HortScience 42(7):1705–1709. 2007.

Nutrient Treatments Used on Field-harvested Colorado Spruce Trees to Maintain Postharvest Quality

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Additional index words. *Picea pungens*, balled and burlapped, transplant shock, mulch holding bed, compost, controlled-release fertilizer, foliar nutrient analysis

***Abstract*. Holding practices for balled and burlapped conifers may inadvertently impact nutrient availability and tree growth. The objective of this study was to examine the effectiveness of several nutrient treatments to maintain or enhance the growth and foliar nutrition of Colorado spruce (*Picea pungens* Engelm.) trees while they were in a mulch-holding bed. Sixty 1.5 to 1.8-m tall Colorado spruce trees with 61-cm (24 inch) diameter root balls were heeled into a holding bed of fresh pine bark mulch during 2002 and 2003. The treatments applied to the root balls were a control (pine bark without fertilizer), 114.2 g Osmocote (Scotts, Marysville, OH) 15N–3.9P–10K distributed over the top of the ball, one Ross Gro-Stake (Easy Gardener, Waco, TX) 10N–4.3P–8.3K Evergreen fertilizer spike (113 g) per ball, one-half cartridge (≈8.5 g) of Ross Root Feeder (Weatherly Consumer Products, Lexington, KY) 10N–5.2P–10K evergreen fertilizer injected into the root ball at four points, or a 1:1 biosolids-based compost:pine bark mixture (by volume). Trunk diameters and tree heights were measured and foliar samples for nutrient analyses were collected before applying these treatments and at the end of the growing season 20 or 17 weeks later. The 2003 trees were transplanted to a landscape site in 2004, and the height growth of their terminal leaders were measured at the end of the next two growing seasons. Overall, Colorado spruce trees appeared normal while they were held in the mulch beds the first season after nursery harvest. Changes in tree height and trunk diameter by the end of the first season after harvest were unaffected by the nutrient treatments. By fall of both years, needles from trees treated with the mixture of 1:1 compost:bark had the highest levels of foliar N, Mg, Ca, S, and B. Trees treated with the fertilizer spike in 2002 had similar levels of N and S in their needles compared with compost:bark-treated trees, whereas in 2003, spike-treated trees had the second highest levels of foliar N and S, and these levels were significantly higher than those of trees receiving the control or other fertilizer treatments with the exception of N in needles from fertilizer-injected trees in 2002. Plant-available N, however, was highest in the root balls of Osmocote- and fertilizer spike-treated trees only in 2003. Leaders on the 2003 trees that received the compost:bark or fertilizer spike treatments grew at least 70% or 36% taller, respectively, than those trees receiving the other treatments by the end of the second growing season in a managed landscape. Although all nutrient treatments failed to promote increases in tree heights and trunk diameters while the trees were held in a mulch bed for the first growing season after digging, the compost:bark mixture and, to some extent, the fertilizer spike improved foliar nutrition during this time.**

Production of balled and burlapped conifers is an important part of the total nursery stock sales of landscape plants grown in the United States. In Idaho, 2005 farm gate value of balled and burlapped plants was U.S. $28.6 million and comprised 71% of all woody nursery stock production in the state (USDA National Agricultural Statistics Service, 2006). Holding methods used for balled and burlapped conifer trees may inadvertently reduce their quality and appearance. By late summer after the trees are dug, balled and burlapped conifers can appear mineral-deficient and unhealthy.

Previous studies have examined the effects of nursery production practices on tree survival and stress resistance in the landscape (Ferrini et al., 2000; Gilman and Beeson, 1996; Lloyd et al., 2006). Alternatively, posttransplanting cultural practices such as irrigation (Gilman and Beeson, 1996) and amending soil around the transplanted root system (Ferrini et al., 2000; Gilman, 2004; Kelting et al., 1998) have also been examined for their effects on subsequent tree growth during establishment in the landscape. Cultural practices used during the holding period between harvest and transplanting into the landscape are often ignored, although holding practices may have profound impacts on plant health and appearance.

Previous studies of conifers (Meyer and Splittstoesser, 1971; Millard and Proe, 1993; Nambiar and Fife, 1991) and deciduous plants (Bi et al., 2004; Deng et al., 1989; Millard and Neilsen, 1989) have demonstrated that nitrogen applied during the previous year can strongly affect growth the next year. Poor mineral nutrition while holding trees in a mulch bed may contribute to a reduction in establishment and growth of trees during the first year or more after transplanting. Therefore, balled and burlapped stock should receive ample mineral nutrition to ensure an adequate growth response after transplanting into the landscape.

The objective of this study was to evaluate nutrient treatments for their effectiveness in maintaining growth and mineral nutrition of balled and burlapped Colorado spruce trees that were held in mulch over the summer. Increases in tree heights and trunk diameters were measured and foliar mineral analyses were completed to determine plant growth responses and nutrient uptake by the trees. In addition, nitrogen availability in the root ball soil was measured to assess fertilizer impact on the soil within the ball while the plants were held in the mulch bed. Finally, growth of terminal leaders was also measured for two growing seasons after 2003 trees were transplanted into a managed landscape.

Materials and Methods

Field-grown Colorado spruce trees (*Picea pungens* Engelm.) 1.5 to 1.8 m tall were purchased from Blue Haven Tree Farm (Coeur d'Alene, ID) and Hash Tree Company (Princeton, ID) in late April of 2002 and 2003, respectively. The root balls on the trees were 61 cm in diameter and 45 cm tall. The root balls were covered with copper-treated burlap and supported by wire baskets. The trees were grown without supplemental field fertilization during their entire production cycle in the nurseries. Sixty uniform trees were selected for each experiment each year.

Ponderosa pine (*Pinus ponderosa*) bark screened to sizes from 13 to 25 mm was used as the mulch in this study, and the bark was fresh from a lumber-processing mill both years. Mulch surrounded the root balls, covering the sides and bottoms of the balls on all plants during the holding experiment. Mulch was mounded up to 45 cm high on the sides of the balls but was kept off the top surface of the balls. The mulch-holding bed was 9.1 m wide by 28.6 m long. Each row contained 15 trees. Trees were spaced on 1.8-m centers within a row, and an additional 0.3 m of space was used between each nutrient treatment

Received for publication 12 June 2007. Accepted for publication 30 July 2007.

This research was supported in part by the Idaho Agriculture Experiment Station and by grants from the Idaho State Department of Agriculture awards NAC/ISDA 2002-3 and NAC/ISDA 2003-3.

We thank Mike Hegedus for donations of EKO Compost™ and William Price for statistical advice.

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within the row. An additional 0.6 m of space was used to separate the rows. The five nutrient treatments (see subsequently) were arranged in a randomized complete block design with four blocks (rows). Three consecutive trees in each row received one of the specified nutrient treatments.

All trees were drip-irrigated three times a week during 2002 with 12 L of water applied to each tree each time. Although cyclic irrigation was used (three cycles per irrigation), this drip system was inadequate because most trees showed symptoms of drought stress during the hottest weather. For this reason, a spray stake irrigation system was used during the 2003 study. All 2003 trees were watered three times a week using cyclic irrigation to be sure the water could be absorbed by the root balls. Water was applied usually in two and sometimes three cycles (15 min of water per cycle resulting in 30 L of water applied per day) on days that the trees were irrigated. Spray stakes moistened the root ball soil and up to 30 cm beyond the edges of the root balls.

Nutrient treatments were chosen for their ease of application because companies that hold conifer trees in mulch beds would prefer to use a simple and easy method for applying nutrients to nursery stock. The nutrient treatments used in this study were pine bark mulch without fertilizer (control), Osmocote 15N–3.9P–10K used at the labeled rate of 114.2 g broadcast over the top of the root ball, one-half cartridge (≈8.5 g) of Ross Root Feeder 10N–5.2P–10K evergreen fertilizer injected into the root ball at four points at the outer edge of the root ball, one Miracle-Gro (Scotts, Marysville, OH) 12N–4.3P–8.3K Evergreen fertilizer spike (113 g) inserted into the root ball in 2002 or one Ross Gro-Stake (Eko Compost, Missoula, MT) 10N–4.3P–8.3K Evergreen fertilizer spike (113 g) per ball in 2003 with a spike inserted at the outer edge of the ball, and mulch mixed 1:1 (by volume) with biosolids-based compost (EKO Compost) surrounding the sides of the root ball. Composts used each year contained similar nutrient contents and had similar chemical characteristics (Table 1). The fertilizer products were applied to the ball or injected as described by the product labels during early June of 2002 or 2003 after the root balls were mulched in place.

The experiment began on 4 June 2002 or 2 June 2003 when fertilizers were applied to the root balls and ended on 25 Oct. 2002 (after 20 weeks) or 29 Sept. 2003 (after 17 weeks). In early June of each year just before the fertilizer treatments were applied, initial tree heights and mean trunk diameters (measured at 51 cm above the root ball) were measured. Mean trunk diameters were determined by measuring the trunk diameter at one point and then measuring the trunk again at a point 90° from the first measurement. Final heights (of the leaders) and mean trunk diameters were measured at the end of the studies. Foliar (needle) samples were also taken just before nutrient treatments were applied for both studies and at the end of the first season in the mulch beds. Approximately 7 to 8 cm of the terminal ends of stems from three randomly selected branches (newest growth on each sampling date) were removed from each tree and dried at 70 °C for 3 d. After drying, needles were removed from the stems and ground by using a Virtis 45 tissue grinder (Virtis Company, Gardiner, NY) before being sent to Midwest Laboratories (Omaha, NE) for foliar mineral analyses. Foliage was analyzed for N, P, K, Mg, Ca, S, Fe, Mn, Zn, Cu, B, and Na content.

To assess N availability in the root ball soil of all trees, mineral N and dissolved organic N levels were determined just before applying nutrient treatments and at the end of each experiment. A soil probe was used to take a 15-cm core sample from each root ball. Soil mineral N and dissolved organic N were determined by K_2SO_4 extraction (Sims et al., 1995) as modified by Sharenbroch et al. (2005). The sum of mineral N and dissolved organic N concentrations (in $\mu g \cdot g^{-1}$) was used as a measure of plant-available N in the soil samples (Murphy et al., 2000).

Trees from the 2003 experiment were transplanted into a managed landscape in May 2004. Some roots on the trees were damaged during removal of the burlap and wire baskets from the root balls before installation. The trees were transplanted in a complete randomized block design as defined by the nutrient treatment they received while in the holding bed. From 10 June to 10 Oct. in 2004 and 2005, the trees received 151 L of supplemental irrigation each week to promote tree establishment. The length of new growth produced by the terminal leader for the 2004 and 2005 growing seasons was measured for each tree. Statistical analyses for the increases in leader length were completed as described subsequently.

Analysis of variance (PROC GLM; SAS Institute, Cary, NC) was completed for changes in terminal leader growth, trunk diameter, foliar mineral levels, and soil N levels. Soil N concentrations from the 2003 experiment were log-transformed before analysis to stabilize variability, and analysis of variance was then completed on the transformed data. Significant differences between treatment means for the plant growth and foliar mineral concentrations were determined by least-square means (by using the pdiff procedure) at the $\alpha = 0.05$ level for the 2002 study as a result of two trees dying from nonexperimental causes (borer infestation). Protected Fisher's least significant difference tests were used to separate means among plant growth data, foliar mineral contents, and soil N concentrations for the different treatments for the 2003 study.

Results

Overall, the Colorado spruce trees held in the pine bark mulch beds appeared normal throughout growing seasons during both years. Needle color of all trees appeared similar regardless of the nutrient treatment used, although foliar nutrition varied among the trees by the end of the growing season. Regardless of the treatment used, needle color on the spruce trees changed to a lighter, off-green color by late fall each year. The experimental trees appeared similar in color to nontransplanted trees at that time of year. After budbreak the following springs, old needles on all trees whose roots were covered with the compost:bark mix returned to a normal green or blue–green color, but those on trees receiving the other nutrient treatments remained a yellow–green color.

Changes in tree height and trunk diameter (as determined by percent change from initial measurements) during the time the trees were held in the mulch bed were unaffected by the nutrient treatments applied to the root balls ($P = 0.494$ for 2002 and $P = 0.645$ for 2003 for changes in tree heights and $P = 0.537$ for 2002 and $P = 0.481$ for 2003 changes in trunk diameters). Mean changes in tree heights were 5.1% in 2002 and 5.9% in 2003. Mean changes in trunk diameters were 6.2% in 2002 and 5.7% in 2003. Likewise, final tree heights and trunk diameters were similar regardless of the nutrient treatment used (data not shown).

Initial (spring) foliar mineral levels were similar for all trees before fertilizer treatments were applied (Table 2) with the exception of Fe in needles from 2002 trees used in the pine bark treatment (control). Needles from these trees had a mean Fe concentration of 152 $mg \cdot kg^{-1}$ compared with the mean Fe content of 117 $mg \cdot kg^{-1}$ in needles from trees used in the other treatments.

The nutrient treatments used during the holding experiments affected mineral nutrition

Table 1. Initial total concentrations of selected minerals and selected chemical properties of composted biosolids (municipal sewage sludge) used in the mulch bed holding experiments for Colorado spruce trees in 2002 and 2003.[z]

	Minerals													Chemical properties		
	N	P	K	Ca	Mg	S	Na	Cl	Zn	Mn	Fe	Cu	B	pH	EC[y]	C:N ratio
Yr	(%)								(mg·kg⁻¹)						(dS·m⁻¹)	
2002	2.0	0.57	1.1	2.1	0.53	0.36	0.08	—	272	428	14,560	178	44	7.3	12.1	13.5
2003	2.0	0.63	1.4	2.1	0.59	0.21	0.11	0.24	228	433	15,875	159	43	7.9	5.5	12.4

[z]Data were from a single sample analyzed each year.
[y]Electrical conductivity (EC) was determined by the saturated extraction method for the 2002 sample and by the 1:5 dilution method for the 2003 sample.

of foliar N, Mg, Ca, S, and B both years, but foliar Mn was affected by these treatments only in 2003 (Table 3). Trees receiving the compost:bark mixture, fertilizer injection, or fertilizer spike had similar levels of foliar N by the end of the 2002 growing season. Needles from trees treated with the mixture of compost:bark, the Osmocote® prills, or the fertilizer spike had the highest yet similar levels of Ca and B in their needles compared with trees receiving the other treatments in 2002 (Table 3). In addition, trees treated with the fertilizer spike or the compost:bark mixture in 2002 also had the highest yet similar foliar Mg and S concentrations. In the 2003 study, needles from trees treated with the mixture of compost:bark contained the highest levels of N, Mg, Ca, S, Mn, and B. Trees treated with the fertilizer spike had the second highest levels of foliar N and S, and these levels were significantly higher than those of trees receiving the other fertilizer treatments (Table 3).

Differences between initial and final foliar nutrient levels were also examined to determine if the nutrient treatments affected the changes over the growing season. The nutrient treatments affected changes for the percent changes for N, S, and Mn in the Colorado spruce needles in 2002 (Table 4). Needles from trees receiving the compost treatment in 2002 had the highest changes for N concentrations followed by needles from trees receiving the fertilizer spike treatment, but the changes in foliar S percentage were similar for compost-treated and fertilizer spike-treated trees. The negative numbers for the percent change of Mn indicated that foliar concentrations of this mineral decreased during the holding experiment. Although mean foliar Mn concentration decreased in needles for all trees in the 2002 study, the change for Mn concentration was the least for compost-treated trees compared with Mn changes in foliage of trees receiving the other treatments.

Nutrient treatments also affected the percent changes of N, Mg, Ca, S, Mn, and B in the spruce foliage in 2003 (Table 4). The N concentration changed the most in needles from trees receiving the compost treatment, and the second highest changes in foliar N levels were in trees treated with the fertilizer spike. Percent changes in foliar S concentrations were similar for compost-treated and fertilizer spike-treated trees, but were higher than those in trees receiving the other treatments. In contrast, the compost treatment resulted in the highest changes of Mg, Ca, Mn, and B concentrations within the tree needles. The negative numbers for percent Ca and Mn changes indicated that foliar concentrations of these two minerals decreased during the 2003 experiment (Table 4), yet foliar Ca levels decreased the least for compost-treated trees.

Trees receiving the compost or fertilizer spike treatments in 2003 retained higher foliar N levels by July 2004 ≈3 months after the trees were transplanted into a managed landscape compared with trees receiving the other nutrient treatments. Needles from compost-treated trees contained ≈1.4% N, which was significantly higher than 1.1% N in needles from fertilizer spike-treated trees (Van Wagoner, 2006). Needles from trees receiving any of the other three treatments contained 0.9% N or less, which was significantly lower than foliar levels of N in trees receiving the compost or fertilizer spike treatments. By 2005, foliar N levels from all trees were similar, regardless of the nutrient treatment (mean = 1.3% N; P = 0.481) (Van Wagoner, 2006).

Plant-available N in the root ball soil was unaffected by the nutrient treatments applied to the trees during the 2002 study ($P = 0.528$), whereas the nutrient treatments affected plant-available N levels in the root ball soil for the 2003 study. Soil from tree root balls that were treated with Osmocote or the fertilizer spike had significantly higher concentrations of plant-available N than soil from root balls receiving the control or compost treatments (Fig. 1). Initial concentrations of plant-available N in the root ball soil before applying the nutrient treatments was similar among all plants each year (data not shown).

Trees from the 2003 experiment were transplanted to a managed landscape in May 2004. Based on casual observations after removing the spruce trees from the mulch bed, compost-treated trees formed many new fibrous roots along all outside edges of the original soil ball, whereas fewer fibrous roots formed on the outside edges of root balls of trees receiving the other treatments. Terminal leader growth of the trees was measured for the 2004 and 2005 growing seasons. The nutrient treatments failed to affect terminal leader growth of the trees by the end of the first growing season in the landscape (2004) ($P = 0.307$). By the end of the second growing season in the landscape (2005), however, leaders on trees treated with the compost:bark mixture during the holding experiment (2003) grew at least 70% taller than those on trees receiving the Osmocote, fertilizer injection, or control treatments (Fig. 2). During 2005, leaders on compost-treated trees averaged 46.1 cm of new growth, and those on fertilizer spike-treated trees increased 36.8 cm, which was at least 36% taller than leaders of trees receiving the other three treatments.

Discussion

The nutrient treatments apparently had little effect on the tree growth while the plants were held over the summer in the mulch bed. For example, leaders on trees

Table 2. Mean initial concentrations of minerals in needles taken from Colorado spruces trees obtained from different nurseries in 2002 and 2003.[z]

	% Mineral content						Mineral content (mg·kg^{-1})				
Yr	N	P	K	Mg	Ca	S	Fe	Mn	Zn	Cu	B
2002	1.0	0.2	0.4	0.1	0.9	0.08	124	417	50	3.3	6.3
2003	1.0	0.1	0.4	0.6	0.5	0.06	59	93	20	1.4	8.4

[z]Each mean is an average of foliar minerals from 60 trees.

Table 3. Mean concentrations of N, Mg, Ca, S, Mn, and B in needles from Colorado spruce trees after being held in a pine bark mulch bed for 20 weeks in 2002 or 17 weeks in 2003.[z]

	N		Mg		Ca		S		Mn		B	
	(%)								(mg·kg^{-1})			
Treatment	2002	2003	2002	2003	2002	2003	2002	2003	2002	2003	2002	2003
Pine bark	1.2 c[y]	1.2 c	0.10 b	0.08 b	0.27 b	0.16 b	0.10 b	0.07 c	220	81 b	2.2 b	11 b
Compost	1.5 a	1.8 a	0.14 a	0.13 a	0.44 a	0.40 a	0.13 a	0.11 a	337	198 a	4.6 a	17 a
Osmocote	1.2 c	1.3 c	0.11 b	0.08 b	0.29 ab	0.17 b	0.10 b	0.07 c	229	94 b	3.5 a	10 b
Injection	1.3 ab	1.2 c	0.10 b	0.08 b	0.25 b	0.16 b	0.10 b	0.07 c	193	97 b	2.9 b	9 b
Spike	1.4 ab	1.6 b	0.12 ab	0.09 b	0.33 ab	0.21 b	0.13 b	0.09 b	297	116 b	3.7 a	10 b

[z]Trees were obtained from different nurseries both years.
[y]Means within a column followed by different letters are significantly different at the 5% level as determined by least-square means for 2002 data or determined by protected Fisher's least significant difference for 2003 data (n = 12).

Table 4. Mean percent changes in foliar nutrient concentrations of Colorado spruce trees that received different nutrient treatments while they were held in a pine bark mulch bed during 2002 or 2003.[z]

	% Mineral change								
	2002			2003					
Treatment	N	S	Mn	N	Mg	Ca	S	Mn	B
Pine bark	16 c[y]	16 b	–44 b	17 c	31 b	–64 b	14 b	–4 b	34 b
Compost	55 a	54 a	–7 a	80 a	99 a	–3 a	95 a	124 a	98 a
Osmocote	23 bc	23 b	–47 b	22 c	31 b	–62 b	26 b	2 b	25 b
Injection	27 bc	20 b	–48 b	17 c	28 b	–66 b	20 b	9 b	11 b
Spike	38 b	46 a	–29 ab	50 b	55 b	–50 b	70 a	38 b	30 b

[z]Changes in nutrient concentrations were determined by sampling spruce needles before fertilizer was applied in early June and at the end of the study in late Oct. for 2002 or sampling spruce needles in late May and late Sept. for 2003.
[y]Means within a column followed by different letters are significantly different at the 5% level as determined by least-square means for 2002 data or by protected Fisher's least significant difference for 2003 data (n = 12).

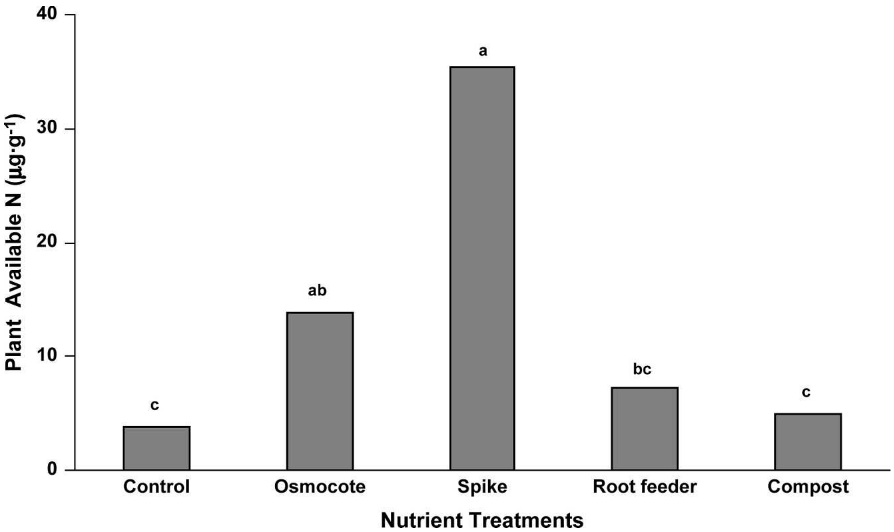

Fig. 1. Mean concentrations of plant-available N in soil samples from root balls of Colorado spruce trees receiving various nutrient treatments in June 2003. Means presented were back-transformed from log-transformed data. Samples were taken in Sept. 2003. Different letters indicate significant differences between treatment means as determined by protected Fisher's least significant difference at the 5% level (n = 12).

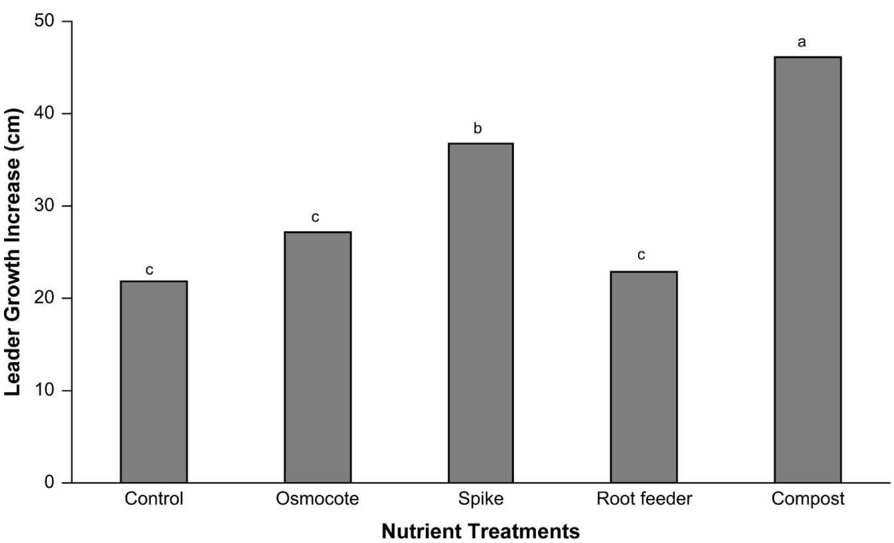

Fig. 2. Mean leader growth increases of transplanted Colorado spruce trees during 2005 after receiving various nutrient treatments while being held in a mulch bed in 2003. Different letters indicate significant differences between treatment means as determined by protected Fisher's least significant difference at the 5% level (n = 12).

whose roots were surrounded by only pine bark mulch (controls) grew an average of 3.7% or 5.5% in 2002 or 2003, yet the trees that were treated with the compost mixture grew only an average of 6.2% or 5.8% in 2002 or 2003, respectively. The nutrient treatments also failed to affect increases in trunk diameter. Therefore, the nutrient treatments failed to improve tree growth while they were being held in the mulch bed during the first growing season after digging.

Transplant shock apparently limited postharvest growth of these trees, regardless of the nutrient treatment applied. Spruce trees in the 2002 experiment were water-stressed mainly as a result of an inadequate irrigation system. Trees in the 2003 experiment experienced little water stress resulting from an improved irrigation system. Despite the differences of water stress and different nursery sources of the trees, the nutrient treatments failed to affect leader growth and trunk diameter increases of the Colorado spruce trees both years. These results indicated that transplant shock strongly affected how much the trees would grow, regardless of the postharvest nutrient treatments they received. Water stress caused by severe root loss at harvest most likely limited shoot elongation even for trees that received good mineral nutrition (compost treatment). After sufficient numbers of roots were regenerated to relieve water stress, nutrient treatments could influence shoot growth as indicated by improved leader growth in the landscape in 2005. Perhaps some nursery cultural practice (e.g., root pruning) could better prepare the trees for digging and reduce the severity of transplant stress, which would enable the trees to grow more the first season after digging.

Although the nutrient treatments failed to improve tree growth while the plants were held in the mulch bed, the treatments affected their foliar nutrition (Table 3). The best nutrient treatment for improving foliar nutrition was the compost:bark mixture used around the root balls, because this treatment increased foliar N, Mg, Ca, S, and B during both years. In the 2003 study, foliar Mn concentration was also highest in compost-treated trees. The fertilizer spike products were slightly different between the two studies, yet they appeared to be the second best treatment, improving foliar concentrations of N and S above those receiving the other treatments with the exception of foliar N levels in trees whose root balls that were injected with fertilizer in 2002 (Table 3). Based on these data, the compost mixture and fertilizer spike appeared to supply the Colorado spruce trees with the most N and S, with the compost being the most effective in supplying these minerals.

Mean percent changes of needle N, S, and Mn in 2002 and needle N, Mg, Ca, S, Mn, and B in 2003 in spruce trees also showed that the compost:bark mixture improved foliar mineral nutrition the best compared with the other nutrient treatments (Table 4). The negative numbers for percent changes of Ca and Mn indicated that the concentrations of these two minerals in the new needles at the end of the season were lower than they were in needles formed at the nursery and present at the beginning of the growing season. Even so, new needles from compost-treated trees had the least amount of negative change for Ca, indicating Ca levels after one season in the mulch bed were closer to those levels in needles at the start of the experiment. The doubling (≈124%) of the Mn concentrations in needles on trees treated with compost during 2003 showed that Colorado spruce trees can absorb large quantities of this mineral if it is available to the roots (Tables 2 and 3).

Nutrient treatments applied to the 2003 trees affected their terminal leader growth only by the end of the second growing season after they were transplanted to a landscape site (2005). Leader growth of transplanted trees was similar by the end of the 2004 growing season because the burlap and wire baskets were removed from their root balls as is standard landscape practice before installation. Removing these materials most likely caused transplant shock and root loss, limiting terminal leader growth in 2004. By 2005, however, the improved foliar nutrition resulting from the 2003 compost or fertilizer spike treatments resulted in more terminal leader growth of these trees compared with that on trees receiving the other nutrient treatments (Fig. 2). In fact, leader growth of compost-treated trees on average was 25% taller than that of fertilizer spike-treated trees, which was the next best treatment. For Sitka spruce (Millard and Proe, 1993; Proe and Millard, 1995), *Taxus* × *media* 'Hicksii' (Meyer and Splittstoesser, 1971), and other coniferous species (Nambiar and Fife, 1991), N concentration in foliage from the previous year strongly influences plant growth the next spring.

Improved leader growth of compost- or fertilizer spike-treated trees in the landscape in 2005 was probably the result of nutrient loading that took place during 2003 in the holding beds. Trees receiving either of these two treatments had significantly higher percentages of N in their needles 3 months after being planted in a managed landscape compared with trees receiving any of the other three nutrient treatments (Van Wagoner, 2006). The higher percentages of N in these trees most likely increased their leader growth during the 2005 compared with trees receiving the other nutrient treatments during 2003. Nutrient loading often increases plant growth rates (Struve, 2002). Nutrient-loaded seedlings of black spruce grew more rapidly than nonloaded seedlings when planted in competitive environments (Imo and Timmer, 2001; Malik and Timmer, 1998). Hence, supplying ample mineral nutrition to Colorado spruce trees while they were held in the mulch bed appeared to promote nutrient loading and subsequently improved leader growth in the landscape.

The success of using the compost:bark mixture for improving foliar nutrition and subsequent leader growth can most likely be explained by several factors. First, the compost was made from biosolids (municipal sewage sludge) and was nutrient-rich. Second, the 50:50 mixture of compost and bark most likely retained more moisture around the outside of the root ball than just the pine bark alone. Perhaps the increased pH of the compost–bark mixture improved root growth as well. Finally, compost-treated trees received mineral nutrients along with the needed moisture outside the root ball soil where the regenerated roots formed. In contrast, the fertilizer spike, Osmocote, and injected fertilizer were applied to the root ball soil where only a few new roots probably formed (Watson and Himelick, 1982). Although the highest amounts of plant-available N were in the root ball soil of trees treated with Osmocote or the fertilizer spike during 2003 (Fig. 1), trees treated with the compost:bark mixture had the highest levels of foliar N in 2003 (Table 3).

The 2002 and 2003 holding experiments provided several insights into how 1.5 to 1.8-m tall Colorado spruce trees responded to being harvested. First, transplant shock had a strong effect on subsequent growth after digging the trees. Second, although increases in tree heights and diameters were similar, the nutrient treatments could influence foliar nutrition of the trees. Finally, foliar concentrations of Ca and Mn should probably be monitored while Colorado spruce trees are being held in a bark mulch bed. The concentrations of Ca in the needles from all trees except those receiving the compost treatment decreased during the holding experiments both years (compare Tables 2 and 3). By the end of the holding experiment in 2003, the foliar Ca concentrations (Table 3) were near deficient levels (Mills and Jones, 1996). If trees are to be held in fresh pine bark mulch, then applying a foliar Ca fertilizer may be worthwhile to avoid potential deficiency problems in subsequent years. Colorado spruce trees appeared capable of absorbing large amounts of Mn as indicated by the high concentrations of this mineral in the needles of all trees in the 2002 study and compost-treated trees in 2003 (Table 3). The normal range for foliar Mn concentration is 22 to 32 $mg \cdot kg^{-1}$ for needles on Colorado spruce trees (Mills and Jones, 1996). A nutrient treatment that contains a high Mn concentration should be applied with caution because this element may be taken up preferentially by Colorado spruce trees in place of Fe, which may induce a deficiency of this latter mineral (Mills and Jones, 1996).

Despite the inadequacy of the irrigation system during 2002 and the origin of the trees (two different nurseries under different cultural practices), the Colorado spruce trees responded similarly during their first growing season after harvest during both years of the study. Although the nutrient treatments failed to influence terminal leader growth and trunk diameter while they were held in the mulch bed during the first growing season after harvest, the compost mixture and, to some extent, the fertilizer spike improved foliar nutrition in the needles during this time. Indeed, after being planted in a landscape the next spring (2004), terminal leaders on trees treated with compost during the 2003 holding experiment averaged 27% more growth by Fall 2005 (the end of the second growing season in a permanent location) than those of fertilizer spike-treated trees, which averaged 33% more leader growth than the next best nutrient treatment (Fig. 2). Using a nutrient-laden compost such as a biosolids-based material or one that has a carbon–to-nitrogen ratio near 12:1 (nitrogen-rich material) mixed with pine bark mulch should provide Colorado spruce trees with the necessary minerals to maintain adequate foliar nutrition and even promote nutrient loading while the trees are being held the first growing season after being dug from the nursery. Therefore, when holding Colorado spruce trees in a nutrient-limited situation such as a mulch bed consisting of fresh pine bark, supplying ample mineral nutrition is essential if the trees are to recover their needle color after winter and resume rapid terminal shoot growth to the largest extent possible despite severe root loss at harvest.

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