 a	535
Perennial peanut	63	45	11.2	2.51	114	69 ab	182	47 b	7.79	869 a	574
Seeded forage peanut	62	40	12.1	3.18	142	78 a	189	59 a	7.19	698 b	537
Organic mulch (OM)											
Municipal solid waste	71	51	11.3	2.95 b	122 b	70 ab	174	60 a	8.18	768 b	541
Wood chips	62	43	8.8	1.86 c	86 b	59 b	192	50 b	7.87	819 ab	554
Sewage sludgeyard trimmings	70	49	13.4	4.03 a	174 a	77 a	176	54 b	9.07	948 a	557
Interaction: OM × LM	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Contrast: PL vs. other	**	**	**	**	**	**	**	NS	NS	NS	**

[1] DAT = days after transplanting; DAS = days after seeding
[2] Percentage of fruit in first harvest
[3] Total of two harvests: 28 Dec 1992 and 15 Jan 1993
[4] Mean separation in columns within mulch types by Duncan's multiple range test, 5% level
NS,** Nonsignificant, significant at $P = 0.01$

(Source: Roe et al., 1994)

among the treatments (Table 1). Each living mulch maintained bed integrity for the duration of winter squash cultivation. Squash plant stands and fruit yields from organic mulched plots were similar to those from the polyethylene mulched plots (Table 1). However, fruit size (g/fruit) was significantly heavier from the organically mulched plots than from the polyethylene mulched plots.

These results suggest that organic mulches in conjunction with living mulches can serve as an alternative to polyethylene mulch. Organic mulches can reduce infection by certain soil borne organisms, enhance soil fertility, increase soil organic matter, and reduce weed growth. However, to achieve yields similar to or higher than a polyethylene mulched crop, a production system will have to take into account organic mulch characteristics, rate utilized, soil borne organisms present, and the vegetable crops grown.

Composts as Soil Amendments

Nutrients are essential components in any vegetable production system. In intensive production systems, inorganic forms of nutrients are applied either pre or post sowing or transplanting. Systems with drip irrigation utilize fertigation as a method of delivering nutrients. With the environmental concerns of groundwater contamination from "over fertilization" in intensive agricultural production areas, particularly in areas with sandy soils such as in south Florida, alternative or partial alternatives to utilization of inorganic fertilizers are being investigated. "Best Management Practices" are being developed for the production systems in these areas.

Compost applied as a soil amendment can improve soil organic matter content, water and nutrient retention in soils susceptible to leaching, and stabilize soil pH. Moreover, composts are sources of macro- and micronutrients. When compared to compost use in temperate climates, however, the benefits can be reduced in hot humid climates because organic matter decomposition is accelerated (Dick and McCoy, 1993).

Our investigation determined the effects on vegetable yields of an MSW compost and a sugarcane filtercake (a sugarcane processing mill waste by-product; LeGrand, 1972) compost applied as soil amendments. Bell peppers were grown on raised beds with and without compost (sewage sludge/yard trimming waste at 134 t/ha) in south Florida on a Riviera fine sandy soil (loamy, siliceous, hyperthermic Arenic Glossaqualf). Compost chemical and nutrient composition are reported in Table 2. Plots were fertilized at 0, 50, or 100% of the growers' standard rate (71N-39P-44K kg/ha broadcast and 283N-278K kg/ha banded in the center of each bed) and covered with polyethylene mulch.

Table 2. Nutrient and heavy metals concentrations of a sewage sludgeyard trimmings compost

C	N	P	K	Ca	Mg	pH	EC
%							dS/m
33.8	1.85	0.80	0.43	3.83	0.24	7.2	4.44
Fe	**Mn**	**Zn**	**Cu**	**Cd**	**Pb**	**Ni**	
mg/kg							
7500	59	208	131	3.2	38	11	

Marketable bell pepper yields and mean fruit size increased as fertilizer rates increased (Table 3). Compared to yields from plots that did not receive compost, bell pepper yields from plots amended with compost were higher when fertilizer was not applied and similar when it was applied at either 50 or 100% of growers' standard fertilizer rate. Regardless of fertilizer rates, fruit sizes were larger in plots amended with compost when compared against plots without compost After pepper harvest, plants were removed, liquid fertilizer was applied through an injection wheel, and "Valient" cucumbers (*Cucumis sativus*) were sown. Marketable yields did not respond to fertilizer residuals (Table 3). However, plots that were previously amended with compost had higher marketable yields than plots without compost (Table 3).

Tomato (*Lycopersicon esculentum*) "Sunny" plants were established on plots amended or unamended with compost (sugarcane filtercake at 224 t/ha). The plots were on raised beds and covered with polyethylene mulch and received 0, 50, or 100% of the standard fertilizer rate (153N-134P_2O_5-280K_2O kg/ha). Experimental methods were reported by Stoffella and Graetz (1996). Chemical composition of the compost is indicated on Table 4. Total and early marketable tomato yields and mean fruit size were higher in plots amended with compost than in unamended plots at equal fertilizer rates (Table 5).

Table 3. Marketable bell pepper and cucumber yields and fruit size as influenced by fertilizer rate and compost

Treatment	Bell pepper				Cucumber		
	X-large	Large	Total	Fruit weight	Total marketable yield	Fruit size	culls
	t/ha	t/ha	t/ha	g/fruit	t/ha	g/fruit	%
Fertilizer rate[1]				No compost			
0	8.5	11.3	19.8	160	20.4	320	30.5
50	18.6	12.5	31.1	193	24.6	321	31.3
100	19.5	12.0	32.0	197	23.3	326	48.2
Fertilizer rate				Compost (134 t/ha)			
0	17.8	12.5	30.3	182	28.0	326	40.8
50	25.5	12.5	35.7	205	26.4	322	46.0
100	22.7	9.2	31.5	208	25.8	333	43.7
Significance							
Compost	**	NS	NS	**	**	NS	NS
Fertilizer	Q*	NS	NS	Q*	NS	NS	NS
Compost × Fertilizer	NS	*	**	NS	NS	NS	NS
LSD[2]		1.8	3.5				

[1] Fertilizer rates expressed as percent of growers' standard rate; 100% rate is equivalent to $354N\text{-}39P_2O_5\text{-}322K_2O$ (kg/ha)
[2] LSD (0.05) value for fertilizer × compost interaction
NS, *, ** Nonsignificant, significant at P = 0.05 or 0.01, respectively; Q = Quadratic

Table 4. Nutrient and heavy metal concentrations, and electrical conductivity (EC) of sugarcane filtercake compost

C	N	C/N ratio	P	K	Ca	Mg	pH	EC
%	%		%	%	%	%		dS/m
34.0	2.52	13.5	0.94	0.08	5.30	0.34	6.66	2.07

Mn	Zn	Cu	Cd	Pb	Ni	Na
mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
324	239	218	1.75	23	5.75	309

(Source: Stoffella and Graetz, 1996)

Table 5. Marketable tomato yield and fruit weight as influenced by fertilizer rate and sugarcane filtercake compost

Compost	Fertilizer rate[1]	Marketable yield		Fruit size
		Early[2]	Total	
- t/ha -		---------------- kg/ha ----------------		- g/fruit -
0	0	566	2212	150
224	0	3486	12188	180
0	50	524	6535	195
224	50	2658	15008	194
0	100	1972	6568	164
224	100	2920	16979	192
Significance				
Compost		**	**	**
Fertilizer		NS	**	**
Compost × Fertilizer		NS	NS	*

[1] Fertilizer rates expressed as percent of growers' standard, 100% rate is equivalent to 153N-134P_2O_5-280K_2O (kg/ha)
[2] Early marketable yields are totals of the first three harvests
NS, *, ** Nonsignificant, significant at $P = 0.05$ or 0.01, respectively

(Source: Stoffella and Graetz, 1996)

These results suggest that sandy soils amended with compost will produce higher vegetable crop yields than unamended soils, regardless of inorganic fertilizer level. Compost may provide supplemental nutrients, particularly when only small quantities of inorganic fertilizer are applied. However, at higher inorganic fertilization rates, compost can improve water retention, reduce nutrient leaching, and/or provide an additional source of organic matter, particularly in infertile soils of southern Florida.

Alternative Weed Control with Compost

By directly competing for light, nutrients, and water or by harboring insects, diseases, and other pests that can damage the crop, weeds can be a major obstacle to high crop yields. Polyethylene mulch has been an effective method for controlling most weed species, except nutsedge, in vegetable crop production systems throughout the world. However, hand hoeing, mechanical cultivation, or herbicides are used to control weeds in the vegetable crop alleys between the mulched beds. These methods can be costly in a vegetable crop production system. Additionally, herbicides can have negative environmental implications.

MSW compost was evaluated as a potential mulch to suppress weeds in vegetable crop alleys. Weed control was compared in vegetable crop alleys that were sprayed with glyphosate, mulched with MSW compost at 224 t/ha, or untreated. The percentages of weed ground coverage 16 and 73 days after treatment on compost-mulched plots were similar to those of herbicide-treated plots (Table 6). Both compost-mulched and herbicide-treated plots had significantly lower weed ground coverage than the untreated plots.

Table 6. Percent ground coverage by all weeds and by broadleaf weeds, and total weed weights as influenced by herbicide and municipal solid waste compost

Weed control method	Ground coverage: Days after application, All weeds: 16	73	Broadleaf weeds	Weed dry weight
	%	%	%	g
Control	56 a[1]	72 a	24 b	28.4 a
Herbicide	27 b	49 a	24 b	9.1 b
Compost	17 b	21 b	85 a	28.3 a

[1] Mean separation by Duncan's multiple range test, 5% level

(Source: Roe et al., 1993)

Immature compost applications or compost water extracts are phytotoxic to emergence and growth (Jimenez and Garcia, 1989; Shiralipour et al., 1991). Plant phytotoxicity from immature compost might be associated with high fatty acids (acetic, propionic, isobutyric, butyric, and isovaleric) concentrations (DeVleeschauwer et al., 1981) or ammonia concentrations (Wong, 1985). Therefore, immature MSW compost was evaluated for its potential to control weeds in vegetable crop alleys. The experiment compared vegetable alley plots sprayed with a herbicide (paraquat), plots mulched with four depths of immature compost (3.8, 7.5, 11.3 and 15 cm), and plots left untreated (weedy control). Compared to the weedy control, the herbicide and all immature compost depths reduced percent weed ground cover for more than 240 days (Fig. 1).

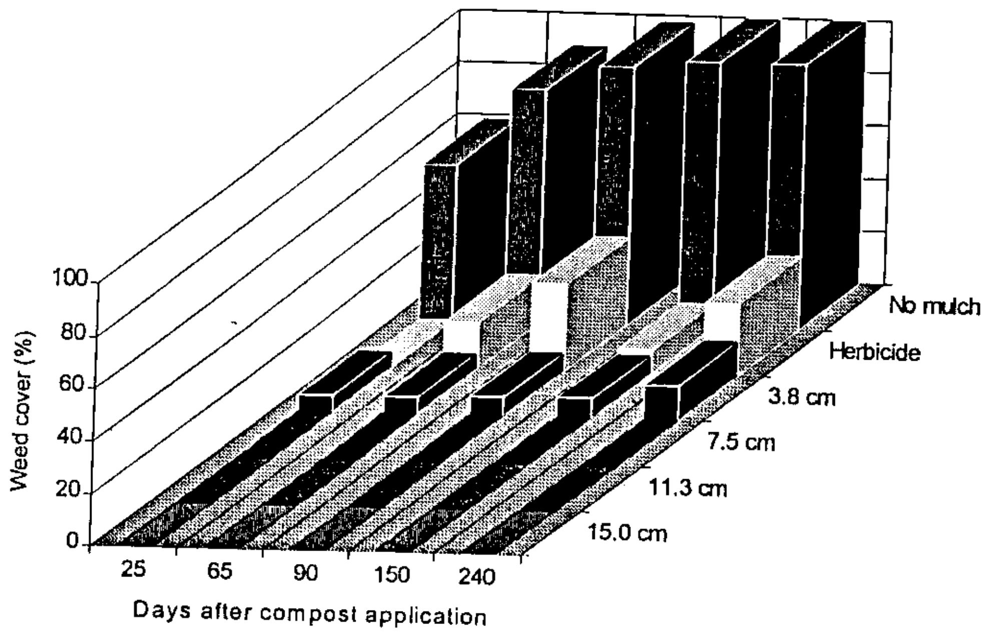

Fig. 1. Effects of immature compost mulch on weed control

The degree of control obtained, particularly from immature compost, suggests that applications may be alternatives to herbicides or inter-row cultivations for weed control in vegetable crop alleys. Moreover, the immature compost will eventually mature in the field and can be soil incorporated into raised beds on which vegetable crops can be established with the potential benefits of increased soil organic matter and nutrients and reduced soil borne pathogen populations.

Nutrient Leaching from Compost Amended Soils

Compost application methods, placement, and rates for vegetable crop production systems are dependent on the crop grown, desired effect, and expected beneficial duration (one or more cropping seasons). Rates can vary from 25 to more than 250 t/ha of material with N contents up to 4%.

In the USA, untreated groundwater is the source of drinking water for 50% of the total population and 97% of the rural area population (National Research Council, 1978). Nitrate-N concentrations higher than 10 mg/l are the maximum contamination standard for drinking water quality (USEPA, 1987). High compost application rates have been reported to result in leaching of NO_3-N, NH_4-N, and PO_4-P from the topsoil. Leaching subsequently results in groundwater contamination (Peverly and Gates, 1994). Daliparthy et al. (1995) have reported leaching of NO_3-N into the groundwater from applications of organic wastes such as sewage sludge and manures. Nitrate leaching has also been reported following applications of inorganic fertilizer (Goodrich et al., 1991; Lea-Cox and Syvertsen, 1996).

Nutrients, particularly NO_3-N, are a concern in the agricultural coastal area of Florida because water tables are shallow, soils are sandy, and rainfall exceeds 100 cm/year. Therefore, we investigated the NO_3-N and NH_4-N leaching rates from five Florida compost sources [sugarcane filtercake (SF), sewage sludge (B), and three mixtures of municipal solid waste and sewage sludge (MSWB1, 2, and 3)] applied on the surface of an Oldsmar fine sand (sandy, siliceous, hyperthermic Alfic Haplaquods). The soil was in 7.5 cm diameter leaching columns which were covered with compost layers equivalent to 100 t/ha. Columns were leached with deionized water at 300 ml/day for five days (equivalent to 34 cm rainfall).

Over the five-day period, leachates reached concentrations of 246 mg/l of NO_3-N (Fig. 2) and 29 mg/l NH_4-N (Fig. 3). Leached nitrogen accounted for 3.3 to 15.8% of the total N among the composts. However, leachate concentrations of NO_3-N peaked after the application of only 300 to 400 ml of water (equivalent to 6.8 to 9.1 cm rainfall). Sewage sludge alone and sugarcane filtercake composts had the highest leaching rates and concentrations of NO_3-N. The investigation demonstrates that NO_3-N leaching should be considered when compost application rates and frequencies are determined, particularly on soils vulnerable to nutrient leaching.

Nitrogen Mineralization of Compost

Nitrogen mineralization is the biological process by which organic N is released as NH_4-N and NO_3-N. Nitrogen mineralization of compost is generally dependent on compost composition, maturity, and environmental

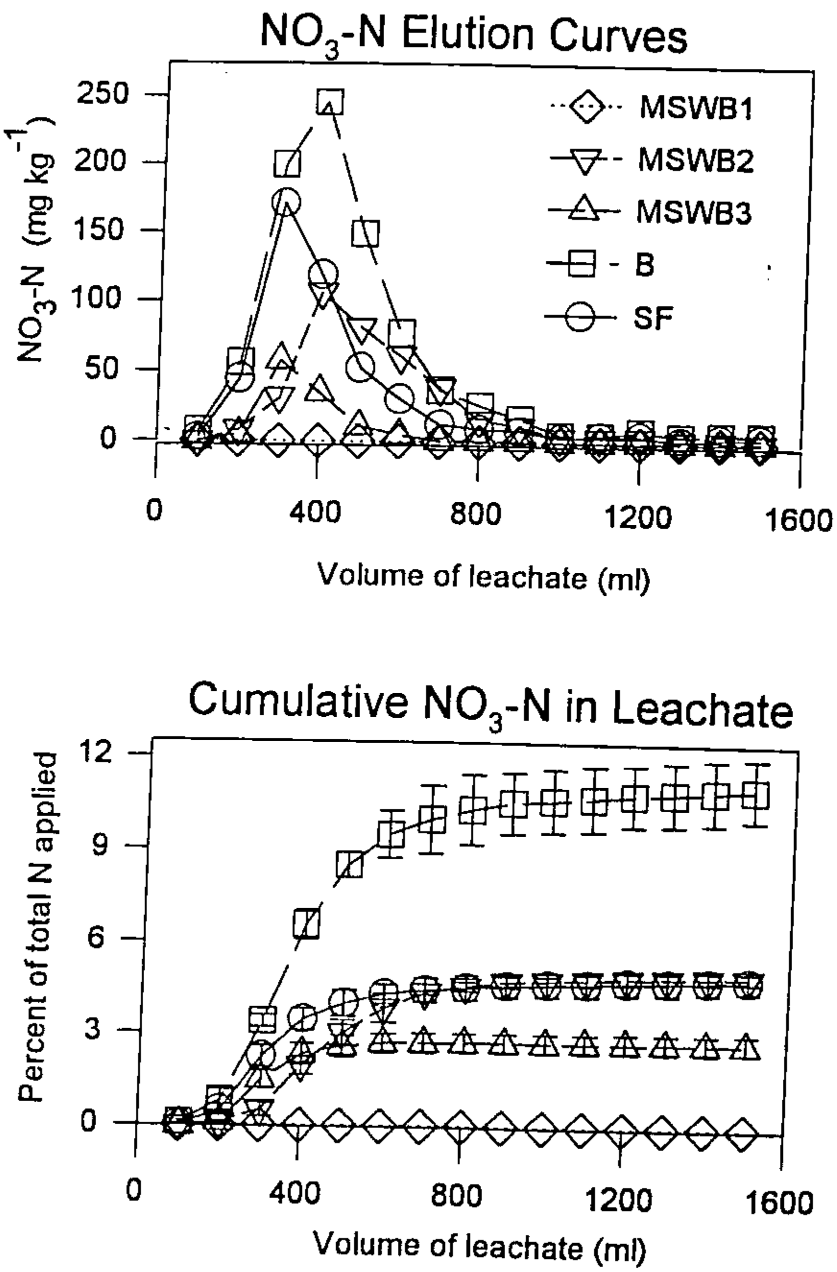

Fig. 2. Elution curves and cumulative leaching of NO_3-N from five compost-amended soil columns. The error bar at each data point represents the standard error of the mean

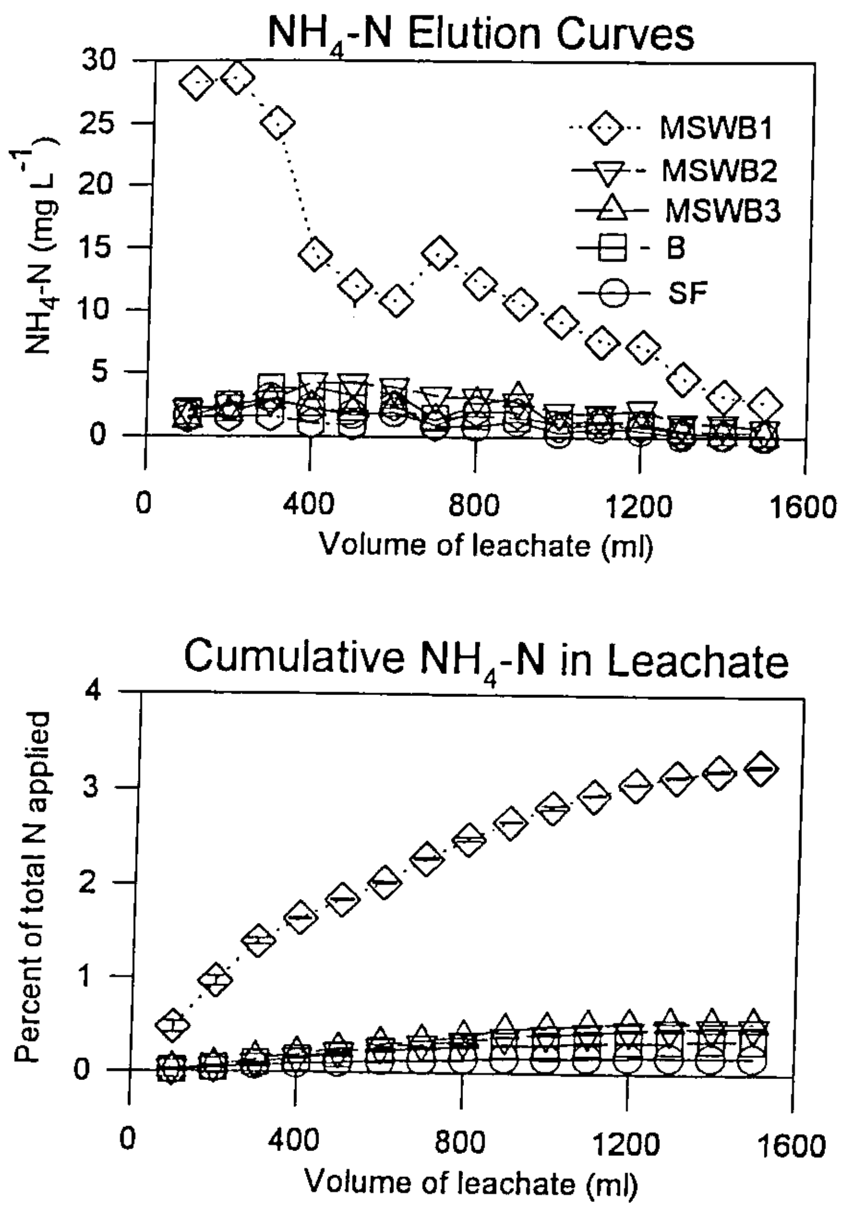

Fig. 3. Elution curves and cumulative leaching of NH_4-N from five compost-amended soil columns. The error bar at each data point represents the standard error of the mean

conditions during and after initial application. Sims (1995) reviewed investigations of mineralization rates of municipal sewage, MSW and sewage sludge co-composts, animal wastes, and industrial organic wastes. Rates ranged from -44 (immobilization of N) to 67%. The N mineralization rate of a compost is important because it determines the application rates and frequencies required to use a material to its potential without creating an environmental hazard. Generally, composts applied to vegetable cropping systems should mineralize rapidly because most species are annual crops that require N relatively quickly.

Nitrogen mineralization rates of five diverse composts produced in Florida were evaluated over a five-month period under a polyethylene-covered raised bed typical of those used in Florida (Hochmuth, 1988). A PVC column (5 cm diameter and 8 cm height) filled with compost was installed into the bed surface. The top of each column was covered by a PVC cap to prevent leaching and volatilization of N. Every 30 days, four columns for each compost were removed from the soil and the compost was analyzed for organic C, total N, and inorganic N (NH_4-N and NO_3-N). After four months in field conditions, compost N mineralization rates varied from -2.1 to 9.1% (Table 7). Carbon-nitrogen (C:N) ratios decreased in the MSW composts. The high C:N ratio of the MSWB1 compost (27) probably resulted in N immobilization (negative mineralization rate, -2.1%) because the microbial population would deplete soil inorganic N as it assimilated the surplus carbon in the material (Table 7).

Table 7. Initial carbon and total nitrogen concentrations, C:N ratios and mineralization rate (after a four-month incubation) of five composts

Compost	C	N	Initial C:N ratio	Final C:N ratio	N mineralization rate
	-------- %	--------			%
MSW + sewage sludge (MSWB1)	34.7	1.28	27	17	-2.1
MSW + sewage sludge (MSWB2)	17.9	0.91	20	12	0.6
MSW + sewage sludge (MSWB3)	23.2	1.60	14	12	1.8
Sewage sludge (B)	19.4	1.63	11	11	9.1
Sugarcane filtercake (SF)	29.5	2.11	14	13	7.6

MSW: Municipal solid waste

Concluding Remarks

Organic wastes are being converted into commercial grades of mulches or composts with increasing frequency. Production technology has improved compost quality and the consistency of quality, and reduced time of production. Commercial quantities and qualities of composts from organic wastes are produced in many parts of the world and are utilized in many crop production schemes.

Composts have been reported to 1) suppress soil borne diseases (Hoitink and Fahy, 1986; Hoitink et al., 1991; Hoitink et al., 1993), 2) control weeds (Roe et al., 1993), 3) serve as an alternative for polyethylene mulch (Roe et al., 1994), and 4) improve soil fertility (Obreza and Reeder, 1994; Sims, 1995; Stoffella and Graetz, 1996).

High heavy metal contents in MSW compost and fecal pathogens in sewage sludge are important quality considerations for horticultural uses of MSW compost (Rosen et al., 1993). High soluble salt concentrations can be a major concern when utilizing sewage sludge (Gouin, 1993). Intermediate organic compounds produced by immature compost can cause plant phytotoxicity (Zucconi et al., 1981). Composts with C:N ratios greater than 30 can cause N immobilization (Rosen et al., 1993).

Compost applications to vegetable cropping systems have generally, but not always, produced a significant yield response. Future investigations should develop production techniques that improve compost quality and methods of application, develop methods of compost utilization as an alternative to pesticides for weed and disease control, and develop "Best Management Practices" for composts as alternatives to inorganic fertilizers in commercial vegetable crop production systems.

References

Daliparthy, J., S.J. Herbert, P.P.M. Veneman, and L.J. Moffitt. 1995. Nitrate leaching under alfalfa corn rotation from dairy manuring. p.39-42. Proceedings of the Conference of Clean Water-Clean Environment-21st Century. V2: Nutrients. 5-8 Mar 1995, Kansas City, Missouri. The Society for Engineering in Agricultural, Food, and Biological Systems. St. Joseph, MO, USA.

DeVleeschauwer, D.O., P. Verdonock, and P. VanAssche. 1981. Phytotoxicity of refuse compost. Biocycle 22:44-45.

Dick, W.A. and E.L. McCoy. 1993. Enhancing soil fertility by addition of compost. In: H.A.J. Hoitink and H.M. Keener (eds.) Science and Engineering of Composting: Design, Environmental, Microbiological, and Utilization Aspects. Renaissance Publications, Worthington, OH, USA.

Eggerth, L.L. 1996. Compost marketing trends in the United States. In: M. DeBertoldi, P. Sequi, B. Lemmes, and T. Papi (eds.) The Science of Composting. Part II. Blackie Academic and Professional, New York, USA.

Florida Department of Environmental Protection (DEP). 1993. Annual Report. Tallahassee, FL, USA.

Goodrich, J.A., B.W. Lykins, and R.M. Clark. 1991. Drinking water from agriculturally contaminated groundwater. J. Envir. Qual. 20:707-717.

Gouin, F.R. 1993. Utilization of sewage sludge compost in horticulture. HortTechnology 3:161-163.

He, X., T.J. Logan, and S.J. Traina. 1995. Physical and chemical characteristics of selected U.S. municipal solid waste composts. J. Environ. Qual. 24:543-551.

Hochmuth, G.J. 1988. Pepper production guide in Florida. Univ. of Florida, Fla. Coop. Ext. Service Cir. 102E.

Hoitink, H.A.J., M.J. Boehm, and Y. Hadar. 1993. Mechanisms of suppression of soilborne plant pathogens in compost-amended substrates. In: H.A.J. Hoitink and M. Keener (eds.) Science and Engineering of Composting: Design, Environmental, Microbiological, and Utilization Aspects. Renaissance Publications, Worthington, OH, USA.

Hoitink, H.A.J. and P.C. Fahy. 1986. Basis for the control of soilborne plant pathogens with composts. Annu. Rev. Phytopathology 24:93-144.

Hoitink, H.A.J., Y. Inbar, and M.J. Boehm. 1991. Status of compost-amended potting mixes naturally suppressive to soilborne disease of floricultural crops. Plant Disease 75:869-873.

Hughes, E.G. 1980. Composting of municipal waste. p.108-134 in: M.W. Bewick (ed.) Handbook of Organic Waste Conversion. Van Hostrand Reinhold, NY, USA.

Jimenez, E.I. and V.P. Garcia. 1989. Evaluation of city refuse compost maturity: A review. Biolo. Wastes 27:115-142.

Lea-Cox, J.D. and J.P. Syvertsen. 1996. How nitrogen supply affects growth and nitrogen uptake, use efficiency, and loss from citrus seedlings. J. Am. Soc. Hort. Sci. 121:105-114.

LeGrand, F.L. 1972. Production of sugar cane. Agronomy Monograph No.1. Univ. of Florida, Gainesville, FL, USA.

National Research Council. 1978. Nitrates: An environmental assessment. National Academy of Sciences, Washington, DC, USA.

Obreza, T.A. and R.K. Reeder. 1994. Municipal solid waste compost use in tomato\watermelon successional cropping. Soil Crop Sci. Fla. Proc. 53:13-19.

Peverly, J.H. and P.B. Gates. 1994. Nitrogen mineralization studies in corn and vineyard plots treated with composts of differing C/N ratio. p.32 (abstr.). Composting Council's 5th National Conference. 16-18 Nov 1994, Washington, DC. The Composting Council, Alexandria, VA, USA.

Roe, N.E., P.J. Stoffella, and H.H. Bryan. 1993. Utilization of MSW compost and other organic mulches on commercial vegetable crops. Compost Science and Utilization 1:73-84.

Roe, N.E., P.J. Stoffella, and H.H. Bryan. 1994. Growth and yields of bell pepper and winter squash grown with organic and living mulches. J. Am. Soc. Hort. Sci. 119:1193-1199.

Rosen, C.J., T.R. Halbach, and B.T. Swanson. 1993. Horticultural uses of municipal solid waste composts. HortTechnology 3:167-173.

Rynk, R. (ed.). 1992. On-farm composting handbook. Northeast Regional Agricultural Engineering Service, Coop. Ext., NRAES-54 Ithaca, NY, USA.

Servis, R. 1992. Ag plastic recycling on horizon. Florida Grower Rancher 85:40.

Shiralipour, A., D.B. McConnell, and W.H. Smith. 1991. Effects of compost heat and phytotoxin on germination of certain Florida weed seeds. Soil Crop Sci. Soc. Fla. Proc. 50:154-157.

Sims, J.T. 1995. Organic wastes as alternative nitrogen sources. In: P.E. Bacon (ed.) Nitrogen Fertilization in the Environment. Marcel Dekker, New York, USA.

Smith, W.H. 1994. Recycling composted organic materials in Florida. Univ. FL., IFAS, Coop. Ext. Service BP-2. Gainesville, FL, USA.

Steuteville, R. 1996. The state of garbage in America. Biocycle 37:54-61.

Stoffella, P.J. and D.A. Graetz. 1996. Sugarcane filtercake compost influence on tomato emergence, seedling growth, and yields. In: M. DeBertoldi, P. Sequi, B. Lemmes, and T. Papi (eds.) The Science of Composting, Part 2. Blackie Academic and Professional, New York, USA.

USEPA (United States Environmental Protection Agency). 1987. Improved protection of water resources from long-term and cumulative pollution + prevention of ground-water contamination in the United States. Office of Ground Water Protection, Washington, DC, USA.

Wong, M.R. 1985. Phytoxicity of refuse compost during the process of incubation. Environ. Pollut. (Series A) 37:159-174.

Zucconi, F., A. Pera, M. Forte, and M. deBertoldi. 1981. Evaluating toxicity of immature compost. BioCycle 22:54-57.