Soil and Redosier Dogwood Response to Incorporated and Surface-applied Compost

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Abstract. Although compost can improve soil properties related to plant growth and water quality, the value of amending landscape beds for trees and shrubs has been questioned. This research assesses short and midterm effects of compost application and bark mulch on soils and plants in landscape beds and compares the effects of compost applied to the surface or incorporated. Trees and shrubs were established in 2001 in a replicated field experiment with the following treatments: 1) unamended control; 2) compost (7.6-cm depth) applied to the surface; 3) 7.6 cm compost incorporated by rototilling to a depth of 20 cm; 4) bark mulch (7.6 cm); 5) compost surface-applied (7.6 cm) + bark mulch (7.6 cm); and 6) compost incorporated + bark mulch. Soil measurements were made one or more times between 2001 and 2007, including bulk density, compaction, infiltration, aggregate stability, soil moisture tension, total carbon (C) and nitrogen (N), nitrate-N, Bray-phosphorus, exchangeable potassium, and pH. Bark and compost mulch depths were determined three times and plant growth measured annually. Half the depth of surface-applied compost and 26% to 41% of the initial soil C increase from incorporated compost remained 5 years after application; and significant changes in bulk density, compaction, infiltration, and nutrients were apparent. Compost incorporation had a greater effect than surface application on soil C, N, and bulk density. Infiltration was similar in incorporated and surface treatments, and nutrient availability was similar except for N. Soil moisture retention was improved with surface-applied compost. Bark had similar effects as surface-applied compost on bulk density, soil moisture retention, and infiltration. During the first 4 years after transplanting, dogwoods in the compost incorporated + bark mulch treatment typically had larger shoot growth indices. By Year 5, treatment no longer influenced shoot growth. Plants in compost-treated plots had darker green leaves. Surface application of compost could provide significant benefits where incorporation is not feasible.

Research in agricultural soils has shown benefits of incorporating organic amendments in improving soil physical properties, including reduced bulk density (Foley and Cooperband, 2002; Tester, 1990), increased infiltration rate (Cox et al., 2001; Martens and Frankenberger, 1992), increased porosity (Giusquiani et al., 1995; Pagliali et al., 1981), improved aggregate stability (Albiach et al., 2001; Cox et al., 2001), and increased plant-available water (Foley and Cooperband, 2002; Giusquiani et al., 1995). Benefits increased with increasing rate of amendment.

Organic amendment research in landscapes has focused on amending the planting holes for woody plants, and in general, few or no benefits have been observed (Day and

Bassuk, 1994; Gilman, 2004; Harris et al., 2004; Hummel and Johnson, 1985; Smalley and Wood, 1995). Amending entire planting beds may enhance woody plant establishment and growth, but additional research is needed in this area (Gilman, 2004). Beeson and Keller (2001) amended the entire planting bed and found 7.6 or 10.2 cm of yard waste compost incorporated to an 18-cm depth improved shoot growth, root elongation, and quality of transplanted azaleas. Potential benefits from organic amendments could be large, not only enhancing growth and survival of trees and shrubs in the

landscape, but also providing a market for recycled organic wastes. However, some have questioned if incorporating organic amendments into planting beds is beneficial. Harris et al. (2004) cautions that decomposition and shrinkage of organic amendment or mulch can lead to grade and planting depth problems if high rates are used.

Surface mulching with organic materials without incorporation has been shown to improve the quality of the underlying soil. Oliveira and Merwin (2001) reported reduced soil bulk density, increased infiltration and porosity, but no change in water-holding capacity in a silty clay loam under deep bark mulch (15 cm reapplied every 3 years) in an orchard compared with a bare soil control. Neilsen et al. (2003) found that biosolids and shredded paper mulches (45 mg·ha⁻¹ applied twice in 7 years) reduced bulk density and increased aggregate stability, available water capacity, infiltration, and soil carbon (C), nitrogen (N), phosphorus (P), and cation exchange capacity in the underlying gravelly sandy loam orchard soil compared with an unmulched control. Mulumba and Lal (2008) made 11 annual applications of wheat straw to an otherwise undisturbed silt loam and found increases in available water capacity, porosity, and aggregate stability.

We are conducting a long-term field study to address questions surrounding the amendment of landscape beds. Specific objectives are to:

1. Assess the short- and midterm effects of compost and bark application on soil properties and growth of redosier dogwood in landscape beds; and
2. Compare effects of incorporation of compost versus compost applied as a surface mulch.

Materials and Methods

Site. The experiment was established at Puyallup, WA, in June 2001. The site is in the Puget lowland of western Washington 55 km south of Seattle. The soil is mapped as a Puyallup fine sandy loam (coarse-loamy over sandy, isotic, mixed, mesic Vitrandic Haploxerolls), and the climate is typical of the maritime Pacific Northwest with mild, dry summers and cool, wet winters. Mean January temperature is 4 °C, mean July temperature is

Table 1. Compost and bark chemical analysis and particle size distribution².

Amendment analysis									
Material	Total C (g·kg ⁻¹)	Total N (g·kg ⁻¹)	C:N	NH ₄ -N (mg·kg ⁻¹)	NO ₃ -N (mg·kg ⁻¹)	Total P (g·kg ⁻¹)	Total K (g·kg ⁻¹)	pH	EC (dS·m ⁻¹)
Compost	220	21	10	593	20	4.2	22	6.5	3.2
Bark	470	2.5	186	25	8	0.3	2	3.8	0.8
Particle size									
Percent retained on sieve									
	12.7 mm	9.4 mm	4.7 mm	2.0 mm	1.0 mm	0.8 mm	0.6 mm	0.4 mm	Fines
Compost	6	1	11	20	17	5	9	8	23
Bark	20	14	22	18	8	2	3	3	9

²Mean of three samples.

C = carbon; N = nitrogen; P = phosphorus; K = potassium; EC = electrical conductivity.

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18 °C, and mean annual precipitation is 1020 mm falling mainly as rain. Most of the precipitation falls between October and May, whereas July and August are very dry, receiving an average of less than 20 mm per month.

Soil texture (0- to 20-cm depth) varies from fine sandy loam to silt loam across the site with sand content ranging from 410 to 560 g·kg⁻¹, silt ranging from 410 to 550 g·kg⁻¹, and clay ranging from 30 to 60 g·kg⁻¹. Soil organic C at the beginning of the experiment was 11 g·kg⁻¹ soil, just over one-half of what is typically found in the Puyallup series. The site is level, receives full sun, and has no barriers to root penetration. It was cropped to field corn for several years before 2001.

Organic amendments. Yard debris compost was received from a local commercial composting facility. It consisted of grass clippings, leaves, weeds, woody trimmings, and other organic yard debris that was composted under cover in an aerated windrow system followed by curing in aerated static piles. Composting and curing was completed in less than 6 weeks. The compost feedstocks contained a high proportion of grass clippings, typical of spring feedstocks in the Northwest. As a result, the N concentration was higher and C:N ratio lower than for compost produced at other times of the year. Bark was a medium-grade Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco] bark obtained from a local supplier. Chemical characteristics and particle size distributions of the compost and bark are summarized in Table 1.

Experimental design. The experiment consisted of a factorial arrangement of three compost treatments (incorporated, surface-applied as mulch, none) by two bark treatments (mulch, none) in a randomized complete block design with four replications. Plot size is 6.1 × 5.2 m with 2.4-m alleys between plots. A wider (9.1 m) alley separates blocks 1 and 2 from blocks 3 and 4.

Application and planting. Compost was delivered to each amended plot on 14 June 2001 using a front-end loader, spread by hand, and leveled to a depth of 7.6 cm. The compost was incorporated to a depth of 20 cm on the appropriate plots using a tractor-drawn rototiller. The entire site was tilled earlier in the spring, but only the plots with compost incorporation were tilled on the day of application. Bark (7.6-cm depth) was applied after application and incorporation of compost.

To simulate the mixture of species found in landscapes, we transplanted six species of container-grown plants, including native and nonnative, deciduous and evergreen trees and shrubs, into the replicated landscape beds. Plants native to the Pacific Northwest included *Cornus sericea* L., redosier dogwood, a deciduous shrub; *Arbutus menziesii* Pursh., Pacific madrone, a broadleaf evergreen tree; and *Chamaecyparis nootkantensis* f. *pendula*, Alaska cedar, an evergreen tree. Nonnative plants included *Arbutus unedo* L., strawberry tree, a broadleaf evergreen tree

Table 2. Effect of compost and bark applications on soil total C and N, pH, Bray-1 P, and exchangeable K in 2006.

Treatment	Total C (g·kg ⁻¹)	Total N (g·kg ⁻¹)	C:N	pH	Bray P (mg·kg ⁻¹)	Exchangeable K (mg·kg ⁻¹)
None	10 d ^z	0.9 d	11.6 a	5.5 a	285 b	276 c
Bark	10 d	0.9 d	11.7 a	5.4 a	299 b	274 c
Compost surface	11 d	1.0 d	11.1 abc	5.4 a	423 a	434 a
Compost surface + bark	14 c	1.2 c	11.3 ab	5.4 a	413 a	388 b
Compost incorporated	17 b	1.7 b	10.4 bc	5.4 a	395 a	379 b
Compost incorporated + bark	21 a	2.0 a	10.2 c	5.2 b	413 a	305 c
No bark versus bark ^y	**	**	NS	NS	NS	NS
No compost versus compost	***	***	*	NS	***	***
Surface versus incorporated compost	***	***	*	*	NS	***
Bark × compost ^x	NS	*	NS	NS	NS	*

^zMeans within a column followed by different letters are significantly different at $P < 0.05$ by protected least significant difference.

^yOrthogonal contrasts. Significance shown at * $P < 0.05$, ** $P < 0.01$, and *** $P < 0.001$. NS = nonsignificant at $P = 0.05$.

^xOrthogonal contrast (no bark versus bark) (no compost versus compost).

C = carbon; N = nitrogen; P = phosphorus; K = potassium.

Fig. 1. Change in depth of compost and bark mulch layers over time, 2001 to 2007. Error bars show SE of means.

Table 3. Effects of compost and bark applications on soil bulk density and infiltration.

Treatment	Bulk density Dec. 2004 (g·cm ⁻³)	Bulk density Mar. 2007 (g·cm ⁻³)	Infiltration July 2005 (mm·min ⁻¹)
None	1.27 a ^z	1.23 a	0.6 b ^y
Bark	1.21 b	1.19 a	2.2 a
Compost surface	1.21 b	1.18 a	1.7 a
Compost surface + bark	1.14 c	1.09 b	5.6 a
Compost incorporated	1.07 d	1.04 bc	2.1 a
Compost incorporated + bark	1.00 e	1.00 c	5.1 a
No bark versus bark ^x	***	**	***
No compost versus compost	***	***	***
Surface versus incorporated compost	***	***	NS
Bark × compost	NS	NS	NS

^zMeans within a column followed by different letters are significantly different at $P < 0.05$ by protected least significant difference.

^yInfiltration statistics were determined using raw data (measured in minutes/2.54 cm) before conversion to reciprocal units (mm·min).

^xOrthogonal contrasts. Significance shown at * $P < 0.05$, ** $P < 0.01$, and *** $P < 0.001$. NS = nonsignificant at $P = 0.05$.

native to Europe and Turkey; *Chionanthus virginicus* L., fringe tree, a deciduous tree native to the southeast United States, and *Rhododendron* 'Henry's Red'. Only data for redosier dogwood are discussed in this article.

Plants were transplanted one per plot between 15 June and 20 June 2001, except for redosier dogwood (four per plot) and Pacific madrone (three per plot). Plants were sorted for uniformity of quality and size before transplanting to allow for maximum uniformity within the experiment and within each replication. Plants were transplanted according to recommended practice; roots at the periphery of the root ball were cut and spread, the planting holes were twice the diameter of the root ball, and the surface of the root ball was ≈ 3 cm above grade (Watson and Himelick, 1997). During transplanting, care was taken to keep mulch layers out of the planting hole.

Plants were irrigated individually at the time of transplanting, and the entire experiment was irrigated at ≈ 5 - to 7-d intervals at a rate of 12 mm per irrigation between 25 June and 7 Aug. 2001. No additional irrigation has been done since then.

Soil and weed measurements. Layers of bark and compost mulch were carefully removed before collecting soil samples for bulk density, aggregate stability, C, and nutrients so that sampling began at the top of the underlying soil. The same process was followed before making infiltration measurements. The layers were carefully replaced after sampling. Surface layers were not removed for penetrometer measurements.

Soil bulk density was determined using a hammer-driven core sampler that collected a 6-cm deep $\times$ 5.4-cm diameter core (Grossman and Reinsch, 2002). Three cores were collected from each plot in Dec. 2004 and Mar. 2007. Infiltration was measured with a simple single-ring falling-head procedure (Soil Quality Institute, 1999) at four locations per plot in July 2005. Aggregate stability samples were collected in Dec. 2004 from a depth of 0 to 8 cm using a trowel. Five subsamples were collected and combined into a single composite sample. Aggregate stability was determined by wet sieving on a nest of sieves (4.25, 2, 1, and 0.25 mm) (Nimmo and Perkins, 2002). Soil texture samples were collected from 21 locations in the alleys between plots in June 2002 and analyzed by the hydrometer method (Gee and Bauder, 1986). Soil compaction was measured with a Rimik recording penetrometer (ICT International, Armidale, NSW, Australia) at least once annually from 2002 through 2006. Penetrometer readings were taken to a depth of 40 cm at nine locations per plot.

Tensiometers (Young and Sisson, 2002) were installed in the spring of 2002 to measure soil moisture tension, an indication of water availability. Two tensiometers were installed per plot within the root zone of a redosier dogwood at depths of 15 and 30 cm below the soil surface. In the spring of 2006, a second pair of tensiometers was installed in

Fig. 2. Penetration resistance, 0- to 30-cm depth, measured by recording penetrometer in Summer 2002, 2005, and 2006. Unamended (U), compost-incorporated (CI), and compost surface (CS) treatments are shown. Means within each depth increment followed by different letters are significantly different at $P < 0.05$ by protected least significant difference.

each plot in an open area where a redosier dogwood had been removed the previous year. Tensiometer readings were taken from 2002 through 2006 at approximate weekly intervals during the spring, early summer, and fall and less frequently during winter and late summer. Tensiometers were read with a pressure transducer with digital readout.

Soil samples (0- to 30-cm depth) were collected in early fall of each year from 2001 through 2004 and analyzed for nitrate-N. A minimum of six cores per plot was collected

and composited. Baseline soil samples collected from the unamended and compost-incorporated plots (0- to 20-cm depth) in 2001 were analyzed for pH, Bray P, exchangeable potassium (K), and total C. Soil samples (0- to 20-cm depth) were collected from all plots in July 2006 and analyzed for the same constituents as in 2001 plus total N. Total C and N (dry combustion), pH (1:2 soil:solution ratio), nitrate-N, Bray P, and exchangeable K were determined using standard procedures (Gavlak et al., 1994). Total C is equivalent to organic C, because

few carbonates or other inorganic C sources are found in western Washington soils.

Depths of bark and compost mulches were determined in Oct. 2002, Dec. 2004, and Feb. 2007. A trowel and ruler were used to measure depth at 16 locations on grids centered within each plot.

Weeds were counted and species identified in randomly selected 1-m² quadrats in each plot in Aug. and Dec. 2001 and Mar. 2002. Weeds were removed by hand after the December measurement. Herbicides were used as needed to control weeds beginning in the spring of 2002.

Redosier dogwood growth and leaf color measurements. Shoot growth, including plant width (widest and narrowest canopy spread), plant height (soil line to tallest terminal bud or flower cluster), and plant caliper (15 cm above the soil line) were measured annually. A shoot growth index was calculated as follows: $[(\text{widest width} + \text{narrowest width})/2] + \text{height}/2$. In late summer, color of the adaxial leaf surface of two fully expanded leaves from the stem midsection was determined quantitatively with a Minolta CR200b Chroma Meter (Minolta, Ramsay, NJ). Measurements were recorded as CIE-LAB coordinates, $L^*a^*b^*$, and the chroma $[C^* = (a^{*2} + b^{*2})^{0.5}]$ and hue angle ($h^\circ = \arctan b^*/a^*$) were calculated (McGuire, 1992). L^* measures the lightness or value of the color from black (equal 0) to white (equal 100). C^* is the degree of color from gray (equal 0) to pure chromatic color and h° is the attribute of color perceived (red, yellow, green, blue, or intermediate between adjacent pairs arranged on a 360° color wheel).

Statistical analyses and calculations. Statistics for soil measurements and plant growth were computed using analysis of variance (ANOVA) with orthogonal contrasts. Means were separated using Fisher's protected least significant difference following a significant ($P < 0.05$) ANOVA (SAS 9.1; SAS Institute Inc., Cary, NC). Orthogonal comparisons were used to test for the influence of bark mulch and compost on soil properties and plant growth, to compare surface application versus incorporation of compost, and to test the interaction between bark and compost effects.

Compost C retained in soil was estimated by comparing soil C on a volumetric basis in compost-incorporated and control treatments in 2001 and 2006. Volumetric soil C was calculated as:

$$\text{Soil C (mg} \cdot \text{g}^{-1}) \times \text{soil bulk density (g} \cdot \text{cm}^{-3}) = \text{soil C}_{\text{vol}} (\text{mg} \cdot \text{cm}^{-3})$$

Means of the 2004 and 2007 bulk density measurements were used for the 2006 calculation, whereas bulk densities at the time of application were estimated as 1.0 g·cm⁻³ for the compost-incorporated treatment and 1.2 g·cm⁻³ for the unamended control.

Fig. 3. Penetration resistance, 0- to 30-cm depth, measured by recording penetrometer in Summer 2002, 2005, and 2006. Bark (B), compost-incorporated + bark (BCI), compost surface + bark (BCS) treatments are shown. Means within each depth increment followed by different letters are significantly different at $P < 0.05$ by protected least significant difference.

Results and Discussion

Soil carbon and nitrogen. Shortly after compost application in 2001, the mean total C concentration in the compost-incorporated treatments was 34 g·kg⁻¹ compared with 11 g·kg⁻¹ in the unamended control. In July

2006, total C was 21 g·kg⁻¹ in the compost-incorporated + bark treatment compared with 10 g·kg⁻¹ for the unamended control (Table 2), equivalent to a retention of 41% (volumetric basis) of the compost C applied in 2001. The compost-incorporated treatment without bark had 17 g·kg⁻¹ total C soil in 2006, equivalent to retention of 26% of compost C. Total N followed the same trends as C (Table 2).

Results indicate that a single application of compost has a substantial long-term effect

Fig. 4. Soil moisture tension at a depth of 15 cm beneath redosier dogwood in 2003 (A) and in 2006 (B) and in open in 2006 (C). Unamended (U), bark mulch (B), compost-incorporated (CI), and compost surface + bark (BCS) treatments are shown.

on soil C and N levels under the environmental conditions of this study. Incorporated compost had a greater effect than surface-applied compost. Bark appeared to increase long-term retention of C and N from compost but had no effect on soil C and N in the absence of compost (Table 2). Soil C:N ratios ranged from 10.2 to 11.7 with the lowest ratios in the treatments with compost incorporated (Table 2).

Mulch depth. Changes in depth of the compost and bark mulches over time also provide an estimate of the persistence of organic amendments. Figure 1 shows reduc-

tion in bark depth averaged over the three bark treatments and in compost depth averaged over the two surface-applied compost treatments. In Feb. 2007, nearly 6 years after compost and bark application, mean compost depth was 4 cm, or 52% of the original application, whereas mean bark depth was 5.8 cm, or 76% of the original application.

Bulk density. Incorporation of compost had a large effect on soil bulk density, reducing bulk density from an average of $1.25 \text{ g}\cdot\text{cm}^{-3}$ in the unamended control to $1.03 \text{ g}\cdot\text{cm}^{-3}$ in treatments with incorporated compost (Table 3). Surface applications of com-

post caused lesser reductions in bulk density. Bark had a significant effect on bulk density, and the combined effect of bark and compost was additive. The incorporation of compost reduces bulk density directly by diluting soil with low-density organic material (Khaleel et al., 1981) and indirectly by increasing soil porosity (Martens and Frankenberger, 1992). Reduced bulk density from surface applications of compost or bark may result from increased porosity from a better rooting environment beneath the mulch and biological mixing of low-density organic matter into the underlying soil. Visual evidence of mixing of surface-applied compost into underlying soil through earthworm channels was apparent in the bulk density samples. Increased soil total C and N in the surface-applied compost treatments under bark also provides evidence of compost mixing. There was little evidence of bark mixing into the underlying soil.

Soil compaction. Because we did not remove the bark before making the penetrometer measurements, treatments with and without bark were analyzed separately. Incorporation of compost significantly reduced soil compaction to a depth of 24 to 30 cm (Figs. 2 and 3). Effects were similar when measurements were made in spring, early summer, or late fall (data not shown). The compost effect on compaction appeared to increase with time in the treatments with bark mulch but decrease with time in the treatments without bark. The effect of surface application of compost is generally smaller and is confounded by having a layer of compost at the soil surface, which offsets the depth measurements by several centimeters.

Aggregate stability. None of the treatments showed a significant effect on aggregate stability as measured by wet sieving 4 years after compost and bark application. Mean aggregate diameter was 2.4 mm and the mean proportion of water-stable aggregates greater than 0.25 mm in diameter was 0.72. Treatments with compost incorporation appeared to have better aggregation by visual inspection of bulk density samples, but the differences were not significant when assessed by wet sieving. Others have reported improved aggregate stability at similar compost application rates (Albiach et al., 2001; Cox et al., 2001), but the time interval between amendment application and aggregate stability measurement was shorter than in this study. Because clay also has a role in aggregate formation, the low clay content of the soils in this study may have hindered further stabilization of aggregates by the amendments.

Infiltration. All treatments significantly increased the infiltration rate of water into the underlying soil compared with the unamended control (Table 3). Both bark and compost increased infiltration rates with no interaction between the two amendments. Surface-applied compost had the same effect on infiltration rates as incorporated compost. Protecting the soil surface with bark or

compost mulch was as effective as incorporating compost into the soil at improving infiltration in this experiment.

Soil moisture tension. Soil moisture tension is an indication of water availability to plants with availability decreasing as soil moisture tension becomes more negative. Soil moisture tension data collected in 2002, 2003, and 2004 at depths of 15 and 30 cm in the root zone of the redosier dogwood showed similar trends (2003 data at 15-cm depth shown in Figure 4A) with the unmulched treatments drying several weeks faster in the spring and early summer than the mulched treatments. Statistical analysis of mean tensiometer readings during the spring drying period of 2003 showed that all treatments with a surface mulch (bark and/or surface-applied compost) retained more soil moisture than the unmulched treatments (Table 4). Incorporation of compost did not improve available water in the root zone based on tensiometer measurements (Table 4).

Data from tensiometers under redosier dogwood in 2005 and 2006 show reduced mulch effects (Fig. 4B shows 2006 data). Statistical analysis of the 2006 data showed no significant differences among treatments in mean soil moisture tension throughout the spring and early summer drying period. We hypothesized that increasing transpiration rates as the plants increased in size eventually offset any measurable water-conserving properties of the compost or bark mulches. In the spring of 2006, we installed an additional set of tensiometers in a section of each plot where a redosier dogwood had been removed, lowering the potential for soil water loss through transpiration. Moisture loss from the soil was reduced in this reduced transpiration situation (Fig. 4C). Statistical analysis showed that bark and surface-applied compost had a significant beneficial effect on soil moisture under these conditions, whereas incorporated compost did not (Table 4). These are similar to the results shown for 2003.

Chemical analyses. Soil pH was elevated in the compost-incorporated treatment (5.9 versus 5.5 in the control) at the beginning of the experiment in 2001 but was slightly lower in 2006 (Table 2). Bray P was very high in all treatments, a legacy of poultry manure and inorganic P applications that occurred before 1990, but treatments with compost were significantly higher than those without compost (Table 2). Because P is less mobile than most other nutrients, we expected P levels to be higher in the compost-incorporated treatments than the compost surface treatments, but measurements made 5 years after compost application showed levels to be similar. Soil K was also higher in the compost treatments with the highest levels in the soil underlying surface applications of compost (Table 2). Soil K in the incorporated compost treatment was 1600 mg·kg⁻¹ in 2001. The 2006 data indicate substantial loss of this element from the upper 20 cm of the soil profile during the 5 years since application.

Weeds. Weed density was measured only during the first year of the experiment. The bark mulches were effective in controlling weeds throughout that period, reducing weed population by 99% compared with the unamended soil (Table 5). The compost mulch was as effective as bark during the first summer after application of amendments, but weeds became established during the fall and winter.

Redosier dogwood growth and leaf color. Shoot growth indices showed significant differences among treatments from 2001 through 2004 (Fig. 5), but not in 2005. Table 6 summarizes significant orthogonal contrasts by year for shoot growth index. Results were similar, although not identical for caliper and average width (not shown). In

2001, the year of transplanting, there was a significant bark × compost interaction for all growth measurements with bark reducing plant growth in the absence of compost having no effect when compost was placed on the surface and increasing plant growth when compost was incorporated (Fig. 5). When bark was placed on unamended soil, apparently enough immobilization of N occurred at the soil–bark interface to slow the growth of the redosier dogwood. When compost was applied, there was sufficient N supplied by the compost to overcome any immobilization. The growth increase from bark mulch on the compost-amended soil was probably caused by improved water availability through decreased evaporation.

Table 4. Effect of compost and bark applications on mean soil water potential measured in tensiometers at 15-cm depth beneath redosier dogwood in 2003 and in open in 2006.

Treatment	2003 late spring ^y	2006 midspring	2006 late spring	2006 early summer
	(mbar)			
None	-470 b ^z	-183 b	-155 b	-334 b
Bark	-217 a	-142 a	-130 a	-231 a
Compost surface	-266 a	-153 a	-130 a	-251 a
Compost surface + bark	-254 a	-140 a	-133 a	-218 a
Compost incorporated	-515 b	-186 b	-155 b	-324 b
Compost incorporated + bark	-259 a	-149 a	-127 a	-232 a

^zMeans within a column followed by different letters are significantly different at $P < 0.05$ by protected least significant difference.

^yLate Spring 2003 = 13 May to 23 June (15 dates); mid-Spring 2006 = 12 Apr. to 12 May (eight dates); late Spring 2006 = 16 May to 15 June (seven dates); early Summer 2006 = 20 June to 18 July (eight dates).

Table 5. Effect of compost and bark applications on weed density.

Treatment	Aug. 2001	Dec. 2001	Mar. 2002
	Weeds (m ⁻²)		
None	97 a ^z	578 a	582 a
Bark	0 b	1 d	3 e
Compost surface	1 b	98 b	117 b
Compost surface + bark	0 b	2 d	6 d
Compost incorporated	31 a	601 a	495 a
Compost incorporated + bark	1 b	5 c	9 c

^zMeans within a column followed by different letters are significantly different at $P < 0.05$ by protected least significant difference. Statistics calculated following log transformation.

Fig. 5. Effect of compost and bark applications on redosier dogwood shoot growth index 2001 to 2004. Treatments are unamended (U), bark mulch (B), compost surface (CS), compost surface + bark (BCS), compost-incorporated (CI), and compost-incorporated + bark (BCI). Means within a year followed by different letters are significantly different at $P < 0.05$ by protected least significant difference.

In 2002 and 2003, redosier dogwood in the compost-amended soil with bark mulch continued to have the largest shoot growth index, which was likely a combination of the N benefits of the incorporated compost and the moisture benefits of the bark mulch. Compost benefits were still apparent in 2004 with greater shoot growth index in the soils with greater shoot growth index in the soils with incorporated and surface-applied compost. By 2005, treatment effects were no longer significant.

Leaves of dogwood plants from the compost-treated plots were darker green (lower L* and chroma, greater hue angle) than leaves from the no-compost plots (Table 7, orthogonal contrasts), which is evidence for a higher N status in the compost treatments. In 2001, dogwood leaves from the bark-only treatment had the most yellow hue and lightest value, suggesting enough N immobilization at the bark-mulch interface to affect leaf color. Treatments with both compost and bark mulch did not show this effect, because of the N supplied by the compost, which would offset immobilization. From 2002 through 2005 (last year of leaf color measurement), only compost affected leaf color. Results from 2003 through 2005 (not shown) were similar to 2002.

Soil nitrate-N. Excessively high levels of soil nitrate-N (Sullivan and Cogger, 2003) were measured in the fall of 2001 for all of the compost treatments (Fig. 6). High levels of soil nitrate-N persisted for the compost-incorporated treatments in 2002. Differences were still apparent in 2004, although nitrate residual for all treatments had returned to low levels by then. Such a high level of residual soil nitrate-N is not normally expected for compost amendments. In this experiment, the compost feedstocks had a high proportion of grass clippings and the resulting compost had a very low C:N ratio (Table 1). Because woody plants are not effective at assimilating large amounts of N, a surplus of leachable N remained in the soil in the fall. The residual rate of N mineralization from the compost was apparently high enough to cause measurable differences in fall nitrate levels during the subsequent years as well. A single application of the N-rich compost produced excessive amounts of N the first 2 years after incorporation, but appeared to supply beneficial amounts of N to the landscape plants for several years thereafter.

Surface versus incorporated applications of compost. Table 8 summarizes compost effects compared with the control based on the data presented previously in this article. Both incorporation and surface application of compost increased soil C and N and decreased bulk density compared with the control. The effects were much greater for the incorporated compost, which was a direct result of the addition of more organic matter into the soil. Incorporation also decreased soil C:N ratio (Table 2) and tended to decrease soil compaction in the subsurface (Figs. 2 and 3). Soil aggregation was more apparent when compost was incorporated,

Table 6. Redosier dogwood shoot growth index orthogonal contrasts, 2001 to 2005.

Treatment	Year				
	2001	2002	2003	2004	2005
No bark versus bark ²	NS	**	*	*	NS
No compost versus compost	***	*	NS	**	NS
Surface versus incorporated compost	NS	NS	NS	NS	NS
Bark × compost	**	NS	NS	NS	NS

²Orthogonal contrasts. Significance shown at * $P < 0.05$, ** $P < 0.01$, and *** $P < 0.001$. NS = nonsignificant at $P = 0.05$.

Table 7. Effect of compost and bark applications on redosier dogwood leaf color measured in 2001 and 2002.

Treatment	2001			2002		
	L* ^z	Chroma ^y	Hue angle ^x	L*	Chroma	Hue angle
None	35 b ^w	16 a	127 b	36 a	20 a	126 c
Bark	37 a	16 a	108 c	35 ab	19 ab	130 bc
Compost surface	32 c	13 b	135 a	33 c	15 c	132 ab
Compost surface + bark	33 c	13 b	132 ab	34 bc	17 bc	132 ab
Compost incorporated	33 c	12 b	131 ab	33 c	15 c	132 ab
Compost incorporated + bark	33 c	13 b	132 ab	34 bc	16 c	133 a
No bark versus bark ^y	NS	NS	***	NS	NS	NS
No compost versus compost	***	*	*	**	***	***
Surface versus incorporated compost	NS	NS	*	NS	NS	NS
Bark × compost	*	NS	***	NS	NS	NS

^zL* is the color lightness or value from 0 = black to 100 = white.

^yChroma is the degree of color from gray (0) to pure chromatic color.

^xHue angles are 0° = red, 90° = yellow, 180° = green, and 270° = blue.

^wMeans within a column followed by different letters are significantly different at $P < 0.05$ by protected least significant difference.

^yOrthogonal contrasts. Significance shown at * $P < 0.05$, ** $P < 0.01$, and *** $P < 0.001$. NS = not significant at $P = 0.05$.

Fig. 6. Effect of compost and bark applications on residual soil nitrate-N, 0- to 30-cm depth, Fall 2001 to 2004. Treatments are unamended (U), bark mulch (B), compost surface (CS), compost surface + bark (BCS), compost-incorporated (CI), and bark mulch + compost-incorporated + bark (BCI). Means within a year followed by different letters are significantly different at $P < 0.05$ by protected least significant difference.

but wet sieving did not show significant differences among treatments.

All compost treatments improved infiltration with no difference between incorporated and surface-applied compost. Surface applications of compost improved available moisture as measured by tensiometers in the early years of the experiment, but this effect declined as the plants grew larger. Soil chemical properties were similar between the surface-applied and incorporated compost treatments with similar levels of Bray P

and slightly lower pH and exchangeable K in the soils with compost incorporated. After the first year, the compost-incorporated treatment consistently had higher levels of residual soil nitrate-N than the surface-applied treatment, which is the result of increased N mineralization when compost is mixed into the soil environment. The combination of compost incorporation and bark had the greatest effect on redosier dogwood growth, but by 2005, differences in growth were no longer significant. Leaf color was improved

Table 8. Summary of surface-applied and incorporated compost effects on soil properties compared with unamended control.

Property	Compost surface	Compost incorporated
Total C	+ ²	++
Total N	+	++
Bulk density	+	++
Compaction	0	+
Aggregate stability	0	0
Infiltration	+	+
Soil moisture tension	+	0
Nutrients	+	+
Nitrate leaching potential	-	--
Plant growth	0	+/-0
Leaf color	+	+

²+, ++ represent benefits compared with control; -, -- represent negative effects; and 0 represents little or no effect.
C = carbon; N = nitrogen.

by both surface application and incorporation of compost.

These data suggest that incorporation of compost has a greater effect than surface application on soil properties that are immediately related to organic amendment (C, N, and bulk density). There was little difference in infiltration and aggregate stability between the two methods of compost amendment and, in the long run, little difference in nutrient availability besides N. Surface application of compost could provide significant benefits where incorporation is not feasible.

Longevity of compost benefits. The data show significant beneficial effects of surface application and incorporation of compost lasting more than 5 years after application and likely to persist longer. Approximately half of the volume of surface-applied compost and 40% of the soil C increase from incorporated compost were present more than 5 years after application; and significant changes in bulk density, compaction, infiltration, and nutrients were apparent. Under the environmental conditions of the Pacific

Northwest, compost applications have long-lasting effects in landscape soils.

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