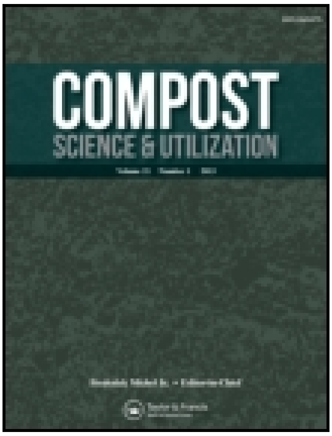

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Compost Effects on Soil Physical Properties And Field Nursery Production

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Field production of ornamental shrubs often results in significant topsoil removal and degradation of surface soil physical properties. Building soil organic matter through compost amendments is one way to ameliorate effects from topsoil removal in woody ornamentals production. We amended field soils with three composts to evaluate their effects on soil physical properties and shrub biomass production. Specifically, we applied either duck manure-sawdust (DM), potato cull-sawdust-dairy manure (PC) or paper mill sludge-bark (PMB) composts to a Plano silt loam soil using two application methods: 2.5 cm of compost incorporated into the top 15 cm of soil (incorporated-only) or 2.5 cm of compost incorporated plus 2.5 cm of compost applied over the soil surface (mulched). We grew three shrub species from liners: *Spirea japonicum* 'Gumball', *Juniper chinensis* 'Pfitzeriana', and *Berberis thunbergia* 'Atropurpurea'. Shrub species and soil amendment treatments were established in triplicate in a randomized split plot design. Total soil carbon (TC), bulk density (ρ_b), aggregate stability, soil moisture retention capacity (MRC), volumetric moisture content (θ_v), and saturated hydraulic conductivity (K_{sat}) were measured over three years (1998 to 2000). We measured above and below ground shrub dry matter production at the end of the first (1998) and second (1999) growing seasons. Mulched treatments resulted in 15%-21% higher TC than the incorporated-only and no-amendment control treatments. Bulk density decreased with increasing TC contents. Greater aggregate stability and the formation of larger aggregates were related to increased TC. Field moisture retention capacity tended to be higher in the incorporated treatments compared to the mulched and nonamended control treatments. Compost amended treatments increased saturated hydraulic conductivity (K_{sat}) sevenfold over the nonamended control. There were no compost effects on shrub biomass until the second year of growth. Barberry was the only species to respond significantly and positively to compost application. Specifically, mulched DM compost produced 39-42% greater total Barberry biomass than the other compost treatments and the nonamended control. Our findings showed that compost effects on soil physical properties differed among composts and their subsequent effects on shrub growth were species specific.

Introduction

Field production of ornamental shrubs often results in significant topsoil removal when the shrubs are harvested. Topsoil removal usually results in soil organic matter (SOM) declines over time. The reduction of SOM has a negative effect on soil physical properties, including water retention capacity, plant available water, aggregation, infiltration and drainage (Stevenson 1994). Use of composts derived from wood and timber by-products along with animal manures or food processing wastes holds promise as an environmentally and economically sound means of rebuilding SOM in ornamental horticulture systems.

Most of the research related to compost use with ornamental horticultural crops has been conducted either under greenhouse conditions or in containerized systems in the field. Although very different from field soil, container systems provide valuable insights about how compost application might affect soil physical properties and plant growth. For example, Tripepi *et al.* (1996) found that amending sandy soil-based container mixes with increasing amounts of composted paper mill sludge decreased mix bulk density and increased waster holding capacity in a linear fashion. In contrast, Atiyeh *et al.* (2001) found that pig manure vermicompost amended to a horticultural bedding medium increased bulk density and decreased total porosity, while it increased container (water holding) capacity. These findings suggest that compost effects on soil physical properties will differ among compost types.

Field studies using compost in horticultural crop production have demonstrated beneficial effects on crop growth in the short term. Gouin and Walker (1977) found that stem length of *Liriodendron tulipifera* L. and C*ornus florida* L. seedlings was greater in sewage sludge compost-amended plots. Robbins *et al.* (1986) doubled prune yields in a 13-year old Italian prune (*Prunus domestica* L.) orchard after a single compost application. Maynard (1998) showed that compost applied as both a soil amendment and mulch reduced first-year mortality of Acer sp. relative to the nonamended control. Stuckey and Hudak (2001) demonstrated that compost application to loblolly pine (*Pinus taeda*) trees produced higher soil moisture, higher survival rates, and greater growth increases than the control group.

These studies provide evidence for the beneficial effects of compost application on soil physical properties and plant growth. However, we found no studies evaluating compost effects on soil properties in horticultural production systems that remove large amounts of topsoil; i.e., field production of ornamental shrubs. Additionally, we found very few studies that identified those soil properties most responsible for ornamental plant growth. The objectives of this study were (i) evaluate effects of different compost types and application methods on soil physical properties in field shrub production; (ii) to quantify compost effects on ornamental shrub growth and (iii) to evaluate relationships between soil physical properties and shrub growth.

Materials and Methods

Site Description and Experimental Design

The experiment was conducted at the University of Wisconsin West Madison Agricultural Research Station between May 1998 and September 2000. The experimental site is located at 43°5′ N and 89°31′ W. The predominant soil type is Plano silt loam, fine silty, mixed, mesic, Typic Argiudoll (U.S. Soil Taxonomy), and the field has less than 2º slope. Baseline soil characteristics were measured prior to compost application (Table 1). The experimental design was a randomized split plot with shrub species as the main effect and compost type and application method as the secondary effects. The experimental design consisted of:

- Three shrub species: *Spirea japonicum* 'Gumball' (Spirea), *Juniper chinensis* 'Pfitzeriana' (Juniper), and *Berberis thunbergia* 'Atropurpurea' (Barberry).
- Three compost types: duck manure-sawdust, potato cull-dairy manure-sawdust, and paper mill sludge-bark.
- Three application methods and rates:
    - ○ Incorporated only = 2.5 cm layer of compost incorporated into the top 15 cm of the topsoil (low rate).
    - ○ Mulched = 2.5 cm incorporated plus 2.5 cm layer of surface applied compost (high rate).
    - ○ No amendment control.

TABLE 1.
Baseline chemical properties of study soil.

Property	Units	Mean†	Standard Deviation
NH_4-N (2 M KCL)	mg L^{-1}	11.6	1.1
NO_3-N (2 M KCL)	mg L^{-1}	15.6	2.3
pH (sat. paste)	–	7.1	0.1
Bray-1 P	mg kg^{-1}	46.3	5.8
Exch. K (1 M Ammon. Acetate)	mg kg^{-1}	316.7	60.1
Exch. Ca (1 M Ammon. Acetate)	mg kg^{-1}	1633.3	53.7
Exch. Mg (1 M Ammon. Acetate)	mg kg^{-1}	685.8	34.2
TC (Dry combustion CHN)	%	2.2	0.1
TN (Dry combustion CHN)	%	0.22	0.01
DTPA-Zn	mg kg^{-1}	<0.04	–
DTPA-B	mg kg^{-1}	33.5	23.5
DTPA-Mn	mg kg^{-1}	84.1	8.0
DTPA-Fe	mg kg^{-1}	135.8	45.2
DTPA-Cu	mg kg^{-1}	<0.01	–
DTPA-Al	mg kg^{-1}	4.6	2.5

† n= 15 samples (5 reps X 3 blocks) collected prior to compost application, May 1998.

Treatments were replicated three times in plots of 2.1 m x 1.2 m. Within each "whole plot" (plant species), there were seven soil treatments: (three compost types x two methods of application) + control.

Compost Material and Application

Duck manure compost (DM) and potato cull (PC) composts were produced at the University of Wisconsin's West Madison Agricultural Research Station. The raw materials used for the duck manure compost were duck manure (excreta +wood shavings bedding) and sawdust in a volumetric ratio of 1:1. For the potato cull compost we mixed potato culls, sawdust and dairy manure in a volumetric ratio of 3:3:1. The paper mill sludge-bark (PMB) compost was obtained from Renewed Earth, Inc. (Kalamazoo, Michigan). The raw materials used for this compost were paper mill sludge and bark, in a volumetric ratio of 1:1.

All composts were produced using open-air turned windrow composting methods. Duck manure and PC compost were composted for eight months, whereas PMB compost was composted for five months. We evaluated compost chemical properties prior to field application (Table 2). There were differences in total carbon, C:N ratios and available nutrients.

TABLE 2.
Chemical characterization of compost materials at time of application to soil (May 1998).

Compost Type†	C:N	TN‡	TC§	Ash	P	K	Ca	Mg	S	Zn	B	Mn	Fe	Cu	Na	pH	EC¶
		g kg^{-1}								mg kg^{-1}							S m^{-1}
DM	17.5	22	385	222	9.33	15.4	27.4	6.1	2.9	317	22.3	480	3209	45.3	1553	8.1	0.095
PC	12.9	16	206	424	4.00	17.3	21.0	8.8	2.2	67	3.0	406	7998	15.2	755	8.4	0.130
PMB	19.7	17	338	197	2.28	3.2	43.9	4.1	4.1	95	6.4	906	3744	16.9	870	7.9	0.035

†DM =Duck manure-sawdust compost; PC = potato Cull-sawdust-dairy manure compost; PMB = Paper mill residuals-Bark compost. ‡TN = total nitrogen (determined using dry combustion). §TC = total carbon (determined using dry combustion). ¶EC = electrical conductivity

Composts were applied to plots on a volume basis. Incorporated only compost plots received 254 m^3 ha^{-1} and mulched compost plots received 508 m^3 ha^{-1}. On average, the total amount of carbon (C) added to the incorporated only compost plots was 11.4 Mg ha^{-1}, and 22.79 Mg ha^{-1} was added to the mulched plots. We incorporated composts into the top 15 cm of soil two weeks prior to planting. Mulched compost treatments did not receive the mulch layer until two months after planting to allow time for seedling establishment.

Planting

We planted 18 rooted vegetative cuttings (liners) per plot on a 0.3 m x 0.3 m spacing. The liners were approximately 15 to 18 cm tall, and were inserted vertically in 15-cm deep holes. We also planted a grass strip (0.5 m wide) between each plot to minimize soil erosion and water movement of compost among plots. During the first growing season, Juniper seedlings were supported with 20-cm long stakes.

Plot Maintenance

Plants were manually watered biweekly (1 cm of water each time) at the beginning of the experiment, and after planting through July 1998. Weeds were removed from each plot through hoeing. The grass in the vegetative strips was mowed every two to three weeks.

No commercial fertilizers were added to the soil during the experiment. In September 1998, we thinned the planting density from 18 plants to nine plants per plot (2.52 m^2) by destructive harvest (aboveground and belowground plant sections).

Soil Measurements

Unless specified differently in each method description, we collected nine cores for each of the seven soil treatments (3 blocks $\times$ 3 plant species) for soil measurements requiring intact soil cores. For soil measurements using a disturbed soil sample, we collected one composite soil sample per plot consisting of at least 10 sub samples, 15 cm soil depth. In all cases, we removed the mulch layer prior to sampling.

Total Soil Organic Carbon

Total soil organic carbon (TC) was measured prior to compost application (baseline; May, 1998), six months after compost application (October 1998) and two years after compost application (May 2000). Soil samples were air-dried and ground with a Nasco-Asplin soil grinder (Nasco, Fort Atkinson, Wisconsin) to pass through a 2-mm sieve. Samples were further ground manually with a mortar and pestle to pass through a 1-mm sieve to homogenize the sample and to increase the accuracy of the analysis. Total soil carbon in the baseline soil samples was determined with a total CHN analyzer (Carlo Erba, 1500-Na, Italy). Postcompost application TC was determined using a combustion total carbon analyzer (DC-190, Rosemount Analytical Inc., Santa Clara, California). Baseline TC content was remeasured with the DC-190 combustion total carbon analyzer, to compare the results with those that had been previously obtained with the total carbon-nitrogen analyzer.

Soil Bulk Density and Porosity

We measured soil bulk density in the top 7.6 cm of the soil profile for three consecutive years prior to and after compost application (May, 1998; June 1999; and June 2000). We collected soil cores using a double-cylinder, hammer-driven core sampler (345-cm^3 metal core; 7.6 cm long × 7.6 cm inner diameter) (Blake and Hartge, 1986). The soil samples were placed in an oven at 105° C until achieving constant weight. The soil bulk density was calculated as the oven-dry mass of the soil sample divided by the core volume. Soil porosity was calculated from the soil bulk density using the equation,

$$\% \text{ Porosity} = 1\text{-(soil bulk density/particle density)} \times 100$$

where particle density was assumed to be 2650 kg m^{-3}.

Aggregate Stability

We measured aggregate stability at the end of the experiment (Spring 2000), using a modified procedure for wet sieving (Kemper and Rosenau 1986). We collected soil samples from the top 7.5 cm of the soil profile using a 20-cm diameter metal ring. We selected a subset of plots for a total of four cores per compost treatment. Since we were most interested in compost type/rate effects, we used Barberry plots only, because its small root biomass was expected to have minimal impact on soil structure. When the soil was still moist, soil samples were gently sieved through an 8-mm screen. Soil aggregates <8 mm in diameter were air-dried for approximately 24 hours. For each air-dried sample of sieved soil aggregates, we prepared three 25.0-gram sub samples for further analysis. These sub samples were placed on a nest of sieves (2.0, 1.0, 0.5, and 0.25-mm opening sieves) and then rewetted slowly using a spray bottle.

We used a wet sieving machine (stroke length of 1.3 cm and frequency of 35 cycles $minute^{-1}$) with the ability to sieve six nests of sieves simultaneously. The samples were immersed in distilled water for 10 minutes and then gently agitated for another ten minutes. The soil remaining in each sieve was collected and oven-dried (105˚ C) to determine dry mass.

After wet sieving, each sample was dispersed in a sodium hexametaphosphate solution (2 g L^{-1}), and then manually re-sieved until only sand particles were left on the sieve. The sand from each sieve was collected, oven-dried and weighed. The oven-dried mass of aggregates per sieve was calculated by subtracting the mass of sand from the oven-dried mass of soil remaining in each sieve. Aggregate stability was characterized as the distribution of aggregate mass in a range of size classes.

Soil Moisture Retention

Soil moisture retention in the saturated to field capacity range was determined annually using intact cores (May 1998; May 1999; and May 2000). Soil cores were saturated with tap water for 24 hours. Once saturated, we placed the samples in a low matric potential range system (0 to approximately -20 J kg^{-1}) and determined volumetric soil moisture contents at matric potentials between 0 and -25 J kg^{-1}. We used an apparatus similar to that used by McGuire and Lowery (1994). Soil moisture release curves were constructed by plotting the volumetric moisture content against matric potentials. Volumetric moisture content at -33 J kg^{-1} was estimated from the soil water release curves.

Soil Moisture Content

Gravimetric soil water content was measured biweekly during the growing season in 1998 and 1999. Composite samples (0-15 cm depth) were oven dried (105° C) until constant weight was achieved. Bulk density was used to convert gravimetric water content to volumetric water content.

Saturated Soil Hydraulic Conductivity

Saturated soil hydraulic conductivity (K_{sat}) was measured on intact soil cores (May 1999 and May 2000) using the falling head method (Klute and Dirksen 1986). Soil cores were saturated with a 0.005 *M* $CaSO_4$, 0.1% phenol, CO_2–free solution for 24 hours. To prevent preferential flow of water along the core wall, a thin layer of soil (≈ 1 mm) along the top edge of the sample was replaced with bentonite clay. Soil cores were placed under a water column, and the change in the water head per change in time was measured. The saturated soil hydraulic conductivity (K_{sat}) was calculated using the following equation;

$$K_{sat} = [aL/A\ (t_2 - t_1)](\log H_1 - \log H_2),$$

where a is the cross-sectional area of the water column, L is the length of the soil sample, A is the cross-sectional area of the soil sample, and $t_2 - t_1$, and $\log H_1 - \log H_2$, correspond to the change in time and change in the water column height, respectively.

Plant Dry Matter Production

In September 1998 and 1999, we harvested five plants per plot (45 plants per treatment or 5 plants × 3 species × 3 blocks) for dry matter (biomass) determinations. At the end of the second growing season (1999) seven Barberry plots were not harvested because of infection with *Fusarium* sp. Aboveground plant biomass included stems and foliage. Each shrub was harvested by cutting the stem at the soil surface. To harvest the belowground (root) biomass, we used a 18-cm long metal core with an inner diameter of 15 cm. Once the aboveground biomass was removed, we placed the core over the remaining stem so that it was in the center of the core. The core was driven into the soil to a depth of approximately 18 cm using a sliding weight. To avoid severe damage of secondary roots, soil was carefully removed from plant roots by rinsing them with tap water.

Aboveground plant parts were also carefully washed with tap water to remove any soil particles. Both aboveground and belowground plant parts were oven dried at 60° C until constant weight was achieved (Delta Range® PR2003 analytical balance, Mettler-Toledo, Switzerland). The aboveground and belowground dry masses were combined to obtain the total plant dry mass production.

Statistical Analysis

The SAS Version 8 "Plot" procedure (SAS Institute, Cary, North Carolina) was applied to identify outliers and test the normality of our data. We used the SAS "Mixed" procedure to conduct an analysis of variance to determine plant species and compost type and/or application method effects on soil properties. We used the same procedure to determine compost effects on shrub biomass production. We performed an analysis of covariance to identify the soil physical variables that had significant effects on plant growth.

Results and Discussion

Statistical analyses revealed that there was an interaction between shrub species and compost treatments. For many of the physical properties measured, we found significant compost effects on soil physical properties only in plots with Barberry. As such, we focus our presentation of soil physical results using data from Barberry plots only. If there were significant compost effects on soil physical properties with other shrub species, they are included and noted in the results.

Total Soil Carbon

Total soil carbon contents (TC) of all compost-amended treatments remained significantly higher than the no-amendment control up to two years after compost application (Figure 1; $p < 0.005$). Nonetheless, TC contents declined from July 1999 to May 2000 among all compost types. All mulched treatments lost approximately twice as much TC as the incorporated-only treatments; however the decomposition rates were similar since twice as much C was added with mulched treatments compared to incorporated-only treatments. During the three years of study (1998 – 2000), all mulched treatments maintained 2.7-4 g kg^{-1} more TC than the incorporated-only treatments ($P < 0.015$). The DM compost maintained the highest TC contents among compost types. This was likely related to the higher C added with the DM compost material.

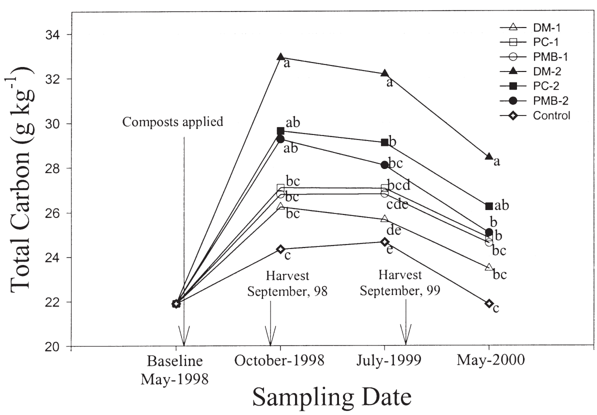


Figure 1. Compost treatment effects on total soil carbon. Barberry plots only. DM= duck manure compost; PC= potato cull compost; PMB= paper mill sludge-bark compost. 1= 2.5 cm-layer compost incorporated into top 15 cm of soil; 2= 2.5 cm incorporated + 2.5 cm applied as mulch. Treatment by date interactions with the same letter are not significantly different (a= 0.05).

Other studies have shown similar effects with single organic amendment applications. Lindsay and Logan (1998) applied anaerobically digested sewage sludge to a Miamian silt loam and observed an increasing linear relationship between TC and sludge application rate. In contrast, Zibilske *et al.* (2000) tested five rates of paper mill sludge and found that soil TC increased only with the highest sludge application rates.

Bulk Density and Porosity

During the first year after compost application there was no significant compost effect on soil ρb ($P = 0.42$). Others have found that amendment effects on ρb take more than one year to manifest themselves, particularly in fine textured soils (Zibilske et al., 2000). Bulk density was significantly lower ($P < 0.05$) in the mulched treatments during 1999 and 2000, among all plant species (Table 3). The mulched DM compost treatment had the lowest ρb among all treatments.

During the second and third year after compost application, ρb was significantly lower in Spirea and Barberry plots compared to Juniper plots. The significantly greater

TABLE 3.
Compost treatments effects on soil bulk density in Barberry plots during 1999 and 2000.

Compost Type	ρb 1999 Incorporated-only (Mg m^{-3})	ρb 1999 Mulched (Mg m^{-3})	ρb 2000 Incorporated-only (Mg m^{-3})	ρb 2000 Mulched (Mg m^{-3})
Duck manure	1.38	1.26	1.24 a	1.13 c
Potato cull	1.40	1.34	1.25 a	1.18 abc
Paper mill sludge-bark	1.40	1.37	1.21 ab	1.16 bc
Control	1.37	1.37	1.24 a	1.24 a

There were no significant differences among compost types and application methods during 1999 (a= 0.1). Data points corresponding to year 2000 with the same letter are not significantly different (a = 0.05). Within a given compost type, data points with the same letter are not significantly different (a= 0.05).

root systems of Spirea (54.63 g) and Barberry (24.21 g) relative to Juniper (8.26 g) might have displaced mineral soil particles with higher particle density, thereby lowering overall soil bulk density. Alternatively, greater root biomass and production of root exudates could have increased soil aggregation, which could have decreased ρb (Zibilske *et al.*, 2000).

In general, mulched treatments resulted in higher soil porosity (Figure 2). Two years after compost application (May 2000), mulched treatments of DM and PMB composts produced significantly higher soil porosity relative to the no-amendment control (p< 0.038). Since porosity is derived from bulk density, we invoke a similar explanation for the mulch effect on porosity; increased aggregation resulted in increased total pore space (Martens and Frankenberger 1992).

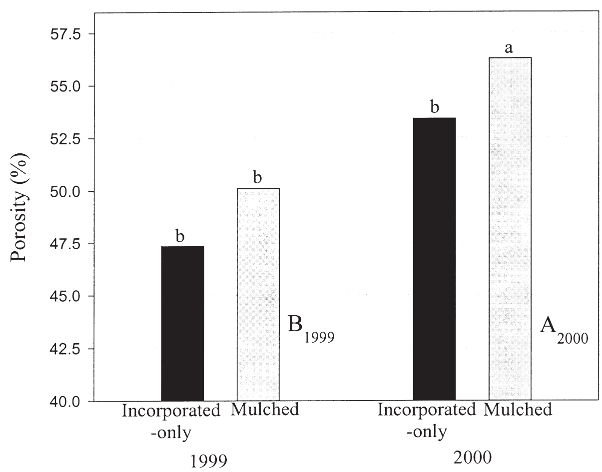
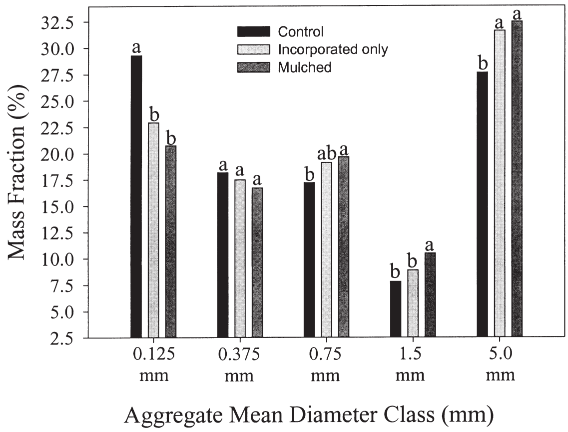


Figure 2. 1999-2000 compost application method/rate effects on total soil porosity averaged over compost types. Barberry plots only. Bars with the same letters are not significantly different (a=0.05).

Aggregate Stability

Soil aggregate stability increased with increasing TC contents. Mulched treatments increased the mass fraction of 5-, 1.5-, and 0.75-mm soil aggregate size classes relative to the incorporated-only treatments and the no-amendment control (Figure 3). Concurrently, the mass fractions of 0.375- and 0.125-mm soil aggregate size classes were lower in the mulched treatments compared to the incorporated-only treatments and no-amendment control. Our findings corroborate those of other studies involving organic amendment applications to soils (Guerrero *et al.* 2000; Chantigny *et al.* 1999). Lindsay and Logan (1998) also reported significant increases in percent water stable aggregates with increasing biosolids application rate. Zi-



$$\text{Mass Fraction} = \left[\frac{\text{mass of aggregates in a given size class}}{\text{Total mass of all aggregate size classes}}\right] \times 100$$

Figure 3. Compost application method effects (averaged across compost types) on aggregate size distribution two years after compost application (spring 2000). Bars within an aggregate size class with the same letter are not significantly different (a=0.05).

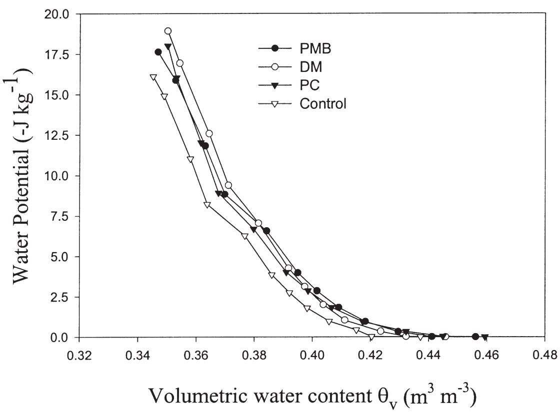


Figure 4. Soil moisture retention curves of compost-amended soils from saturation to field capacity (0-20 -J kg^{-1}). PMB= paper mill-bark compost; DM= duck manure compost; PC= potato cull compost.

bilske *et al.* (2000) observed that aggregation increased with increasing sludge C addition for the 2- and 1-mm size fractions, while it stayed the same in the 0.25-mm fraction.

Soil Moisture Retention

We compared moisture retention for the low-tension range of the curve only (saturated to field capacity conditions). One year after compost application (1999), the DM-compost amended soils had higher water retention compared to PC- and PMB-compost amended soils and in the no-amendment control soil (Figure 4). When evaluating the relationship between TC and estimated volumetric water content at field capacity (θ_{v33}), there was a significant inverse relationship between θ_{v33} and TC content ($r^2=0.40$; $p=0.0007$). The addition of DM compost promoted the formation of slightly larger pores relative to PC and PMB composts. This could have allowed soil water release at lower energies and lowered soil water retention in the low-tension range of the moisture retention curve. Wei *et al.* (1985) also observed that water retention decreased for the sludge-treated soils at water potentials ≥ -33J kg^{-1}. They highlighted that this was a positive effect on a silty clay loam soil, since this soil has very poor drainage.

Volumetric Moisture Content Under Field Conditions

During the first growing season (1998) among all shrub species, field-measured volumetric soil moisture content (θ_v) was higher in the mulched treatments (0.264 m^3 m^{-3}; mean of all dates) than in the incorporated-only treatments (0.235 m^3 m^{-3}; mean of all dates) and the no-amendment control (0.242 m^3 m^{-3}; mean of all dates) (p=0.059). Epstein *et al.* (1976) and Wei *et al.* (1985) reported similar findings with the application of sludge and compost. Compost treatment differences disappeared in the second growing season (1999). Compost decomposition and reduction of the mulch layer may have reduced the amendment effect on θ_v. Nonetheless, θ_v was approximately 4% lower in the no-amendment control compared to compost-amended treatments.

Our findings suggest that the effect of organic amendments on moisture retention and volumetric water content differed depending on the moisture status of the soil. In the wet end of the soil moisture release curve (≥ -33 J kg^{-1}), higher TC resulted in lower water retention and lower volumetric water content. When the soil dried and reached higher soil water potentials (≈ -766 J kg^{-1}), higher TC corresponded to greater θ_v. The net result was an evening out of the soil's moisture status with addition of compost.

Saturated Soil Hydraulic Conductivity

There was no significant treatment effect on saturated soil hydraulic conductivity during the first growing season (1998). One year later, the conductivity rate K_{sat} was two to eight times higher in all the amended treatments compared to the nonamended control (Table 4). These findings were similar to those of Wei *et al.* (1985) and might have been related formation of larger and more stable aggregates. Two years after compost application (spring 2000), there was still a trend of higher K_{sat} in compost-treated plots relative to control plots, but it was not statistically significant. Loss of organic carbon from compost-amended plots likely weakened the compost effect on aggregation and hence, saturated hydraulic conductivity.

TABLE 4.
Compost effects on saturated hydraulic conductivity (K_{sat}).

Treatment	1999 cm sec^{-1} × 10^{-3}		2000† cm sec^{-1} × 10^{-3}
DM-1	8.96	a	2.22
PC-1	5.99	a	5.34
PMB-1	10.7	a	8.86
DM-2	4.40	a	4.81
PC-2	17.6	a	4.99
PMB-2	11.3	a	5.37
Control	2.73	b	2.89

DM= duck manure; PC= potato cull; PMB= paper mill-bark composts. 1= incorporated only; 2= incorporated + mulched. † No significant treatment differences in 2000.

Compost Effects on Shrub Biomass Production

There were no significant compost type or application method effects on biomass production across plant species during the first growing season (Table 5; $p < 0.42$). Despite the positive effects of compost application on soil physical properties, they did not translate to short-term effects on shrub growth. Other studies with woody plants have shown similar delays in plant response to compost application. Typically, woody plants respond two to three years after compost application (Robbins *et al.* 1986).

The only significant effect of compost on plant growth during the second growing season was for the duck manure compost mulch treatment on Barberry. None of the other treatments had a significant (Table 5; $P < 0.1$) effect on growth of any of the species. Root biomass production was not significantly affected by compost application method ($P = 0.25$); however, root biomass was 11% higher in the mulched treatments than in the no-amendment control. The root: shoot ratio in the mulched treatment of DM compost was 27% lower than in the other treatments, which suggests that root growth in the mulched treatment of DM compost was less likely to be under drought stress, soil compaction or poor soil aeration, thus, favoring shoot growth. Studies of woody ornamentals in container production have shown plant species-specific responses to compost (Chong *et al.* 1994; Hoitink *et al.* 1997). Maynard (1998) also

TABLE 5.
Barberry's root, shoot and total biomass production and root/shoot ratio during first and second growing seasons.

Compost Type	Application Method	Root Biomass	Shoot Biomass	Plant Biomass†	Root/shoot Ratio
1998			g		
Duck manure compost	Incorporated-only	5.69	14.86	20.55	0.38
Duck manure compost	Mulched	6.30	14.16	20.46	0.45
Potato cull compost	Incorporated-only	7.56	14.22	21.77	0.53
Potato cull compost	Mulched	5.33	15.07	20.40	0.35
Paper mill sludge-bark	Incorporated-only	4.63	10.82	15.45	0.43
Paper mill sludge-bark	Mulched	7.57	16.60	24.16	0.46
No-amendment control		5.41	12.18	17.59	0.45
		NS‡	NS	NS	
1999§					
Duck manure compost	Incorporated-only	26.30 b	116.41 b	142.72 b	0.23
Duck manure compost	Mulched	31.84 b	221.55 a	253.39 a	0.14
Potato cull compost	Incorporated-only	¶	¶	¶	¶
Potato cull compost	Mulched	21.24 b	125.93 b	147.17 b	0.17
Paper mill sludge-bark	Incorporated-only	23.61 b	126.64 b	150.24 b	0.19
Paper mill sludge-bark	Mulched	23.06 b	129.60 b	152.65 b	0.18
No-amendment control		24.43 b	130.98 b	155.41 b	0.19

† Plant biomass = (Root + Shoot biomass) ‡ NS = Not significant. § For 1999, data points within a given biotype with the same letter are not significantly different (□= 0.1). Lower case letters correspond to treatment comparisons. Capital letters indicate compost type comparisons. ¶ Missing data due to *Fusarium* sp. infestation. Biomass production by application method was calculated with DM and PMB data only.

found species-specific benefits of compost use and different responses to different application rates in a field trial using MSW-biosolids compost in shade tree production.

In conclusion, the compost treatments had measurable beneficial effects on soil physical properties, but those improvements did not translate into statistically significant benefits for plant growth, except for Barberry. Among the composts used, mulched duck manure compost had the greatest beneficial effect on Barberry growth. It may be that physical properties were not limiting plant growth in a two-year growing cycle (e.g., Spirea is considered a very fast growing species and tolerant of "poor" soils). Alternatively it is possible that the shrubs like Juniper exemplify species whose growth is too slow to respond to changes in soil physical properties over the short term.

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