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Effects of Fertilization on Red Alder Growth on Vancouver Island, Year 10 Results

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INTRODUCTION

Red alder (Alnus rubra Bong.) is the most widespread deciduous, broadleaved tree species in British Columbia's low-elevation forests. Alder has rapid juvenile growth rates; fixes atmospheric nitrogen and increases N availability on N-limited sites (Binkley et al. 1994); is immune to laminated root rot Phellinus weirii (Thies and Sturrock 1995); contributes to habitat diversity in a conifer-dominated landscape; and can provide a variety of valuable wood products. Such characteristics make alder an attractive species for which to manage in small-scale forestry, and they make red alder a species of interest given the expected changes in regional climate.

Because alder can be an aggressive competitor to its coniferous associates, its eradication from conifer plantations in coastal British Columbia was pursued during the past three decades. However, recent increased demand for high-quality alder lumber has led to concerns that the current inventory of alder, most of which arose from natural stands (Bluhm and Hibbs 2006), will be insufficient in the future (Mason 2003). Plantation culture on appropriate sites can produce high-quality and valuable alder logs in as little as 25 to 30 years (Bluhm and Hibbs 2006).

Eastern Vancouver Island has significant potential for commercial production of red alder (Massie et al. 1994). To develop that potential, the nutritional needs of young red alder need to be understood. This knowledge can help determine: (1) on which sites plantations should be established; (2) which mineral nutrients are deficient and are thus limiting productivity; and (3) the extent to which productivity is increased by additions of those nutrients, and at what economic and environmental costs.

On Vancouver Island, data from experiments conducted in a glass house and in the field indicate that P deficiencies may limit the growth of young red alder (Brown and Courtin 2003a, 2006, 2007). In five single-tree plot experiments, P that was added to the soil within a year after planting increased foliar P concentrations and stem growth. At Year 3, heights, basal diameters, and stem volumes of fertilized trees increased by as much as 25, 36, and 96%, respectively, compared to trees in unfertilized plots (Brown and Courtin 2007). Additions of other elements had little or no effect. On relatively moist sites in coastal British Columbia, additions of P to the soil at the time of planting increased stem volumes by ~60% by Year 3.[1]

It is unknown how long the effects of P that is added near the time of planting might persist. Such information is needed to assess the costs and benefits of adding nutrients to the soil at the time of planting. Effects of P additions on growth of pine plantations in P-deficient Australian soils persisted through an entire rotation (Turner et al. 2002); adding P at the time of planting increased growth of hybrid poplar for 10 years in P-deficient soils on eastern Vancouver Island.[2] Conceivably, long-term growth of red alder could also be increased by P additions near the time of establishment, at least in

[1] K.R. Brown and P.J. Courtin. 2009. Growth and foliar nutrition responses of red alder to P fertilization at planting on moist sites in coastal British Columbia. Research Section, Coast Forest Region, British Columbia Ministry of Forests and Range. Nanaimo, BC. Unpublished manuscript.

[2] K.R. Brown. 2005. Tree growth and soil carbon accumulation in two 10 year old hybrid poplar plantations on eastern Vancouver Island. Pacific Forestry Centre, Canadian Forest Service, Victoria, BC. Internal report.

P-deficient soils. This extension note documents and discusses stem growth responses of young red alder up to 10 years after the site was fertilized with P and other elements. Year 3 responses were reported previously (Brown and Courtin 2007).

METHODS

The five experiments were located on eastern Vancouver Island. The Campbell River airport/upper (CRU) and Campbell River airport/lower (CRL) experimental sites were near the Campbell River airport, while the Harry Road (HR) site was located near Snowden Road north of Campbell River. The Fanny Bay/wet (FBW) and Fanny Bay/dry (FBD) sites were located along Cowie Creek near Fanny Bay (Table 1). Elevations ranged from 70 to 120 m. Study sites were in the Coastal Western Hemlock very dry maritime (CWHxm) biogeoclimatic subzone (Green and Klinka 1994). Soil moisture and fertility classifications (Green and Klinka 1994), site characterization for growing alder (Courtin et al. 2002), soil textures, and extractable P concentrations are summarized in Table 1.The plantations were <1 year old when fertilization took place. The experiments were initiated in 1998/99. The CRU site was planted following the harvest of a Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) stand. All remaining sites were planted following the harvest of an alder stand.

Single-tree plots were employed in the study because the plantations available for study were relatively small and varied in the numbers and distribution of trees. Only healthy trees were selected for treatment and a minimum distance of 8 m was maintained between treatment trees. Treatments consisted of factorial combinations of P (P0, P1, P2), added as triple super phosphate (TSP, 0-45-0; N-P-K), and as "F" fertilizer (F0, F1), which is a blend of potassium magnesium sulphate (0-0-22-11Mg-22S) and fritted micronutrients. Nitrogen was not added to either fertilizer; P and Ca were added to the TSP, and the F fertilizer supplied nutrients other than N, P, and Ca (Table 2). This basic set of six treatments was applied to all five plantations. In three plantations (CRL, CRU, and HR), sufficient numbers of trees were present to allow addition of a fourth level of P (P3), with or without F (P3F0, P3F1), resulting in a total of eight treatments.

Treatments were completely randomized throughout each of the younger plantations, and the initial number of replicate plots per treatment ranged from 17 (FBD, FBW) to 25 (CRU, CRL, and HR). Plantations received 0, 10, 20, and 30 g P $tree^{-1}$ in the P0, P1, P2, and P3 treatments, respectively. The rates of P chosen were similar to or higher than those applied elsewhere to fast-growing conifers at the time of planting (e.g., Birk 1994), but less than rates that have been shown to induce growth responses in fast-growing hybrid poplar on eastern Vancouver Island (van den Driessche 1999).

Fertilizer was placed in two (P1), four (P2), or six (P3) dibble holes that were dug 0.2 to 0.3 m from (and spaced equidistant around) the seedling, which is consistent with operational fertilization practice that would occur at or near the time of planting. Prior to fertilization, understory vegetation was removed from around each seedling to a distance of ~0.3 m, in order to facilitate the uptake of added nutrients.

In the winter of 2007/08, treated trees were located, and height and dbh at 1.3 m from ground level were measured. Thus, Year 10 responses were measured in four 11-year-old plantations, and Year 9 responses were measured in one 9-year-old plantation. For comparisons over time, we re-analyzed the growth data after 3 years from the same trees. At Year 3, mean heights from these trees did not differ from the previously reported means of all trees present (Brown and Courtin 2007). Basal diameter was measured at Year 3, but dbh was not. To estimate Year 3 dbh, we applied the following regressions relating basal diameter and dbh that were developed from a 4-year-old alder plantation which was also

Table 1. Selected site characteristics for the five experimental sites (adapted from Brown and Courtin 2007).

Study site[a]	Lat / Long	Soil moisture regime	Soil nutrient regime	Site productivity[b]	Bray-P (mg kg^{-1})	Soil texture
Campbell River airport/upper (CRU)	49°58'N 125°18'W	Moderately dry	Poor to medium	Poor	124.9	Loamy sand to sandy
Campbell River airport/lower (CRL)	49°58'N 125°18'W	Very moist	Rich to very rich	Good	3.5	Loamy
Fanny Bay/wet (FBW)	49°30'N 124°51'W	Very moist to wet	Very rich	Poor to medium	6.8	—
Fanny Bay/dry (FBD)	49°30'N 124°51'W	Moist	Rich to very rich	Good	3.0	Loam
Harry Road (HR)	50°06'N 125°24'W	Fresh to moist	Rich	Good	6.8	Loam

[a] All sites were located in the Coastal Western Hemlock very dry maritime biogeoclimatic subzone (CWHxm).
[b] Adapted from Courtin et al. 2002.

Table 2. Nutrient additions (g tree^{-1}), by treatment for fertilized plots.

Treatment[a]	P (g tree^{-1})	K (g tree^{-1})	Ca (g tree^{-1})	Mg (g tree^{-1})	S[b] (g tree^{-1})	Fe (g tree^{-1})	Mn (g tree^{-1})	Zn (g tree^{-1})	B (g tree^{-1})	Cu (g tree^{-1})	Mo (g tree^{-1})
P1	10		6								
P2	20		12								
P3[c]	30		18								
F1		5.5		3.5	6.5	3.2	1.3	1.2	0.6	0.6	0.015

[a] Nutrients were not added in the P0 and F0 treatments, therefore no data are included here.
[b] Sulphur concentrations in the TSP were not determined, but typically are ~1%. This would mean S additions were ~0.5, 1.0, and 1.5 g S in the P1, P2, and P3 treatments, respectively.
[c] The P3 treatment was applied only at the CRU, CRL, and HR sites.

located on eastern Vancouver Island and had been fertilized at Year 1 (Brown and Courtin 2003b):

For unfertilized trees:
$dbh = -4.634 + 0.691bd$, $r^2=0.86$, $n=316$

For trees receiving 10 or 20 g P tree^{-1}:
$dbh = -2.923 + 0.688bd$, $r^2=0.82$, $n=309$

For trees receiving 30 g P tree^{-1}:
$dbh = -2.954 + 0.675bd$, $r^2=0.87$, $n=274$

where dbh is diameter at breast height in mm, and
bd is basal diameter in mm.

Growth data were analyzed by analysis of covariance (ANCOVA) using initial height or basal diameter, as appropriate, as the covariate. Numbers of measurement trees (and plots) per treatment varied with site at the time of establishment and at the time of measurement as a result of stem breakage, mortality, and missing tags. Hence, analyses were done by site. Least squares means were compared by planned contrast and by least significant difference (LSD) with a Bonferroni correction (Milliken and Johnson 1992) for significant interactions. Analyses were performed using JMP (SAS Institute, Cary, NC).

RESULTS AND DISCUSSION

Effects of P additions on stem dbh and basal area were detectable at Year 10 at four of the five study sites, but were not detectable at Year 9 at the HR site (Table 3, Figure 1). This 10-year period constitutes more than 25% of the expected rotation length for plantation-grown alder in this area (Bluhm and Hibbs 2006). However, P additions led to increases in height only at the CRU site.

The linear effect of P was significant for height, basal area, and dbh at the CRU site, and for basal area and dbh at the two Fanny Bay sites (FBD and FBW) (Table 3, Figure 1), suggesting that greater amounts of P added at those sites might have further increased growth. The interaction of P x F treatments was significant ($\alpha = 0.05$) at the CRU site for height and basal area (data not shown); additions of F increased both height and basal area, but only when P was not added. Otherwise, additions of the F blend did not increase growth. Earlier analyses of growth and foliar elemental concentrations in these plantations suggested that: (1) P additions alleviated deficiencies of P, but not of other elements, and (2) the F fertilizer blend had little or no effect on growth, despite increasing foliar concentrations of some other elements (Brown and Courtin 2007).

Survival, growth of unfertilized trees, and growth responses to P additions seemed to vary with site. Few of the original measurement trees were located for re-measurement in 2007: only 22% at the CRU site, but as high as 73% at the HR site. Some trees were probably not located and re-measured because tags were no longer present. However, mortality through Year 10 may have been high at the CRU and FBW sites. At both sites, standing trees were missing where measurement trees should have been. At the CRU site, documented mortality through Year 3 was high (47%) (Brown and Courtin 2007), which was likely a consequence of a spring frost that occurred immediately before fertilization took place and due to the subsequent occurrence of summer moisture stress (Brown 1999). At Year 3, mortality at the FBW site was lower (~9%; Brown and Courtin 2007), but the site was relatively wet, with standing water present on the site into the growing season. Given the number of missing or dead measurement trees, we assume mortality was high at the FBW site between Year 3 and Year 10. At the CRL, FBD, FBW, and HR sites, scraping and breakage of stems by elk were frequent, which might have contributed to the number of dead or missing trees.

At Year 9 for the HR site, and at Year 10 for the other sites, stem growth of unfertilized trees was less on the sites initially classified as being of poor productivity for alder (CRU and FBW) (Courtin et al. 2002), but it was greater in the sites classified as being of good productivity (CRL, FBD, and HR) (Figure 1). For example, basal areas of unfertilized trees were two times greater at the CRL and HR sites than at the CRU site.

Conversely, responses to P additions were greater at "poor" sites. Basal areas of individual trees increased by 129% (70 cm^2 tree^{-1}) at the CRU site and by 100% (54 cm^2 tree^{-1}) at the FBW site, but by only 31% (33 cm^2 tree^{-1}) at the CRL site and only 34% (26 cm^2 tree^{-1}) at the FBD site. Basal area did not increase at the HR site.

The greater response to P additions at the dryer CRU site and the wetter FBW site is consistent with earlier studies of red alder seedlings

Table 3. ANCOVA summaries, showing significance (*p*) levels for height, dbh, and basal area at Year 9 for the Harry Road site and at Year 10 for the other sites, after additions of phosphorus (P) and other nutrients (F). Planned contrasts for the P treatments are shown only if significant (α = 0.10).

Study site	Trees alive and measured			Source	Probability (*p*)		
	Year 10 (no.)	Year 3 (no.)	Year 0, time of fertilization (no.)		Height	dbh	Basal area
Campbell River airport/upper (CRU)	43	100	200	P main	0.018	0.066	0.093
				P linear	0.003	0.014	0.014
				F	0.183	0.267	0.418
Campbell River airport/lower (CRL)	82	145	200	P main	0.623	0.180	0.178
				P0vsP123		0.067	0.069
				F	0.048	0.092	0.116
Fanny Bay/wet (FBW)	29	87	102	P main	0.500	0.030	0.037
				P linear		0.010	0.015
				F	0.720	0.773	0.771
Fanny Bay/dry (FBD)	59	86	102	P main	0.275	0.047	0.048
				P linear		0.021	0.017
				F	0.548	0.082	0.146
Harry Road (HR)	145	159	200	P main	0.603	0.425	0.381
				F	0.900	0.129	0.133

(Radwan 1987; Radwan and DeBell 1994). In the wet soils of the FBW site, extractable soil P levels were at levels associated with reduced growth in red alder (Harrington and Courtin 1994; Brown and Courtin 2003a). Poor aeration may have further restricted root growth, root respiration, and elemental uptake (Radwan and DeBell 1994). P additions may therefore have compensated for inherently lower P availability and uptake. In contrast to the FBW site, extractable soil P levels at the relatively dry CRU site were very high (25 times greater on average than at the other four sites), yet P additions still increased foliar P concentrations at Year 1 (Brown and Courtin 2007) and stem growth.

Given the general pattern of early mortality on the site, soil sampled for chemical analysis may not have been representative of soil under surviving trees (e.g., the mean soil P level for the site may have been greater than that under surviving measurement trees). However, even if soil P levels were high, low levels of soil moisture at this moderately dry site might have restricted P transport to roots and P uptake. Added P might have stimulated fine root growth and subsequent uptake of moisture, P, and other elements. Greater foliar concentrations of P (Brown and Courtin 2007) may also be associated with greater water-use efficiency (Brown and Courtin 2003a) and tolerance of moderate moisture stress.

It is also possible that the greater growth response to the addition of P at the CRU and FBW sites could be an indirect response to either greater mortality or to the distribution of mortality on each site. Greater mortality in these two "poor" sites might have increased the availability of limiting resources to the remaining trees. Measurements of growing space around each measurement tree might have provided useful insight. Beneficial effects of P additions may also have been greater in those microsites which were not too dry or too wet; that is, so dry or so wet as to cause tree mortality. What constitutes "dry" or "wet" for alder remains to be quantified.

Differences in site quality were also potentially confounded with differences in site history (e.g., the CRU site was dominated by Douglas-fir prior to plantation establishment, while other sites were dominated by red alder), seedling quality, and planting practices (e.g., timing of planting following harvest, planting site selection). However, the CRU and CRL sites were adjacent to one another; had the same seedling stock type, initial spacing, and planting crew; and were planted and fertilized at the same time. Differences in

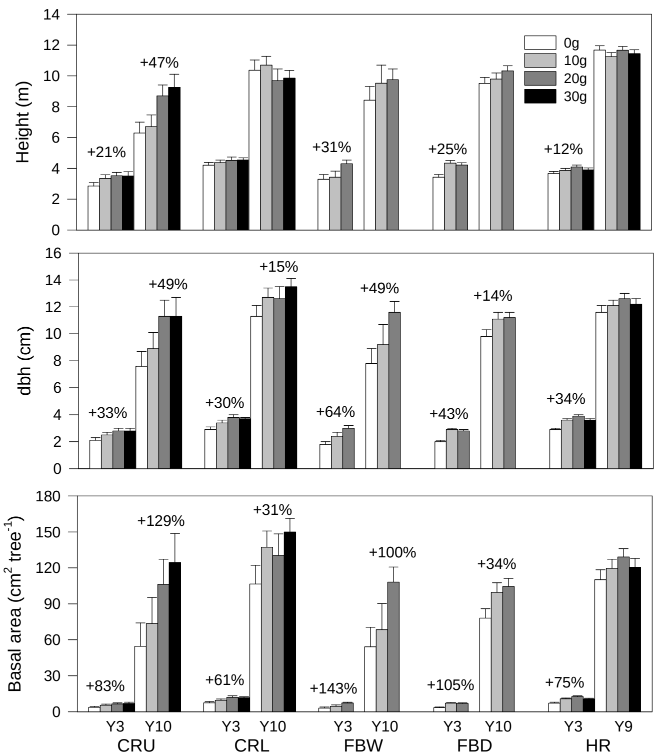

Figure 1. Effects of P added (mean and standard error) to the soil within one year after planting, on height, dbh, and basal area of red alder, at Year 9 for the Harry Road site and at Year 10 for the other sites. Percentage increases shown are associated with the significant planned contrasts shown in Table 2. For comparison, Year 3 results are shown (Brown and Courtin 2007) for the same subset of trees as those measured in Year 10.

growth response were therefore associated mainly with site differences. The same is true for the two Fanny Bay sites.

Growth responses to P additions were also significant at Year 3 on these sites (Brown and Courtin 2007), although the response pattern changed between Year 3 and Year 10 (Figure 1). At Year 3, P-fertilized trees were significantly ($\alpha = 0.10$) taller on all sites, and absolute increases in basal area in P-fertilized trees were as great or greater in the sites initially classified as productive. Available P levels in soil were low in the productive sites at the time the experiments were established (Brown and Courtin 2007), which may have limited early growth. Over time, P may have become less limiting to unfertilized trees as mycorrhizal associations developed, or P (or other nutrients) might have become more limiting to faster-growing fertilized trees. Additional research could clarify how site factors affect growth responses of alder to P additions and why that might change over time.

In general, long-term growth responses to fertilization are difficult to evaluate when using single-tree plots. Stand-level mortality and density around treated trees may vary, with unknown consequences for growth of treated trees. Leaf litter from treated and adjacent untreated trees tends to mix over time, so that litterfall inputs of nutrients become more similar. Likewise, roots of treated and adjacent untreated trees intermingle and compete for resources in the same soil volumes. This makes responses of individual treated trees to P additions especially believable because the actual effects are underestimated (Cellier and Correll 1984). Conversely, early increases in growth of treated trees could confer size and competitive advantages over adjacent unfertilized trees. These advantages (greater capture of light, moisture, and nutrients other than P) could increase over time and would be indirect effects rather than direct effects of early P additions on P uptake and use in growth. Ultimately, large multi-tree plots are required in order to make quantitative estimates of long-term responses of alder to P additions. Such experiments are currently underway (e.g., Brown and Courtin 2003b).

CONCLUSIONS

- Adding P (up to 30 g P tree^{-1}) to the soil within a year after planting was found to increase growth of individual red alder trees at Year 10 in four of five plantations studied on eastern Vancouver Island, British Columbia. I.e., the response was sustained for a period that was >25% of the expected rotation length.

- Maximum growth rates were associated with P addition rates of 20 to 30 g P tree^{-1}.

- Additions of elements other than P did not increase growth.

- Increases in dbh ranged from 1.4 to 3.8 cm, and increases in basal area ranged from 26 to 70 cm^2 tree^{-1}.

- The single-tree plot experimental design does not account for stand-level responses in growth and mortality. To obtain accurate projections of stand-level growth response requires that long-term, multi-tree-per-plot, fertilization experiments be established.

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