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Seedling nutrient response to soil mixing and mounding treatments on a lower productivity hypermaritime site in north coastal British Columbia

Introduction

On the outer north coast of British Columbia, high forest productivity is generally associated with sites on steep slopes with good soil drainage and aeration, and a history of natural disturbance by windthrow or landslide events. These disturbance events tend to mix soil layers, slowing the build up of surface organic material, exposing mineral soil, and improving nutrient availability (Bormann et al. 1995). In contrast, the lower productivity cedar-dominated sites found on the gentle terrain of the Hecate Lowlands are imperfectly to poorly drained and have much lower levels of available nutrients (Kranabetter and Banner, in prep). This may be due, in part, to the lack of disturbance on these sites, allowing the accumulation of deep organic layers. These stands are currently the focus of considerable management interest because of their vast extent and the potentially merchantable redcedar and cypress they contain. There is some evidence suggesting that forest productivity following logging and site preparation will be greater than that indicated by the old growth condition. There is also valid concern, however, that logging these wet, lower productivity forests could result in site degradation, paludification (bog formation) and regeneration failure.

This Extension Note presents preliminary results from an operational mounding trial established north of Prince Rupert, B.C. The study is concerned with attempting to improve site productivity on imperfectly to poorly drained sites and addresses two specific issues. The first, the subject of Extension Note #44 (Shaw and Banner 2001), concerns seedling growth response on artificially mounded and unmounded microsites. Measurements included seedling height, basal diameter (calliper), root and shoot biomass, and length of lateral roots. The second issue, and the subject of this extension note, deals with seedling nutrition on five substrate types created by mixing and mounding

Five year old pine growing on a mound.

treatments. We hoped to determine the impact of manipulating soil mineral and organic content on seedling nutrition and growth. To do this, we compared tree growth across a range of substrates—three mounded and two non-mounded. The study attempts to identify trends in site productivity resulting from these mounding and mixing treatments by analyzing foliar nutrient content in planted seedlings across the range of substrate types.

Study description

The Port Simpson Operational Trial was initiated in 1990 and has since been incorporated into a larger integrated research project established in 1997 by Forest Sciences staff in co-operation with the North Coast Forest District. The project, entitled "Pattern, process and productivity in hypermaritime forests", or HyP^3 (pronounced "hip-cubed"), is aimed at developing guidelines for the sustainable management of lower productivity cedar-hemlock forests, most of which are currently excluded from the operable land base of north coastal B.C. (for more information on the extent of the HyP^3 project see Extension Note #38 [Banner and Shaw 1999]).

The study area is located 30 km northwest of Prince Rupert near the village of Port Simpson (Figure 1), within the very wet, hypermaritime Coastal Western Hemlock subzone, central variant (CWHvh2, see Banner et al. 1993). The study area is largely dominated by the Redcedar-Hemlock-Salal site series (Banner et al. 1993), considered zonal for the CWHvh2 variant. The major tree species prior to harvest were western hemlock (*Tsuga heterophylla*), western redcedar (*Thuja plicata*), yellow cedar or cypress (*Chamaecyparis nootkatensis*), with

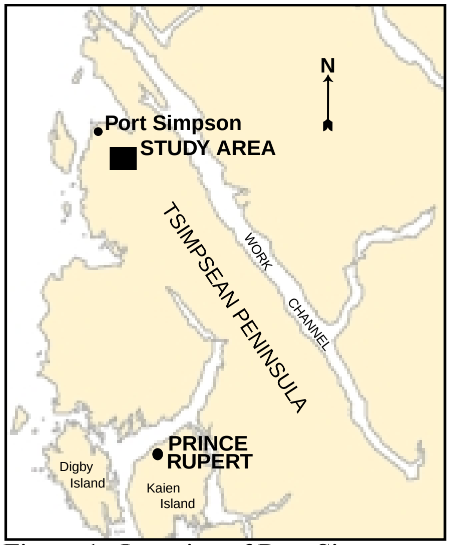

Figure 1. Location of Port Simpson study area on the north coast of B.C.

minor amounts of mountain hemlock (*Tsuga mertensiana*), Sitka spruce (*Picea sitchensis*), and shore pine (*Pinus contorta* var. *contorta*). Mean height and diameter at breast height (dbh) of main canopy trees was 20 m and 65 cm respectively. Gross volume per ha was 500 m^3 and net volume per ha averaged 280 m^3.

Variability in soil composition and depth is common on the outer north coast. In general, the soils of the study area are made up of deep surface organic horizons (average depth 52 cm). This organic layer is mostly composed of forest humus on drier microsites and sphagnum peat on wetter ones. In most cases, this layer overlays a thin mantle of mineral soil, often less than 50 cm deep. For the most part, the soils are classified as Podzolic and the horizons are derived from metamorphic bedrock (schist and gneiss).

The study area was logged in late summer/fall of 1990. Following harvest, the treatment area was divided into eight plots, four to be mounded and four to be left as controls. Average plot size was approximately 0.18 ha. Once layout was complete, mounds were created using a John Deere 790 DLC excavator equipped with a bucket and thumb attachment. The objective was to build the mounds by overturning one scoop of soil and mixing the mineral horizons with the surface organic horizons. Mounds averaged 0.5 m in height and 1.5 m in diameter. Mound density varied from 250 to 670 per ha. The mounding treatment resulted in five substrate types (Table 1). The two non-mounded substrates are controls representing post-harvest conditions typical of poorer forested sites of the north coast. These sites are high in organic matter and imperfectly to poorly drained. In the mounded treatments, soil variability resulted in three substrate types differing by degree of mixing and mineral and organic composition. In the spring of 1991, mounded and unmounded plots were planted with equal proportions of western hemlock, western redcedar and shore pine. Height and calliper of planted trees were measured in 1991, 1992, 1994, and 1996. In 1997, 28 soil samples were collected for chemical analysis and foliar samples of new growth were taken from the upper crown of 63 planted trees. Soil and foliar samples were collected from each of the five substrate types. Tests on foliar and soil chemistry were performed in the lab and the data were analysed using statistical

Table 1. Substrate description of mounds at Port Simpson.

Substrate	Composition
A	Undisturbed LFH and LFH with surface disturbance (non-mounded)
B	Undisturbed peat and peat with surface disturbance (non-mounded)
C	Mineral mound with low organic incorporation
D	Mineral mound with moderate to high organic incorporation, usually H
E	Organic mound, dominantly O (peat) material

tests to identify differences in soil and foliar chemistry on different substrate types. Foliar nutrient results were gathered for cedar, hemlock and pine; only the results for pine are presented here.

Results

The Port Simpson mounding trial is the first of its kind on the north coast, and though the results are useful, the data set is small and the subsets are uneven. For this reason, these results are only an initial look at trends in seedling nutrition in response to mounding and mixing treatments. Better understanding will come from additional trials that are either underway or planned.

After 6 years, the best seedling growth response, measured by height, calliper, and root and shoot biomass, was found on the pure mineral, and the mixed mineral/ organic mounded sites (For more details on seedling growth response on mounded and non-mounded microsites see Extension Note #44 [Shaw and Banner 2001]). Results of the foliar nutrient analysis support these findings (Figure 2 and 3). In general, shore pine needles from seedlings growing on mineral mounds had the greatest content of all macro and micro nutrients. The mineral/forest floor mix of substrate D yielded a slightly lower content of macro and micro nutrients, followed by mounded peat (substrate E). The non-mounded peat of substrate B yielded the lowest foliar nutrient content of all substrates tested.

Table 2. Listing of macro- and micronutrients.

Macro nutrients	Micro nutrients
Nitrogen (N)	Copper (Cu)
Phosphorus (P)	Zinc (Zn)
Potassium (K)	Iron (Fe)
Sulphur (S)	Boron (B)
Calcium (Ca)	Manganese (Mn)
Magnesium (Mg)	Aluminum (Al)

Five out of six macro nutrients were shown to be deficient for all substrates when compared to pot test data gathered by Ballard and Carter (1986). Nitrogen (N) and potassium (K) deficiencies exist for all substrate types, but are least severe on the mineral mounds. Phosphorus (P) was only slightly deficient for all substrate types, and no deficiencies were observed for calcium (Ca). Magnesium (Mg) deficiencies were slight to moderate on all sites, except the mounded and non-mounded peat, which experienced little, if any, deficiency.

Needle mass was significantly different among substrates. Needles collected from trees on the more productive mineral and mixed mineral/organic sites were generally more robust and had greater mass per needle, compared with needles from less productive sites.

Concentration measurements expressed as a percentage of foliage weight do not reflect differences in site productivity. Instead, nutrient content (mg per 100 needles) was found to provide more meaningful comparisons of foliar nutrient levels for shore pine growing on the various substrate types.

Shore pine appeared to be more sensitive to effects of mounding and mixing treatments than western redcedar or western hemlock. Of the three species tested, shore pine was the only one with consistently significant differences in foliar nutrient content across substrate type.

Soil chemistry was also analyzed, but its role as an indicator of nutrient availability is limited. Ballard and Carter (1986) point out that while soil analysis is used to measure the supply of elements presumably available, foliar analysis provides an index of the amount actually taken up by the trees. The interpretation of soil analysis is especially complex when forest soil depth and composition are extremely variable, as in the

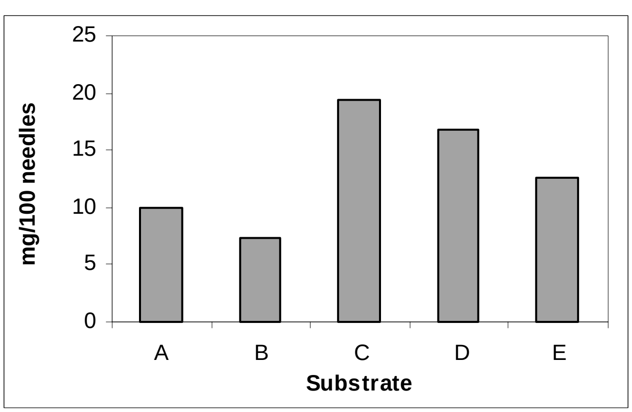

Figure 2. Nitrogen content of pine needles from trees growing on five substrate types.

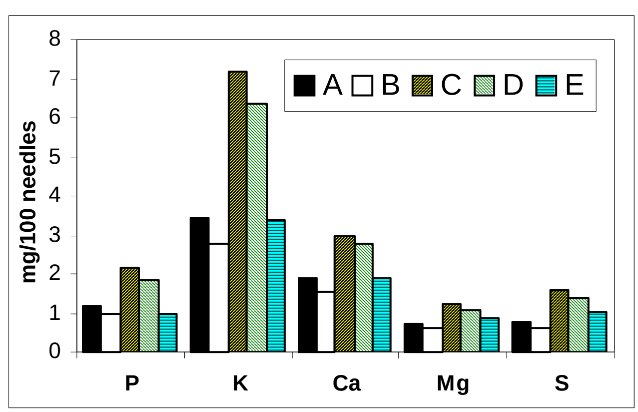

Figure 3. Macronutrient content of pine needles from trees growing on five substrate types.

Table 3. Results of soil chemical analysis of the five substrate types tested at Port Simpson.

Substrate	Bulk density (Kg/m^3)	pH	Total C (g/m^2)	Total N (g/m^2)	C/N Ratio	Available P (g/m^2)	Exchangeable K (g/m^2)	Exchangeable Ca (g/m^2)	Exchangeable Mg (g/m^2)
A	357.71	3.60	28255	628.79	45.74	0.79	6.46	164.06	36.37
B	272.09	3.68	24938	665.67	37.28	0.57	4.42	167.82	23.52
C	939.56	4.33	8869	212.50	41.31	1.28	3.29	2.87	1.31
D	536.84	3.79	23988	521.78	47.90	4.61	5.63	65.44	20.39
E	283.58	3.45	27256	622.00	49.79	0.72	4.28	77.52	27.77

Note: g/m^2 refers to a standard soil sample 1m x 1m x 20cm deep.

case at Port Simpson. Results of the soil chemical analysis are presented here to help characterize each of the substrate types (Table 3).

Discussion

All foliar nutrients tested followed a similar pattern across substrate types. In general, the mineral mounds yielded the highest nutrient content, followed closely by the mixed mineral/forest floor material. In all cases, foliar nutrient content was lower on the organic substrates. Nutrient availability from mounding mineral soil, however, did not improve enough to completely eliminate N and P limitations inherent in the site.

These results could be explained in part by the improved aeration and increased decomposition created by mounding and mixing of mineral soil. Recent studies by Kranabetter and Banner (2000) suggest, however, that decomposition rates in the top 15 cm are quite similar across sites of varying moisture regime and productivity on the outer coast. Results imply that the decline in tree productivity across site series may be more strongly related to the increasingly poorer nutrient content of the organic matter, rather than just from lower decomposition rates. Of the two non-mounded substrates, LFH (forest floor) showed greater nutrient availability than peat. This is likely due to the nature of these organic materials. Not only is the LFH material better drained and aerated than the sphagnum peat, it is also composed of more nutrient rich plant residues compared to the more acidic nutrient poor peat mosses that dominate the peaty materials of substrate B.

The plant nutrients most often discussed in the literature are N, P, K, Ca, and Mg. In this study, foliar N levels correspond with those reported by Kayahara et al. (1995). In their study, foliar N was found to have a consistent relationship with site index, a commonly used measure of site productivity. Variability in site productivity produced by mounding and mixing treatments in our study also follows a trend of increased N with increased productivity. According to Ballard and Carter (1986) nitrogen is the most commonly deficient nutrient in the Pacific Northwest and it was deficient on all substrates and treatments of our study. Nitrogen deficiency is usually due to low rates of mineralization (Ballard and Carter 1986). Low mineralization can be due to low soil pH that prevents many soil animals and micro-organisms from colonizing the soil. Soil moisture and aeration also affect mineralization (Ballard and Carter 1986). Increased saturation in the non-mounded substrates as well as the higher water retention capacity of the mounded organic substrates (compared with mineral substrates) may explain the decrease in foliar N in all organic substrates (A, B, and E). Mineralization may also have been affected by aeration and mixing. The drier, better drained substrates (either through greater amounts of mineral material or increased height above water table) have the potential for greater circulation of oxygen through the rooting zone, thereby increasing the amount of mineralization possible.

Foliar P was also found to increase with site productivity, and was slightly deficient on all substrate types. Fertilization studies by Chappell et al. (1992) also found a positive relationship between site productivity and foliar P levels. One contributor to the total P available to plants is soluble inorganic phosphate. Phosphate is found in especially small concentrations if soil pH is less than 5.0 (Ballard and Carter 1986). This was the case for all soils sampled and can explain some of the resulting deficiencies. Most of the remaining P is tied up in organic matter, some of which is released into the soil solution during decomposition. As a result, sites with greater rates of decomposition and mineralization, such as the mineral and mixed mineral/forest floor substrates of C and D may be less likely to suffer P deficiencies.

A study conducted by Kranabetter and Banner (in prep) suggests that phosphorus levels may also influence available N. They cite studies by Chapin et al. (1978), Cole and Heil (1981), and Vitousek and Howath (1991) that show the effect of P on microbial growth and activity has a large influence on N cycling and fixation. Kranabetter and Banner (in prep) suggest one reason for reduced P availability in lower productivity north coastal forests may be due to restricted rooting within the mineral horizons that occurs on the deep, poorly drained organic soils dominating the landscape. We suspect that the mixing and mounding treatment may act to improve this condition by allowing seedlings to root into mineral soil. The trends in the data seem to support this theory since the mineral and mixed mineral/organic sites have the greatest available P levels and the unmounded organic sites have the least. In addition, poor bedrock types, such as granite, are inherently low in P content and slow to weather, and so can also restrict P availability. Further studies on the role of P on seedling nutrition and productivity are being carried out at the Oona River operational trial on Porcher Island.

Potassium was highest in the mineral substrates and decreased in the mounded and non-mounded organic substrates. After N and P, soils are usually most deficient in K, and the balance of K, Mg, and Ca may be very important (Salisbury and Ross 1992). The use of Ca and Mg is closely linked, and excesses of one may induce or aggravate deficiencies of another (Ballard and Carter 1986). This was not a factor in our study as Ca was not found to be deficient in any of the substrates, and Mg was only marginally deficient. Although a trend of decreasing Ca content with decreasing soil productivity was noted, even the lowest levels found in the non-mounded peat were not deficient. Native conifers have been found to be able to extract an adequate amount of Ca, even when exchangeable Ca falls as low as 0.001% (Ballard and Carter 1986).

We suspect the difference in species response between pine, hemlock and cedar may be due to greater internal cycling or translocation of nutrients in hemlock and cedar foliage similar to results published by Van den Driessche (1974). When experiencing stress created by nutrient deficiencies, hemlock has been shown to respond by transferring nutrients from old foliage into the tissues of young foliage, thereby moderating the impact of nutrient poor conditions (Banner et al. 1987). In our study this response may be responsible for weaker trends between more productive sites (substrate C and D) and less productive sites (substrate A and B) for cedar and hemlock. Shore pine, however, has not been found to respond to nutrient stress in this way. The nutrient content of new growth in shore pine, therefore, is more likely to reflect differences in nutrient availability among substrate types. Other studies are being carried out on seedling and sapling nutrition of western redcedar, western hemlock and Sitka spruce on sites of varying productivity in the CWHvh2 (Kranabetter and Banner, in prep) to better determine species response to differences in nutrient availability.

Summary

Preliminary results suggest that mounding and mixing can result in a positive seedling growth response by way of a net increase in nutrient availability. Our results suggest that the greatest improvement in nutrient availability results from mounding and mixing of mineral and mixed mineral/forest floor materials. We also found that organic soils are more likely to suffer nutrient deficiencies resulting in reduced seedling growth and survival, and mounding of these soils seems to result in only marginal improvements. These results are preliminary and future investigations should focus on understanding how different tree species respond to mixing and mounding treatments as well as examining acceptable levels of site disturbance, optimal treatment methodologies, and financial viability of these site preparation techniques. The HyP^3 Project hopes to address some of these issues in future operational trials. At present, another trial is underway at Oona River on Porcher Island, south of Prince Rupert. Harvesting was completed in the fall of 2000 and site treatments were applied during the summer of 2001. We are building on our experience from Port Simpson by emphasizing soil mixing while creating slightly elevated microsites. Emphasis at the Oona River trial will be on improving conditions for the establishment and growth of western redcedar as well as yellow cedar.

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