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Douglas-fir Fertilization with Biosolids: Five-year Results at Whistler, B.C.

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Abstract

Biosolids at 750, 1000, and 1500 kg-n/ha and conventional fertilizer at 225 kg-n/ha were applied in each of three seasons (spring, summer, and fall) to a 15-year-old coastal Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) plantation that had recently been precommercially thinned and pruned. Five-year results showed that rate and timing effects were independent. No height-growth response was evident, but annual diameter growth for all biosolids treatments averaged three times higher than for conventional fertilizer. Seasonal application differences were small but statistically significant. All plots, including the controls, experienced extensive top damage from snow and ice. Similar to growth, damage was greatest with biosolids fertilization. The study shows promise for biosolids fertilization as a viable alternative to conventional fertilization, but application in locations prone to snow and ice damage should be avoided.

Forest Application of Biosolids

Municipal wastewater treatment facilities produce large quantities of biosolids (also known as sewage sludge) as the end product. Many municipalities are faced with a biosolids disposal problem and

are constantly looking for ways to turn that liability into an opportunity. Biosolids are high in plant nutrients and organic matter, which makes them well suited for use as an organic fertilizer and soil amendment.

Since the late 1970s, forest application of biosolids has generated considerable interest and research (see "References"). As a fertilizer, biosolids contain nitrogen, phosphorus, and potassium, as well as many micronutrients. The accompanying organic matter can also improve soil water-holding capacity, which may have a synergistic effect on nutrient availability. Biosolids are currently used to fertilize agricultural, forest, and range lands and are applied as a soil amendment during reclamation of disturbed land.

Both the wastewater source and the treatment process affect the suitability of biosolids as a fertilizer. Biosolids produced from nonindustrial sources are usually preferred for forest application because, by dry weight, they generally contain higher concentrations of readily available plant nutrients and lower concentrations of heavy metals and other environmental toxins.

Rate and timing are the standard prescription questions that must be addressed when considering fertilization. In theory, spring application has the advantage of cool temperatures to minimize ammonia volatilization, low

precipitation to minimize leaching loss, and rapid tree growth to maximize tree uptake. Application rates must strike a balance between tree nutritional needs and the potential for soil and water contamination. The rate and timing of biosolids fertilization is site-specific and depends on the characteristics of the biosolids, the characteristics and nutrient status of the stand, and the biogeoclimatic conditions. Application rates for biosolids are often expressed in kilograms of elemental nitrogen per hectare (kg-n/ha), which allows for comparison with conventional fertilizer rates and responses.

Tree growth responses observed with biosolids fertilization compare favourably with conventional fertilizer responses. In many cases, growth response appears to exceed conventional fertilizers in both magnitude and duration. Plausible explanations include more complete nutrition (multiple nutrients) and organic matter contributions in the form of slow-release nutrient reserves and improved soil properties, including nutrient and water-holding capacity.

Over the last 20 years, operational forest application programs have become established in several communities across North America. Since 1985, King County, Washington (Seattle) has operated one of North America's most prominent and successful forest application programs. In 1998, 31 750 wet-tonnes of King County biosolids were applied to Weyerhaeuser, Washington State, and county forestlands; application rates currently range from 360 to 1200 kg-n/ha.

Despite initial enthusiasm for forest application of biosolids in British Columbia during the late 1980s and early 1990s, operational application programs have yet to be established in British Columbia. The principal reasons are differences in terrain and forest tenure. Operational application of biosolids uses ground-based

pumping or slinging equipment, so rough terrain and difficult access limit its use in many coastal locations. Some municipalities in British Columbia, including the Greater Vancouver Regional District (gvrld), have developed active biosolids programs, but forestry application currently accounts for a very small percentage. In fact, hybrid poplar is currently the sole forestry use for gvrld biosolids. Meanwhile, many British Columbia municipalities continue to landfill their biosolids while remaining hopeful that mutually beneficial ventures can one day be established with forest companies and Crown land management agencies in the province.

Whistler Study

In 1993, experimental plots (ep1177) were established on the Whistler Interpretive Forest to compare fertilization of Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) with biosolids and conventional nitrogen fertilizer. The study area lies within the Southern Moist Submaritime Coastal Western Hemlock biogeoclimatic subzone (CWHms1). At an elevation of 960 m, Douglas-fir on this site is nearing the upper limit of its ecological range. The 15-year-old (site index 35 m) plantation chosen for the study had been precommercially thinned to 600 stems per hectare and pruned to 3 m one year before plot establishment and fertilization. At time of fertilization, the stand averaged 9.3 m tall and 12.9 cm in diameter. One year after fertilization, an unusually heavy snow and ice storm caused considerable damage throughout the stand.

Thirty 0.09-ha plots were established, representing two replications of a complete 3 by 5 factorial of three application seasons (summer [August 1993], fall [November 1993] and spring [June 1994]), and five fertilizer treatments (Table 1). Plots were

table 1 *Fertilizer treatments*

Treatment	Rate (kg-n/ha)	Dry weight ^a (T/ha)
Control	0	0
Conventional fertilizer ^b	225	na
Biosolids ^c	750	25.0
Biosolids	1000	33.3
Biosolids	1500	50.0

a Oven-dry weight of biosolids was 10% of wet weight.

b Applied as urea in spring and fall, and as ammonium nitrate in summer to minimize volatilization.

c Dewatered secondary nonindustrial biosolids rewatered with 3% biosolids.

arranged in a randomized complete block design with application season confounded with blocks. Plots were spatially clustered in three blocks of 10 (two replications of the five fertilizer treatments), with each block having a single seasonal application timed to facilitate biosolid application logistics. This confounding of application season with blocking makes it impossible to statistically separate the effects of timing from any block-location effects, such as site productivity differences. The biosolids averaged 2.4–3.9% total nitrogen and 0.04–0.20% ammonium nitrogen by dry weight; biosolids were applied in a rewatered slurry with a hose and pump.

Treatment effects were examined for both diameter and height growth. After adjusting for differences in pretreatment measurement dates, no significant pretreatment differences were evident among the plots. Five-year growth trajectories through remeasurement data available from years 1, 2, 3, and 5 appeared to be linear for each treatment. This streamlined the analyses, allowing growth analyses to focus on difference in annual increment, which is the slope of the linear 5-year growth trajectory.

In addition to the growth analyses, differences in fifth-year standing live volume per hectare and cumulative mortality and damage incidence were

examined. All statistical analyses were conducted using analysis of variance in combination with orthogonal contrasts. For this report, statistically significant effects were determined at the $p < 0.10$ level; effects also significant at the $p < 0.05$ level were noted.

Five-year Study Results

Statistical analyses indicated that the fertilizer treatment effects were independent of the seasonal application effects. This allowed the rate and timing effects to be examined separately (Figure 1).

None of the fertilizer treatments or seasonal application timings showed any significant effects on height growth. Diameter-growth among the three application seasons ranged from 1.0 to 1.2 cm/yr; the greatest growth resulted from the fall application, which was significantly greater ($p < 0.05$) than the spring, but not greater than the summer application. However, confounding with blocking in the experimental design makes it impossible to attribute these differences solely to the application season.

There were no significant diameter-growth differences among the three biosolids application rates, which averaged 1.2 cm/yr. However, all three biosolids application rates showed significantly greater ($p < 0.05$) diameter growth than either

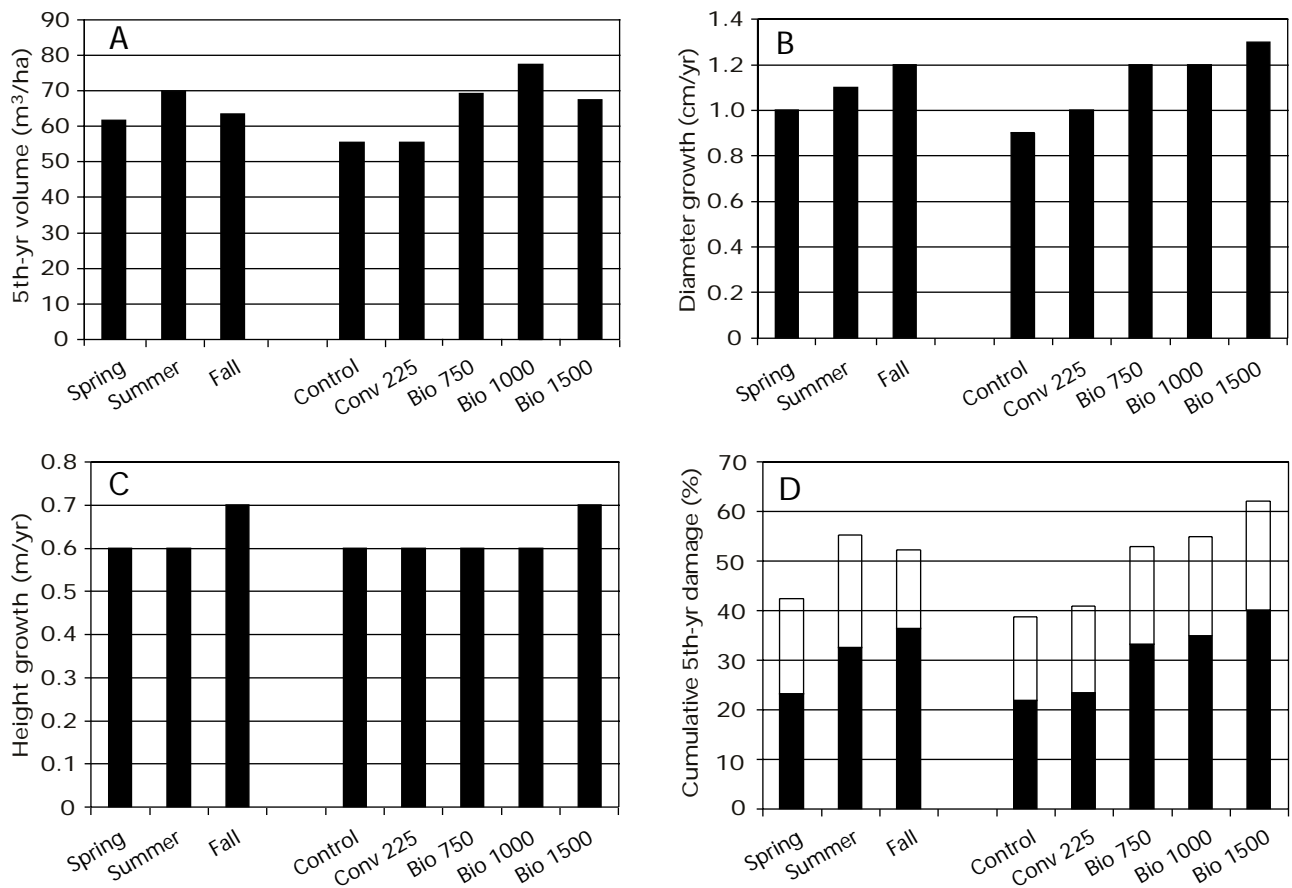


figure 1 Average results by application season and fertilizer treatment. (A) Fifth-year standing volume; (B and C) 5-year periodic annual growth rates for diameter (B), and height (C); and (D) contribution of multiple leaders (solid bars) to cumulative fifth-year total plot damage.

the control or conventional fertilizer (0.9 and 1.0 cm/yr, respectively). Although smaller in magnitude, the difference in diameter growth between conventional fertilizer and the control was still statistically significant. During the first 5 years, diameter-growth response from biosolids (0.3 cm/yr) was three times greater than that of conventional fertilizer (0.1 cm/yr).

All plots, including controls, experienced substantial top and stem damage in the first 3 years after the thinning, pruning, and fertilizer treatments. The combined damage ranged from a low of 39% on the controls to 63% for the heaviest biosolids rate. There were no significant differences in damage among the three seasonal application timings. Treatment effects on damage followed patterns similar

to growth responses. That is, damage across all biosolids rates exceeded that of either the control or conventional fertilizer by a significant margin, about 15% on average. There were no significant differences in damage among the three seasonal application timings. Top damage accounted for most of the damage regardless of treatment, with multiple leaders being the most prevalent damage.

Despite the high incidence of damage, mortality over the same 5-year period was relatively low and averaged less than 5%. In fact, nearly two-thirds of the plots experienced no mortality at all over the first 5 years. Treatments with the highest growth rates, that is (summer and fall applications of biosolids) tended to also have the highest mortality and damage rates.

Fifth-year standing live volume per hectare for all the biosolids treatments averaged nearly 30% higher than that of either the control or conventional fertilizer. However, this difference was not statistically significant, indicating a considerable amount of variation that could not be accounted for in the analyses.

Operational Implications

Given the absence of a height-growth response after 5 years, this site appears to have not responded to fertilization in a normal fashion. However, all other indicators show that an expected fertilization response was realized on this site. Pretreatment foliar nutrient levels averaged 1.14%, which is well within Douglas-fir's critical deficiency range of 1.05– 1.30%. Post-treatment increases in diameter growth and foliar nutrient concentrations indicate that both conventional and biosolids fertilization had positive effects on this site.

The height:diameter ratio for this stand was 0.72 at the time of thinning and pruning. Stands with height: diameter ratios of more than 0.70– 0.80 are considered to have a higher risk of windthrow and lower-stem breakage, especially after thinning. Despite a moderate level of risk, the extensive stand damage was not life-threatening (mortality < 5%). Damage was confined mostly to the upper crowns and was predominantly multiple leaders, broken tops, and crooks. However, fertilization definitely exacerbated top damage; perhaps the increased leaf area collected more snow and ice. This increased top damage may have also obliterated any height-growth response to fertilization.

This study supports the potential for biosolids as a viable alternative to conventional nitrogen fertilizer. These 5-year data support many other studies that show that response from biosolids exceeds that of conventional fertilizer. Continued monitoring of

this site will determine whether these elevated growth rates outlast the 6- to 10-year response duration normally observed with conventional fertilizer.

This study found relatively small differences among the spring, summer, and fall application timings tested. Consequently, biosolids fertilization can follow application schedules designed to minimize environmental concerns without seriously compromising response. Similarly, there appears to be no growth response advantage to biosolids application rates higher than 750 kg-n/ha, at least for the first 5 years.

The potential for biosolids fertilization remains largely unrealized in British Columbia. The biological benefits are well documented and are further supported by this study at Whistler. However, there are associated land tenure, regulatory, environmental, social, and economic issues that need to be worked out before biosolids application can be adopted as a viable operational alternative to conventional fertilization in British Columbia.

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Web Sites

Greater Vancouver Regional District Biosolids Program (Nutrifor)
<http://www.gvrd.bc.ca/nutrifor/biosolids/index.html>

Managing Nitrogen from Biosolids (an operational biosolids application manual)
<http://faculty.washington.edu/clh/nmanual/nmanual.html>

Seattle-King County Forest Application Program
<http://dnr.metrokc.gov/WTD/biosolids/Forest.html>

Other informative Web sites can be located by searching on forest biosolids.