Horticultural Uses of Municipal Solid Waste Composts

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Summary. Composting of municipal solid waste (MSW) has received renewed attention as a result of increasing waste disposal costs and the environmental concerns associated with using landfills. Sixteen MSW composting facilities are currently operating in the United States, with many more in the advanced stages of planning. A targeted end use of the compost is for horticultural crop production. At the present time, quality standards for MSW composts are lacking and need to be established. Elevated heavy metal concentrations in MSW compost have been reported; however, through proper sorting and recycling prior to composting, contamination by heavy metals can be reduced. Guidelines for safe metal concentrations and fecal pathogens in compost, based on sewage sludge research, are presented. The compost has been shown to be useful in horticultural crop production by improving soil physical properties, such as lowering bulk density and increasing water-holding capacity. The compost can supply essential nutrients to a limited extent; however, supplemental fertilizer, particularly N, is usually required. The compost has been used successfully as a sphagnum peat substitute for container media and as a seedbed for turf production. High soluble salts and B, often leading to phytotoxicity, are problems associated with the use of MSW compost. The primary limiting factor for the general use of MSW compost in horticultural crop production at present is the lack of consistent, high-quality compost.

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The use of municipal solid waste (MSW) compost for agricultural and horticultural purposes has received intermittent attention over the past 30 years. For practical purposes, MSW can be defined as the waste generated by the domestic and industrial sector of a municipality, excluding sewage sludge (McCalla et al., 1977). However, MSW compost in some instances may be produced with sewage sludge as an added N source. A primary goal of composting MSW is to end up with a less-odorous and more-stable organic matter source that can be recycled beneficially.

Sanderson (1980) concluded that, in the United States, economics was the greatest deterrent to MSW compost production and use. Until recently, composting MSW has been much more expensive than other waste disposal systems such as landfilling and incineration. According to a report compiled by the United States Environmental Protection Agency (EPA) (1971) composting facilities developed in the United States before 1970 have either ceased operation or experienced only sporadic operation. Landfilling has been widely practiced as the cheapest and easiest solution to the solid waste problem. However, existing landfills are closing because they have reached capacity or because of more-stringent pollution control requirements. Stricter environmental regulations make new landfill sites difficult to permit, resulting in a scarcity of landfill space across the country (U.S. EPA, 1991). Disposal of garbage into landfills is now four to seven times more expensive than it was 10 years ago (Halbach, 1992) making alternatives to landfilling more attractive. In a recent study of waste disposal costs in Minnesota, MSW composting was still, on average, more expensive ($69.43) on a per-ton basis than landfilling ($47.63) or incineration ($63.58) (Halbach, 1992). These figures should change in favor of MSW composting as landfills are closed and air emission standards are increased. As the long-term economic and environmental costs of various waste disposal technologies are weighed, composting of MSW now appears to be more feasible than it was in the past.

There are currently 16 MSW composting

facilities operating in the United States; all except one have been constructed since 1984 (Kitwana, 1992). Six more facilities are currently under construction and at least 33 are in the advanced stages of planning. Of the 16 facilities in operation, 10 listed horticulture/landscaping as the primary end use for the compost. Horticultural crops generally require higher inputs (especially organic matter) than agronomic crops and are, therefore, perceived as a more lucrative market for the compost. Some general horticultural uses of the compost have been as a soil conditioner, sphagnum peat substitute in potting media, slow-release source of nutrients, and as a mulch. Whether the horticultural industry will be able to use all the compost projected to be produced remains to be seen (Alexander, 1990; LaGasse, 1992). However, many different types of MSW compost will be available, making it important to understand both potential advantages and limitations of the products currently being produced for horticultural use.

Process of composting municipal solid waste

Ultimate characteristics and quality of the compost are dependent on how the MSW is sorted and processed prior to composting, as well as how the material is composted. The technology now exists to prepare large quantities of MSW for composting.

Garbage transported to composting facilities initially is sorted and large items such as furniture and appliances are removed. Subsequent processing varies with each particular composting facility; however, a generalized scheme can be summarized as follows: after the large noncompostable materials are removed, the remaining waste is screened to various sizes. Most of the ferrous metals are recovered with a magnet. Aluminum is recovered either manually or through an automated eddy current procedure. Glass, plastic, and other noncompostable materials are removed by further screening and sorting. Ideally, the remaining materials that are to be composted would include yard waste, paper, cardboard, and food scraps. Once the organic materials are obtained, the composting process is dependent on providing adequate moisture (to about 55%) and aeration for microbial degradation. A source of N, such as sewage sludge, animal manure, or urea, can be added to speed up the degradation process. Before the compost is ready to be marketed, further screening or separation is usually done. More technical details of the MSW sorting and composting process have been summarized previously (Glaub et al., 1984; Hachicha et al., 1992; Hughes, 1980; Kubota and Nakasaki, 1991).

Compost quality and safety

The importance of compost quality for horticultural crop production cannot be over-emphasized. The ability to market, or even give away, MSW compost will be dependent on producing a uniform and safe product. Safety needs to be considered in terms of human and plant pathogens and heavy metal concentrations, as well as handling problems due to sharp glass and metal. While horticultural standards for composts have not been defined precisely, the end user of the compost obviously will have different needs (Gouin, 1989). For example, requirements will be different for use in landscaping compared to use in a potting mix. From an agronomic or horticultural standpoint, C/N ratio, maturity, odor, pH, soluble salts, B content, ammonium content, physical properties, moisture content, and nutrient availability are of prime importance and need to be known before the compost is used (Walker and O'Donnell, 1991). One of the critical needs for MSW compost use is to come up with suitable quality standards for these parameters to which horticulturists and compost producers can refer,

Some of the quality standards for MSW composts are easier to measure than others. Definitions of maturity are still somewhat controversial and will require more research to sort out the standards (Garcia et al., 1992). lnbar et al. (1990) and He et al. (1992) summarized and described many different testing procedures for compost maturity. Specific tests for maturity include plant and animal bioassays, microbial activity or respiration, chemical analyses, physical analyses, spectroscopic analyses, and degree of humification.

Immature composts have been shown to cause phytotoxicity, possibly due to intermediate organic compounds produced during the initial stage of decomposition (Zucconi et al., 1981a). As the compost matures, phytotoxicity decreases (Zucconi et al., 1981b). A desirable C/N ratio would be between 15:1 to 20:1. Within this range, tie-up of N is minimal. Although knowledge of C/N ratio is desirable, C/N ratio alone as a measure of maturity is usually not sufficient. Obviously, if the C/N ratio is above 30, some immobilization of N will occur; however, a compost may still be immature if the raw material being composted has a C/N ratio less than 15. lnbar et al. (1990) suggested that a combination of different techniques be used to determine maturity.

The Minnesota Pollution Control Agency (1989) requires that particlesize be kept to a range of <10 mm with no more than 4% (dry-weight basis) greater than this size. Glass, plastic, and metal must be kept to a minimum. Off-odors will detract from compost quality and are often an indication that further composting is necessary. Soluble salts in composts must be known. Levels higher than 2 to 3 $dS\cdot m^{-1}$ (saturated paste) will result in marginal necrosis in many plant species.

The pH of the finished compost is usually alkaline, which is desirable for limiting availability of heavy metals, but may induce micronutrient deficiencies, especially in ericaceous plants. Haan (1981) reported a possible pH-induced decrease in plant tissue Mn concentrations and increase in Mo concentrations with continued MSW compost use. The direct effect of high pH on micronutrient availability may be modified when compost is used. The high organic component of the compost potentially may act as a complexing agent, thereby increasing availability of some micronutrients (Bar-Ness and Chen, 1991).

Most governmental agencies regulate the safety aspects of compost rather than quality per se. Many of these regulations are based on criteria for heavy metals and organics in sewage sludge (Walker and O'Donnell, 1991). At present, most states have their own limits for metal concentrations in sewagesludge, often leading to confusion over what a safe limit should be. The U.S. EPA recently has established safe metal concentrations in sewage sludge as well as metal-loading limits for land application (503 sludge management regulations; U.S. EPA, 1989, 1993). The limits proposed were based on pathways for the potential transfer of sludge-applied trace contaminants to individuals most likely to be exposed (Chaney, 1990a; Ryan and Chaney, 1993). The 503 regulations issued by EPA (1993) are presented in Table 1. For comparison, current guidelines for metal concentrations allowable for Class I compost based on Minnesota Pollution Control Agency (MPCA) rulesalso are provided (MPCA, 1989). According to MPCA rules, if the compost meets the criteria for Class I compost, it can be used without any restrictions. Compost not meeting the criteria for Class I compost is considered Class II compost and requires special permits before it can be used. In Minnesota and many other states, addition of sewage sludge is not allowed in Class I compost. If sewage sludge is added, then the compost is considered Class II and subject to application restrictions. The dual standards for MSW compost and sewage sludge will have to be modified in the future.

Table 1. ***Chemical specifications for Class I compost suggested by the Minnesota Pollution Control Agency (MPCA, 1989) and maximum pollutant concentrations in clean sewage sludge suggested by the U.S. Environmental Protection Agency (U.S. EPA, 1993). All concentrations are expressed on a dry-weight basis.***

Pollutant	MPCA	U.S.EPA
	mg•kg⁻¹	
Arsenic	ND[z]	41
Cadmium	10	39
Chromium	1000	1200
Copper	500	1500
Lead	500	300
Mercury	5	17
Molybdenum	ND	18
Nickel	100	420
Selenium	ND	36
Zinc	1000	2800

[z]*ND = not defined.*

Tests for most heavy metals are relatively standard and inexpensive with current analytical technology. Analysis of contaminants such as Hg and most of the organic compounds are more. complicated, resulting in significant costs. As a result, routine analyses for many organic compounds are not conducted, resulting in a product that looks good, but may not be safe. As pointed out by Richard (1990) a major challenge in MSW composting is to produce a safe product. Even with the screening, sorting, and grinding technologies, hazardous wastes can still be present in the end product. Toxic organic chemicals resistant to biological degradation and heavy metals may persist. When this occurs, use of the compost results in a dilution of the hazardous components, but also may result in contamination of the environment and pose human health risks. Richard (1990) further points out that some companies are marketing MSW compost without adequately addressing contamination with hazardous wastes.

Extensive preprocessing is essential in order to produce a safe and usable compost from MSW for horticultural purposes. Compost quality can be generally improved if the organic wastes are collected separately from hazardous components and inorganic materials (Fricke et al., 1989; Richard et al., 1993).

Most municipal solid wastes will contain fecal matter from animal pets and used disposable diapers; therefore, another safety precaution that needs to be considered is potentially harmful pathogens in the resulting compost (Boutin and Moline, 1987; Farrell, 1993; Pahren, 1987). Much of the research has been conducted with sewage sludge compost; however, the conclusions drawn from sewage sludge (a worst-case scenario) would be applicable to MSW composts. Research conducted by Yanko (1988) has shown that salmonellae frequently are detected in composted sewage sludge, while viruses and viable helminth (intestinal nematode) eggs are rarely found. The composting process itself is considered a useful treatment in controlling fecal pathogens, provided that high-enough temperatures are attained during the composting process. Temperatures of 55C for at least 15 days as well as turning of the pile five times are required for windrow composting. The static aerated pile or in-vessel method requires an operating temperature of 55C or more for 3 days. Recent regulation by EPA requires that, for sewage sludge compost, fecal coliform not exceed a density of 1000/g of solids, as measured by most probable number methodology (U.S. EPA, 1993).

In addition to fecal pathogens, secondary pathogens also may pose health concerns (Boutin and Moline, 1987). Molds such as *Aspergillus fumigatus* can cause respiratory problems, and certain gram-negative bacteria found in decomposing waste can cause various allergic reactions. Most of these concerns, however, are for workers involved in the composting process rather than for those using the finished compost.

Characteristics of MSW composts

Chemical properties of MSW composts have been reviewed recently in detail by He et al. (1992). Composts vary greatly in composition depending on the site of production. The moisture content varies from 20 to 50% (w/w). Following combustion, the ash content is in a narrow range near 50% of the dry weight. The pH is neutral to slightly alkaline. Carbon content is about 300 $g \cdot kg^{-1}$ dry weight, with an N content ranging from 5 to 18 $g \cdot kg^{-1}$ dry weight. The content of trace metals is higher than most agricultural soils, but, with the exception of lead, lower than average levels found in sewage sludge. The chemical characteristics of MSW compost are depend greatly on the material composted and the composting method. To illustrate this point, chemical properties of two MSW composts produced in Minnesota by various methods and with variable inputs are compared (Table 2).

One of the composts analyzed was a whole-stream compost produced in St. Cloud, Minn., by the in-vessel method from solid waste that had gone through minimal sorting and materials recovery (O'Leary, 1989). A small amount of sewage was added to this compost in the vessel. The residence time in the vessel was 4 to 5 days, after which the material was windrowed outdoors and composted for 6 weeks. The second compost was produced in Thief River Falls, Minn., through a composted refuse-derived fuel process where the solid waste had first undergone ferrous recovery, shredding, and density fractionation (O'Leary, 1989). The lighter fraction (primarily paper) was used to produce fuel pellets and the heavier fraction was windrowed outdoors and composted for 6 weeks. Nitrogen was determined by Kjeldahl procedures (Bremner and Mulvaney, 1982) and carbon was determined using dry combustion procedures (LECO Corp., St. Joseph, Mich.). Other elements were determined by inductively coupled plasma spectrophotometry (ICP) following overnight ashing and dissolution of the ash in 2 N HCl (Munter and Grande, 1981). The total analysis does not provide much information on availability of the elements to plants, but it is useful for predicting potential benefits and limitations of the compost. Compost pH was determined in a 1 compost : 1 water mixture. Electrical conductivity was determined on a 1 compost: 5 water mixture.

Table 2. ***Selected chemical analyses of two MSW composts.***

Chemical property	Type of compost: Whole-stream[z]	Type of compost: Refuse-derived[y]
pH (1 compost : 1water, v/v)	8.2	7.8
EC[x] (1 compost : 5 water, v/v, $dS \cdot m^{-1}$)	4.0	2.5
Carbon ($g \cdot kg^{-1}$)	231	101
Nitrogen ($g \cdot kg^{-1}$)	14	7
C/N ratio	16.5	14.4
Phosphorus ($g \cdot kg^{-1}$)	4	2
Potassium ($g \cdot kg^{-1}$)	5	2
Trace elements ($mg \cdot kg^{-1}$)		
Boron	45	35
Zinc	744	940
Copper	294	623
Lead	235	332
Cadmium	4	2

[z]Compost was produced in St. Cloud, Minn. by an in-vessel method from solid waste that had undergone minimal sorting and metals recovery. Some sewage sludge was added.
[y]Compost was produced in Thief River Falls, Minn.; solid waste was shredded followed by ferrous recovery; the paper fraction was used to produce fuel pellets; remaining material was composted.
[x]EC = electrical conductivity.

Both composts had a C/N ratio <20. Soluble salts were higher in the whole-stream compost, but salt levels in both composts were higher than desirable for many horticultural uses. The whole-stream compost generally had a higher nitrogen concentration, which was most likely the result of using sewage sludge. As with most mature composts produced aerobically, the pH of both composts was in the alkaline range. Metal concentrations were generally higher in the refuse-derived fuel compost despite material sorting. The most likely explanation is that the paper fraction, which normally would dilute metal contaminants, was separated out for fuel consumption.

Cadmium and lead are the main metals often singled out as potentially toxic to animals. Plants can accumulate Cd with no toxic effects, but animals are much more sensitive to this element (Chaney, 1990a). Levels of Cd in the two composts tested were low relative to health standards set by state and federal agencies, but still above general background levels for agricultural soils (Holmgren, 1993). In contrast to Cd, Pb does not accumulate to any extent in plants. The primary health concern for Pb is from direct ingestion. The refuse-derived fuel compost had Pb levels (>300 $mg \cdot kg^{-1}$) that might be considered limiting for use in some situations (Chaney, 1990b).

In a systematic study to determine the impacts of a specific component of the waste stream, B.D. Cook, T.R. Halbach, C.J. Rosen, and J.F. Moncrief (unpublished data) have shown that increasing the content of disposable diapers increased soluble salts and total concentrations of Al, B, C, Cl, N, K, Si, and Na in the compost. These results indicate that changes in thecomposition of the waste stream can affect the composition of the end product. It is clear, therefore, that if MSW compost is to be used in horticultural crop production generalizations about the chemical and physical properties are not adequate and individual analyses of each product will be required.

Growth and nutritional responses of horticultural plants to MSW compost

Fruit and vegetable crops. Of all the horticultural crops, use of MSW composts in production of fruits and vegetables represents the greatest risk because of direct human consumption of the produce. Despite this concern, numerous studies have been conducted with these crops to obtain risk estimates of metal uptake or leaching, as well as general crop response to the composts (Dyer and Razvi, 1987; Fritz and Venter, 1988; Guidi et al., 1990; Haan, 1980; Hoffmann and Schweiger, 1983; Purves and MacKennzie, 1973; Assche and Uyttebroeck, 1982).

Many of the early studies on crop growth have shown that MSW composts could supply essential plant nutrients, but not in the quantity required for optimum yields (Fuller et al., 1960; Terman et al., 1973). Compost plus supplemental fertilizer, particularly N, usually is required to obtain yields similar to the fertilized control. Long-term studies on land application of MSW compost have shown beneficial effects to corn growth, as well as favorable effects on soil properties such as pH, increased organic matter, and enhanced supply of plant nutrients (Mays and Giordano, 1989). Heavy metals increased in the top 30 cm, but no downward movement was detected below this depth 19 years after application.

Perhaps the greatest benefit of land application of MSW compost is as a soil conditioner through increased organic matter content. Addition of MSW compost to soil improves physical properties by increasing total soil porosity and aggregate stability in a manner similar to manure (Pagliai et al., 1981) Addition of MSW compost to field soils has been shown to decrease bulk density of a loamy sand and a clay loam (Kreft, 1987). Available water-holding capacity increased in the sandy soil with compost addition, but was not affected in the clay loam soil.

Even though MSW composts generally cannot supply all the N needed for production of crops, a typical application of the compost will contain substantial amounts of N. For example, land application of 50 $Mg \cdot ha^{-1}$ (dry-weight basis) may contain 250 to 500 kg N. Release of this N with time needs to be considered in order to prevent environmental problems related to nitrate leaching, particularly if yearly applications are made.

Vegetable crops grown on compost-amended soils have shown positive yield responses compared to non-amended soils (Bryan and Lance, 1991; Giordano et al., 1975; Purves and MacKenzie, 1973). These yield increases have been attributed to improved soil physical properties and, to a lesser extent, enhanced nutrient availability (Bell, 1973).

Several studies with vegetable crops have also shown that MSW composts can increase soluble salts and boron in the medium and may result in inhibition of seed germination and/or yield depression (Purves and MacKenzie, 1973; Wong and Chu, 1985). The response of lettuce ('Valmaine', Thompson and Morgan) and corn (AP 099, Agripro) to two composts of varying salt and B content was determined (C.J.R., unpublished data). A "control" compost was made from normal waste-stream components in St. Cloud, Minn., in a closed vessel for 3 days and on an open curing pad for 120 days. This compost represents a background level of 2% diapers (moist weight) in the waste stream. The control compost had a B content of 20 $mg \cdot kg^{-1}$ and soluble salts of 5.8 $dS \cdot m^{-1}$ (saturated paste). A "test" compost was made by spiking the normal waste stream with the compostable part of disposable diapers (6% by wet weight) and composting in a closed vessel for 3 days followed by open curing for 120 days. The test compost had about four times the content of disposable diapers compared to the normal waste stream compost. The test compost had a B content of 27 $mg \cdot kg^{-1}$ and soluble salts of 9.6 $dS \cdot m^{-1}$. Plants were grown in 1.2-liter containers filled with: 1) loamy sand soil without compost; 2) soil with 5% (by weight) control compost; or 3) soil with 5% test compost. Equivalent masses of growing media (1600 g dry weight per container) were used for each treatment. Half the containers were fertilized with 780 mg N, 360 mg P, and 630 mg K per container. No fertilizer was added to the remaining containers. All containers were irrigated with demineralized water. A saucer was placed under each container to prevent leaching. Lettuce plants were harvested 47 days after seeding and corn plants were harvested 31 days after seeding. Tissue was dried at 60C and ground to pass through a 30-mesh screen. Tissue Na and B were determined by ICP (Munter and Grande, 1981). Tissue Cl was determined after water-extraction using the ferric thiocyanate method (Technicon Instruments Corp., Tarrytown, N.Y.). Soluble salts in the media were determined at harvest on saturated extracts. Each treatment was replicated four times in a randomized complete-block design.

Soluble salts in the media increased with addition of either compost and with fertilization (Tables 3 and 4). Without added fertilizer, lettuce growth increased in soils amended with compost from both sources, whereas corn growth was not affected significantly. Salt from both compost sources had more of a negative effect on corn growth than on lettuce growth, although symptoms of salt toxicity (marginal scorching) were apparent in both species. Addition of fertilizer to the control compost-amended soil resulted in similar growth to that with fertilized soil without compost for lettuce, but inhibited growth of corn. Symptoms of salt toxicity were significantly less apparent if fertilizer was added, presumably due to a growth dilution effect. That is, the added fertilizer promoted growth and resulted in a lower total concentration of salt in the tissue. Addition of fertilizer to the test-compost-amended soil resulted in less dry mass than that produced with fertilizer and no compost with lettuce or corn. Tissue concentrations of boron were at levels considered to be excessive in corn grown with either compost (Jones et al., 1991). The concentration of boron in lettuce leaves was not at a level likely to cause toxicity. Sodiumand Cl concentrations in corn and lettucetissue increased significantly with compost addition. Excessive Na accumulation was more of a factor in growth of lettuce than of corn, while Cl was accumulated to a higher degree in corn than in lettuce. Results of this study show clearly the need to apply fertilizer to compost-amended soil to obtain adequate growth. However, soluble salts in MSW compost needs to be controlled and monitored carefully, particularly if fertilizer is added. The effect of boron in the MSW compost on plant growth will depend on the species grown.

Table 3. ***Total above-ground dry matter accumulation, soil electrical conductivity, and tissue concentration of Cl, Na, and B in lettuce plants (cv. Valmaine) in response to compost type and fertilizer application. Measurements were taken 47 days after seeding.***

Treatment	Above-ground dry matter (g/pot)	Soil EC[z] ($dS \cdot m^{-1}$)	Tissue concn. of Cl ($g \cdot kg^{-1}$)	Na ($g \cdot kg^{-1}$)	B ($mg \cdot kg^{-1}$)
Soil	0.96	0.4	2.4	0.4	29
Soil + fertilizer[y]	8.29	1.3	0.9	1.4	20
Control compost[x]	1.90	1.8	17.2	4.6	31
Control compost + fertilizer	7.63	1.6	16.4	3.2	26
Test compost[w]	2.12	2.5	12.9	9.0	34
Test compost + fertilizer	5.69	3.4	14.6	7.8	31
Significance[v]	**	**	**	**	**
BLSD[u]	0.76	0.4	2.4	0.9	4

[z]EC, electrical conductivity (extract from saturated paste).
[y]Fertilizer supplied at the rate of 780 mg N, 360 mg P, and 630 mg K per container.
[x]Compost was added to soil at the rate of 5% by weight; "control" compost = compost produced from normal waste stream components.
[w]Compost was added to soil at the rate of 5% by weight; "test" compost = compost produced from normal waste stream plus disposable diapers.
*[v]**Significant at the 1% level.*
[u]Waller–Duncan Bayesian k-ratio t test for minimum significant difference, k = 100.

Table 4. ***Total above-ground dry matter accumulation, soil electrical conductivity, and tissue concentration of Cl, Na, and B in corn plants (Agripro AP 099) in response to compost type and fertilizer application. Measurements were taken 31days after seeding.***

Treatment	Above-ground dry matter (g/pot)	Soil EC[z] ($dS \cdot m^{-1}$)	Tissue concn. of Cl ($g \cdot kg^{-1}$)	Na ($mg \cdot kg^{-1}$)	B ($mg \cdot kg^{-1}$)
Soil	0.66	0.3	1.1	45	11
Soil + fertilizer[y]	7.78	1.5	0.5	57	9
Control compost[x]	0.93	1.1	22.1	62	24
Control compost + fertilizer	3.69	2.6	15.3	105	23
Test compost[w]	1.00	2.1	24.6	106	54
Test compost + fertilizer	3.92	3.1	16.9	197	43
Significance[v]	**	**	**	**	**
BLSD[u]	1.29	0.4	0.9	30	8

[z]*EC, electrical conductivity (extract from saturated paste).*
[y]*Fertilizer supplied at the rate of 780 mg N, 360 mg P, and 630 mg K per container.*
[x]*Compost was added to soil at the rate of 5% by weight; "control" compost = compost produced from normal waste stream components.*
[w]*Compost was added to soil at the rate of 5% by weight; "test" compost = compost produced from normal waste stream plus disposable diapers.*
[v]***Significant at the 1% level.*
[u]*Waller–Duncan Bayesian k-ratio* t *test for minimum significant difference, k = 100.*

Chu and Wong (1987) found lower levels of Cd, Cu, Mn, Pb, and Zn in tomato fruit than in carrot roots or white cabbage leaves when plants were grown on MSW compost-amended soils. Concentrations of Zn and Cu generally increased, Mn decreased, and Cd and Pb either did not change or were variable with increasing compost application. When MSW composts with a low metal content were applied to three different soils, metal concentrations in spinach were not affected by increasing compost application (Guidi et al., 1990). High pH of the compost and the increase in organic matter content of the medium due to compost addition reduced metal bioavailability.

Use of MSW composts for fruit production generally is restricted to a surface/mulch application. Positive growth responses to MSW compost applied as a mulch to papaya have been reported (Bryan and Lance, 1991). Application of MSW compost to commercial vineyards in Germany has been practiced for many years to reduce erosion on steep slopes (Hughes, 1980). Volkel (1988) reported that, despite increases in heavy metals in the vineyard soils with compost application, heavy metal content of vine leaves, must, and wine were not affected. Growth of vegetables on vineyards previously receiving MSW compost applications had slightly elevated Cd and Pb concentrations, but were below levels considered to be harmful (Hoffman and Schweiger, 1983).

Greenhouse and landscape crops. Nursery and floricultural crops representa logical use for MSW composts (Sanderson, 1980; Sievert, 1973). These crops are not used for human or animal consumption and their production practices require large quantities of high-quality organic matter. The compost can be used directly in the nursery as a soil conditioner with a limited release of nutrients before planting or as a mulch after planting (BioCycle Staff, 1991) For container crops, composts are considered to be a low-cost substitute for sphagnum peat (Bugbee and Frink, 1989; Siminis and Manios, l990; Verdonck, 1988). Media amended with MSW compost resulted in equal or superior growth for various woody plants compared to sphagnum peat-amended media (Sanderson and Martin, 1974) provided that additional fertilizer was applied. Release of nutrients from MSW composts was much lower than comparable rates of amendment with poultry manure compost (O'Leary, 1989). In that study, dry matter production of tomatoes and snapdragons was significantly higher with poultry manure compost than with MSW compost if fertilizer was not added. In other studies, chrysanthemums grown in compost-amended media exhibited marginal leaf injury that was related to boron toxicity or salt injury (Gogue and Sanderson, 1975). Initial problems of salt or boron injury tended to diminish with time as the medium was leached with normal watering. Similar results were reported for *Forsythia* and *Thuja* response to MSW compost, except that problems of B toxicity were not eliminated by leaching of the compost (Lumis and Johnson, 1982). The B content of the compost used by Lumis and Johnson was 4.5 times greater than the compost used by Gogue and Sanderson (225 $mg \cdot kg^{-1}$ vs. 51 $mg \cdot kg^{-1}$).

Preliminary work using various waste products for woody and herbaceous plant production systems has been conducted in the Univ. of Minnesota Teaching, Research, and Extension Nursery program (B.T.S., unpublished data). Both benefits and potential problems associated with the use of these products have been observed. Product inconsistencies, off-odors, unknown product composition, and unpredictable plant growth responses are potentially negative or limiting factors. Some of the composts tested have shown significant potential as a peat substitute; however, cultural management requirements associated with the use of these composts still remain to be quantified.

Physical properties of the growing media can be affected by compost addition. O'Leary (1989) reported that the bulk density of a sphagnum peat-based medium increased with increasing compost addition and that air-filled porosity generally decreased. Siminis and Manios (1990) reported that use of compost increased total solids of the medium and decreased available water-holding capacity. Based on their studies, 20% by volume is the maximum amount of compost that should be added to an otherwise peat-based potting medium.

As with any component for a container medium, a thorough test of chemical and physical properties of the compost should be done before it is used. For MSW compost, pH, soluble salts, ammonium, and B, in particular, should be monitored closely so that phytotoxicity does not occur. In many cases, leaching of the compost may be necessary before use in a potting medium; however, uncontrolled leaching may lead to other environmental concerns.

Use of MSW compost for turf and landscape plants is also feasible. Research on effects of MSW compost on growth of plants in the landscape is less extensive. Use of the compost in these situations would be primarily as a soil conditioner (before planting) or as a mulch (after planting). Fitzpatrick (1989) reported generally positive effects of MSW composts on growth of tropical landscape plants.

A commercial method of growing sod in a seedbed over plastic has opened the possibility of using various composted waste materials as the seedbed (Neel et al., 1978). Sod production on a solid waste compost over plastic initially contributed to poor coloration and lack of vigor due to high salinity (Cisar and Snyder, 1992). The poor growth was temporary and, after 5 months, sod grown on fertilized compost had sufficient coverage for harvest.

Conclusions and future directions

Solid waste recycling efforts can be enhanced by using MSW compost for horticultural crop production. However, use of MSW composts will depend on whether quality of the product can meet the standards of the industry and whether the cost is competitive with that of other organic materials currently used. The main attributes of MSW compost are that it can substitute for a portion of the sphagnum peat in container media and that it can improve soil physical properties. The compost can supply essential plant nutrients; however, the release rate is slow, and supplemental fertilization with N, P, and K is usually necessary.

Persistent problems often reported were the high levels of soluble salts and boron, often leading to phytotoxicity and growth suppression. Soluble salts and boron can be minimized by leaching, but leachate management is also a concern. The temporal nature and wide variability of MSW are challenges for composting facilities to produce a product of consistent quality. Tests will have to be run on each load produced to ensure quality and safety of the material. Heavy metal contamination is a concern; however, through proper sorting and recycling prior to composting, the contamination by heavy metals can be kept to a level that is acceptable for use by most segments of the horticultural industry.

Literature Cited

Alexander, R. 1990. Expanding compost markets. BioCycle 32(8):54-59.

Assche, C. van and P. Uyttebroeck 1982. Demand, supply and application of domestic waste compost in agriculture. Agr. Wastes 4:203-212.

Bar-Ness, E. and Y. Chen. 1991. Manure and peat based iron-organo complexes. II. Transport in soils, p. 47-52. In: Y. Chen and Y. Hadar (eds.). Iron nutrition and interactions in plants. Kluwer, Boston.

Bell, R.G. 1973. The role of compost and composting in modern agriculture. Compost Sci. 14(6):24-25.

BioCycle staff 1991. Plant nurseries cut costs with compost. Biocycle 32(5):72.

Boutin, P and J. Moline. 1987. Health and safety aspects of compost preparation and use, p. 198-209. In. M. de Bertoldi (ed.). Compost: Production, quality, and use. Elsevier, London.

Bremner, J.M. and C.S. Mulvaney. 1982. Nitrogen—total. In: A.L. Page (ed.). Methods of soil analysis. Amer. Soc. of Agron., Madison, Wis. No. 9, Part 2. 2nd ed.

Bryan, H.H. and C.J. Lance. 1991. Compost trials on vegetables and tropical crops. BioCycle 32(3):36-37.

Bugbee, G.J. and C.R. Frink. 1989. Composted waste as a peat substitute in peat-lite media. HortScience 24:625-627.

Chancy, R.L. 1990a. Twenty years of land application research. Part I. BioCycle 31(9):54-59.

Chaney, R.L. 1990b. Twenty years of land application research. Part II. BioCycle 31(10):68-73.

Chu, L.M. and M.H. Wong. 1987 Heavy metal contents of vegetable crops treated with refuse compost and sewage sludge. Plant Soil 103:191-197.

Cisar, J.L. and G.H. Snyder. 1992. Sod production on a solid waste compost over plastic. HortScience 27:1219-222.

Dyer, J.M. and A.S. Razvi. 1987. Assessing the risk of solid waste compost. BioCycle 28(3):31-36.

Farrell, J.B. 1993. Fecal pathogen control during camposting, p. 282-300. In: H.A.J. Hoitink and H.M. Keener (eds.). Science and engineering of cornposting. Renaissance, Worthington, Ohio.

Fitzpatrick, G.E. 1989. Solid waste composts as growing media. BioCycle 30(9):62-64.

Fricke, K., W. Pertl, and H. Vogtmann. 1989. Technology and undesirable components in compost of separately collected organic wastes. Agr. Ecosys. Environ. 27:463-469.

Fritz, D. and F. Venter. 1988. Heavy metals in some vegetable crops as influenced by municipal waste composts. Acta Hort. 222:51-62.

Fuller, W.H. and G. Johnson, and G. Sposito. 1960. Influence of municipal refuse compost on plant growth. Compost Sci. 1(3):16-19.

Garcia, C., T. Hernandez, F. Costa, and M. Ayuso. 1992. Evaluation of the maturity of municipal waste compost using simple chemical parameters. Commun. Soil Sci. Plant Anal. 23:1501-1512.

Giordano, P.M., J.J. Mortvedt, and D.A. Mays. 1975. Effect of municipal wastes on crop yields and uptake of heavy metals. J. Environ. Qual. 4:394-399.

Glaub, J.C., L.F. Diaz, and G.M. Savage. 1984. Preparing municipal solid waste for composting. BioCycle 25(8):32-36.

Gogue, G.J. and K.C. Sanderson. 1975. Municipal compost as a medium amendment for chrysanthemum culture. J. Amer. Soc. Hort. Sci. 100:213-216.

Gouin, F.R. 1989. Compost standards for horticultural industries. Biocycle 30(8):42-48.

Guidi, G.V, G. Petruzzelli, G. Vallini, and A. Pera. 1990. Plant productivity and heavy metal contamination. BioCycle 31(6):46-48.

Haan, S. de. 1981. Results of municipal waste compost research over more than fifty years at the Institute for Soil Fertility at Haren/Groningen, the Netherlands. Neth. J. Agr. Sci. 29:49-61.

Hachicha, R., A. Hassen, N. Jedidi, and H. Kallali. 1992. Optimal conditions for MSW composting. BioCycle 33(6):76-77.

Halbach, D. 1992. Cost of solid waste disposal options in Minnesota. Waste Education Series, Minn. Ext. Serv. Univ. of Minn. NR-FS-6066-B.

He, X.T., S.J. Traina, and T.J. Logan. 1992. Chemical properties of municipal solid waste composts. J. Environ. Qual. 21:318-329.

Hoffmann, G. and P. Schweiger. 1983. Cd- and Pb-contents of vegetables grown on soils of former vineyards treated with municipal waste-compost. Acta Hort. 133:173-178.

Holmgren, G.G., M.W. Meyer, R.L. Chaney, and R.B. Daniels. 1993. Cadmium, lead, zinc, copper, and nickel in agricultural soils of the United States. J. Environ. Qual. (In press.)

Hughes, E.G. 1980. Composting of municipal wastes, p.108-134. In: M.W. Bewick (ed.). Handbook of organic waste conversion. Van Nostrand Reinhold, New York.

Inbar, Y., Y. Chen, Y. Hadar, and H.A. Hoitink 1990. New approaches to compost maturity. BioCycle 31(12):64-68.

Jones, J.B., B. Wolf, and H.A. Mills. 1991. Plant analysis handbook. Micro-Macro Publ., Inc. Athens, Ga.

Kitwana, M.K. 1992. U.S. solid waste composting facility profiles. National Composting Program. U.S. Conf. of Mayors, Washington, D.C.

Kreft, D. 1987 Soil physical properties as influenced by the addition of municipal compost. MS thesis. Univ. of Minnesota. St. Paul.

Kubota, H. and K. Nakasaki. 1991. Accelerated thermophilic composting of garbage. BioCycle 32(6):66-68.

LaGasse, R.C. 1992. Marketing organicsoil products. BioCycle 33(3):30-33.

Lumis, G.P. and A.G. Johnson. 1982. Boron toxicity and growth suppression of *Forsythia* and *Thuja* grown in mixes with municipal waste compost. HortScience 17:821-822.

Mays, D.A., and P.M. Giordano. 1989 Landspreading municipal waste compost. BioCycle 30(3):37-39.

McCalla, T.M,, J.R. Petersen, and C. Lue-Hing. 1977 Chapter 2. Properties of agricultural and municipal solid wastes. In: L.F. Elliot (ed.). Soils for management of organic wastes and wastewaters. Soil Sci. Soc. Amer., Madison, Wis.

Minnesota Pollution Control Agency. 1989. Solid waste management rules. State Office Bldg., St. Paul. p. 151-155.

Munter, R.C. and R.A. Grande. 1981. Plant tissue and soil extract analysis by ICP-atomic emission spectrometry, p. 653-672. In: R.M. Barnes (ed.). Developments in atomic plasma spectrochemical analysis. Heyden and Sons, London.

Neel, P.L., E.O. Burt, P. Busey, and G.H. Snyder. 1978. Sod production in shallow beds of waste materials. J. Amer. Soc. Hort. Sci. 103:549-553.

O'Leary, J.L. 1989. Evaluation of solid waste compost as a medium amendment for greenhouse production of bedding plants. MS thesis. Univ. of Minnesota, St. Paul.

Pagliai, M., G. Guidi, M. La Marca, M. Giachetti, and G. Lucamante. 1981. Effects of sewage sludges and composts on soil porosity and aggregation J. Environ. Qual. 10:556-561.

Pahren, H.R. 1987. Microorganisms in municipal solid waste and public health implications. CRC Crit. Rev. in Environ. Control. 17(3):187-228.

Purves, D. and E.J. MacKenzie. 1973. Effects of applications of municipal compost on uptake of copper, zinc, and boron by garden vegetables. Plant Soil 39:361-371.

Richard, T. 1990. Clean compost production. BioCycle 31(2):46-47.

Richard, T., P. Woodbury, V. Breslin, and S. Crawford. 1993. MSW composts: Impacts of separation on trace metal contamination, p. 401-421. In: H.A.J. Hoitink and H.M. Keener (eds.). Science and engineering of composting. Renaissance Publ., Worthington, Ohio.

Ryan, J.A. and R.L. Chancy. 1993. Regulation of municipal sewage sludge under the Clean Water Act Section 503: A model for exposure and risk assessment for MSW-compost, p. 422-450. In: H.A.J. Hoitink and H.M. Keener (eds.). Science and engineering of composting. Renaissance Publ., Worthington, Ohio.

Sanderson, K.C. 1980. Use of sewage refuse compost in the production of ornamental plants. HortScience 15:173-178.

Sanderson, K.C. and W.C. Martin Jr. 1974. Performance of woody ornamentals in municipal compost medium under nine fertilizer regimes. HortScience 9:242-243.

Sievert, R.C. 1973. Using composted wastes in the greenhouse. Compost Sci. 14(6):8-10.

Siminis, H.I. and V.I. Manios. 1990. Mixing peat with MSW compost. BioCycle 31(11):60-61.

Terman, G.L., J.M. Soileau, and S.E. Allen. 1973. Municipal waste compost: effects on crop yields and nutrient content in greenhouse pot experiments. J. Environ. Qual. 2:84-89.

United States Environmental Protection Agency. 1971. Composting of municipal solid wastes in the United States. Publ. SW-47r.

United States Environmental Protection Agency. 1989, Standards for the disposal of sewage sludge: proposed rule 40 CFR Parts 27 and 503. Fed. Reg. 54(23):5746-5902.

United States Environmental Protection Agency. 1991. Solid waste disposal criteria. EPA/0SW-FR-91-004 FRL-4011-9, 40 CFR parts 257 and 258. Fed. Reg. 56(196):50978-51119.

United States Environmental Protection Agency. 1993. Standards for the use or disposal of sewage sludge: final rules 40 CFR parts 257, 403, and 503. Fed. Reg. 58(32):9284-9415.

Verdonck, O. 1988. Composts from organic waste materials as substitutes for the usual horticultural substrates. Biol. Wastes 26:325-330.

Volkel, R. 1988. Field experiments on the application of refuse compost to vineyards in the southern area of the Upper Rhine (in German). Proc. 99th VDLUFA Congr. Koblenz, German Fed. Rep. VDLUFA-Schriftenreihe 23:467-476. [Cited in Hort. Abstr. 1989. 59:835 #7312.]

Walker, J.M. and M.J. O'Donnell. 1991. Comparative assessment of MSW compost characteristics. BioCycle 32(8):65-69.

Wong, M.H. and L.M. Chu. 1985. The response of edible crops treated with extracts of refuse compost of different ages. Agr. Wastes 14:63-74.

Yanko, W.A. 1988. Occurrence of pathogens in distributionand marketing municipal sludges. Rpt. No. EPA/1-87/014 (NTIS #PB 88-154273/AS).

Zucconi, F., A. Pera, M. Forte, and M. de Bertoldi. 1981a. Evaluating toxicity of immature compost. BioCycle 22(2):54-57.

Zucconi, F., M. Forte, A. Monaco, and M. de Bertoldi. 1981b. Biological evaluation of compost maturity. BioCycle 22(4):27-29.