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Potential Compost Benefits for Restoration Of Soils Disturbed by Urban Development

Craig G. Cogger
Washington State University, Puyallup Research and Extension Center, Puyallup, Washington

Compost amendment of soils degraded by urban development is seen as a way to improve soil and landscape quality, reduce runoff, and create a high-value market for locally produced compost. This review evaluates literature on organic soil amendments used in agriculture and horticulture, and extends results to disturbed soils in urban landscapes. Research on agricultural use of organic amendments consistently shows soil bulk density and penetration resistance decreasing with increasing amendment rate, and aggregate stability, porosity, and infiltration rate increasing with amendment rate. The effect of organic amendments on plant available water is less clear. Although organic amendments increase soil water holding capacity, much of the increase may not be available to plants. The nutrient benefits of compost amendments are often overlooked. Composts with a C:N ratio of 20:1 or less can provide significant amounts of nitrogen and other nutrients, improving the establishment of turf and landscape plants, and reducing the amount of supplemental nutrients needed. Materials with a high C:N ratio immobilize N, which can retard plant establishment. Results suggest that compost amendment rates of about one-third by volume should be suitable for establishing landscape beds in humid, temperate environments in soils degraded by development. Rates of 15 to 25% by volume are suggested for lawn establishment..

Introduction

Urban and suburban development degrades the soil environment. Development of a forested area involves removal of vegetation, stripping of topsoil, compaction by equipment, and sometimes the addition of imported fill. Development on agricultural soils usually follows a similar process, except that there is little or no original vegetation to remove. Development typically results in loss of soil organic matter, loss of structure and permeability, and increased compaction. The effects of compaction include increased bulk density; decreased macroporosity, aeration and infiltration capacity; increased runoff and erosion; and restricted root growth (Kozlowski 1999). Development results in an overall decline in the environment for plant growth (Jim 1998) and an increase in runoff (Partsch *et al.* 1993).

Organic amendments can ameliorate these negative effects. Increasing concern about the effects of development on soil and water quality, and increasing volumes of compost produced from local organic wastes provides opportunities for high value use of local compost to improve urban soils. In the rapidly developing Puget Sound region of western Washington, regulatory agencies are developing guidelines for soil improvement through site management and organic amendments, as a part of a comprehensive stormwater management program (Washington State Department of Ecology 2001).

The purpose of this review is to evaluate scientific literature on organic soil amendments to provide a basis for guidelines for compost use in urban soils. This review addresses the following questions:

Is there a good scientific basis for the expected benefits of organic amendments in urban soils?

How long are the organic amendments effective?

How much organic matter should be added to achieve these benefits?

Is there a good scientific basis for the expected benefits of organic amendments in urban soils?

Soil Physical Properties

Organic carbon and bulk density. Khaleel *et al.* (1981) published an extensive review of the literature on the effects of organic amendments on soil physical properties. Their review covered a wide range of organic amendments (including biosolids, animal manures, municipal composts, and domestic solid waste) used in a wide range of soil types and environments. Maximum application rates in the referenced studies ranged from about 100 to 400 Mg/ha/yr (dry weight). They noted that soil organic carbon content increased and bulk density decreased as the amount of organic amendment increased. Greatest bulk density reductions occurred in coarse-textured soils. Soil organic carbon increased the most in cooler climates, where the rate of organic decomposition was slower. Haynes and Naidu (1998) concluded that the degree of decomposition of organic amendments played a major role in organic carbon accumulation, with the greatest accumulation occurring with the addition of stabilized amendments such as compost.

According to Khaleel *et al.* (1981) decreases in bulk density resulted primarily from simple dilution of high-density mineral matter by the low-density organic amendments. Other researchers have attributed increased porosity as a key contributor to reduced bulk density. Martens and Frankenberger (1992) (Table 1) compared poultry manure, biosolids, barley straw, and alfalfa applied to a sandy clay loam at total rate of 75 Mg/ha split over three applications during an 18-month period. Three years after the initial application, soil bulk density had decreased by 7 to 11%. The decrease was greatest in the third year, after considerable decomposition of the organic amendments had occurred. Martens and Frankenberger (1992) concluded that increased porosity (resulting from improved aggregation and structure) was a major factor responsible for the long-term decrease in bulk density because the simple effects of dilution by less dense organic matter should have peaked after 18 months.

Pagliai *et al.* (1981) and Giusquiani *et al.* (1995) used thin section analyses and directly measured increased soil porosity following compost additions. Pagliai *et al.* amended a sandy loam soil with compost made from municipal solid waste and biosolids at rates of 75 and 225 Mg/ha/yr for two years. Most of the increase in porosity occurred in pores with diameters of 30 to 50 um (they defined these as capillary pores, which increase plant available water) and pores with diameters of 50 to 500 um (they defined these as transmission pores, which increase soil infiltration and aeration). Similar effects on porosity occurred at both application rates.

Giusquiani *et al.* (1995) evaluated thin sections in the fourth and fifth years following repeated applications of a municipal solid waste compost to a clay loam soil. Rates of 10, 30, and 90 Mg/ha/yr for four years increased the proportion of pores with diameters of 50 to 500 um and pores > 500 um. Porosity (pores > 50 um) increased with increasing compost application, at a rate of 0.08% increased pore space (whole soil basis) per Mg/ha/yr compost applied. Bulk density decreased from 1.55 g/mL in the untreated plots to 1.46 g/mL at the 10 Mg/ha/yr rate and 1.38 g/mL at 90 Mg/ha/yr. They attributed the decline in bulk density to increased porosity, based on their thin section analyses.

Aggregate stability. Soil aggregation is the binding of sand, silt, and clay particles into larger units, or peds. These aggregates typically range from 0.25 to 10 mm in diameter in the surface soil. They are important because the pores between them are large enough to transmit water.

Haynes and Naidu (1998) and Krull *et al.* (2004) reviewed the effects of organic amendments on aggregate stability. They noted that fresh and decom-

TABLE 1.
Summary of amendment effects on soil physical properties from studies discussed in text. Repeated applications.

Study	Martens & Frankenberger	Pagliai *et al.*	Giusquiani *et al.*	Albiach *et al.*	Foley & Cooperband
Duration of study (yr)	2	2	5	5	2
Time from last application to last measurement (month)	7	5	20	<12	12
Amendments[1]	Poultry manure, biosolids, straw, alfalfa	**Biosolids-MSW[2] compost**, biosolids, manure	**MSW compost**	**MSW compost,** biosolids, swine manure	**Paper mill residuals** raw and **composted**
Application rate	25 Mg/ha applied 3 times	75 and 225 Mg/ha/yr for 2 yr	0, 30, 90 1Mg/ha/yr for 5 yr	24 Mg/ha/yr for 5 yr	Variable, 22-78 Mg/ha/yr for 2 yr
Soil texture	Sandy clay loam	Sandy loam	Clay loam	Sandy loam	Loamy sand
Crop	Fallow	Corn	Corn	?	Vegetable rotation
			Amendment Effects[3]		
Organic matter	+		+	+	+
Bulk density	+		+		+
Infiltration	+				
Porosity		+	+		
Aggregate stability	+	+		+	
Available water			+		+

[1]Composted amendments are in bold. Not all amendments are listed for all experiments. [2]MSW = municipal solid waste compost. [3]+ is a positive effect for at least one treatment, - is a negative effect, and 0 is no effect of amendment. Blanks indicate no data.

posed organic materials play different roles in stabilizing soil aggregates. Fresh organic materials (e.g., cover crop residues) break down rapidly, stimulate soil biological activity, and produce water soluble carbohydrates that act like glue to stabilize soil aggregates. The effects of fresh organic matter last from a few weeks to a growing season. Composted materials stabilize aggregates slowly, but their effects are longer-lasting. Fungi that decompose compost also enhance aggregate stability by the physical binding effects of their filamentous structure.

Martens and Frankenberger (1992) evaluated the effects of biosolids, barley straw, and alfalfa amendments on soil aggregation. After addition of the organic amendments, they measured a 22 to 59% increase in aggregate stability and increased concentrations of soil saccharides. The increased aggregate stability was correlated with saccharide concentrations for the first two years of the study, but not the third year. The authors concluded that by the third year humus was more important than saccharides in stabilizing soil structure. Third-year field infiltration rates increased by 18 to 25% over untreated soil, which was attributed to improved aggregation and increased porosity.

Albiach *et al.* (2001) measured humic materials, carbohydrates, and aggregate stability in agricultural soils that had received annual amendments of municipal solid waste compost, biosolids, and swine manure (24 Mg/ha/yr for 5 years) and in unamended controls. By the fifth year, all amended plots had greater aggregate stability than the control. Plots treated with the compost had the greatest aggregate stability and highest quantity of humic materials.

Cox *et al.* (2001) compared the effects of a single application of straw (22 Mg/ha) and animal manure-greenwaste-coal ash compost (110 Mg/ha) on aggregate stability in an eroded silt loam soil (Table 2). Both materials increased biological activity the first year after application, and straw increased aggregate stability. By the second year the straw effect was no longer significant, but biological activity remained higher and aggregate stability was improved with the compost.

Hydraulic conductivity. Khaleel *et al.* (1981) reported that effects of amendments on soil hydraulic conductivity were more variable than for bulk density or aggregate stability. Hydraulic conductivity was especially increased by amendment rate in finer-textured soils. Aggelides and Londra (2000) observed increasing hydraulic conductivity in loam and clay soils with increasing rates of municipal solid waste-biosolids compost. Hydraulic conductivity doubled in the loam soil and tripled in the clay soil at the highest compost rate (156 Mg/ha) compared with unamended soils.

Plant available water. Soil water holding capacity depends on two factors: 1) the number and size of pores in the soil and 2) the surface area of the soil particles. Porosity controls water holding capacity at lower moisture tension (wetter soil), whereas surface area controls water holding capacity at higher moisture tension (drier soil). Organic matter increases water-holding capacity at both low and high tensions by increasing porosity and surface area, especially in coarse-textured soils (Khaleel *et al.* 1981; Krull *et al.* 2004; Rawls *et al.* 2003; Bauer and Black 1992. Khaleel *et al.* (1981) found that water-holding capacity often increased by similar amounts at the wet and dry ends of the plant-available range, and the net change in available water was small.

TABLE 2.
Summary of amendment effects on soil physical properties from studies discussed in text. Single application.

Study	Cox *et al.*	Mamo *et al.*	Gentilucci *et al.*	Tester
Time from application to last measurement (yr)	2	2	2	5
Amendments[1]	**Manure-coal ash compost**	**MSW[2] compost**	**MSW, food, and leaf composts**	**Biosolids compost**
Application rate	110 Mg/ha	270 Mg/ha	5 and 10 cm depth	60, 120, 240 Mg/ha
Soil texture	Silt loam	Loamy sand	Sandy loam	Sand
Crop	Barley, pea, wheat	Corn	Turfgrass	Tall fescue
	Amendment Effects[3]			
Organic matter	+		+	+
Bulk density	+	+	+	+
Infiltration/permeability	+		+	
Porosity			+	
Aggregate stability	+			
Available water			+	

[1]Composted amendments are in bold. Not all amendments are listed for all experiments. [2]MSW = municipal solid waste compost. [3]+ is a positive effect for at least one treatment, - is a negative effect, and 0 is no effect of amendment. Blanks indicate no data.

Not all water held in soil is available to plants. Giusquiani *et al.* (1995) measured a linear increase in available water with increasing compost rate in a low organic matter, clay loam soil following 5 years of compost amendments. Foley and Cooperband (2002) reported an increase in available water from applications of composted and uncomposted paper mill residuals to a loamy sand, which diminished during the growing season. In contrast, increased available water persisted for at least two years after the application of municipal solid waste, leaf, and food waste composts to a low-organic matter, eroded sandy loam soil (Gentilucci *et al.* 2001).

Different definitions of available water can confound data interpretation. Field capacity is defined as water that is held in the soil after free drainage of a wet soil has ceased (typically 2 or 3 days). The moisture tension at field capacity is typically defined as 10 or 33 kPa. The permanent wilting point is defined as 1500 kPa, and water held at tensions between field capacity and the permanent wilting point is assumed to be available. These definitions only approximate field conditions, which are affected by soil texture, contrasting layers in the soil, type of plant, and type of cropping system (Hillel 1998). Irrigation is typically applied long before soils reach the wilting point, so traditional definitions of available water lose some of their usefulness. Water held only at the wetter end of the range may be the most important in many situations. The entire range may be more important in drought tolerant landscapes that receive little or no irrigation.

McCoy (1992) observed an increase in water held between 33 kPa and 1500 kPa, but not water held between 33kPa and 200kPa, with organic amendments applied to sand. By contrast, Gentilucci *et al.* (2001) measured increased available water between 33kPa and 200 kPa and between 200 and 1500 kPa.

Available water measurements do not account for other potential changes in the root environment resulting from incorporation of organic amendments. Increases in root distribution or root density could improve access to available water by the plant. Mamo *et al.* (2000) could not measure an increase in plant available water one year after applying a high rate (270 Mg/ha) of municipal waste compost to a loamy sand agricultural soil, but did see reduced moisture stress in corn grown on the plots, suggesting that the root system had greater access to available water.

Plant Nutrient Supply from Compost

Composts contain all of the essential plant nutrients. The availability of some nutrients (especially N) in compost is lower than from uncomposted materials because composting converts soluble nutrients into organically-bound forms, which must first mineralize before they will become plant-available. Nutrient supply can be substantial, despite the low rate of availability, if large amounts of compost are applied to land

Plant available nitrogen. Most research on N availability from composts has been done using agricultural field experiments or laboratory incubations. This section describes several recent studies on N availability from composts.

Sullivan *et al.* (1998) evaluated six food waste composts with C:N ratios in the range of 20-25:1. The composts were incorporated into a sandy loam soil at a rate of 155 Mg/ha, and the site was planted with tall fescue for forage. Compost did not affect yield or N uptake in the establishment year, but yields and N uptake were greater in the compost-treated plots in subsequent years. Apparent N recovery in the harvested tall fescue was about 4% of compost N applied in the second and third years (Sullivan *et al.* 1998). In the fourth through seventh years, apparent N recovery averaged 2% per year (Sullivan *et al.* 2003). A total of 15 to 20% of the applied N was recovered in the crop during the seven-year period.

Sullivan *et al.* (2002) compared food waste compost applied at a rate of 155 Mg/ha with a zero-compost control plus various rates of fertilizer N on tall fescue forage. The compost treatment had greater forage yield and N uptake than the zero-compost treatment when no inorganic N was added, but the yield and N uptake difference disappeared as the inorganic N rate increased. This showed that the compost effect on tall fescue yield and N uptake was due to N supply. Other yield-enhancing benefits of the compost (e.g., water holding capacity, non-N nutrient supply, tilth) were not realized in the productive soil series (Puyallup fine sandy loam; coarse-loamy over sandy Vitrandic Haploxerolls) employed in this study.

In contrast, Cox *et al.* (2001) measured significant improvements in soil physical properties (Table 2) but did not see a beneficial compost effect on crop yield until the third year after application. They attributed this effect to N immobilization from the compost (C:N 32:1). Laboratory incubations showed that N immobilization persisted for at least 18 months following application of the compost.

Mamo *et al.* (1999) found that municipal solid waste composts (mean C:N 20:1) applied at a rate of 90 Mg/ha/yr provided half of the N needed for a corn crop in the first two years of applications. By the third year compost alone provided sufficient N for maximum yield. Mamo *et al.* (1999) also made a one-time application of 270 Mg/ha of compost and grew corn for three years. They calculated a net N mineralization of about 4% each year from the single application.

Mamo *et al.* (1998) applied municipal solid waste composts with C:N ratios of 14:1 and 33:1 to corn. In the first year after compost application apparent recovery of compost N was 8% for the low C:N compost and negative for the high C:N compost. In the second and third years, about 2 to 5% of the compost N was recovered in the crops for both compost sources.

In laboratory incubations with compost made from municipal solid waste and tobacco waste (C:N 29:1) in soils ranging in texture from sand to heavy sandy loam, Egelkraut *et al.* (2000) observed net N immobilization for a period ranging from 47 to 131 days. The length of the immobilization period increased with fineness of soil texture.

Results of this and other research (Hadas and Portnoy 1994; Chen *et al.* 1996; Sims 1990) indicate that composts with a C:N ratio of 20-25:1 or less will generally supply N to plants during the first growing season, while immobilization becomes more likely as C:N increases. Using composts with C:N greater than 30:1 will require additional N fertilizer during the first growing season (and sometimes longer) to achieve adequate establishment and growth of plants. The benefit of nutrient supply during establishment is lost, and extra management is needed to maintain a healthy and functional landscape where materials with high C:N ratios are used.

Nitrate Leaching. Accumulation of nitrate in the soil at the end of the growing season presents a risk for winter leaching because little of the nitrate may be taken up by plants during the winter, and nitrate is very soluble in water percolating through the soil.

Sullivan *et al.* (1998) measured no increase in soil nitrate-N in the fall following application of 155 Mg/ha (5 cm) of food waste compost (C:N 20:1 to 25:1) to tall fescue. Tall fescue is efficient at uptake of N through a long growing season (Whitehead 1995). Mamo *et al.* (1998) saw a small increase in post-harvest soil profile nitrate (< 20 kg/ha) when a low C:N (14:1) compost was applied to corn at a rate of 90 Mg/ha. Borken *et al.* (2004) reported that 0.2 to 7.8% of applied N was leached below a depth of 100 cm, following application of a 1.5 cm layer (1440 kg/ha total N) of low C:N (10:1) compost to mature forest stands. Nearly all of the loss occurred in the first 17 months after compost application.

Soil nitrate levels depend as much on vegetation and management as on the amount of compost N applied; thus, it is hard to extrapolate from the results cited above to urban landscapes. Nitrate accumulation and leaching would be a greater concern where high rates of low C:N compost are applied in landscapes that do not take up large amounts of N (viz., woody plants). The concern is less for lawns because grasses are efficient N accumulators over a long season (Whitehead 1995).

Non-N nutrients and pH. He *et al.* (2001) reviewed research on plant nutrients other than N in compost. Composts contain all essential plant elements. The amount and availability of the nutrients vary depending on the compost feedstocks. Yard trimmings composts generally contain less P than biosolids composts but have a greater proportion of their P in available form. Yard trimmings composts also contain substantial amounts of K (often 1% or more on a dry weight basis) compared with biosolids composts, which contain much less K. Most of the K is readily available to plants. Chen *et al.* (1996) measured similar amounts of P in cow manure and biosolids composts, but cow manure compost contained considerably more K than biosolids compost.

Compost pH is generally near neutral to slightly alkaline. Composts containing alkaline feedstocks (such as alkaline stabilized biosolids or ash) have higher pH. Most research has shown a small effect of compost amendment on soil pH, typically increasing soil pH by 0 to 1 unit (Sims 1990; Maynard 1994; Hornick 1988; Stamatiadis *et al.* 1999; Epstein *et al.* 1976). Because composts can raise soil pH, Alexander (2001) suggests caution when adding compost (esp., alkaline compost) to soils where acid-loving plants will be grown.

How long are the organic amendments effective?

Because compost decays over time, the beneficial effects of a single application are expected to be transient. Tester (1990) studied the residual effects of biosolids compost applied at 60, 120, and 240 Mg/ha incorporated into a sandy loam soil in Maryland, and planted with tall fescue forage. The compost treatments had more soil organic matter, lower bulk density, and lower penetration resistance five years after the compost application. About half of the compost organic matter, based on changes in soil organic carbon content, remained in the soil profile. Sullivan *et al.* (2003) incorporated 155 Mg compost/ha into a fine sandy loam in western Washington, and planted tall fescue forage. They estimated that 18% of the compost C remained seven years after application. These studies suggest that a single compost application will provide benefits for at least several years under humid, temperate climate conditions.

How much organic matter should be applied to benefit degraded urban soils?

Most of the research on compost and other organic amendments has been done in agricultural cropping systems. The following is an attempt to summarize the few studies that address the use of compost for establishing of lawn and landscape plantings in nonagricultural soils.

Lawns

Healthy turf has a dense, fibrous root system that continually supplies the soil with organic matter through root exudates and sloughing of dead root tissue. Porter *et al.* (1980) measured soil organic nitrogen (an indicator of organic matter) at 99 sites on Long Island, New York beneath lawns that ranged in age from <1 year to 125 years. Organic N increased with age of the turf, with about half of the increase occurring during the first ten years after establishment.

Qian and Follett (2002) compared organic matter levels in soils from golf course fairways that ranged in age from 1 to 45 years. Average organic matter levels in the upper 12 cm of soil ranged from 1.8% in the youngest fairways to 4.2% in fairways established 30 or more years earlier.

The main purpose of using organic amendments for lawn establishment is to provide an environment that will provide establishment of a healthy root system (Stahnke *et al.* 2000). Turf scientists from Pennsylvania, New Jersey, and California have evaluated a variety of composts for the establishment of turf for home lawn conditions (Table 3) (Landschoot and McNitt 1994; Gentilucci *et al.* 2001; Ries *et al.* 2004). All three studies were done in soils that were deficient in organic matter.

All of the researchers reported that compost applications were beneficial to turf establishment and growth across the range of rates studied. Landschoot and McNitt (1994) observed that the compost treatments reduced soil bulk density and increased infiltration compared with untreated and topsoil-amended controls. The composts supplied a portion of the nutrient requirements for the turfgrass for at least two growing seasons, with the nutrient supply depending on the type of compost. Gentilucci *et al.* (2001) reported improved turf establishment with compost amendments in the first year of their study, and improved turf quality in years 2 and 3. The only exception was for their municipal solid waste compost, which had a C:N of 42:1 and had slower turf establishment than the control in Year 1. They also measured increased soil porosity and available water. Ries *et al.* (2004) reported improved turf quality under traffic in the second year after establishment, a softer surface, and increased root mass. Infiltration improved only at the highest compost application rate.

Landschoot (1995) recommended that compost be applied at a rate of 2.5 to 5 cm and incorporated to a 10 to 15 cm depth for establishing home lawns. The higher rate would be suitable for soils that were low in organic matter, such as subsoils. Landschoot did not recommend compost applications to soils that already have adequate amounts of organic matter, because fewer benefits would be expected relative to the cost. Turf specialists from other parts of the U.S. have adopted similar recommendations (Table 4).

TABLE 3.
Experimental conditions for research on compost applications for turf establishment

Location	Compost Type	Application Rates (cm)	Depth of Incorporation (cm)	Soil Texture	Turf Variety
Pennsylvania	Yard debris, biosolids, manure	2.5 and 5	10 to 15	Clay loam	Kentucky Bluegrass
New Jersey	Yard debris, leaf, MSW	5 and 10	15	Sandy loam (eroded)	Kentucky Bluegrass
California	Yard debris	2.5, 4, and 5	10	Sandy loam	Common Bermudagrass

TABLE 4.
Compost application recommendations for turf establishment in different environments.

University	Recommendation
Penn State Landschoot, 1995	2.5 to 5 cm incorporated into 10 to 15 cm of soil. Higher rate is for soils low in organic matter.
Kansas State Fagerness and Keeley, 2000	2.5 to 5 cm incorporated 20 to 25 cm deep.
WSU Stahnke *et al.*, 2000	Maximum 20 % by volume, or 2.5 to 5 cm incorporated 15 to 20 cm deep. Most useful for sandy and clay soils.
Kentucky Powell, 2000	2.5 cm incorporated 10 to 15 cm deep for soils low in organic matter.
Utah State Farrell-Poe, 1997	2.5 to 5 cm incorporated as deep as possible. Higher rate is for sandy and clay soils.
Wyoming Blaylock and Davis, 1994	5 to 10 cm incorporated 25 to 30 cm deep.

Landscape Plants

Published research on organic amendments for woody landscape plants has focused almost entirely on amendment of planting holes. A number of studies have evaluated the use of organic amendments in planting holes in compacted, disturbed soil typical of urban areas, and have found no benefit (Watson and Kupkowski 1991; Watson *et al.* 1992, 1993; Day and Bassuk 1994). Autio and Greene (1991) compared two organic amendments (50% dairy compost amended into native soil and 50% peat amended into native soil) with unamended soil used in planting holes for apple trees in a fine sandy loam orchard soil. Trees planted in the holes with organic amendments had significantly greater trunk diameter and shoot growth in the first year after transplanting, but differences were not significant in the second or third years.

Day and Bassuk (1994) reviewed a number of studies, and concluded that performance of plants in amended holes may be poorer than in unamended holes when low rates of irrigation water are supplied. This may be caused by an interface effect, where the plant takes moisture rapidly from the planting hole, and capillary movement of moisture from the surrounding soil into the hole is slow. This problem diminishes once the roots become established in the surrounding soil. At higher rates of irrigation, the amended holes may provide some benefit during establishment. Amendments may also be detrimental in wet soils, where the planting holes are saturated or nearly saturated with water for periods of time.

Planting beds present a different environment from planting holes. Within a bed, there are no planting hole interfaces, and once roots grow beyond the root ball moisture movement across interfaces would not be a problem. In this regard, beds are similar to agricultural soils. We would expect the benefits of compost amendments (e.g., reduced bulk density, improved infiltration, increased aggregate stability, reduced resistance to penetration, and increased nutrient supply) to play an important role in improving the planting environment in beds.

How much compost should be added to achieve these benefits in landscape beds? No published research was found that directly addresses this question. Harris *et al.* (1999) question if amending a bed with organic materials is justified. They suggest that breaking up compacted soil without amendment would be adequate for establishing trees and shrubs in beds. Harris *et al.* (1999) do recommend mulching landscape beds with organic materials, such as composts, to reduce erosion and improve the environment for plant growth.

The research cited in this review suggests that organic amendment of beds could provide important benefits in degraded soils. Some studies in agricultural soil showed measurable changes in soil physical properties occurring at organic application rates of 40 to 60 Mg/ha (about 2 cm or less), with increasing effects at higher application rates. In uncompacted soils that contain adequate amounts of organic matter and receive adequate irrigation, the only measurable benefit observed to plants is from the nutrients supplied by the organic amendment. In degraded soils, the other benefits should become more apparent. These benefits are likely to persist beyond the establishment period of the landscape.

How much compost is too much?

If research shows increasing physical benefits with increasing compost application rate up to the maximum rates studied (about 1/3 by volume of the amended soil), is there an upper limit on compost application to degraded soils? In arid locations where salt accumulation is a problem, the salt content of the soil-compost mix may limit compost application rates (Alexander 2001). If the salt content exceeds the tolerance of the plants to be grown, a better source of compost would need to be found, or lower rates applied. In poorly drained soils, compost applications may lead to prolonged wetness and anaerobic conditions. High rates of nitrogen-rich composts may cause excessive nitrate leaching in the first year of two after application. Craul (1999) noted that compost amendment rates of 50% by volume or greater have led to excessive settling and waterlogging of urban soils. In most degraded landscapes, compost applications of 5 to 8 cm, amended 20 to 25 cm deep should provide long-term improvement of the soil environment.

Conclusions

Most of the research on the effects of organic amendments on soil physical properties has been done in agricultural systems. Research results have shown the positive effects of compost on aggregate stability, bulk density, porosity, infiltration rates and total water holding capacity of soils. Compost amendment increased plant available water in some studies, but not in others. Data on the longevity of compost benefits are limited, but suggest that some of the effects of compost are still present more than five years after application in a humid, temperate environment.

Little direct research has been published on amending soils disturbed by urban development. Amendment guidelines for establishing lawns or landscape beds in these soils have largely been based on agricultural and orchard research. Research on the effects of compost quality, rate, and depth of incorporation for lawn and landscape establishment in different environments would strengthen the scientific basis for recommendations to improve soils degraded by urban development. The areas of greatest research need are the effects of compost amendments on water relations in urban landscapes, including water use, plant moisture stress, and runoff.

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