Compost Effects on Soil Chemical Properties and Field Nursery Production[1]

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Abstract

Field production of ornamental shrubs results in significant topsoil removal and degradation of soil chemical properties. We amended field soils with compost to evaluate effects on soil chemical properties and shrub biomass production. We applied either duck manure-sawdust (DM), potato cull-sawdust-dairy manure (PC) or paper mill sludge-bark (PMB) composts to a silt loam soil as a) incorporated 2.5 cm (1 in) of compost tilled into the top 15 cm (6 in) of soil or b) incorporated + mulched 2.5 cm (1 in) tilled into soil + 2.5 cm (1 in) applied over the soil surface. We grew *Spirea japonicum* 'Gumball', *Juniper chinensis* 'Pfitzeriana' and *Berberis thunbergia* 'Atropurpurea' seedlings and measured total and plant available nutrients and shrub biomass production and nutrient contents over two growing seasons. Total soil C was 15–21% higher in all mulched treatments compared to incorporated-only and no-amendment control treatments. Total soil N, P and Cu, available P, S, Ca, Mg, K, pH and EC increased with increasing TC. Mulched DM compost produced significantly higher DTPA-extractable Zn relative to other treatments. In the second growing season, mulched DM compost produced 39–42% greater total barberry biomass than all other treatments. Among all shrub species, the best soil chemical predictors of plant growth were TC, TS, soluble P, exchangeable Ca and K and DTPA-Zn. The best tissue nutrient-content predictors of plant growth were total shoot N, P and Zn and root Zn. The unique growth response of barberry to mulched DM compost suggests that all shrubs may not respond to compost amendments, particularly over the short term.

Index words: soil fertility, soil zinc, soil organic matter.

Species used in this study: *Spirea japonicum* 'Gumball', *Juniper chinensis* 'Pfitzeriana' and *Berberis thunbergia* 'Atropurpurea'.

Significance to the Nursery Industry

Compost application to soils in field nursery production holds promise as a means to ameliorate the loss of soil organic matter from topsoil removal when ornamental shrubs are harvested using ball and burlap methods. Increasing soil organic matter (TC) was positively and in most cases significantly correlated with increases in soil nutrient concentrations as well as pH and EC. Compost application was particularly important for increasing Zn availability. The effects of a single addition of compost diminished over the two years of study. However, the compost amended soils continued to maintain higher TC and nutrient contents relative to the unamended control even after two growing seasons.

Composts differed in their effects on soil chemical properties and shrub growth. In general, soil nutrient concentrations were highest in the DM and PC amended soils. Mulched treatments produced higher soil nutrient concentrations and induced higher plant nutrient uptake. Shrub growth response to compost application was plant species specific. Only barberry responded significantly to compost application in the second growing season. Barberry is considered intermediate in growth rate compared to spirea (fast growing) and juniper (slow growing). It is possible that intermediate growth-rate species would benefit most from short to intermediate improvements in soil fertility. Fast-growing spirea may be insensitive to respond to these intermediate-term changes in soil fertility, whereas juniper may grow too slow. We recommend chemical analysis of composts prior to use to determine nutrient supply potential. We also recommend evaluation of woody shrub production goals (including duration of production) before compost use to determine if the benefits of compost use will be realized.

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Introduction

Field production of landscape shrubs often results in significant topsoil removal when the shrubs are harvested using ball and burlap methods. In turn, topsoil removal decreases soil organic matter (SOM), as subsoil becomes the surface soil. The reduction of SOM has a negative effect on soil chemical properties, since SOM is linked to nutrient mineralization (N, P, S), cation exchange capacity, micronutrient chelation, pH buffering and binding of heavy metals (29).

Negative effects of SOM reduction might ultimately affect plant growth and crop marketability. To ameliorate these effects, horticultural scientists have evaluated the use of organic amendments as components of growing media (e.g., sewage sludge, animal manures, compost). Most research related to compost use with ornamental horticultural crops has been conducted either under greenhouse conditions or in containerized systems in the field (19, 25, 28). In some cases, compost use in container mixes improved nutrient availability and crop growth; in others, certain composts immobilized nutrients or induced salt stress, resulting in depressed crop growth. Several species grown in media with high amounts of compost (75 or 100% of the total mix) had reduced growth compared to no-compost controls.

Greenhouse and container experiments provide valuable insights about how compost application might affect soil chemical properties and plant growth under field conditions. Field studies using compost or digested biosolids to grow other crops also confirm potential benefits including increased CEC and nutrient availability and pH buffering (9, 12, 22, 24). In most cases, improvements in soil chemical properties resulted in higher crop nutrient uptake and yields.

These studies provide evidence for the beneficial effects of compost application on soil chemical properties and plant growth. However, very few field experiments have been conducted to evaluate compost effects on soil chemical properties and landscape shrub growth. Moreover, none of the studies that we reviewed evaluated the negative effects of removing topsoil during the harvesting (ball and burlap) of woody ornamentals. Finally, very few studies have identified the soil and plant variables that most influence woody ornamentals biomass production, and how their interaction might affect the growth of ornamental shrubs. The objectives of this study were (i) to measure short- (annual) and intermediate- (two years) term changes in soil chemical properties from compost application in field nursery production; (ii) to evaluate ornamental shrub growth in compost-amended soils; and (iii) to relate changes in soil chemical properties to ornamental shrub growth by identifying the best soil chemical predictors of plant growth and nutrient uptake.

Materials and Methods

Site description and experimental design. The experiment was conducted at the University of Wisconsin West Madison Agricultural Research Station (43°5' N and 89°31' W) between May 1998 and September 2000. Soil type is Plano silt loam, fine silty, mixed, mesic, Typic Argiudoll (U.S Soil Taxonomy), and the field has less than 2% slope. 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 experiment 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; and two application methods and rates (incorporated only and mulched). The incorporated only received 2.5 cm (1 in) layer of compost incorporated into the top 15 cm (6 in) of topsoil (low rate), while the mulched treatment received 2.5 cm (1 in) incorporated plus 2.5 cm (1 in) layer of surface applied compost (high rate). A non-amended treatment was included as a control. Treatments were replicated three times in plots of 2.1 m × 1.2 m (7 ft × 4 ft). Within each 'whole plot' (plant species), there were seven soil treatments (three compost types × two methods of application + control).

Compost materials 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 (1:1 by vol). For the potato cull compost we mixed potato culls, sawdust and dairy manure (3:3:1 by vol). The paper mill sludge-bark (PMB) compost was obtained from Renewed Earth, Inc. (Kalamazoo, MI). The raw materials used for this compost were paper mill sludge and bark (1:1 by vol).

All composts were produced aerobically 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 1).

Composts were applied to plots on a volume basis. Incorporated-only compost- plots received 254 cu m/ha (135 yds/A) and mulched compost plots received 508 cu m/ha (267 yds/A). On average, the total amount of carbon (C) added to the incorporated-only compost plots was 11.4 mg/ha (5 t/A), and 22.8 mg/ha (10 t/A) was added to the mulched plots. Composts were incorporated into the top 15 cm (6 in) of soil two weeks before 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 × 0.3 m (1 ft × 1 ft) spacing. The liners were approximately 15 to 18 cm (6–7 in) tall, and were inserted vertically in 15-cm (6 in) deep holes. We also planted a grass strip (0.5 m wide; 1.6 ft) 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 (8 in) long stakes.

Plot maintenance. Plants were manually watered biweekly (1 cm (0.4 in) of water each time) at the beginning of the experiment, and after planting through July 1998. Based on recommendations from a local woody ornamentals producer, none of the treatments received commercial (soluble) fertilizer over the duration of the experiment. Weeds were removed from each plot by hoeing. The grass in the vegetative strips was mowed every two to three weeks. In September 1998, we thinned the planting density from 18 plants to nine plants per plot (2.52 sq m; 27 sq ft) by destructive harvest (aboveground and belowground plant sections).

Soil measurements. We measured baseline characteristics of soil chemical properties prior to compost applications (May 1998) for which we took one composite sample per whole plot (plant species). Subsequently, for all total and plant available nutrients, organic matter, pH and EC, we collected one composite sample per treatment plot on July 1998, October 1998, May 1999, October 1999, and May 2000. Composite soil samples, consisting of nine soil cores, were taken with a 2.0-cm (0.8 in) diameter soil probe from the top 15 cm (6 in) of soil. Soil samples were air dried and ground with a Nasco-

Table 1. Chemical characterization of compost materials at time of application to soil (May 1998).

Compost[z]	C:N	TN[y]	TC[x]	Ash	P	K	Ca	Mg	S	Zn	B	Mn	Fe	Cu	Na	pH	EC[w]
		g/kg							mg/kg								dS/m
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	9.5
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	13.0
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	3.5

[z]DM = duck manure-sawdust compost; PC = potato cull-sawdust-dairy manure compost; PMB = paper mill residuals-bark compost. Composts analyzed in duplicate (n = 2 for all composts).

[y]TN = total nitrogen.

[x]TC = total carbon.

[w]EC = electrical conductivity.

Asplin soil grinder (Nasco, Fort Atkinson, WI) to pass through a 2-mm (0.08 in) sieve, and sent to the Soil and Plant Analysis Laboratory of the University of Wisconsin-Madison for analyses.

Total soil carbon (TC) content was measured before compost application (May 1998) as well as post compost application (October 1998 and May 2000). Previously ground samples were further ground manually with a mortar and pestle to pass through a 1-mm (0.04 in) sieve. Total soil carbon was determined via dry combustion; baseline soil samples (May 1998) TC was measured using a CHN analyzer (Carlo Erba, 1500-NA, Italy), while subsequent TC measures were made using a Dohrman TC analyzer (DC-190, Rosemount Analytical Inc., Santa Clara, CA). Total soil N was determined using a flow injection analyzer (Quik-chem 8000 automated ion analyzer, Lachat Instruments) following digestion with sulfuric acid and a metal catalyst (Cu, Se). Nitrogen content in soil digests was calculated using the formula; N (mg/kg) = [50 / (weight of sample × concentration in the digest)].

Total soil P, K, Ca, Mg, S, Zn, Mn, Fe, Cu, Al, Na, Cd, Co, Cr, Li, Ni, Mo, and Pb were measured following a nitric-perchloric acid digestion (5 ml of 6:1 mix of concentrated HNO_3:$HClO_4$, added to 0.5 g of soil), using inductively-coupled plasma-optical emission spectroscopy (ICP-OES; Model 14033700,Thermo Jarrel Ash Corporation, MA). DTPA extractable micronutrients were determined by treating samples (10 g) with 20 ml DPTA extracting solution adjusted to pH 7.3. Element concentrations were measured using ICP-OES.

Exchangeable Ca, Mg, K, and Na were measured by extracting 1.5-g soil samples with 15 ml of 1 *N* NH_4OAc, adjusted to pH 7. Magnesium concentration was measured using atomic absorption spectrophotometry, and Ca, K, and Na concentrations were determined by flame photometry. Exchangeable ammonium and soluble nitrate were extracted from soil (2.5 g) with 25 ml of 2M KCl. The KCl-extract was filtered through a 0.45-μm filter and analyzed for mineral N forms using a flow injection analyzer.

Plant available P and K were extracted from 1.5-g soil samples with 15 ml of Bray-1 extracting solution (0.03 *N* NH_4F in 0.025 *N* HCl solution). Available P was measured colorimetrically. Soil solution P was also measured in the field using anion exchange resin membranes (5, 6). Bray-1 K was analyzed by flame photometry. Plant available SO_4^2 was determined through precipitation of $BaSO_4$ and turbidity measurement. Soil pH and electrical conductivity of samples from the baseline (May 1998), May 1999 and May 2000 soil samplings, were measured in water in a 1:1 soil:deionized water ratio.

Plant dry matter production and tissue nutrient contents. In September 1998 and 1999 we harvested five plants per plot (45 plants per treatment) 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 an 18-cm (7 in) long metal core with an inner diameter of 15 cm (6 in). 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 (7 in) 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 60C (140F) until constant weight was achieved. The aboveground and belowground dry masses were combined to obtain the total plant dry mass production.

Oven dried tissue samples were ground in a Wiley Mill grinder to pass through a 2-mm (0.08 in) stainless steel sieve. After grinding, all plants harvested from the same plot were combined into one composite sample (7 compost treatments × 3 reps × 3 plant species = 63 total samples) and reground to pass through a 1-mm (0.04 in) sieve. The Soil and Plant Analysis Laboratory at University of Wisconsin-Madison determined macro and micronutrients, heavy metal and total nitrogen contents in above-and belowground plant tissue samples using a nitric-perchloric acid digestion and ICP-OES. Total N in plant tissue samples (0.1–0.15 g) was measured following sulfuric acid digestion with a flow injection analyzer. The N content in plant tissue samples was calculated as described for total soil N.

Statistical analyses. The SAS Version 8 'Plot' procedure (SAS Institute, Cary, NC) was applied to identify outliers and test the normality of our data. We used the SAS 'Mixed' ANOVA procedure to determine plant species and compost type and/or application method effects on soil properties. We performed an analysis of covariance to identify the soil chemical variables that had significant effects on plant growth. A Pearson correlation coefficient of 0.65 was used as the threshold value to identify the variables that were significantly correlated. We performed multiple regression analysis with soil chemical properties and plant biomass to determine which soil chemical properties had the greatest influence on shrub growth. We conducted this analysis for each species and harvest year and repeated the multiple regression procedure for plant nutrient content effects on shrub growth ($\alpha = 0.1$ for both multiple regressions).

Results and Discussion

Analysis of variance for compost treatment by plant species effects on soil chemical properties lacked a significant interaction. Therefore, we present all soil chemical data by treatment averaged across the three plant species (n = 9).

Compost effects on soil chemical properties. Total soil carbon (TC). During the first year after compost application, mulched treatments maintained significantly higher TC contents relative to the incorporated-only treatments ($P \leq 0.0005$; Fig. 1). This likely was due to the substantially higher amounts of carbon added to the soil with the mulched treatments. In particular, the mulched DM compost produced the greatest increase in TC compared to the other two compost types. This result was likely a function of 12–50% more TC in DM compost compared to PC and PMB composts (Table 1). Studies applying composts to field soils have documented linear relationships between TC added from organic amendments and soil organic matter (22, 20). In contrast, other studies have shown that soil TC increased only with very high application rates of organic amendments (17, 7).

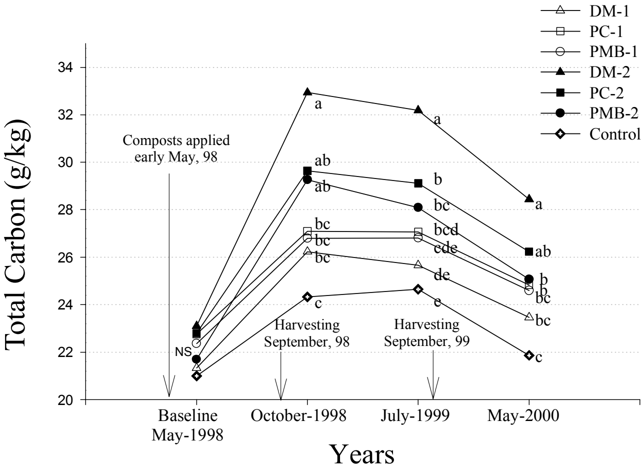

Fig. 1. Compost treatment effects on total soil carbon over time (barberry plots only) DM = duck manure compost; PC = potato cull compost; PMB = paper mill sludge bark compost; 1 = 2.5 cm (1 in) layer of compost incorporated; 2 = 2.5 cm (1 in) incorporated + 2.5 cm (1 in) surface applied as mulch. Treatments within a date with the same letter were not statistically different (α = 0.05).

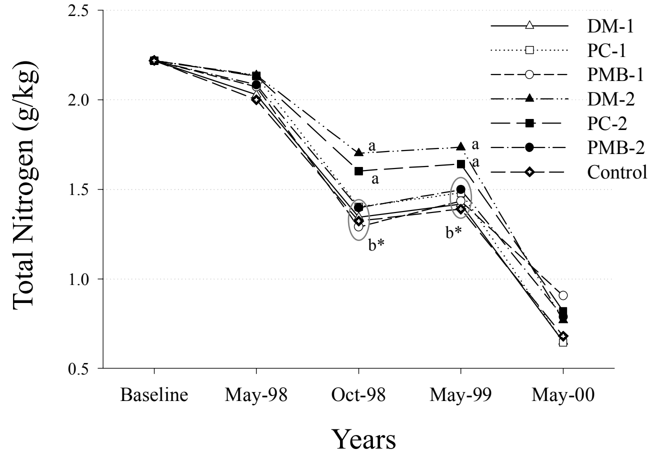

Fig. 2. Compost effects on changes in total soil nitrogen averaged across shrub species. DM = duck manure compost; PC = potato cull compost; PMB = paper mill sludge bark compost; 1 = 2.5 cm (1 in) layer of compost incorporated; 2 = 2.5 cm (1 in) incorporated + 2.5 cm (1 in) surface applied as mulch. Treatments within a date with the same letter were not statistically different (α = 0.001); b* signifies that all data points within the circle were not statistically different.

Total soil carbon decreased over time; likely a function of organic matter decomposition and some topsoil removal with plot maintenance and shrub harvest. Mulched treatments had 55–65% greater TC loss than incorporated only and no amendment control treatments (data not shown). This loss may have been due to a stimulation of soil microbial activity following addition of large amounts of carbon (16). Foley (10) also reported that higher application rates of raw and composted paper mill residuals in a loamy sand soil tended to have greater decay rates.

Relationship between total carbon and nutrient concentrations in soil. Total soil C was positively related to total soil N, P and S and Bray-1 P (Table 2). Increases in soil N, P and S were likely directly related to compost additions. For example mulched DM compost produced the highest soil TP content, and had the highest TP concentration of the three composts added (Table 1).

Table 2. Linear regression analysis between total soil carbon and the total concentrations of selected soil nutrients.[z]

Variable[y]	Slope	Intercept	r^2	P-value
TN	41.62	–98.26	0.346	<0.0001
TP	31.86	–263.9	0.502	0.0616
AP	7.96	–142.7	0.424	<0.0001
TS	9.78	–7.0	0.635	0.035
AS	0.01	+2.3	0.001	0.0016
ExCa	35.3	+1108	0.149	<0.0001
ExMg	4.45	+581.4	0.018	0.0032
ExK	32.19	–491.3	0.310	<0.0001
ExNa	0.82	+4.3	0.221	0.1006
DTPA-Zn	0.42	–7.8	0.323	<0.0001
TCu	0.17	+7.5	0.047	<0.0001
EC	4.85	–4.4	0.189	0.0238

[z]Data from all treatments and all sampling dates were used to determine regression coefficients (n = 63 samples/date × 4 dates = 252).

[y]TN = total nitrogen; TP = total phosphorous; AP = Bray extractable phosphorous; TS = total sulfur; ExCa = exchangeable calcium; ExK = exchangeable potassium; ExNa = exchangeable sodium; DTPA-Zn = DTPA extractable zinc; TCu = total copper; EC = electrical conductivity.

We also observed a significant positive correlation (but weak; $r^2 = 0.19$) between soil EC and TC (Table 2). At the end of the first growing season, electrical conductivity (EC) was higher in the amended treatments relative to the non-amended control; 1.3 dS/m vs. 0.93 dS/m, respectively. This was likely related to the high EC values of the composts (3.5–13.0 dS/m; Table 1). However, EC declined in amended treatments during the second year of study. In nursery production, EC less than 1.5 dS/m in 2:1 water: soil extracts is considered satisfactory for seed germination, but too low for good plant growth (8). In contrast to our findings, several authors have reported large increases in EC in soils amended with compost or other organic matter sources (9, 26, 27, 3). More recently, Clark (4) and Madejon (15) reported only slight increases in EC following organic amendment application.

Total nitrogen. As with TC, total soil nitrogen (TN) concentrations decreased over time (Fig. 2). Among the three shrub species, N uptake per plant increased significantly ($P < 0.0001$) from 1998 to 1999 (11). Nitrogen mineralization from added organic matter coupled with an increase in plant N uptake over time probably influenced the decrease in soil TN. Mulched DM and PC composts produced the highest soil TN during the first two years of study ($P < 0.007$), likely because these two composts had C:N ratios less than 20:1 (Table 1); the threshold below which net N mineralization is likely to occur.

Available phosphorus. Two weeks after compost application (May 1998) the concentration of Bray-1 P (AP) was significantly higher ($P = 0.0004$) in the soils amended with DM and PC composts relative to the non-amended control (Fig. 3). However, AP in PMB compost-amended soils was similar to AP in the non-amended control over the study's duration ($P = 0.41$). The mulched DM compost treatment main-

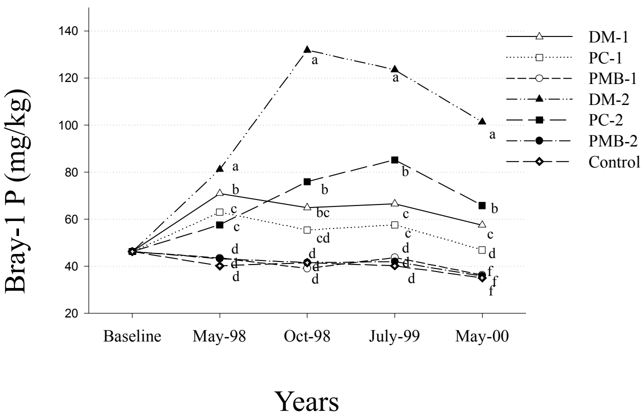

Fig. 3. Compost effects on changes in plant-available P (Bray-1) averaged across shrub species. DM = duck manure compost; PC = potato cull compost; PMB = paper mill sludge bark compost; 1 = 2.5 cm (1 in) layer of compost incorporated; 2 = 2.5 cm (1 in) incorporated + 2.5 cm (1 in) surface applied as mulch. Treatments within a date with the same letter were not statistically different (α = 0.001).

tained a significantly higher soil AP concentration over the two growing seasons compared to PC and PMB composts ($P < 0.0001$). The initial treatment trends in AP likely were related to total P contents of each compost (Table 1).

Soil AP decreased during the second year after compost application (July 1999 to May 2000), especially in the mulched treatments of DM and PC composts (Fig. 3). Among the three shrub species, the total amount of P uptake per plant significantly increased ($P < 0.0001$) from 1998 to 1999 (11). Similar to N, greater plant P uptake over time likely contributed to a decrease in AP. The treatment trends and patterns of change over time seen in TN and AP were similar for available K and Ca (11).

DTPA extractable zinc. During the first and second growing seasons, soils amended with mulched DM compost exhibited significantly higher DTPA-extractable Zn than the PC and PMB compost treatments ($P < 0.0001$; Table 3). All compost-amended treatments produced a 17% increase in DTPA Zn and shrub Zn uptake increased dramatically (by 85%) between the first and second growing season (11). As with other nutrients, DM compost contained 70-80% higher Zn concentrations than the other two composts (Table 1). Studies applying other organic amendments like sewage sludge have shown increases in DTPA-Zn with moderate to high application rates (1, 14).

Shrub biomass production. There were no significant compost type or application method effects on biomass production across plant species during the first growing season (15.5–24.2 g/plant; $P = 0.42$). Despite the positive effects of compost application on soil chemical properties, they failed

Table 3. Compost treatment effects on soil nutrient concentrations in barberry plots during 1999.

Compost treatment[z]	DTPA-Zn[y]	TN	TP	TC	TS	Avail. $H_2PO_4^-$
	mg/kg					
DM-1	4.3b	1.4c	464.7bc	25.8de	179.9b	0.36b
PC-1	4.9b	1.5bc	405.8d	27.2bcd	172.7b	0.22b
PMB-1	2.6b	1.5bc	418.7cd	26.9cde	173.9b	0.09b
DM-2	8.0a	1.9a	580.9a	32.3a	215.8a	1.56a
PC-2	3.2b	1.6b	509.2b	29.3b	207.1a	0.48b
PMB-2	2.7b	1.5bc	393.0d	28.2bc	182.2b	0.1b
Control	2.6b	1.4c	400.3d	24.8e	165.6b	0.09b
P-value[x]	0.0031	0.0004	<0.0001	0.0003	0.0011	<0.0001

[z]DM = duck manure compost; PC = potato cull compost; PMB = paper mill sludge-bark compost. 1 = incorporated-only treatments; 2 = mulched treatments; n = 3 for each treatment.

[y]DTPA-Zn = DTPA extractable Zn; TN = total nitrogen; TP = total phosphorous; TC = total carbon; TS = total sulfur; ExCa = exchangeable calcium; ExK = exchangeable potassium; ExMg = exchangeable magnesium; Avail. $H_2PO_4^-$ = available P measured with anion exchange membranes.

[x]Means with the same letter were not statistically different according to the P value provided.

Table 4. Barberry root, shoot and total biomass production in 1999 (second growing season).

Compost type	Application method	Root	Foliar	Total plant[z]
		g dry matter		
Duck manure compost	incorporated-only	26.30b	116.40b	142.70b
Duck manure compost	mulched	31.80b	221.60a	253.40a
Potato cull compost	incorporated-only	[y]	[y]	[y]
Potato cull compost	mulched	21.24b	125.93b	147.17b
Paper mill sludge-bark	incorporated-only	23.61b	126.64b	150.24b
Paper mill sludge-bark	mulched	23.06b	129.60b	152.65b
Control	—	24.43b	130.98b	155.41b

[z]Values within columns with the same letter were not significantly different (α = 0.1).

[y]Missing data due to *Fusarium* sp. infestation.

Table 5. Nutrient uptake in barberry plants at second harvest (1999).

Compost treatment	FTN[z]	FP	FCa	FMg	FK	FZn
	g/plant					mg/plant
DM-1	1.3b[y]	0.12b	0.47c	0.16b	0.67b	1.4b
PC-1[x]	—	—	—	—	—	—
PMB-1	1.76b	0.17b	0.67bc	0.23b	0.81b	1.8b
DM-2	3.13a	0.31	1.28a	0.42a	1.51a	3.8a
PC-2	1.44b	0.16b	0.54bc	0.20b	0.87b	1.7b
PMB-2	1.58b	0.20b	0.73b	0.23b	0.89b	2.2b
Control	1.61b	0.18b	0.68bc	0.24b	0.79b	1.8b
P-value	0.042	0.022	0.003	0.011	0.048	0.026

[z]FTN = Foliar N; FP = Foliar P; FCa = Foliar Ca; FMg = Foliar Mg; FK = Foliar K; FZn = Foliar Zn.

[y]Within columns, treatments with the same letters were not significantly different (P value provided for each variable).

[x]PC-1 not determined due to insufficient plant material.

to influence short-term changes (4 months) in 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 (21).

After two growing seasons, only barberry grown with the mulched DM compost had significantly greater biomass production than plants grown in the other compost treatments and the non-amended control (Table 4). The lack of significant mulch effect with either PC or PMB composts might have been related to the lack of significant mulch effect on TC and soil nutrients (i.e., DTPA-Zn, TN, AP, ExCa, and ExK) in those treatments (Table 3).

Barberry was the only plant species whose growth was significantly affected by compost treatment (Table 4) (P = 0.09). Root biomass production was not significantly affected by compost application method (P = 0.25); however, the root: shoot ratio in the mulched treatment of DM compost was 27% lower than in the other treatments (11). This result indicated that root growth in mulched DM compost was less likely to be under water or nutrient stresses, thus, favoring shoot growth.

In general, the improved plant growth observed in the mulched DM compost treatment was probably influenced by significantly higher soil nutrient concentrations measured in this treatment, particularly TC, TN, TP, TS and DTPA-Zn (Table 3). Furthermore, plant uptake of N, P, K, Ca, Mg and Zn in mulched DM compost shrubs was nearly doubled compared to all other treatments (Table 5).

Studies of woody ornamentals in container production have shown plant species-specific responses to compost (2, 13). Maynard (18) also 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. Others corroborate different organic amendment effects on crop growth between incorporated and mulched organic amendments (25).

Table 6. Results from multiple regression analysis to determine soil nutrients most predictive of barberry total plant biomass production during 1998 and 1999.

Effect[z]	Estimate	Pr > |t|
1998 Model r^2 = 0.7514		
Intercept	12.2628	0.1072
NO_3^-	–0.224	0.0102
TCu	–1.6775	0.0304
TC	11.5936	0.0017
ExK	0.06825	0.0003
AP	–0.1873	0.0004
NH_4^+	–10.319	0.0002
1999 Model r^2 = 0.85		
Effect	**Estimate**	**Pr > |t|**
Intercept	–135.17	0.019
TC	42.1204	0.0015
ExCa	0.05111	0.0118
Avail. $H_2PO_4^-$	53.5837	0.0016

[z]NO_3^- = nitrate-N; TCu = total copper; TC = total carbon; ExCa = exchangeable calcium; TC = total soil carbon; ExK = exchangeable potassium; AP = Bray-1 phosphorous; Avail. $H_2PO_4^-$ = anion exchange membrane P; NH_4^+ = ammonium-N.

Soil nutrient models to predict plant biomass production. Multiple regression analysis revealed that during the first growing season (1998), the best predictors of shrub biomass production were TC, available N forms (NO_3-N and NH_4-N), ExK, AP, and total Cu (TCu) (Table 6). There was a strong linear relationship between foliar Cu and plant biomass production (r^2 = 0.72). During the second growing season (1999), TC, ExCa, and soil solution P (similar measure to AP) were the best predictors of biomass production.

In the second growing season, DTPA Zn had a significant positive effect on root biomass production (data not shown; r^2 = 0.93; P < 0.0001) and shrub Zn uptake (r^2 = 0.7; P = 0.03). Prior to compost application, the soil DTPA-Zn concentration was <0.4 mg/kg; this concentration is lower than what is required for most crops (0.9 mg/kg is considered the threshold for sufficiency (23)). In the second growing season, DTPA Zn had increased tenfold over baseline (pre-amendment) DTPA-Zn (from <0.04 to >4 mg/kg).

Compost application improved soil chemical properties by increasing total and available forms of critical plant nutrients. It was particularly important for increasing Zn availability and maintaining soil organic matter (or total soil C). As such, composts have the potential to ameliorate the nutrient depleting effects of mining topsoil when ornamental shrubs are harvested as balled an burlapped plants. However, not all composts had beneficial effects on soils and shrubs. Adding a compost mulch layer had a greater impact on two-year shrub production than incorporating compost into soil alone. Moreover, the shrub response to compost applications was species specific. Only barberry responded significantly to compost application in the second growing season. Barberry is considered intermediate in growth rate compared to spirea (fast growing) and juniper (slow growing). It is possible that intermediate growth-rate species would benefit most from short to intermediate improvements in soil fertility. Fast-growing spirea may be insensitive to respond to these intermediate-term changes in soil fertility, whereas juniper may grow too slow.

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