

## Tree Physiology

1. 1994. Annual Report - Forest Research Laboratory, Oregon State University. Forest Research Laboratory, Oregon State University. ii + 29 pp.

**Keywords:** genetic tree improvement  
tree/stand protection  
tree phenology  
tree physiology

**Abstract:** Highlights of research conducted during 1993-1994 are presented, including: preliminary results of a 2-year (1992-94) field cold hardiness study of Douglas fir [*Pseudotsuga menziesii*] in Oregon, USA involving open pollinated progeny of 40 parents at a high and a low elevation; results of a progeny test on the frequency of second flushing of Douglas fir near Orleans, France; and variation in stable carbon isotope ratios (a measure of water use efficiency) among varieties and populations (coastal and Rocky Mountain) of Douglas fir.

2. 1997. PNWTIRC Annual Report 1996-97, Pacific Northwest Tree Improvement Research Cooperative. Oregon State University, Oregon, USA. ii + 29 p.

**Keywords:** genetic tree improvement  
tree/stand protection  
tree phenology  
growth  
wood quality  
tree physiology

**Abstract:** The report describes highlights for 1996-97, current research (3 projects), student project updates (3 projects), planned Douglas fir [*Pseudotsuga menziesii*] seed orchards for the new millennium and other planned activities of the PNWTIRC, a research cooperative operating in the Pacific Northwest area of North America (USA and Canada). Details are included of publications and finances. Details of the 3 current research projects and the 3 student projects, which all concern Douglas fir, are presented as short papers including brief results: (1) Influence of second flushing on cold hardiness; (2) Seedling drought physiology study; and (3) Quantitative trait loci influencing cold hardiness; (4) Seedling cold hardiness; (5) Growth response of saplings to drought; and (6) Measurement study follow-up: age-age correlations in forking defects.

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3. 2000. Annual Report 1999/2000 - Pacific Northwest Tree Improvement Research Cooperative. Oregon State University, Oregon, USA. 31 p.

**Keywords:** genetic tree improvement  
tree/stand protection  
tree physiology  
reproduction

**Abstract:** Includes highlights of 1998-1999; a note to the cooperative members from Tom Adams; Introduction; Current research on seedling drought physiology of Douglas fir [*Pseudotsuga menziesii*], field drought study - genetics of drought sensitivity in older trees, early testing revisited, miniaturized orchard study, pollen contamination study; activities planned for 2000-2001; list of staff publications and abstracts; and a summary of financial support for the fiscal year 1999-2000.

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4. Adams, T., T. Anekonda and C. Lomas. 1999. Annual Report 1998-99, Pacific Northwest Tree Improvement Research Cooperative. 33 p.

**Keywords:** genetic tree improvement  
tree/stand protection  
tree/stand health  
growth  
tree physiology

**Abstract:** Summaries are given of research projects on improvement of Douglas fir [*Pseudotsuga menziesii*] in the Pacific Northwest: seedling drought physiology; genetics of dark respiration and its relationship with drought hardiness; response of saplings to drought, as measured by growth ring variables; use of microsatellite marker loci to identify pollen contamination in seed orchards; and evaluation of miniaturized seed orchard designs.

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5. Aitken, S.N. and W.T. Adams. 1996. Genetics of fall and winter cold hardiness of coastal Douglas-fir in Oregon. *Canadian-Journal-of-Forest-Research* 26(10): 1828-1837.

**Keywords:** genetic tree improvement  
tree/stand protection  
tree/stand health  
tree physiology  
genetic relationships

**Abstract:** Genetic variation in autumn cold hardiness was studied in two western Oregon breeding populations of coastal Douglas fir (*Pseudotsuga menziesii* var. *menziesii*), one on the west slope of the Cascade Mountains and the other in the Coastal Range. On six sampling dates (September, October and November 1992 and January, September and October 1993), shoot cuttings from 40 open-pollinated families in each of two progeny test sites for each breeding zone were subject to artificial freezing at two test temperatures. Damage in each shoot was recorded as visible injury to needle, stem and bud tissue separately. Considerable family variation was found for cold injury scores in all tissues in early to mid autumn, but differences were often smaller or nonsignificant in late autumn and midwinter. Individual heritability estimates for needle cold injury were low (<0.40) and generally decreased in late autumn and midwinter. Family rankings for autumn cold hardiness, however, are expected to be relatively consistent over sites and years, although needles appear to display more family-by-site

interaction than stems or buds. Genetic correlations between tissues in cold injury varied considerably and were sometimes weak, indicating that the evaluation of a single tissue is probably not adequate for assessing overall cold hardiness of genotypes. Autumn and winter cold hardiness seem to be largely under separate genetic control since genetic correlations between hardiness at these two stages were weak. This study confirms earlier results in Washington breeding populations and shows that coastal Douglas fir families can be effectively ranked for autumn cold hardiness by conducting artificial freeze tests on cut shoots in mid-autumn (October) and scoring damage to stems and at least one other tissue.

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6. Aitken, S.N. and W.T. Adams. 1997. Spring cold hardiness under strong genetic control in Oregon populations of *Pseudotsuga menziesii* var. *menziesii*. *Canadian-Journal-of-Forest-Research* 27(11): 1773-1780.

**Keywords:** genetic tree improvement  
tree/stand protection  
tree/stand health  
tree phenology  
tree physiology  
genetic relationships

**Abstract:** Genetic variation in spring cold hardiness of shoots prior to bud break was studied in two Oregon breeding populations of *Pseudotsuga menziesii* var. *menziesii*, one on the west slope of the Cascade Mountains and the other in the Coast Range. In March and April 1993, and April 1994, shoot cuttings from 40 open-pollinated families in each of two progeny test sites in each breeding zone were subjected to artificial freezing. Visible cold damage to needle, stem, and bud tissues was recorded. Date of bud burst (all sites), and injury resulting from a 1992 natural frost event (one site), were also recorded. Spring cold injury varied widely among families. Individual heritabilities for spring cold injury scores averaged 0.76 in the Coastal zone and 0.42 in the Cascade zone. Genetic correlations among tissues, sites, sampling dates, and years, and between April cold injury and date of bud burst were high, in most cases over 0.80. Correlations were also strong between natural frost damage in 1992 and artificial cold injury scores in 1993. Artificial freeze testing stem tissues of cut shoots sampled in April from a single test site should effectively rank families in this region for spring cold hardiness.

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7. Aitken, S.N., W.T. Adams, N. Schermann and L.H. Fuchigami. 1996. Family variation for fall cold hardiness in two Washington populations of coastal Douglas-fir (*Pseudotsuga menziesii* var. *menziesii* (Mirb.) Franco). *Forest-Ecology-and-Management* 80(1/3): 187-195.

**Keywords:** genetic tree improvement  
tree/stand protection  
tree/stand health  
tree physiology  
tree phenology  
genetic relationships

**Abstract:** In order to assess the genetics of autumn (fall) cold hardiness in coastal Douglas fir (*Pseudotsuga menziesii* var. *menziesii*), shoot cuttings were collected in October from saplings (9-year-old trees) of open-pollinated families in two progeny tests in each of two breeding zones in Washington, one in the Coast range (80 families) and one on the west slope of the Cascade Mountains (89 families). Samples from over 5500 trees were subjected to artificial freezing and visually evaluated for needle, stem and bud tissue injury. The extent to which cold injury is genetically related to tree height and shoot phenology (timing of bud burst and bud set) was also evaluated. Significant family variation was found for all cold hardiness traits; however, individual heritability estimates were relatively low (ranging from 0.09 to 0.22). Significant family-by-test site interaction was detected for needle injury in the Cascade breeding zone, but not in the coastal zone. Genetic correlations ( $r_A$ ) among needle, stem and bud tissues for cold damage were weak ( $0.16 < r_A < 0.58$ ) indicating that genes controlling autumn cold hardening are somewhat different for different tissues. Timing of bud burst and bud set were only weakly correlated with cold injury ( $r_A < 0.49$ ). Thus, bud phenology is a poor predictor of autumn cold hardiness in this species. There was no consistent relationship between tree height and cold injury in the coastal zone. In the Cascade zone, taller trees appeared to be more susceptible to cold injury, but the association was weak (mean  $r_A = 0.38$ , range 0.20-0.72).

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8. Anekonda, T.S., M.C. Lomas, W.T. Adams, K.L. Kavanagh and S.N. Aitken. 2002. Genetic variation in drought hardiness of coastal Douglas-fir seedlings from British Columbia. *Canadian-Journal-of-Forest-Research* 32(10): 1701-1716.

**Keywords:** genetic tree improvement  
tree/stand protection  
growth  
tree/stand health  
genetic relationships  
tree physiology

**Abstract:** Genetic variation in drought hardiness traits and their genetic correlations with growth potential and recovery traits were investigated in 39 full-sib families of coastal Douglas-fir (*Pseudotsuga menziesii* var. *menziesii*) from southwestern British Columbia, Canada. Seedlings of these families were grown in raised nursery beds and subjected to three moisture regimes each in the second (well-watered or control, mild, and moderate drought) and third (control, severe drought, and recovery from second-year moderate drought) seasons. Traits assessed included drought hardiness (foliage damage, cavitation of xylem tracheids, xylem hydraulic conductivity, and height and diameter growth increment) in the drought treatments, growth potential (total height and diameter) in the control treatment, and height and diameter growth increments in the recovery treatment. Xylem cavitation in the growth ring produced in a particular year was nearly three times greater under the moderate drought and four times greater under the severe drought than in the control treatment. Xylem hydraulic conductivity of seedlings in the severe drought treatment was 40% lower than conductivity of seedlings under the control treatment. Mean foliage damage in seedlings subjected to severe drought (third season) was much greater (33%) than in seedlings subjected to mild or moderate drought (second season). Families differed significantly in most drought hardiness traits, with individual tree heritabilities averaging 0.19. Thus, much potential exists for identifying drought-hardy families at the seedling stage and using this information for deployment or breeding purposes. In addition, most hardiness traits were strongly

intercorrelated (genetic correlations often exceeded |0.80|) indicating that these traits are controlled largely by the same set of genes and that selection for hardiness based on one trait will increase hardiness as reflected in the other traits as well. Genetic correlations were only moderate (0.49) between hardiness traits measured in different years, perhaps due to the large difference in severity of the drought applied in the two seasons. Although injury to seedlings, as reflected in foliage damage and xylem cavitation, was relatively low under the moderate drought of the second season, it did result in reduced growth increment the following (recovery) year. Growth potential under favourable moisture regimes was nearly uncorrelated with drought hardiness, suggesting that drought hardiness could be improved in this southwestern British Columbia breeding population without negatively impacting growth potential in favourable moisture conditions.

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9. Barclay, H.J. and H. Brix. 1984. Effects of urea and ammonium nitrate fertilizer on growth of a young thinned and unthinned Douglas-fir stand. *Canadian-Journal-of-Forest-Research* 14(6): 952-955.

**Keywords:** fertilization  
thinning  
growth  
tree physiology  
tree/stand health

**Abstract:** The effects were studied of 2 sources of nitrogen fertilizer applied at rates of 224 and 448 kg/ha N on growth of thinned and unthinned plots established in 1970 in a 24-yr-old stand on southern Vancouver Is., British Columbia. Ammonium nitrate yielded higher growth of diam. and vol. than urea over a 9-yr period, particularly with thinning. Ht. growth was not affected by nitrogen source. The efficiency of nitrogen fertilizing in terms of stem vol. response per kilogram of nitrogen applied was greatest with ammonium nitrate in thinned plots. Tree mortality increased substantially with fertilizing for both sources, and decreased markedly with thinning.

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10. Barclay, H.J. and H. Brix. 1985a. Effects of high levels of fertilization with urea on growth of thinned and unthinned Douglas-fir stands. *Canadian-Journal-of-Forest-Research* 15(4): 730-733.

**Keywords:** fertilization  
thinning  
growth  
tree physiology  
tree/stand health

**Abstract:** Diameter height and volume growth were documented for 9 yr after thinning and fertilizing in a 24-yr-old stand on a poor site on southern Vancouver Is. The treatments involved 3 thinning treatments (0, 1/3, and 2/3 b.a. removed) and 6 fertilizer treatments (0-1344 kg/ha N) with urea. Increments for both diameter and gross volume increased with the rate of fertilizer application and

responses were still apparent 9 yr after treatment. For unthinned plots, the 9-yr volume growth responses were 30, 50, and 80% with fertilizer rates of 224, 448, and 896 kg/ha N, respectively. The efficiency of fertilizer use, measured as stem volume response per unit of nitrogen applied, decreased with rate of fertilizer application, but this result may change over a longer response period. There was a positive interaction between fertilizing and thinning such that high amounts of both mutually enhanced growth. Mortality increased with fertilizing, but only noticeably in unthinned plots.

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**11.** Binkley, D. and P. Reid. 1985. Long-term increase of nitrogen availability from fertilization of Douglas-fir. *Canadian-Journal-of-Forest-Research* 15(4): 723-724.

**Keywords:** fertilization  
growth  
tree physiology  
soil properties

**Abstract:** [See FA 44, 4708; 46, 1837] Most Douglas-fir stands respond to nitrogen fertilizing by increasing stem growth for less than 8 yr, but one plantation at the United States Forest Service Wind River Experimental Forest in Washington State has responded for over 15 yr. In this study nitrogen concn. of foliage and fresh litter were shown to be higher in the fertilized plots (470 kg/ha N) 18 yr after fertilizing. Retranslocation of N from senescent needles was not affected and stem growth per unit N in the canopy was similar between unfertilized and fertilized plots. An index of soil N availability in the fertilized plots was twice that of unfertilized plots. The higher stem growth, leaf area, and stem growth per unit leaf area demonstrated in an earlier study appeared to be related to a sustained increase in soil N availability rather than increased N-use efficiency. An examination of soil N transformation processes is needed to complete the explanation of the unusually prolonged fertilizer response in these plots.

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**12.** Birchler, T.M., R. Rose and D.L. Haase. 2001. Fall fertilization with N and K: effects on Douglas-fir seedling quality and performance. *Western-Journal-of-Applied-Forestry* 16(2): 71-79.

**Keywords:** nursery operations  
nursery fertilization  
growth  
tree physiology  
tree morphology  
tree/stand health

**Abstract:** Coastal Douglas fir (*Pseudotsuga menziesii*) 1+1 seedlings from coastal Oregon, USA, were applied with two fertilizers (NH<sub>4</sub>NO<sub>3</sub>+K<sub>2</sub>SO<sub>4</sub> and (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub>+KCl) at four rates (0, 80, 160, 320 kg N and K/ha) split over three application dates (September 19, October 13, November 1, 1996). Fertilizer type did not affect total Kjeldahl nitrogen (TKN) levels on any of the sampling dates. By January 10, TKN concentrations had increased 16, 30 and 34%, and chloride concentrations had increased 57, 77 and

112% relative to the seedlings without fertilizer, for 80, 160 and 320 kg N+K/ha treatments, respectively. Nitrate levels increased briefly after the first application of NH<sub>4</sub>NO<sub>3</sub>+K<sub>2</sub>SO<sub>4</sub>. Potassium levels remained relatively unchanged. Levels of most other nutrients, as well as foliar dry weight, increased between September 16 and January 10, but these increases were generally unrelated to the fertilizer treatments. Root growth potential and cold hardiness did not differ among treatments. Seedlings that received 160 or 320 kg N/ha broke bud an average of 3 days earlier than the seedlings without fertilizer. Chlorophyll fluorescence (Fv/Fm) of seedlings with fertilizer was consistently higher than that of seedlings without fertilizer on November 13 and December 30. These treatment differences were not reflected in seedling outplanting performance after one growing season.

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**13.** Black, C.H. 1988. Interaction of phosphorus fertilizer form and soil medium on Douglas-fir seedling phosphorus content, growth and photosynthesis. *Plant-and-Soil* 106(2): 191-199.

**Keywords:** nursery operations  
nursery fertilization  
growth  
tree physiology  
photosynthesis

**Abstract:** Douglas-fir seedlings were grown in containers in peat-vermiculite or mineral soil each amended with different levels of concentrated superphosphate (CSP) or a granulated North Carolina phosphate rock (RP). Dilute acid-fluoride extractable phosphorus (DAP), seedling photosynthesis, weights, and tissue P concentrations were measured at 65 + 3 and 105 + 3 days. DAP was highly correlated with soluble fertilizer P (but not total P) added at the beginning of the experiment. Considerable soluble P was lost from peat-vermiculite but not from the mineral soil. Seedling total P content was proportional to the amount of soluble P per container at both harvests, but was greater for a given level of soluble P in the organic versus the mineral medium. Added soluble P increased foliar P concentrations, plant P content, and dry weight. Net carbon uptake was highly correlated with added levels of soluble P, foliar P concentrations, and with total P content. The internal efficiency of P from the RP source was less than P from CSP with respect to P content versus growth, net CO<sub>2</sub> uptake, and net photosynthesis rates. At the end of the experiment, seedling P content plus DAP remaining in the media for the higher fertilizer rates accounted for 75% of the originally added soluble P in the mineral soils, but for only 15% in the organic media.

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**14.** Blake, J.I., H.N. Chappell, W.S. Bennett, S.R. Webster and S.P. Gessel. 1990. Douglas fir growth and foliar nutrient responses to nitrogen and sulfur fertilization. *Soil-Science-Society-of-America-Journal* 54(1): 257-262.

**Keywords:** fertilization  
tree physiology  
growth

**Abstract:** Nitrogen-fertilizer response in conifer stands of the Pacific Northwest has been related to soil and foliar S, and growth has sometimes been enhanced by the addition of S. Five stands of Douglas fir (*Pseudotsuga menziesii*) in Washington or Oregon, with low to moderate quantities of sulfate in the mineral soil horizon, were treated with N (urea) alone or with S (as ammonium sulfate). The results indicated that levels of soil sulfate did not provide local or site-specific predictions of the magnitude of the gain from applying N with S. The observed treatment effects were highly variable. Foliar N concentrations in the N plus S treatment were generally higher than in the N treatment. Little change in foliar S content occurred in the N plus S plot. Periodic annual growth response to N over the study period was inversely related to site index and directly related to foliar N content.

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15. Bledsoe, C.S. and R.J. Zasoski. 1983. Effects of ammonium and nitrate on growth and nitrogen uptake by mycorrhizal Douglas-fir seedlings. *In* Tree root systems and their mycorrhizas. Ed. D. Atkinson. pp. 445-454.

**Keywords:** nursery operations  
nursery fertilization  
growth  
tree physiology  
tree morphology  
tree/stand health

**Abstract:** In a greenhouse pot study, 1-yr-old mycorrhizal (inoculated with *Hebeloma crustuliniforme*) and non-mycorrhizal Douglas fir seedlings were grown in sandy forest soil amended with 10% of clay minerals (bentonite and/or kaolinite) and ammonium or nitrate fertilizer. Ht. growth, root and shoot DM and accumulation of nitrogen and P were greater in mycorrhizal than non-mycorrhizal seedlings, especially in the nitrate treatment. Ammonium interacted with kaolinite to reduce survival which again was poorer in the absence of mycorrhiza.

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16. Brand, D.G. 1986b. Competition-induced changes in developmental features of planted Douglas-fir in southwestern British Columbia. *Canadian-Journal-of-Forest-Research* 16(2): 191-196.

**Keywords:** planting operations  
tree morphology  
tree physiology  
growth

**Abstract:** From measurements in 1- to 5-yr-old plantations, developmental characteristics of Douglas fir were tested against a competition index based on measures of the brush canopy surrounding individual trees. The most promising characteristics for assessing competition were specific leaf area, the allometric relationship of ht. to b.a. and bud production on nodal shoots. Measures of foliar N and leaf internode length were less well correlated with the competition index. Comparing these results with



those of laboratory studies indicated that, on the study sites, brush competition effects on planted trees are expressed through adaptation to reduced light intensity. Developmental variables relating to moisture and nutritional status were not as strongly related to the competition index. This may reflect reduced tree demand or secondary brush canopy effects.

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17. Brix, H. 1993. Fertilization and thinning effect on a Douglas-fir ecosystem at Shawnigan Lake: a synthesis of project results. B.C. Ministry of Forests FRDA-Report 196. X + 64 p.

**Keywords:** fertilization  
thinning  
growth  
tree morphology  
tree/stand health  
carbon allocation  
wood quality  
tree physiology  
photosynthesis  
economics

**Abstract:** Treatments were initiated in 1970-71 in a 24-year-old Douglas fir (*Pseudotsuga menziesii*) near Shawnigan Lake, Vancouver Island, British Columbia, to determine the effects of 3 intensities of thinning (removing none, one-third and two-thirds of basal area) and 3 levels of urea fertilizer (0, 224 and 448 kg N/ha) on the growth and biology of the trees. Subsidiary experiments were established during 1972-87 to examine the effects of high doses of urea (672-1344 kg N/ha), ammonium nitrate as an N source instead of urea, understorey response to thinning and fertilizer, and responses to P and S fertilizer.

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18. Brix, H. and A.K. Mitchell. 1983. Thinning and nitrogen fertilization effects on sapwood development and relationships of foliage quantity to sapwood area and basal area in Douglas-fir. *Canadian-Journal-of-Forest-Research* 13(3): 384-389.

**Keywords:** fertilization  
thinning  
tree morphology  
tree physiology

**Abstract:** A 24-yr-old stand in British Columbia was treated in 1971-72 with various intensities and combinations of N fertilization and thinning. For 5-9 yr after treatments, trees were sampled to determine effects on foliage quantity and sapwood characteristics at varying stem ht. together with their relationships. Sapwood width remained relatively constant up the stem where heartwood was present, but the number of annual rings it contained decreased with ht. The sapwood width at b.h. increased with stem diam.; treatments had little effect on % sapwood at b.h. The ratio of foliage mass to

sapwood cross-sectional area changed for different portions of the crown and was lower when based on sapwood area at b.h. than at base of live crown. Significant linear relationships of foliage mass and area to sapwood area at b.h. were found, but relationships of foliage to b.a. were just as close for all treatments; treatments significantly affected these relationships with control trees having the lowest regression slopes.

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19. Brix, H. and A.K. Mitchell. 1986. Thinning and nitrogen fertilization effects on soil and tree water stress in a Douglas-fir stand. *Canadian-Journal-of-Forest-Research* 16(6): 1334-1338.

**Keywords:** thinning  
fertilization  
soil properties  
tree physiology

**Abstract:** Soil and tree water potentials were studied for 10 yr in a Douglas fir stand near Shawnigan Lake, British Columbia that was treated when 24 yr old with heavy thinning (removing superscript 2/3 of b.a.) and/or fertilization with 448 kg N/ha as urea. Control plots were not thinned or fertilized. Throughout the 10 yr, thinning increased soil water potential during the dry summer periods (July-early Oct.) by as much as 1 MPa. The effect of fertilization on soil water potential was slight and nonsignificant, and only apparent towards the end of the study in spite of large increases in leaf area (50% after 7 yr). Fertilization increased water use efficiency. The favourable soil water conditions produced by thinning led to improved shoot water potential only during predawn and early morning. Removal of understorey in a thinned and fertilized plot did not affect soil or shoot water potential.

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20. Carr, W.W. 1987. Restoring productivity on degraded forest soils: two case studies. B.C. Ministry of Forests FRDA-Report 002. vi + 21 p.

**Keywords:** site preparation  
fertilization  
tree physiology  
growth  
soil properties

**Abstract:** The use of green fallowing was studied at 2 sites, viz. (a) a coastal site at Koksilah, 15 km NW of Shawnigan Lake, British Columbia, where extensive subsoil exposure had resulted from roading operations in a highly productive Douglas fir (*Pseudotsuga menziesii*) and western hemlock (*Tsuga heterophylla*) stand, and (b) an inland site 30 km S. of Vanderhook including several landings and skid roads which had been deep-ripped to a depth of 50 cm, reducing soil density to 1350 kg/m<sup>3</sup>. Plots at (a) were seeded in 1976 at 100 kg/ha with a grass/legume mixture including 3 spp. of *Trifolium* and *Lotus corniculatus*, and received NPK (10:30:10) at 450 kg/ha. Site nutrient levels improved substantially over 5 yr with N showing the greatest gains, and Douglas fir seedlings (1+2) planted in 1977

responded with increased foliar N and K contents and 300% greater ht. growth. Plots at (b) were seeded in 1981 at 40 kg/ha with a legume mixture of 3 spp. of Trifolium, Medicago sativa and L. corniculatus, and received NPK (19:19:19) at 300 kg/ha. Nutrient gains were found after 2 yr for P, K and especially N, and although foliar nutrient contents and growth of lodgepole pine (*Pinus contorta*) seedlings showed no increase, the enhancement of site nutrient capital is considered to be a gain likely to benefit commercial forestry production.

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**21.** Chapman, R.J. 1984. Growth, nitrogen content and water relations of sludge-treated Douglas-fir seedlings. *Forestry-Abstracts* 45(7): 385-386.

**Keywords:** fertilization  
growth  
tree physiology

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**22.** Chastagner, G.A., R.S. Byther, J.D. MacDonald and E. Michaels. 1984. Impact of Swiss needle cast on postharvest hydration and needle retention of Douglas-fir Christmas trees. *Plant-Disease* 68(3): 192-195.

**Keywords:** tree/stand protection  
tree/stand health  
tree physiology

**Abstract:** Healthy Douglas-fir (*Pseudotsuga menziesii*) Christmas trees were compared with those infected by *Phaeocryptopus gaeumannii* for needle loss and dehydration after cutting. The presence of infected needles increased the rate of dehydration (as measured by changes in xylem water potential) of cut trees placed in water or left dry. Fungicide applications 1 yr before harvest significantly improved retention of 1-yr-old needles on trees displayed either wet or dry, whereas applications during the year of harvest made no difference in retention of either current-season or 1-yr-old needles.

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**23.** Childs, S.W. and L.E. Flint. 1987. Effect of shadeboards, shelterwoods, and clearcuts on temperature and moisture environments. *Forest-Ecology-and-Management* 18(3): 205-217.

**Keywords:** planting operations  
tree/stand health  
soil properties  
tree physiology  
tree phenology

**Abstract:** A comparison was made of two common techniques used to improve seedling survival on hot, dry reforestation sites. Adjacent shelterwood and clearcut sites in SW Oregon, USA, planted with 2+0 Douglas fir, were located and instrumented to compare temp. and moisture. In addition, cardboard shadecards were placed beside half of the seedlings studied. Seasonal measurements or observations of soil moisture, soil temp., solar radiation, air temp., stomatal diffusion resistance, seedling phenology and survival provided the basis for comparisons. Shelterwoods and shadecards improved seedling survival in relation to the clearcut. Both treatments affected soil temp. but the nature of the effects was different. The shelterwood canopy reduced solar radiation incident at the soil surface and caused cooler soil temp. throughout the soil profile. Shadecards reduced soil temp. only to a depth of 20 mm. Both treatments reduced the duration of periods of high soil temp. Shelterwood treatment delayed seasonal water loss and reduced seedling water stress as measured by stomatal resistance. Shadecards did not significantly affect seedling stomatal resistance. Differences in seedling survival caused by shadecards and shelterwoods are apparently due to different influences on the seedling microclimate. Shelterwood causes a large reduction in soil temp. as well as decreased seedling water stress. Shadecards modify the soil temp. less extensively and so have less effect on seedling survival.

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24. Cochran, P.H., W. Lopushinsky and P.D. McColley. 1986. Effect of operational fertilization on foliar nutrient content and growth of young Douglas-fir and Pacific silver fir. Pacific-Northwest-Research-Station,-USDA-Forest-Service Research-Note PNW-RN-445. 10 p.

**Keywords:** fertilization  
tree physiology  
growth

**Abstract:** During 1979-80, sulfated urea (pelletted) was applied to conifer stands in the Wenatchee National Forest, west of Cle Elum, Washington. Nitrogen concn. in current needles of Pacific silver fir (*Abies amabilis*) showed a significant 1.9-fold increase after fertilizer treatment compared with a non-significant 1.3-fold increase in Douglas fir (*Pseudotsuga menziesii*). A significant 2.5-fold increase in foliar N also occurred in bracken (*Pteridium aquilinum*). Analysis of foliage from untreated trees indicated N deficiency in *A. amabilis*, but N concn. in Douglas fir was above threshold values. Fertilizer treatment did not affect foliar S in either species, but increased needle surface area for *A. amabilis*. Tree diam. growth, stand b.a. growth and vol. growth were all increased by fertilizer treatment.

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25. Coleman, M., J. Dunlap, D. Dutton and C. Bledsoe. 1987. Nursery and field evaluation of compost-grown conifer seedlings. *Tree-Planters' Notes* 38(2): 22-27.

**Keywords:** nursery operations  
nursery fertilization  
growth

tree physiology  
tree/stand health

**Abstract:** Seedlings of Douglas fir (*Pseudotsuga menziesii*), noble fir (*Abies procera*) and ponderosa pine (*Pinus ponderosa*) were raised in beds that had been treated with 0, 2, 4 or 6 inches of compost (fir/hemlock sawdust and municipal sewage sludge, 3:1) at a nursery in Carson, Washington. In autumn 1983, the 2+0 stock was lifted, stored until spring 1984 and then planted out on Mt. St. Helens, Washington (Douglas fir), near Estacada, Oregon (noble fir) or E. of the Cascade crest near Leavenworth, Washington (ponderosa pine). Data are given on the ht., biomass and concn. of N, P, Zn, Cu, Pb, Ni and Cd after 1 yr in the nursery beds and on the ht. and survival for 2 yr after planting. The responses of the seedlings to the compost, the immobilization of nutrients and the accumulation of heavy metals are discussed.

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26. Coleman, M.D., C.S. Bledsoe and B.A. Smit. 1990. Root hydraulic conductivity and xylem sap levels of zeatin riboside and abscisic acid in ectomycorrhizal Douglas fir seedlings. *New-Phytologist* 115(2): 275-284.

**Keywords:** nursery operations  
nursery fertilization  
tree morphology  
tree physiology  
mycorrhizal response

**Abstract:** The hypothesis that root hydraulic conductivity (LP) of ectomycorrhizal root systems is greater than that of non-mycorrhizal systems, and different to that of vesicular-arbuscular (VA) mycorrhizas was tested in a greenhouse experiment, by measuring hydraulic qualities of roots while accounting for seedling size and P content. Plant growth substances (abscisic acid and zeatin riboside) expressed from roots during the experiments were also measured. Douglas fir (*Pseudotsuga menziesii*) seedlings inoculated with the ectomycorrhizal fungi *Laccaria bicolor* and *Hebeloma crustuliniforme*, and non-inoculated seedlings infected naturally with *Thelephora* were grown under 3 rates of P fertilization (1, 10 and 100 micro M P). After 9 months, seedling morphology, tissue P concn., LP and plant growth substance concn. in xylem sap were measured. Increased tissue P and decreased root/shoot ratio correlated with increased LP in each mycorrhizal treatment; when adjusted for the effect of these 2 factors, LP of *Laccaria* and *Hebeloma* seedlings was still lower than that of *Thelephora* seedlings. In a subsequent experiment, LP of seedlings with *Hebeloma* and *Rhizopogon vinicolor* mycorrhizas was compared with that of non-mycorrhizal seedlings (grown at 100 mM P) and no differences were found among treatments. The lack of an ectomycorrhizal effect on LP is quite different from the enhancement of host LP by VA mycorrhizas. Zeatin riboside concentrations of *Thelephora*- and *Hebeloma*-infected seedlings were similar, yet higher than with *Laccaria*. There was no relationship between plant growth substances and LP in ectomycorrhizal Douglas fir, despite lower zeatin riboside concentrations for *Laccaria*-inoculated plants.

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27. Copes, D.L. 1989. Bark scoring problem grafts in five Douglas-fir seed orchards: a case history. Pacific-Northwest-Research-Station,-USDA-Forest-Service. Research-Note PNW-RN-487. 12 p.

**Keywords:** genetic tree improvement  
tree grafting  
tree/stand health  
tree physiology

**Abstract:** Grafted seed orchards of Douglas fir (*Pseudotsuga menziesii*) often suffer tree losses caused by delayed graft incompatibility. Bark scoring (to improve translocation across the graft union) was performed in April, June and August 1983 and 1985 on 379 trees, 5-16 yr old, in 5 seed orchards in western Oregon. Cuts were made with a small chainsaw every 3.1 to 4.3 cm across the defective union. Effects of scoring were assessed in 1984 and 1986. Many trees showed improved vigour after treatment and annual mortality was only 1.6% when all defective grafts were treated. The greatest improvement in average compatibility occurred in trees treated in April, when the youngest grafts responded most favourably. Inherent and induced incompatibility was found, with brownline round the entire or part of the circumference of the union, respectively. Wound tissue in induced incompatible grafts was usually free of brownline, but brownline appeared in all wound tissue of inherently incompatible grafts. These latter grafts will require bark scoring every 2-3 yr to maintain a live cambium at the union.

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28. Crouch, G.L. and M.A. Radwan. 1981. Effects of nitrogen and phosphorus fertilizers on deer browsing and growth of young Douglas-fir. Pacific-Northwest-Forest-and-Range-Experiment-Station,-USDA-Forest-Service. Research-Note PNW-RN-368. 15 p.

**Keywords:** fertilization  
tree/stand health  
growth  
tree physiology

**Abstract:** N and P fertilizers were applied in March 1968 singly or in combination at a rate equivalent to 200 lb/acre of N or P to young trees (2-5 ft tall) in Oregon and Washington. Trees were examined and measured for up to 4 yr. In the first year after treatment trees given the N-only fertilizer in Washington were more heavily browsed by black tailed deer (*Odocoileus hemionus columbianus*), but this effect disappeared in the second year. Height growth was increased by N-only treatment in taller trees in Oregon after 1 and 2 yr, but the effect had disappeared after 4 yr. Total N content was significantly increased by the N and N + P treatments in the first year, but this effect also disappeared after 2 yr. The amounts of moisture, ash, Ca and P, and diam. growth were not affected by any treatments.

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29. Dangerfield, J. and H. Brix. 1981. Comparative effects of ammonium nitrate and urea fertilizers on tree growth and soil processes. *In* Proceedings: Forest Fertilization

Conference, University of Washington, Seattle, Washington, USA. *Eds.* S.P. Gessel, R.M. Kenady and W.A. Atkinson. pp. 133-139.

**Keywords:** fertilization  
thinning  
growth  
tree physiology

**Abstract:** Growth response of Douglas-fir to ammonium nitrate and urea, applied at rates of 200 and 400 pounds per acre (224 and 448 kilograms of nitrogen per hectare), was studied over a 7-year period at Shawnigan Lake, B.C. Diameter growth was 21 and 9 percent better, respectively, for the two rates with ammonium nitrate than with urea in unthinned plots and 7 percent better for plots that had been thinned and received 400 pounds per acre (448 kilograms nitrogen per hectare). Foliar nitrogen concentrations also increased most with ammonium nitrate fertilization during the first 2 years, indicating that nitrogen from this source was initially more readily available to the trees. This is explained in part by the greater mobility of nitrate supplied by ammonium nitrate and by nitrogen immobilization in buildup of bacterial populations with urea.

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**30.** DeBell, D.S., R.R. Silen, M.A. Radwan and N.L. Mandel. 1986. Effect of family and nitrogen fertilizer on growth and foliar nutrients of Douglas-fir saplings. *Forest-Science* 32(3): 643-652.

**Keywords:** fertilization  
growth  
tree physiology

**Abstract:** Urea (224 kg N/ha) was applied to 12-yr-old Douglas fir of 12 open-pollinated families growing near Corvallis, Oregon. Ht. and d.b.h. were measured before fertilization in Feb. 1979 and 4 growing seasons later, and tree vol. were estimated. Vol. increment varied among families, but was increased by an av. 7% by fertilizer. Concentrations of foliar nutrients, analysed in winter 1979 and 1980, differed significantly between families and in response to fertilization. The familyxfertilizer interaction was not significant for any growth or foliar nutrient measured.

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**31.** Dosskey, M.G., L. Boersma and R.G. Linderman. 1993. Effect of phosphorus fertilization on water stress in Douglas fir seedlings during soil drying. *Plant-and-Soil* 150(1): 33-39.

**Keywords:** fertilization  
tree/stand protection  
growth  
tree physiology  
photosynthesis

**Abstract:** A growth chamber experiment was conducted to determine if P fertilizing to enhance the P nutrition of otherwise N and P deficient Douglas fir (*Pseudotsuga menziesii*) seedlings reduces water stress in the seedlings during drought periods. Seedlings were grown in pasteurized mineral soil under well watered conditions and fertilized periodically with a small amount of nutrient solution containing P at three levels: 0, 20, or 50 mg/litre. By age 6 months, leaf nutrient analysis indicated that N and P were deficient in control (0 mg P/litre) seedlings. The highest level of P fertilizer, which doubled leaf P concentration, did not affect plant biomass, suggesting that N deficiency was limiting growth. When these seedlings were subjected to drought, there was no effect of P fertilizing on leaf water potential or osmotic potential. Furthermore, P fertilized seedlings had lower stomatal conductance and net photosynthesis rate. These results indicate that enhanced P nutrition, in the presence of N deficiency, does not reduce water stress in Douglas fir seedlings during drought periods.

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**32.** Driessche, R.v.-d. 1983. Growth, survival, and physiology of Douglas-fir seedlings following root wrenching and fertilization. *Canadian-Journal-of-Forest-Research* 13(2): 270-278.

**Keywords:** nursery operations  
nursery fertilization  
tree/stand health  
tree morphology  
tree physiology  
growth

**Abstract:** Seedlings at different nurseries on Vancouver Island were subjected to wrenching treatments during their 2nd year of growth using a fixed blade at 20-25 cm below the bed surface. In the first experiment, wrenching reduced water potential of trees on unirrigated loam soil by an av. of 300 kPa during Aug. and Sept. Wrenched trees lifted in Oct. and stored at 2 degrees C until May, showed 25% higher survival than unwrenched trees 1 yr after planting. Trees lifted in Dec. had uniformly high survival (98%) and showed no effect of wrenching. Wrenched trees from irrigated plots had lower shoot length relative growth rates (RGR) than unwrenched trees during the year after planting. In the second experiment, wrenching treatments were applied to seedlings, growing in a loamy sand, for different periods between 15 May and 11 Sept. as follows: (a) no wrenching, (b) early summer, (c) midsummer, (d) late summer and (e) all summer. Three fertilizer treatments (none, and 2 amounts of NPK) were applied to each wrenching treatment, and seedlings were lifted for storage at 2 degrees C in Oct. and Dec. Stored trees and freshly lifted trees were planted at 700 m alt. on 3 March. Wrenching increased root dry wt., particularly when additional fertilizer was applied, but had no measurable effect on cold hardiness or root growth capacity. Nevertheless, late summer wrenching increased survival 5 and 7% above control 1 and 2 yr after planting. Wrenching had little subsequent effect on new shoot growth of planted trees during the 2 yr after planting. However, late-summer wrenched trees showed significantly more new shoot growth than all-summer wrenched trees. More fertilizer reduced cold hardiness and survival of cold-stored trees, but increased root growth capacity. Cold hardiness (measured by electrical impedance) was correlated with survival of cold-stored trees after planting ( $r^2 = 0.82$ ). Root growth capacity, averaged over all fertilizer treatments was closely correlated with survival of stored and freshly lifted trees ( $r^2 = 0.93$ ). Foliar nutrient concn. were reduced by wrenching, but fertilizing increased nutrient reserves within the seedling.



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**33.** Driessche, R.v.-d. 1984a. Response of Douglas fir seedlings to phosphorus fertilization and influence of temperature on this response. *Plant-and-Soil* 80(2): 155-169.

**Keywords:** nursery operations  
nursery fertilization  
growth  
tree physiology  
carbon allocation  
tree morphology

**Abstract:** In pot experiments levels of P fertilizers equivalent to 300 kg/ha were adequate for maximum growth of Douglas fir (*Pseudotsuga menziesii* var. *menziesii*) seedlings over 14-18 weeks, and resulted in available soil P levels of 80 ppm after 15 weeks' growth. Maximum growth in pots was obtained with shoot P concentrations of 0.18%-0.20%, with higher values at lower temperatures, but the optimum concentration for one-year-old (1-0) nursery seedlings was 0.16% P. Growth of seedlings was greatly restricted at a soil temperature of 5 degrees C and an air temperature of 12 degrees C. At a soil temperature of 10 degrees C and an air temperature of 14 degrees C seedling P requirement was greater than at soil and air temperatures of 20 degrees C. Monoammonium phosphate was more effective than calcium superphosphate in stimulating growth in pots and nursery beds. Triple superphosphate was also effective in the nursery. Diammonium phosphate, potassium dihydrogen phosphate and phosphoric acid had no advantages as P sources in the nursery. Available P levels of 100-130 ppm, in the loamy sand and sandy loam nurseries studied, and needle P concentrations of 0.18%, when sampled in October, were associated with maximum growth of two-year-old (2-0) seedlings. P fertilization decreased the root/shoot ratio, but did not alter the allometric relationship of shoot to root. Improving the P status from a low level increased the root growth capacity in 2-0 seedlings and P fertilization of potted seedlings increased the dry weight/height ratio. Uptakes per seed bed ha of 236 kg N, 31 kg P, 81 kg K and 73 kg Ca by 2-0 seedlings were comparable with, or greater than, uptake rates of agricultural crops. Recoveries of 6-11% of P from fertilizer were recorded in the nursery.

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**34.** Driessche, R.v.-d. 1984b. Seedling spacing in the nursery in relation to growth, yield, and performance of stock. *Forestry-Chronicle* 60(6): 345-355.

**Keywords:** nursery operations  
growth  
tree morphology  
carbon allocation  
tree physiology  
tree/stand health

**Abstract:** In 3 experiments at nurseries in coastal British Columbia *Picea sitchensis*, *P. glauca*, *Pinus contorta* var. *latifolia*, *Thuja plicata* and coastal and interior varieties of *Pseudotsuga menziesii* were

sown in May 1979, 1980 or 1982 and grown at spacings ranging from 0.5 to 12 cm. A 1-cm increase in spacing increased seedling dry wt. by 0.5-1.5 g and root collar diam. by 0.2-0.25 mm up to a spacing of about 8-10 cm. Above this, response was less. Ht. of 2-yr-old seedlings was increased slightly or even decreased by wider spacing. Height : diameter ratios decreased sharply and shoot : root dry wt. decreased or remained unchanged with wider spacing. The number of needle primordia in 2-0 *P. menziesii* buds increased up to a spacing of 2 cm, and the number of 1st and 2nd order branches were also increased by wider spacing. Increases in root growth capacity were associated with wider spacing in *T. plicata* and *Picea sitchensis*. In a test of 3 types of precision seeders, none produced anything like accurate seed placement. Irregularity was increased by 10-20% non-viable seed and winter mortality. Increased spacing of 2-5 cm between seedlings was justified by the yield of acceptable seedlings only when the culling standard was increased to a root collar diam. of about 6 mm. Three yr after planting out the survival of *P. glauca* was increased 11% by wider spacing. After 2 yr *P. sitchensis* survival was increased 13% by wider spacing. Both species grown at wider spacing maintained a ht. and diam. advantage over those from close spacing.

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**35.** Driessche, R.v.-d. 1987. Importance of current photosynthate to new root growth in planted conifer seedlings. *Canadian-Journal-of-Forest-Research* 17(8): 776-782.

**Keywords:** nursery operations  
tree physiology  
photosynthesis  
tree morphology

**Abstract:** Reports are given of 6 experiments. Two-yr-old seedlings of Douglas fir and Sitka spruce, labelled with  $^{14}\text{C}$  in Oct. and kept outdoors, contained  $^{14}\text{C}$  in old roots but little in new roots when placed in a growth chamber in Jan. New roots were highly radioactive in seedlings labelled with  $^{14}\text{C}$  after 12 days' growth in Jan., indicating that current photosynthate was the primary C source for new roots. These results agreed with an experiment in which the number and wt. of new roots on 1+1 Douglas fir transplants were directly related to light intensity. Net photosynthesis ( $P_n$ ) of similar Douglas fir nursery stock after cold storage was inadequate to supply C for respiration and new root growth under 16-h photoperiods of 200  $\mu\text{E}/\text{m}^2\text{s}$ , although new root growth occurred. This suggested that reserves contributed to respiration. Douglas fir seedlings began transpiration immediately after planting in moist soil. Two-yr-old lodgepole pine seedlings grown outdoors over winter with root systems maintained at  $\leq 10$  degrees C produced more new roots in spring than seedlings grown outdoors without heated roots or in a greenhouse; no relations were observed between new root growth and  $P_n$ .

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**36.** Driessche, R.v.-d. 1988a. Nursery growth of conifer seedlings using fertilizers of different solubilities and application time, and their forest growth. *Canadian-Journal-of-Forest-Research* 18(2): 172-180.

**Keywords:** nursery operations

nursery fertilization  
growth  
carbon allocation  
tree physiology  
tree/stand health

**Abstract:** Beginning in May 1982, seedlings of Douglas fir and white spruce were grown for 2 yr in a bare-root nursery in southern British Columbia. Seedlings were treated with four types of commercial fertilizers (slow-release Osmocote, ammonium phosphate, ammonium sulphate and Hi-Sol, a soluble fertilizer with 20-20-20 NPK) at 2 different frequencies during both years to give total N applications of 0, 210 or 350 kg/ha. In addition, Douglas fir seedlings that had been grown for 2 yr without fertilizer were treated with the same amounts of fertilizer as a late season treatment during 1 Sep.-20 Oct. 1983. Ammonium fertilizers produced larger seedlings than Osmocote and Hi-Sol. Dry wt. increased with application rate, but frequency of application had only a small effect. Fertilizer increased the proportion of stem dry matter and decreased the proportion of needle and root dry matter. Dry wt. of 2+0 white spruce seedlings was correlated with soil pH, extractable NO<sub>3</sub> and available P measured in Sep. of the first growing season. Douglas fir seedlings were planted out in Mar. 1984. Late-season fertilized seedlings had greater N and P tissue concn. than seedlings fertilized during the growing season. Survival and growth rate after planting were also both greater in late-season fertilized seedlings. Results suggested that fertilizer composition was more important than fertilizer solubility for nursery growth.

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**37.** Driessche, R.v.-d. 1988b. Response of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) to some different fertilizers applied at planting. *New-Forests* 2(2): 89-110.

**Keywords:** nursery operations  
nursery fertilization  
fertilization  
growth  
tree/stand health  
tree physiology

**Abstract:** Four fertilizer experiments to assess type of fertilizer, dosage and timing, were conducted on eastern Vancouver Island, BC, Canada. Two-yr-old, bare root planting stock was used except in experiment 3, where container stock was compared with bare root stock. Little growth response was obtained after one year, but height growth responses of 12 to 31% were measured after 3 to 6 yr with fertilizers supplying 8.4 to 16.8 g N per tree. Growth responses were little affected by type of fertilizer and were primarily due to N, with release rate having no marked effect. The exception to this was triple superphosphate which did not increase growth but did increase survival. Survival was reduced by ammonium sulphate and to a lesser extent by Agriform (NPK). Container seedlings responded more to fertilization at planting than bare root seedlings. Seedling N, P and K concn. and contents declined following planting for 6 months and only started to recover after July. Application of fertilizer caused a small increase in seedling nutrient concn. regardless of date, but this had no detectable effect on dry weight measured 6 wk later.

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**38.** Driessche, R.v.-d. 1991b. Influence of container nursery regimes on drought resistance of seedlings following planting. II. Stomatal conductance, specific leaf area, and root growth capacity. *Canadian-Journal-of-Forest-Research* 21(5): 566-572.

**Keywords:** nursery operations  
tree/stand protection  
tree physiology  
tree/stand health

**Abstract:** Seedlings of Douglas fir (*Pseudotsuga menziesii*), lodgepole pine (*Pinus contorta*) and white spruce (*Picea glauca*) were grown in a container nursery from February to July 1988 and then exposed to three temperatures and three levels of drought stress applied factorially during mid-July to October 1988. Seedlings were retained in a shelter house until January 1989, when they were cold-stored until early May. Measurements of stomatal conductance (gs), transpiration (E), and specific leaf area (SLA) were made at the end of the treatment period in September 1988 and again after growth the following year at the end of June. Root growth capacity (RGC) was tested in early May 1989. Results were considered in conjunction with performance of other samples of the same plants that had been planted in sand beds in April 1989, where irrigation was regulated to provide three levels of moisture stress. Low temperature (13 degrees C) generally reduced gs and E, which were adjusted for xylem pressure potential, and SLA, in all species by the time nursery treatment was completed at the end of September. No effect of nursery temperature treatment on gs or E could be detected when new needles were measured in June and July (after 9 to 12 weeks of growth), but SLA of lodgepole pine increased with nursery temperature treatment, and SLA of white spruce decreased with treatment. RGC was higher for the 13 degrees C treatment than for the 16 and 20 degrees C treatments. Survival of outplanted seedlings was mainly inversely related to nursery temperature. Low nursery temperature reduced gs, E, and SLA and increased RGC. SLA of planted lodgepole pine increased with level of nursery drought treatment, and severe nursery drought increased gs under stress, when measured in June. No other effects of drought were detected, although drought treatment was effective in increasing survival of planted seedlings. It is suggested that other mechanisms, such as osmotic adjustment, were responsible for the results observed.

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**39.** Driessche, R.v.-d. 1992b. Changes in drought resistance and root growth capacity of container seedlings in response to nursery drought, nitrogen, and potassium treatments. *Canadian-Journal-of-Forest-Research* 22(5):740-749.

**Keywords:** nursery operations  
nursery fertilization  
tree/stand protection  
tree/stand health  
growth  
carbon allocation  
tree physiology

**Abstract:** Douglas fir (*Pseudotsuga menziesii*), lodgepole pine (*Pinus contorta*), and white spruce (*Picea glauca*) seedlings, each represented by two seed lots, were grown in Styroblock containers in a greenhouse and plastic shelter house from February 1989 to January 1990. The seedlings were exposed to two N treatments (20 and 200 mg/litre) and three K treatments (5, 25 and 100 mg/litre) arranged factorially within three drought treatments. After winter storage, seedlings from a complete set of treatments were planted into hygric, mesic and xeric sand beds during 12-14 March. Increasing nursery drought stress increased survival of Douglas fir and lodgepole pine after planting, and high N treatment level increased survival of lodgepole pine and white spruce. Under xeric conditions, combined nursery drought and high N treatments increased survival of lodgepole pine by 33%, indicating the importance of nursery cultural regime for stock quality. Increase in nursery drought stress did not decrease seedling size by much; increase in N increased seedling size one season after planting. A positive relation between shoot : root ratio and survival in lodgepole pine and white spruce indicated that increase in N increased both shoot growth and drought resistance over the N range investigated. Only Douglas fir showed an interaction between drought and N treatment and a small response in both survival and dry weight to K application. Root growth capacity, measured at the time of planting, showed an approximate doubling in all species due to high N treatment, and was also increased in white spruce by drought stress. Survival and root growth capacity were poorly correlated, but dry-weight growth in sand beds was well correlated with root growth capacity. Shoot dry weight and percentage N in shoots measured after nursery growth were correlated with root growth capacity. Manipulation of root growth capacity by changing nursery treatment was possible without altering resistance to drought stress after planting.

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**40.** Entry, J.A., K. Cromack, Jr., R.G. Kelsey and N.E. Martin. 1991. Response of Douglas-fir to infection by *Armillaria ostoyae* after thinning or thinning plus fertilization. *Phytopathology* 81(6): 682-689.

**Keywords:** thinning  
fertilization  
tree/stand protection  
growth  
tree morphology  
carbon allocation  
tree/stand health  
tree physiology

**Abstract:** Second-growth stands of Douglas-fir (*Pseudotsuga menziesii*) were thinned to a 5- x 5-m spacing (TT); additional plots were thinned and fertilized once with 360 kg of N (as urea)/ha (TF). An unthinned, unfertilized stand (UT) served as a control. Ten years after treatment, trees were inoculated with 2 isolates of *A. ostoyae*. Trees receiving the TF and TT treatments produced greater diameter growth, leaf area, and wood production/msuperscript 2 leaf area per year than did those under the UT treatment. Rates of infection by *A. ostoyae* were highest in trees that received the TF and lowest in trees that received the TT treatment. Concn of sugar, starch and cellulose in root bark tissue were highest in trees receiving the TF treatment and lowest in trees receiving TT treatment. Concn of lignin, phenolics and protein-precipitable tannins were highest in root bark from TT trees and lowest in root bark from TF trees. Biochemical parameters of root bark tissue were regressed with incidence of infection; coefficients of determination (rsuperscript 2) ranged from 0.07 (starch) to 0.57 (phenolic compounds).

Ratios of the energetic costs of phenolic and of lignin degradation to the energy available from sugars (Epd:Eas and Eld:Eas) were correlated with incidence of infection ( $r^2 = 0.77$  and  $0.70$ , respectively). It is concluded that thinning combined with fertilization may predispose *P. menziesii* trees to infection by *A. ostoyae* by lowering concn of defensive compounds in root bark and increasing the energy available to the fungus to degrade them.

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**41.** Gagnon, J., C.G. Langlois, D. Bouchard, F.I. Tacon and F. Le Tacon. 1995. Growth and ectomycorrhizal formation of container-grown Douglas-fir seedlings inoculated with *Laccaria bicolor* under four levels of nitrogen fertilization. *Canadian Journal of Forest Research* 25:1953-1961.

**Keywords:** nursery operations  
nursery fertilization  
growth  
carbon allocation  
tree physiology  
tree morphology  
mycorrhizal response  
soil properties

**Abstract:** Container-grown Douglas fir (*Pseudotsuga menziesii*) seedlings were inoculated at the time of sowing with a *Laccaria bicolor* mycelial suspension produced in a fermentor. They were grown in a peat moss-vermiculite substrate under four levels of N fertilization (7.2, 14.4, 21.6 and 28.7 mg/seedling per season (N1, N2, N3 and N4, respectively)) to determine the N level suitable for both ectomycorrhizal development and seedling growth. After 18 weeks in the greenhouse, seedlings inoculated with *L. bicolor* had 44%, 32%, 44% and 5% of their short roots mycorrhizal when fertilized with N1, N2, N3 and N4, respectively. Only when they were fertilized with N4 did the *L. bicolor* seedlings have significantly greater shoot height than the controls. For the other growth parameters, they were not significantly different from control seedlings for any of the N levels. After 18 weeks, regardless of the level of N, seedlings inoculated with *L. bicolor* had significantly lower N concentrations (%) and contents (mg/seedling) than the uninoculated ones. Consequently, for the same production of biomass, the mycorrhizal seedlings had taken up less N than the nonmycorrhizal ones. The efficiency of applied N, expressed in terms of produced biomass, decreased when the N fertilization increased; mycorrhizal and nonmycorrhizal seedlings did not tend to be different. The efficiency of the absorbed N also decrease with the level of applied N, but less rapidly, and tended to be greater for the mycorrhizal seedlings than for the nonmycorrhizal ones. Therefore, the mycorrhizal infection improved the utilization of the absorbed N. N3 was the best of the four N levels used, since it was the only one that maximized both the ectomycorrhizal formation and the growth of the seedlings. In other words, a total seedling N concentration of 1.6% and a substrate fertility of 52 p.p.m. N are appropriate to optimize both the ectomycorrhizal development and the growth of Douglas fir seedlings.

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42. Graff, J.E., Jr., R.K. Hermann and J.B. Zaerr. 1999a. Dry matter and nitrogen allocation in western redcedar, western hemlock, and Douglas fir seedlings grown in low- and high-N soils. *Annals-of-Forest-Science* 56(7): 529-538.

**Keywords:** nursery operations  
nursery fertilization  
growth  
tree physiology

**Abstract:** Seedlings of western red cedar (*Thuja plicata*), western hemlock (*Tsuga heterophylla*), and Douglas fir (*Pseudotsuga menziesii*) were transplanted into each of 48 pots with soils of low or high levels of available NO<sub>3</sub><sup>-</sup> (and total N) and assigned to one of four treatments: unamended control; amendment with 60 mg kg<sup>-1</sup> (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub>; amendment with 15 mg kg<sup>-1</sup> of the nitrification inhibitor dicyandiamide (DCD) or amendment with both (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> and DCD. Dry weight and N content increments of seedling tissues were determined after 8 weeks. Seedlings grown on the low-N soil accumulated 65 % of the dry matter and 40 % of the N accumulated by seedlings grown on the high-N soil. Retranslocation of N from year-old foliage and the stem/branch components of western red cedar and Douglas fir, but not western hemlock, was an important source of N for current-year foliage and roots of low-N-grown seedlings. Western hemlock achieved the greatest relative dry-matter increment ( $\text{Loge}(\text{DM}_{\text{final}}) - \text{Loge}(\text{DM}_{\text{initial}})$ ; RDMI) and relative N increment ( $\text{Loge}(\text{N}_{\text{final}}) - \text{Loge}(\text{N}_{\text{initial}})$ ; RNI) in each soil and accumulated 35 % more N from the low-N and 10 % more N from the high-N soils than the other species. The RDMI of western red cedar was intermediate between that of western hemlock and Douglas fir, whereas its RNI on each of the soils was lowest. The results suggest that western hemlock is more efficient than western red cedar or Douglas fir in acquiring inorganic N, especially from low-N soils.

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43. Graff, J.E., Jr., R.K. Hermann and J.B. Zaerr. 1999b. Ionic balance and organic acids in western redcedar, western hemlock, and Douglas-fir seedlings grown in low- and high-N soils. *Canadian-Journal-of-Forest-Research* 29(6): 669-678.

**Keywords:** fertilization  
tree physiology

**Abstract:** Seedlings of western redcedar (*Thuja plicata*), western hemlock (*Tsuga heterophylla*) and Douglas fir (*Pseudotsuga menziesii*) were transplanted into soils collected in early May 1987 from 2 sites with low (near Carson, Washington) and high (near the Oregon coast) levels of available NO<sub>3</sub><sup>-</sup> (and total N). Current-year foliage was sampled after 10 weeks to determine the effect of N availability on foliar cation-anion balance (C-A) and the concentrations of low molecular weight organic acids of the 3 species. Carboxylate concentrations were estimated by using the difference between sums of cations and anions (C-A): 750 mequiv/kg for *Thuja plicata*, 351 mequiv/kg for *Tsuga heterophylla* and 266 mequiv/kg for *P. menziesii*. Quinic acid was a primary constituent, accounting for 40% of the total for *Thuja plicata* and 75% for *Tsuga heterophylla* and *P. menziesii*. Oxalic acid was present in greatest concentration in the foliage of *Thuja plicata* (65 mequiv/kg) but was a minor constituent in both other species. The quantified acids accounted for only 15% of the C-A of *Thuja plicata* but >80% of the C-A of the other species. It is suggested that a considerable portion of the C-A balance not accounted for in *Thuja plicata* may be associated with the accumulation of CaCO<sub>3</sub> and that litterfall deposition of CaCO<sub>3</sub>



may lead to the consumption of H<sup>+</sup> ions and enrichment of exchangeable soil Ca in the rooting zone of long-lived Thuja plicata trees. No statistically significant differences between the soils were detected with regard to C-A or the concentration of organic acids.

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44. Green, R.N. and R.E. Carter. 1993. Boron and magnesium fertilization of a coastal Douglas-fir plantation. *Western-Journal-of-Applied-Forestry* 8(2): 48-53.

**Keywords:** fertilization  
growth  
tree/stand health  
tree physiology

**Abstract:** A study was made of the role of boron and magnesium nutrition in the occurrence of severe growth distortion symptoms in Douglas-fir (*Pseudotsuga menziesii*) in the Skwawka River valley of south coastal British Columbia. Four fertilizer treatments, including boron (2.25 kg/ha B), magnesium (42 kg/ha Mg), boron plus magnesium, and a control, were applied in conjunction with planting on a site believed to be deficient in these nutrients. After 5 growing seasons, only treatments containing boron (B and B + Mg) showed improved height growth compared to controls. The incidence of leader dieback, swollen leading shoots, and foliage distortion was significantly related to treatment, with virtually no occurrence in plots treated with boron. Seedling uptake of applied boron was high, with foliar concentrations of 45 p.p.m. found after the second growing season. Foliar B levels declined to 13-15 p.p.m. after 5 growing seasons. No significant increase in foliar magnesium levels was detected for either of the magnesium treatments. The reduction in the incidence of leader dieback, and shoot and foliar symptoms, in seedlings treated with B indicate that these symptoms were the result of boron deficiencies. This is the first study to verify boron deficiency in coastal Douglas fir through fertilizer trials.

[OSU Link](#)

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45. Haase, D.L. and R. Rose. 1994. Effects of soil water content and initial root volume on the nutrient status of 2+0 Douglas-fir seedlings. *New-Forests* 8(3): 265-277.

**Keywords:** nursery operations  
tree/stand protection  
tree physiology  
growth  
tree morphology

**Abstract:** Two-year-old bareroot Douglas fir (*Pseudotsuga menziesii*) seedlings from a NW Oregon provenance were graded on the basis of four root-volume categories - 5 to 8, 9 to 10, 11 to 13, and 14 to 20 cmsuperscript 3 - and transplanted into pots and subjected to one of four moisture-stress treatments (6, 12, 18, and 24% soil water content) for 16 weeks. Macronutrient concentrations and contents of both old (i.e. nursery-grown) and new (i.e. grown during moisture stress treatment) foliar tissue were determined. A reduction in soil water content resulted in high concn of phosphorus, potassium, and



particularly nitrogen in both old and new foliar tissue. This was attributed to reduced growth, translocation, metabolic activity, and nutrient requirement in response to moisture stress. Seedlings with relatively greater root volumes exhibited higher nutrient concn and contents, as well as increased growth. Thus, increased total root biomass per unit of soil area with increasing seedling root volume may have resulted in greater nutrient use, supply, uptake, and storage. It is suggested that relations between initial root volume and water stress can be applied to nursery cultural practices in order to increase seedling adaptation to a specific stress.

[OSU Link](#)

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**46.** Haase, D.L., J. Trobaugh and R. Rose. 1999. Douglas-fir container stock grown with fertilizer-amended media: some preliminary results. Rocky Mountain Research Station, USDA Forest Service National Proceedings: Forest and Conservation Nursery Associations 1999, 2000, and 2001. RMRS P-24. 31-32 pp.

**Keywords:** nursery operations  
nursery fertilization  
growth  
tree physiology  
tree/stand health

**Abstract:** This paper presents the initial results of a study conducted in a nursery in Oregon, USA, to quantify the response of container grown Douglas-fir (*Pseudotsuga menziesii*) seedlings to various fertilizer treatments (Simplot's 13-13-13 and 17-5-11, and Scotts Company's 18-5-12 and 15-9-10) in terms of height, stem diameter and foliar nutrient content.

**47.** Harrington, T.B., R.G. Wagner, S.R. Radosevich and J.D. Walstad. 1995. Interspecific competition and herbicide injury influence 10-year responses of coastal Douglas-fir and associated vegetation to release treatments. *Forest-Ecology-and-Management* 76(1/3): 55-67.

**Keywords:** release treatments  
chemical release  
manual release  
growth  
tree/stand health  
tree physiology  
stand conditions

**Abstract:** Responses of competing vegetation and planted Douglas fir (*Pseudotsuga menziesii* var. *menziesii*) were studied for 10 years after six herbicide and manual release treatments in the Washington and Oregon Coast Ranges. Studies were installed in six 2- or 3-yr-old plantations, with Douglas fir densities of 988 to 1482 plants/ha at time of planting and 721 to 1282/ha 2 to 3 years later. Research objectives were to quantify regional, long-term responses of vegetation (Douglas fir and non-coniferous species) to various levels of competition, light and soil water availability, and intensity versus importance of factors influencing Douglas fir growth. Three treatments reduced shrub cover relative to the untreated check: triclopyr in year 1, glyphosate in years 1-5, and repeated control (via several

herbicide applications) in years 1-10. Reductions in woody cover from glyphosate stimulated increases in herb cover in years 3 and 5, while repeated control reduced herb cover in years 1, 2 and 5. Through year 10, Douglas fir survival (86-99%) varied little among treatments. Visual symptoms of herbicide injury to Douglas fir from triclopyr (45% of trees) and glyphosate (17% of trees) were associated with 0.1-0.2 m reductions in first-year height. After adjusting for tree size, Douglas fir growth in stem basal area 2 years after triclopyr was less than that of the untreated check, suggesting prolonged effects of herbicide injury. Because it sustained low levels of interspecific competition, caused minimal tree injury, and prevented overtopping cover from red alder (*Alnus rubra*), repeated control was the only treatment in which Douglas fir size (9.8 m height and 21 cm basal diameter in year 10) significantly exceeded ( $P < 0.02$ ) that of the untreated check (7.8 m height and 12 cm diameter).

[OSU Link](#)

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**48.** Harrison, R.B., C.L. Henry and D.S. Xue. 1994b. Magnesium deficiency in Douglas-fir and grand fir growing on a sandy outwash soil amended with sewage sludge. *Water, Air, and Soil Pollution* 75(1/2): 37-50.

**Keywords:** fertilization  
tree/stand health  
tree physiology  
soil properties

**Abstract:** Soil and plant samples were collected from chlorotic plantations of grand fir (*Abies grandis*) and Douglas fir (*Pseudotsuga menziesii*) near Seattle, Washington state, USA, in winter 1989. The soils had been amended in 1981 with an average of 300 dry t/ha of municipal sewage sludge. The sludge amendment resulted in an N application rate of approximately 8000 kg/ha. Foliage analysis indicated that a severe Mg deficiency (0.25 g/kg in sludge-treated vs. 0.93 g/kg in untreated areas) might be the cause of chlorosis. No other nutrient showed concentrations in the deficient or toxic ranges. Trace metal levels in foliage were increased significantly for Ni, Cd and Cr at sludge-treated sites, but were not at toxic levels. Soil samples taken to a depth of 1.4 m indicated the potential for soil acidification (up to 0.9 pH unit) in soil surface horizons. In addition, exchangeable Ca, Mg and K may have been depleted in surface horizons. Exchangeable Al and Fe were greater in the surface of sludge-treated sites. These observations, and the loss of much of the nitrogen added during the sludge amendment, indicated that nitrification and cation leaching were the most likely mechanism for acidification and depletion of exchangeable cations. Fertilizing the plantation with MgSO<sub>4</sub> or dolomitic limestone was carried out in spring 1990. New foliage collected in June 1990 was non-chlorotic and significantly higher in Mg concentration than unfertilized foliage (1.1. vs. 0.7 g/kg, respectively). The results of this study indicate that it is important to assess the potential for initiating a nutrient deficiency due to secondary effects of sludge application in forest systems.

[OSU Link](#)

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**49.** Heilman, P. 1983. Effects of surface treatment and interplanting of shrub alder on rowth of Douglas-fir on coal spoils. *Journal-of-Environmental-Quality* 12(1): 109-113.

**Keywords:** planting operations  
site preparation  
mechanical preparation  
growth  
tree physiology  
soil properties  
tree/stand health

**Abstract:** Annual growth of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) planted on topsoiled spoils at a coal mine near Centralia, Wash., was monitored for the first 6 y after planting. Treatments were contour bedding, contour bedding plus interplanted Sitka alder (*Alnus sinuata* (Reg.) Rydb.), and unbedded control. The bedding significantly increased growth of Douglas-fir in all 5 y of the study. Total height growth after 5 y was 35% greater than control on the bedding only plots, and 43% greater on the bedding plus Sitka alder plots. Height growth of Douglas-fir in the mixed stand was significantly greater during the 2nd and 3rd y of the study, but after 5 yr, no significant difference was evident in total height between the mixed and pure Douglas-fir plots. Concentration of N in Douglas-fir foliage was significantly increased by bedding in the fifth but not in the fourth year. Interplanting with Sitka alder had no significant effect on N in Douglas-fir foliage. The top 0.3 m of soil in the ridged portion of the bedded area contained significantly less moisture over a summer than did the top 0.3 m of the unbedded soil. At deeper depths, however, soil moisture was not significantly affected by bedding. Wind damage caused by a severe storm that occurred after 5 y was very much greater on the unbedded plots (49% wind-thrown vs. 9 to 15% wind-thrown on the bedded plots) despite the smaller size of the trees on unbedded plots.

[OSU Link](#)

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50. Helgerson, O.T. 1990b. Response of underplanted Douglas-fir to herbicide injection of sclerophyll hardwoods in southwest Oregon. *Western-Journal-of-Applied-Forestry* 5(3): 86-89.

**Keywords:** nursery operations  
release treatments  
chemical release  
stand conditions  
tree physiology  
tree/stand health  
growth

**Abstract:** Low-value broadleaf sclerophyll forests in SW Oregon, typically composed of tanoak (*Lithocarpus densiflorus*), Pacific madrone (*Arbutus menziesii*) and chinkapin (*Castanopsis chrysophylla*), may be converted to commercially valuable Douglas fir (*Pseudotsuga menziesii*) by underplanting. Results are given of studies of container-grown plug and nursery-grown bareroot fir seedlings planted out in March 1983 on plots in which all broadleaf stems had been previously (September 1981) injected with triclopyr amine. Although 60% broadleaf cover was killed by injection, 7 years later ground cover was significantly greater on these treated plots because of sprouting. Seedlings planted beneath treated broadleaf trees experienced greater daytime, but less predawn, moisture stress; plugs survived better than bareroots; and survival of seedlings on treated plots was not significantly better until 2 years after

planting. Herbicide injection also resulted in increased height, diameter and volume growth rates of Douglas fir seedlings, and is recommended for the establishment of a conifer stand.

[OSU Link](#)

[Non-OSU Link](#)

**51.** Henry, C.L. 1987. Growth response, mortality, and foliar nitrogen concentrations of four tree species treated with pulp and paper and municipal sludges. *In The-forest-alternative-for-treatment-and-utilization-of-municipal-and-industrial-wastes*. Eds. Cole, D.W., C.L. Henry, and W.L. Nutter. University of Washington Press, Seattle, Washington, USA. pp. 258-265.

**Keywords:** nursery operations  
nursery fertilization  
soil properties  
growth  
tree/stand health  
tree physiology

**Abstract:** Four nursery beds at the University of Washington Charles Lathrop Pack Demonstration Forest were each divided into plots that received 8 sludge treatments before being planted with seedlings of Douglas fir, *Abies procera* or *Pinus monticola*, or cuttings of *Populus deltoides* X *P. trichocarpa*. Each sludge and the unamended soil were analysed for total solids, total C, P and K, total N and NH<sub>4</sub>-N. Ht. and diam. were measured after planting in April 1984 and again in Feb. 1985. N was determined in foliage sampled during Oct. (*Populus*) or Feb. (other species). Addition of pulp and paper sludge alone and combined with municipal sludge provided predictable growth responses when compared with the C : N ratio of each treatment. Av. response was positive when the C : N ratio was more favourable than that of untreated soil, but av. response was negative when soil was treated with primary pulp and paper sludge with a very high C : N ratio. Treatments that produced the greatest growth also increased seedling mortality.

[Non-OSU Link](#)

**52.** Hobbs, S.D. and K.A. Wearstler, Jr. 1985. Effects of cutting sclerophyll brush on sprout development and Douglas-fir growth. *Forest-Ecology-and-Management* 13(1/2): 69-81.

**Keywords:** release treatments  
manual release  
stand conditions  
tree physiology  
growth

**Abstract:** In SW Oregon, varying amount of brush were removed from a sclerophyll brushfield dominated by *Quercus chrysolepis* and *Arctostaphylos patula* with scattered *Pseudotsuga menziesii* saplings. Brush removal was accomplished by slashing (cut by chainsaw) near ground level at three intensities: (1) total removal, (2) partial removal, and (3) an untreated control. Sclerophyll brush species responded within 3 weeks of slashing by vigorous sprouting, which was greatest in total brush removal areas where 861 513 sprout stems/ha developed during the first year. Soil water potentials and

predawn xylem pressure potentials of Douglas fir were less negative in total removal areas than in partial removal and untreated control areas. Relative growth rates of Douglas fir saplings temporarily increased in total and partial brush removal areas, but were not significantly different from the untreated control 3 yr after treatment. Slashing of sclerophyll brush to release long-suppressed Douglas fir is not recommended because of rapid brush recovery by sprouting.

[OSU Link](#)

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**53.** Hopmans, P. and H.N. Chappell. 1994. Growth response of young, thinned Douglas-fir stands to nitrogen fertilizer in relation to soil properties and tree nutrition. *Canadian-Journal-of-Forest-Research* 24(8): 1684-1688.

**Keywords:** fertilization  
growth  
soil properties  
tree physiology

**Abstract:** Application of 224 kg N/ha to young, thinned stands of Douglas fir (*Pseudotsuga menziesii*) at 35 sites in W. Oregon and Washington significantly increased basal area and volume increment over 8 years following treatment. However, response varied considerably between sites, and relative volume increment exceeded 10% at only 19 of the 35 sites. Response to applied N was evaluated in relation to forest floor and soil variables as well as to levels of N in foliage. Relative responses in basal area and volume were significantly correlated with total N concentration and the C/N ratio of the soil. However, these relationships explained only part (18-22%) of the observed variation in response. In contrast, relative response was strongly correlated with the level of N in the foliage of non-fertilized trees at 11 sites, accounting for 94% of the variation between sites. It is suggested that foliar N could be used to predict growth responses to N fertilizers in young thinned Douglas fir stands.

[OSU Link](#)

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**54.** Jacobs, D.F., R. Rose and D.L. Haase. 2003a. Development of Douglas-fir seedling root architecture in response to localized nutrient supply. *Canadian-Journal-of-Forest-Research* 33(1): 118-125.

**Keywords:** nursery operations  
nursery fertilization  
tree morphology  
tree physiology  
growth

**Abstract:** Three months following sowing, Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) seedlings were transplanted into pots with controlled-release fertilizer (CRF) applied at rates of 0, 8, 16, and 24 g/2200 cm<sup>3</sup> soil as a single uniform layer beneath the root system. Seedlings were destructively harvested periodically, and roots were divided into vertical segments above (S1), within (S2), and below (S3) the fertilizer layer. Two months following transplant, the number of active root tips was positively correlated with CRF rate in S1 and negatively correlated with rate in S2 and S3. At 6 months, root

penetration into S3 was severely restricted at 16 and 24 g. This was attributed to detrimental changes in soil osmotic potential in S2. Fertilizer improved seedling growth at 8 g after 6 months compared with controls but was inhibitory at 24 g. Photochemical quantum yield was higher in all CRF treatments compared with controls 3 months following transplant, which corresponded with rapid initial CRF nutrient release. Despite improvements in nutrient release technology with CRF, high application rates may result in excessive concentrations of fertilizer nutrients in media, which can restrict root penetration and negatively affect seedling growth. Conservative application rates and improvements in CRF technology will help reduce the potential for adverse effects on seedling development.

[OSU Link](#)

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**55.** Jacobs, D.F., R. Rose, D.L. Haase and P.D. Morgan. 2003b. Influence of nursery soil amendments on water relations, root architectural development, and field performance of Douglas-fir transplants. *New-Forests* 26(3): 263-277.

**Keywords:** nursery operations  
fertilization  
tree physiology  
tree morphology  
growth  
carbon allocation  
soil properties  
tree/stand health

**Abstract:** This experiment evaluated the influence of manure, peat, and vermiculite incorporated at low and high rates (0.0118 and 0.0236 m<sup>3</sup>/m<sup>2</sup>) and under two soil moisture regimes on Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) seedling (1+0 for 1+1) xylem water potential (Phi xylem), whole-plant growth, root architectural development, and subsequent field performance under fertilized and non-fertilized conditions. Trends in soil moisture retention were observed (high manure > high peat > control) but there were no differences in Phi xylem. Root length in the wetter soil moisture experiment was initially (three months) greatest for seedlings in high vermiculite and least in high manure but there were no differences among treatments at lifting (eight months). Mean height was greatest for seedlings grown in vermiculite and peat (wetter nursery experiment) after two field seasons. Field fertilization (35 g/seedling) with controlled-release fertilizer in the planting hole stimulated height growth initially, but decreased height and diameter growth during the second growing season. Dramatic improvements associated with the use of nursery soil amendments were not realized, but the failure to identify negative effects, a potential reduction in disease incidence, and improvement of nursery soil physical and chemical properties may justify their use.

[OSU Link](#)

[Non-OSU Link](#)

**56.** Jermstad, K.D., D.L. Bassoni, N.C. Wheeler, T.S. Anekonda, S.N. Aitken, W.T. Adams and D.B. Neale. 2001b. Mapping of quantitative trait loci controlling adaptive traits in coastal Douglas-fir. II. Spring and fall cold-hardiness. *Theoretical-and-Applied-Genetics* 102(8): 1152-1158.

**Keywords:** genetic tree improvement  
tree/stand protection  
genetic relationships  
tree physiology  
tree phenology

**Abstract:** Quantitative trait loci (QTLs) affecting fall and spring cold hardiness (cold resistance) were identified in a three-generation outbred pedigree of coastal Douglas-fir (*Pseudotsuga menziesii* var. *menziesii* [*Pseudotsuga menziesii*]) in a field experiment conducted in Washington and Oregon, USA, during 1996-97. Eleven QTLs controlling fall cold hardiness were detected on four linkage groups, and 15 QTLs controlling spring cold hardiness were detected on four linkage groups. Only one linkage group contained QTLs for both spring and fall cold hardiness, and these QTLs tended to map in close proximity to one another. Several QTLs were associated with hardiness in all three shoot tissues assayed in the spring, supporting previous reports that there is synchronization of plant tissues during de-acclimatization. For fall cold hardiness, co-location of QTLs was not observed for the different tissues assayed, which was consistent with previous reports of less synchronization of hardening in the fall. In several cases, QTLs for spring or fall cold hardiness mapped to the same location as QTLs controlling spring bud flush. QTL estimations, relative magnitudes of heritabilities, and genetic correlations based on clonal data in this single full-sib family, supports conclusions about the genetic control and relationships among cold hardiness traits observed in population samples of Douglas-fir in previous studies.

[OSU Link](#)

[Non-OSU Link](#)

57. Karl, M.G. and P.S. Doescher. 1993. Regulating competition on conifer plantations with prescribed cattle grazing. *Forest-Science* 39(3): 405-418.

**Keywords:** release treatments  
manual release  
stand conditions  
tree physiology  
soil properties

**Abstract:** On conifer plantations, competitive understorey vegetation often retards growth and establishment of tree seedlings. Livestock grazing is one method of controlling the understorey vegetation and increasing the availability of site resources to tree seedlings. It was hypothesized that prescribed cattle grazing ameliorates water stress of young tree seedlings by reducing root growth of competing understorey species. On a Douglas-fir (*Pseudotsuga menziesii*) and ponderosa pine (*Pinus ponderosa*) plantation in SW Oregon planted in 1986, seedling water stress was evaluated using the pressure chamber technique and gravimetric soil water determinations in 1986-89. Root growth of orchardgrass (*Dactylis glomerata*), the major understorey competing species, was quantified in 1988 and 1989 using the root periscope/mini-rhizotron technique. Seedling water stress levels during spring and summer were similar in cattle-grazed areas and ungrazed areas in 1986 to 1988, but in summer 1989, water stress was reduced significantly in the grazed area. Soil water content was higher in the grazed area in 1989, especially at the 10-20 cm soil depth. End of season (July) orchardgrass root growth in grazed plots was 18% less in 1988 and 15% less in 1989 than root growth in ungrazed plots. It is concluded that repeated cattle grazing of orchardgrass reduced transpirational surface area and root

growth sufficiently to increase soil water availability to tree seedlings. Thus, prescribed cattle grazing on conifer plantations can enhance seedling physiological status by acting as a regulator of above- and belowground competition.

[OSU Link](#)

[Non-OSU Link](#)

58. Kelsey, R.G., G. Joseph and E.A. Gerson. 1998. Ethanol synthesis, nitrogen, carbohydrates, and growth in tissues from nitrogen fertilized *Pseudotsuga menziesii* (Mirb.) Franco and *Pinus ponderosa* Dougl. ex Laws. seedlings. *Trees: Structure and Function* 13(2): 103-111.

**Keywords:** nursery operations  
nursery fertilization  
tree physiology

**Abstract:** Seedlings of Douglas fir (*Pseudotsuga menziesii*) and ponderosa pine (*Pinus ponderosa*) were grown in a controlled environment and given nutrient solutions containing 0 (-N) or 150 ppm nitrogen (+N). Seedling growth, and the concentrations of N and carbohydrates in their tissues were affected by the treatments. Metabolically active tissues, such as roots, incubated with a limited supply of O<sub>2</sub> became hypoxic faster and synthesized more ethanol than less active tissues, such as needles. All tissues that were incubated for 4 h in N<sub>2</sub> synthesized ethanol. Needles incubated in N<sub>2</sub> and light had much lower quantities of ethanol than needles in N<sub>2</sub> and dark, suggesting that O<sub>2</sub> from photosynthesis limited internal anoxia. Most tissues from +N seedlings synthesized greater quantities of ethanol in N<sub>2</sub> anoxia than tissues from -N seedlings, probably because they were able to produce more enzymes with a greater availability of N. However, this increase in ethanol synthesis between N treatments was most pronounced in the phloem. Ethanol and soluble sugar concentrations were negatively related in needles and positively related in roots of +N seedlings, but not -N seedlings. Starch concentrations had no effect on the amount of ethanol produced by any tissue. Regardless of N treatments, all tissues from ponderosa pine produced more N<sub>2</sub>-induced ethanol than Douglas-fir, in part because its tissues contained different concentrations of soluble sugars and N as a consequence of phenological differences between the species. However, ponderosa pine tissues may also maintain greater quantities of anaerobic enzymes, or their isoenzymes than Douglas fir.

[OSU Link](#)

[Non-OSU Link](#)

59. Khan, S.R., R. Rose, D.L. Haase and T.E. Sabin. 1996. Soil water stress: its effects on phenology, physiology, and morphology of containerized Douglas-fir seedlings. *New-Forests* 12(1): 19-39.

**Keywords:** nursery operations  
growth  
tree physiology  
tree phenology

**Abstract:** Containerized 3-month-old Douglas fir (*Pseudotsuga menziesii*) seedlings were subjected to six moisture-stress treatment (ranging from 7 to 65% soil water content by volume) for 12 weeks. At the end of this period, there were significant differences in phenological, physiological, and morphological



responses among the seedlings in the various moisture-stress treatments. In general, seedlings grown under very high or very low soil moisture conditions were adversely affected, while those grown under moderate conditions (29 to 53% water content) exhibited optimum growth, bud development, and nutrient and starch reserves. The use of vector analysis was found to be helpful in data interpretation. The results indicate the importance of closely monitoring nursery moisture regimes in order to achieve the best seedling quality.

[OSU Link](#)

[Non-OSU Link](#)

**60.** Kimball, B.A., G.R. Johnson, D.L. Nolte and D.L. Griffin. 1999. An examination of the genetic control of Douglas-fir vascular tissue phytochemicals: implications for black bear foraging. *Forest-Ecology-and-Management* 123(2/3): 245-251.

**Keywords:** genetic tree improvement  
tree/stand protection  
growth  
tree physiology  
genetic relationships

**Abstract:** Silvicultural practices can influence black bear (*Ursus americanus*) foraging preferences for Douglas fir (*Pseudotsuga menziesii*) cambial-zone vascular tissues, but little is known about the role of genetics. To study the impact of genetic selection, vascular tissue samples were collected from Douglas fir trees in 6 half-sib families from 5 different sites in north central Oregon. Four replications of 3-tree non-contiguous plots were sampled at each site to examine inter-and intra-site variation. Tree growth was measured as tree diameter at breast height, and the absolute concentrations of 26 different terpenoids were determined by gas chromatography/flame ionization detection from ethyl acetate extracts. The simple carbohydrates fructose, glucose, and sucrose, and the phenolic glycoside coniferin were quantified using anion-exchange chromatography with pulsed amperometric detection. Cluster analysis was used to reduce the number of variables used in analyses of variance. Results for the families studied here indicate that tree growth and some terpenoids were under some level of genetic control. Furthermore, allocation of constitutive terpenoids in vascular tissues was not at the expense of tree growth. The sugars present in vascular tissue were affected by environment (site) and genetics (family) and their interaction.

[OSU Link](#)

[Non-OSU Link](#)

**61.** Kimball, B.A., D.L. Nolte, D.L. Griffin, S.M. Dutton and S. Ferguson. 1998a. Impacts of live canopy pruning on the chemical constituents of Douglas-fir vascular tissues: implications for black bear tree selection. *Forest-Ecology-and-Management* 109(1/3): 51-56.

**Keywords:** pruning  
tree/stand protection  
growth  
tree physiology  
tree/stand health

**Abstract:** The impact of live canopy pruning (removal of all live and dead whorls between the ground and 5 m height, resulting in removal of ~40% of the live canopy) on the carbohydrate and terpene content of vascular tissue was investigated in the lower bole of Douglas fir (*Pseudotsuga menziesii*) on 4 sites in NW Oregon. Cambial zone vascular tissue samples were collected from pruned and unpruned trees in the lower bole and within the live canopy. Current year's radial growth was estimated from the mass of vascular tissue removed from the 800 cm<sup>2</sup> area sampled from each tree. Chemical analyses were conducted to determine the concentration of carbohydrates and terpenes in the samples. Results indicated that 2 yr following treatment, pruning resulted in reduced growth and decreased carbohydrate content of the vascular tissue. Pruning had no effect on the terpene concentration of the vascular tissue. The impact of pruning on the foraging selection of black bears (*Ursus americanus*) was evaluated by surveying bear damaged trees in a 50 acre stand of pruned and unpruned timber. Odds ratios indicate that black bears were 4 times more likely to forage unpruned than pruned Douglas fir. Tree selection may be explained in part by the higher availability of carbohydrates in the unpruned tree with respect to the pruned tree.

[OSU Link](#)

[Non-OSU Link](#)

62. Kimball, B.A., E.C. Turnblom, D.L. Nolte, D.L. Griffin and R.M. Engeman. 1998b. Effects of thinning and nitrogen fertilization on sugars and terpenes in Douglas-fir vascular tissues: implications for black bear foraging. *Forest-Science* 44(4): 599-602.

**Keywords:** fertilization  
thinning  
tree/stand protection  
tree physiology  
tree/stand health

Abstract: Analyses of vascular tissue samples from Douglas fir (*Pseudotsuga menziesii*) trees collected in test plots in W. Washington and NW Oregon, USA, showed that both thinning and N fertilizer application caused the sugar concentration of vascular tissues in the lower bole to increase. However, these treatments had no effect on the concentrations of hydrocarbon monoterpenes, oxygenated monoterpenes or sesquiterpenes. These results may explain the observations that black bears (*Ursus americanus*) prefer to forage in thinned and fertilized stands, as the bears maximize sugar intake and minimize terpene intake while foraging.

[OSU Link](#)

[Non-OSU Link](#)

63. Lavender, D.P. and S.G. Stafford. 1985. Douglas-fir seedlings: some factors affecting chilling requirement, bud activity, and new foliage production. *Canadian-Journal-of-Forest-Research* 15(2): 309-312.

**Keywords:** nursery operations  
tree/stand health  
tree physiology  
tree phenology

**Abstract:** Potted 2-yr-old seedlings were exposed to a range of natural and artificial environments at the Forest Research Laboratory, Oregon State University during the autumn and winter before a 9-wk period in an environment designed to permit active shoot growth. Seedling response demonstrated (i) that exposure to a period of short (9 h), mild (20 degrees C) days prepared seedlings for the beneficial effects of subsequent chilling (4.4 degrees C) temperatures and (ii) that the physiology of dormancy of Douglas-fir seedlings may be adversely affected by environments that differ markedly from those prevailing in the Pacific Northwest during the autumn.

[OSU Link](#)

[Non-OSU Link](#)

**64.** Lavender, D.P. and R.B. Walker. 1981. Nitrogen and related elements in nutrition of forest trees. In Proceedings: Forest Fertilization Conference, University of Washington, Seattle, Washington, USA. Eds. S.P. Gessel, R.M. Kenady and W.A. Atkinson. pp. 15-22.

**Keywords:** fertilization  
tree physiology  
soil properties  
mycorrhizal response

**Abstract:** This paper discusses the principal inorganic ions used by forest trees and their respective roles in tree physiology, their common range of concentration in coniferous foliage, and the general symptoms associated with their deficiency. The factors governing effective concentrations of each ion at an active metabolic site are redistribution or internal nutrient cycling, nutrient uptake, and soil status (temperature, moisture, and concentration of each nutrient). Also described are endogenous patterns of nutrient storage and translocation, and the possible effects of fertilizers upon them and upon the mechanisms of ion uptake, especially the effect of pH change associated with urea applications upon the mycorrhizal complement of western hemlock (*Tsuga heterophylla*).

[OSU Link](#)

[Non-OSU Link](#)

**65.** Litvak, M.E., J.V.H. Constable and R.K. Monson. 2002. Supply and demand processes as controls over needle monoterpene synthesis and concentration in Douglas fir [*Pseudotsuga menziesii* (Mirb.) Franco]. *Oecologia* 132(3): 382-391.

**Keywords:** nursery operations  
nursery fertilization  
tree/stand protection  
tree/stand health  
tree physiology

**Abstract:** We measured the relative control that resource availability (as a supply-side control) and wounding (as a demand-side control) exert on patterns of monoterpene synthesis and concentration in Douglas fir [*Pseudotsuga menziesii* (Mirb.) Franco] needles. While supply-side controls should alter monoterpene production due to changes in the availability of substrate (carbohydrates), demand-side controls alter the need for a defensive product. We examined these relationships by measuring

constitutive (performed) and wound-induced rates of monoterpene synthesis and pool sizes in trees grown under ambient and elevated (ambient +200 micro mol mol<sup>-1</sup>) CO<sub>2</sub>, ambient and elevated (ambient +4 degrees C) temperature, and in trees grown under four levels of nitrogen fertilization (0, 50, 100 and 200 micro g g<sup>-1</sup> N by weight). Monoterpene pool size decreased at elevated CO<sub>2</sub>, increased at elevated temperature and did not change in response to nitrogen fertilization. Overall, we did not find that foliar nitrogen, carbon balance, or rate of monoterpene synthesis alone were consistent predictors of monoterpene concentration in current-year Douglas fir needles. In addition, despite a wound-induced decrease in monoterpene pool size, we found no evidence for induction of monoterpene synthesis in response to wounding. The influence of either resource availability or wounding on rates of monoterpene synthesis or accumulation cannot be explained by traditional supply-side or demand-side controls. We conclude that monoterpene synthesis in first-year Douglas fir needles is controlled by fairly conservative genetic mechanisms and is influenced more by past selection than by current resource state.

[OSU Link](#)

[Non-OSU Link](#)

**66.** Livingston, N.J. and T.A. Black. 1987a. Stomatal characteristics and transpiration of three species of conifer seedlings planted on a high elevation south-facing clear-cut. *Canadian-Journal-of-Forest-Research* 17(10): 1273-1282.

**Keywords:** planting operations  
tree physiology

**Abstract:** One-yr-old containerized seedlings of Douglas fir, western hemlock and *Abies amabilis* were planted in spring 1981-82 with various shade and irrigation treatments on a 30 degrees S.-facing slope at 1150 m alt. on Mt. Arrowsmith, Vancouver Island, British Columbia. Stomatal responses to environmental and physiological variables were measured for 2 yr. Responses of stomatal conductance to global solar irradiance, air temp., changes in turgor and soil water potentials, and changes in vapour pressure deficit did not differ between years or between planting dates for any species. A simple multiplicative boundary-line model was developed to describe the variability in stomatal conductance and to estimate daily seedling transpiration.

[OSU Link](#)

[Non-OSU Link](#)

**67.** Livingston, N.J. and T.A. Black. 1987b. Water stress and survival of three species of conifer seedlings planted on a high elevation south-facing clear-cut. *Canadian-Journal-of-Forest-Research* 17(9): 1115-1123.

**Keywords:** planting operations  
tree/stand protection  
tree physiology  
tree/stand health

**Abstract:** Container-grown seedlings (1+0) of Douglas fir, western hemlock and *Abies amabilis* were planted in spring 1981 and 1982 at 1150 m alt. on a 30 degrees S.-facing slope

on Mt. Arrowsmith, Vancouver Island, British Columbia. Treatments at planting included inclining seedlings to the SW (thus shading the root collar with the foliage) and provision of shade cards and/or irrigation. Control seedlings received no treatment. Seasonal and diurnal courses of twig xylem water potential, turgor potential and osmotic potential were measured and the relation between transpiration and soil water potential was determined. Seedling survival was recorded in April 1982-84. Douglas fir seedlings showed a high degree of drought tolerance by considerable osmotic adjustment that enabled seedlings to maintain turgor throughout the growing season. Douglas fir seedlings thus survived severe drought and maintained daily transpiration rates that were never less than 50% of those of irrigated seedlings. Transpiration rates were reduced, however, on days of high vapour pressure deficits because of stomatal closure. Western hemlock and, especially, *A. amabilis* lacked both stress avoidance and stress tolerance mechanisms and consequently suffered high mortality. In April 1984, untreated Douglas fir seedlings had 72-82% survival, while treated seedlings had 81-95% survival. Shade cards and/or irrigation increased survival of western hemlock and *A. amabilis*, but not to the rates shown by Douglas fir.

[OSU Link](#)

[Non-OSU Link](#)

**68.** Lopushinsky, W. 1986. Effect of jellyrolling and acclimatization on survival and height growth of conifer seedlings. Pacific-Northwest-Research-Station,-USDA-Forest-Service Research-Note PNW-RN-438. 14 p.

**Keywords:** planting operations  
growth  
tree/stand health  
tree physiology

**Abstract:** Jellyrolling is a preplanting treatment that involves dipping roots of seedlings in a vermiculite/water slurry and wrapping the roots in wet burlap to form a roll. Studies were made at 14 sites in Oregon and Washington during 1984 using bare root seedlings of *Pinus ponderosa*, *P. contorta* or *Pseudotsuga menziesii*. Results showed that there was no advantage in survival, ht. growth or moisture stress from jellyrolling or acclimatizing (storage in a tent or shed at ambient temp. for 24 h before planting) seedlings rather than dipping roots in a peat moss/water slurry at the planting site.

[OSU Link](#)

[Non-OSU Link](#)

**69.** Lopushinsky, W. and T.A. Max. 1990. Effect of soil temperature on root and shoot growth and on budburst timing in conifer seedling transplants. *New-Forests* 4(2): 107-124.

**Keywords:** planting operations  
tree morphology  
tree phenology  
tree physiology

**Abstract:** Results are presented of studies of tree seedling morphological responses to a wide range (0-30 degrees C) of soil temperatures and the effects of soil temperature on needle water potential and

stomatal conductance in ponderosa pine (*P. ponderosa*). Bare-root 2-year-old seedlings from high-altitude seed sources in the Cascade Mountains (Washington and Oregon states) were used for the morphological study. Root growth in Douglas fir (*Pseudotsuga menziesii*), Pacific silver fir (*Abies amabilis*), noble fir (*Abies procera*), lodgepole pine (*Pinus contorta*) and ponderosa pine began when soil temperature exceeded 5 degrees C. Root growth increased rapidly after 10 degrees C and attained maximum values at 20 degrees C. At 30 degrees C, no root growth occurred in the firs; in the pines, root growth was 30 to 39% of maximum. Maximum shoot growth also occurred at 20 degrees C. In ponderosa pine, height growth of seedlings from a high-altitude source was unaffected by cold soil, but in low-altitude seedlings it was reduced. Budburst in Douglas fir and the pines was delayed up to 11 days by cold soil, whereas in silver fir and noble fir, it was only slightly delayed. Prior to new root growth in ponderosa pine, xylem pressure potentials and stomatal conductances during the afternoon indicated reduced stomatal opening at all soil temperatures, whereas 23 days later, stomata were open to a greater degree when temperatures exceeded 10 degrees C. Implications of these results are briefly discussed: although root growth was initiated at soil temperatures of 5 degrees C, this does not imply that seedlings should not be transplanted until soils reach that temperature.

[OSU Link](#)

[Non-OSU Link](#)

70. Lu, S., K.G. Mattson, J.B. Zaerr and J.D. Marshall. 1998. Root respiration of Douglas-fir seedlings: effects of N concentration. *Soil-Biology-and-Biochemistry* 30(3): 331-336.

**Keywords:** nursery operations  
nursery fertilization  
growth  
carbon allocation  
tree morphology  
tree physiology  
mycorrhizal response

**Abstract:** Six-month-old Douglas-fir (*Pseudotsuga menziesii*) seedlings were grown at three N concentrations and with controlled root temperatures in Oregon, USA. Measurements of root respiration were conducted on undisturbed root systems by passing humidified air with 1000 micro l/litre CO<sub>2</sub> through root boxes onto an infrared gas analyser. The effects of N on soil respiration were sought by examining total root respiration rate per seedling, specific root respiration rate/g root dry wt, and root dry wt after N fertilization. Total respiration rates of seedlings grown at 50 mg N/litre concentration were significantly higher than those grown at 10 or 200 mg N/litre. Seedlings grown at N concentration of 200 mg/litre had significantly smaller roots than those grown at the two lower N concentrations. The specific respiration rate increased as N concentration was increased from 10 to 50 mg N/litre, but remained constant as N was further increased from 50 to 200 mg/litre. The increase of total respiration rate with the increase in N concentration from 10 to 50 mg/litre was attributed to the increase in specific respiration, whereas the subsequent decrease in total respiration with the increase in N concentration from 50 to 200 mg/litre was attributed to the decrease in root dry wt. The depression of soil respiration after the addition of N fertilizers to relatively fertile soil may be explained by reduced root and mycorrhizal mycelial growth.

[OSU Link](#)

[Non-OSU Link](#)

71. Manter, D.K. and K.L. Kavanagh. 2003. Stomatal regulation in Douglas fir following a fungal-mediated chronic reduction in leaf area. *Trees: Structure and Function* 17(6): 485-491.

**Keywords:** tree/stand protection  
tree physiology  
tree/stand health

**Abstract:** Pathogens can cause chronic premature needle abscission in coniferous species. To assess the potential impacts on tree productivity, stomatal regulation was investigated in Douglas fir with chronic stomatal occlusion and defoliation from varying levels of the Swiss needle cast (SNC) fungus, *Phaeocryptopus gaeumannii*. Levels of SNC disease and subsequent defoliation were manipulated by choosing six sites with varying levels of disease and by foliar applications of fungicides on six trees per site. Diurnal measurements of leaf water potential ( $\Psi$  leaf), stomatal conductance ( $g_s$ ) and vapor pressure deficit ( $D$ ) were made on six fungicide treated and six control trees per site. In addition, leaf specific hydraulic conductance was calculated on a single branch ( $KL_B$ ) from three trees per treatment per site. Stomatal conductance at  $D=1$  kPa ( $g_{sref}$ ) was negatively correlated with fungal colonization (number of fruiting bodies present in needle stomata) and positively correlated with  $KL_B$ . Despite reduced needle retention in diseased trees,  $KL$  declined due to a reduction in sapwood area and permeability (i.e., increasing presence of latewood in functional sapwood). In general, stomatal sensitivity to  $D$  for all foliage was consistent with stomatal regulation based on a simple hydraulic model [ $g_s=KL(\Psi_{soil}-\Psi_{leaf})/D$ ], which assumes strict stomatal regulation of  $\Psi$  leaf. However, when fungal presence reduced maximum  $g_s$  below the potential maximum supported by hydraulic architecture, stomatal sensitivity was lower than expected based on the theoretical relationship:  $d g_s/d \ln D=0.6 g_{sref}$ . The results indicate that losses in productivity associated with physical blockage of stomata and defoliation are compounded by additional losses in  $KL$  and a reduction in  $g_s$  in remaining functional stomata.

[OSU Link](#)

[Non-OSU Link](#)

72. Margolis, H.A. and R.H. Waring. 1986a. Carbon and nitrogen allocation patterns of Douglas-fir seedlings fertilized with nitrogen in autumn. I. Overwinter metabolism. *Canadian-Journal-of-Forest-Research* 16(5): 897-902.

**Keywords:** nursery operations  
nursery fertilization  
tree physiology

**Abstract:** Dormant Douglas fir seedlings (2+0) in a western Oregon nursery were fertilized with ammonium nitrate in Oct. 1983 and harvested for biochemical analyses before fertilization and in Nov. 1983 and Feb. and Mar. 1984. Free amino acid (FAA) concn. and total N in the needles of fertilized seedlings showed a large increase 1 month after fertilization. FAA concn. of fertilized seedlings decreased in needles during winter, but remained stable in stems and fine roots. Just before budbreak in mid-Mar., FAA concn. increased significantly in needles and stems. Total N increased 1 month after fertilization, remained stable during winter and tended to decrease just before budbreak. Starch and total nonstructural carbohydrate concn. of needles and stems were lower in fertilized than in unfertilized seedlings just before budbreak. When data from all harvests were combined, sugar concn. of fine roots were lower in fertilized seedlings. The depletion of carbohydrate reserves following

N fertilization probably reflected increased maintenance respiration which required synthesis of additional enzymes.

[OSU Link](#)

[Non-OSU Link](#)

**73.** Margolis, H.A. and R.H. Waring. 1986b. Carbon and nitrogen allocation patterns of Douglas-fir seedlings fertilized with nitrogen in autumn. II. Field performance. *Canadian-Journal-of-Forest-Research* 16(5): 903-909.

**Keywords:** nursery operations  
nursery fertilization  
tree phenology  
growth  
tree physiology

**Abstract:** Douglas fir seedlings (2+0), unfertilized or fertilized with ammonium nitrate in Oct. 1983, were planted out in Feb. 1984 near Corvallis, Oregon. Rye grass was grown on half the plots to induce water stress during the typical summer drought. Sucrose was applied to soil around each seedling to stimulate microbial growth and thus to immobilize nitrogen in the microbial biomass and create nitrogen stress in Douglas fir. Fertilized seedlings had earlier budbreak, produced more shoot growth and had higher relative growth rates, net assimilation rates and leaf area ratios than unfertilized seedlings. Grass significantly increased predawn moisture stress in both fertilized and unfertilized seedlings by early Aug. By 3 Sep., unfertilized seedlings growing with grass were significantly more stressed than other seedlings. Fertilizer did not have a significant effect on concn. of free amino acids and total N at the end of the growing season, but grass competition affected both N and carbohydrate chemistry.

[OSU Link](#)

[Non-OSU Link](#)

**74.** McClain, K.M. and D.P. Lavender. 1988. Tissue water relations and survival of conditioned conifer seedlings during drought stress. *In* Proceedings: 10th North American Forest Biology Workshop, 'Physiology and genetics of reforestation', University of British Columbia, Vancouver, British Columbia, July 10-22, 1988. Eds. J. Worrall, J. Loo-Dinkins and D.P. Lester. pp. 177-185.

**Keywords:** nursery operations  
tree/stand protection  
tree physiology  
tree/stand health

**Abstract:** Jack pine (*Pinus banksiana*) and Douglas fir (*Pseudotsuga menziesii*) 23-week-old seedlings were subjected to an 8-week drought stress period on two soil types (sandy clay loam and loamy sand) in protected cold frames in a nursery in Oregon in July-August 1984. Before transplanting, treatments consisting of daily or weekly irrigations, combined with 0 or 100 p.p.m. KCl, were applied to the seedlings for 6 weeks. The results showed that weekly irrigated (stress conditioned) seedlings maintained higher water potentials than daily irrigated (non-stress conditioned) seedlings. Decreases in water potential were more rapid for seedlings grown on sand than for seedlings grown on loam. By the



end of the assessment period, relative water contents of Douglas fir on sand and loam were 88.3% and 91.5%, respectively, and 72.7% and 81.8%, respectively, for jack pine. Turgor pressures were maintained at higher levels in Douglas fir than in jack pine on both soil types. On sand, mortality in both species was dependent on conditioning treatment, indicating that stress conditioning enhanced seedling drought resistance during a period of rapidly increasing soil water deficit. KCl treatment was not implicated in response to drought, but increased mortality of jack pine on sandy clay loam.

#### [Non-OSU Link](#)

75. McKay, H.M. 1994. Frost hardiness and cold-storage tolerance of the root system of *Picea sitchensis*, *Pseudotsuga menziesii*, *Larix kaempferi* and *Pinus sylvestris* bare-root seedlings. *Scandinavian-Journal-of-Forest-Research* 9(3): 203-213.

**Keywords:** nursery operations  
tree/stand protection  
tree physiology  
tree/stand health

**Abstract:** During the winter of 1990-91, fine roots of 2-year-old, undercut and wrenched *Pseudotsuga menziesii*, *Larix kaempferi* [*L. leptolepis*], *Pinus sylvestris*, and *Picea sitchensis* (Alaskan, Queen Charlotte Islands and Oregon provenances) were tested using electrolyte leakage for frost hardiness and tolerance to storage at +1 degrees C for 30 and 90 days as excised roots. *Pseudotsuga menziesii* and *Pinus sylvestris* showed only minor changes in root frost hardiness with a maximum of -4 degrees C and -7 degrees C respectively. *Larix leptolepis* and *Picea sitchensis* developed much greater root frost hardiness; *L. leptolepis* had a maximum hardiness of -12 degrees C while *Picea sitchensis* (Queen Charlotte Islands) reached -13 degrees C during the winter. The root frost hardiness of *Picea sitchensis* increased with the provenance's latitude. There were clear species and provenance differences in the level of long-term cold-storage tolerance attained, increasing in the order *Pseudotsuga menziesii*, *Pinus sylvestris* and *Picea sitchensis* (Oregon), *L. leptolepis*, *Picea sitchensis* (Queen Charlotte Islands), and *Picea sitchensis* (Alaskan). In spite of highly significant correlations between root electrolyte leakage after cold-storage and frosting tests, root frost hardiness did not accurately indicate all aspects of long-term cold tolerance and has limitations as a means of determining safe cold-storage dates.Tr.

#### [OSU Link](#)

#### [Non-OSU Link](#)

76. McKay, H.M. and A.D. Milner. 2000. Species and seasonal variability in the sensitivity of seedling conifer roots to drying and rough handling. *Forestry-Oxford* 73(3): 259-270.

**Keywords:** planting operations  
tree physiology  
tree/stand health  
tree phenology

**Abstract:** The ability of the fine root system of 2-year-old bare-rooted planting stock of *Picea sitchensis* of Queen Charlotte Islands (British Columbia, Canada), Oregon and Alaskan (USA) provenances, *Pseudotsuga menziesii*, *Larix kaempferi* and *Pinus sylvestris* to withstand standard drying and rough

handling treatments was tested at regular intervals from September 1990 until April 1991, at a nursery in NE England. Details are given of nursery treatments (sowing in spring 1989; undercutting in year 2 in June-mid-August, depending on species, and wrenching at 2-wk intervals until mid-October; and lifting at 2-wk intervals from September-November 1990 to April 1991). Electrolyte leakage was used to quantify the damage to the fine roots. Stressed seedlings had significantly greater leakage values than untreated seedlings and dried seedlings had significantly greater leakage values than roughly handled seedlings, but the responses varied with species and lifting date. After drying, leakage values increased in the order *P. sitchensis* (Oregon and Queen Charlotte Islands), *P. sylvestris*, *L. kaempferi*, *P. sitchensis* (Alaskan), *P. menziesii*. Leakage values after rough handling increased in the order *P. sitchensis* (Alaskan and Queen Charlotte islands), *L. kaempferi*, *P. sitchensis* (Oregon), *P. sylvestris*, *P. menziesii*. Leakage values were greatest in early September. During September and October there was a rapid downward trend in leakage. From December to February, leakage values decreased very slowly. In March leakage values of untreated and roughly handled seedlings increased slightly but decreased further in dried seedlings. These results indicate that great care must be taken during autumn planting to protect bare-rooted seedlings, particularly *P. menziesii*, from drying and to a lesser extent rough handling. Fine root leakage values following drying and rough handling had a significant linear relationship with the logarithm of the number of days required for the terminal bud to burst.

[OSU Link](#)

[Non-OSU Link](#)

77. Miller, R.E., M.V. Atherton and J.E. Wilcox. 1986. Comparative effects of three nitrogen fertilizers applied in fall and spring to a 29-year-old Douglas-fir plantation. *Canadian-Journal-of-Forest-Research* 16(5): 910-917.

**Keywords:** fertilization  
growth  
tree/stand health  
tree physiology

**Abstract:** Stand growth and mortality were monitored for 13 yr after application of urea, ammonium nitrate or urea + ammonium sulphate (224 kg N/ha) in autumn 1967 and spring 1968 to plots in a 29-yr-old Douglas fir plantation on Vancouver Island, British Columbia. The treatments and a control were replicated 3 times. Foliar analysis indicated insufficient available N before treatment and an increase in available N 1 and 2 yr after fertilization. Addition of N at this location did not have a practical effect on stand growth and the field experiment was not sufficiently sensitive to detect real differences between N sources or season of application. Suggestions are included for improving field trials.

[OSU Link](#)

[Non-OSU Link](#)

78. Mitchell, A.K., H.J. Barclay, H. Brix, D.F.W. Pollard, R. Benton and R. DeJong. 1996. Biomass and nutrient element dynamics in Douglas-fir: effects of thinning and nitrogen fertilization over 18 years. *Canadian-Journal-of-Forest-Research* 26(3): 376-388.

**Keywords:** fertilization  
thinning

precommercial thinning  
carbon allocation  
tree physiology  
growth  
soil properties

**Abstract:** The effects of thinning (two-thirds of basal area removed) and N fertilizer (448 kg N/ha as urea) on biomass and nutrition of a 24-year-old Douglas fir (*Pseudotsuga menziesii*) stand at Shawnigan Lake, British Columbia, were studied over 18 years. At years 0, 9, and 18 after treatments, the aboveground biomass and N, P, K, Ca, and Mg contents of stemwood, stem bark, foliage, and dead and live branches were determined (kg/ha), and increments in these properties (kg/ha per year) were calculated for the 0-9 and 9-18 year periods. Foliar biomass was increased by both treatments during the first period and also by thinning in the second period. Aboveground net primary production (ANPP) per unit of foliage biomass (foliage efficiency) was increased by treatments in the 0-9 year period. The combined effects of increased foliage mass and foliage efficiency resulted in increased total biomass production. Thinning and fertilizer application increased the uptake of all elements except for P with fertilizer. This increase may have contributed to the long-term increase in stem growth. Retranslocation of elements before foliage shedding was important for tree nutrition, but was not improved by fertilizer during the 9-18 year measurement period. The efficiency of N use in dry matter production (ANPP/unit of N uptake) was decreased by fertilizer. This implied that poor sites would respond to fertilizer better than rich sites.

[OSU Link](#)

[Non-OSU Link](#)

79. Mitchell, A.K. and T.M. Hinckley. 1993. Effects of foliar nitrogen concentration on photosynthesis and water use efficiency in Douglas-fir. *Tree-Physiology* 12(4): 403-410.

**Keywords:** fertilization  
tree physiology  
photosynthesis

**Abstract:** Leaf-level physiological processes were studied in Douglas fir (*Pseudotsuga menziesii*) to determine whether apparent increases in stand-level water use efficiency (WUE) observed in response to nitrogen (N) fertilization were attributable to foliar N effects on carbon fixation rates or on stomatal control of water loss. Photosynthesis and transpiration were measured at different light intensities and ambient CO<sub>2</sub> molar fractions and comparisons were made between current-year shoots with average foliar N concentrations of 1.58% (high-N) and 1.25% (low-N). Photosynthetic rates and foliar N concentrations were positively correlated. In response to light, photosynthesis and stomatal conductance were closely coupled and a similar coupling was observed in response to different ambient CO<sub>2</sub> concentrations. Partitioning the photosynthetic responses into mesophyll and stomatal components indicated that foliar N altered mesophyll conductance but not stomatal control of water loss. High-N shoots had significantly greater rates of photosynthesis and transpiration than low-N shoots and, as a result, instantaneous WUE did not differ significantly between high-N and low-N shoots.

[OSU Link](#)

[Non-OSU Link](#)

**80.** Nason, G.E., D.J. Pluth, R.T. Hardin and W.B. McGill. 1990. Dynamics of foliar N in Douglas-fir after spring and fall application of ammonium nitrate and urea. *Canadian-Journal-of-Forest-Research* 20(9): 1515-1523.

**Keywords:** fertilization  
tree physiology

**Abstract:** Foliar N dynamics were studied from 1982 to 1984 after spring or autumn application of ammonium nitrate or urea at 200 kg N/ha to an intermediate-productivity 38-yr-old Douglas fir (*Pseudotsuga menziesii*) stand growing on Humo-Ferric Podzols on Vancouver Island, British Columbia. Douglas fir responded by increasing the N concentration of existing foliage, and both the concentration and content of N in new shoots. Six months after spring fertilization, N concentration in current foliage averaged 30 and 21% above that of the control for ammonium nitrate and urea, respectively. N concentration of current foliage was increased after 2 years in the ammonium nitrate treatment only. When ammonium nitrate was applied in autumn, peak N concentration in current foliage occurred after 6 months (in mid-spring), at 25% above that of the control. Autumn application urea did not affect current foliage N concentration until the next autumn, when a 19% increase over that of the control was observed. In the first autumn after fertilization (seasons of application combined), ammonium nitrate caused a 26% increase over control in N content of current foliage, whereas urea caused a 13% increase. This superiority of ammonium nitrate over urea was attributed to the nitrate ion.

[OSU Link](#)

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**81.** Nason, G.E., D.J. Pluth and W.B. McGill. 1988. Volatilization and foliar recapture of ammonia following spring and fall application of nitrogen-15 urea to a Douglas-fir ecosystem. *Soil-Science-Society-of-America-Journal* 52(3): 821-828.

**Keywords:** fertilization  
tree physiology  
soil properties

**Abstract:** Seasonal effects on the volatilization and vegetal recapture of  $\text{NH}_3$  following application of pelleted  $^{15}\text{N}$  urea at 200 kg N ha<sup>-1</sup> to a 40-yr-old Douglas-fir [*Pseudotsuga menziesii*] ecosystem were investigated. Volatilization totalled 14 and 0.7% of applied N in spring and autumn, respectively, and the difference appeared to be related to precipitation patterns following fertilization. Volatilization was generally enhanced by small spring rainfalls while depressed by larger autumn rains. The isotopic abundance of evolved  $\text{NH}_3$  fluctuated from >90 to <10% of that of the fertilizer source. These fluctuations reflected the role of precipitation in the regulation of spatial heterogeneity of urea and urease in soil. Under spring conditions  $\text{NH}_3$  was recaptured by potted Douglas-fir seedlings. Seedlings at 10 cm above the forest floor captured 16 times as much  $\text{NH}_3$  as seedlings positioned at the 150-cm elevation. Labelled N was distributed among seedling tissues in the order: current foliage > 1-year-old foliage > roots which is consistent with anabolic incorporation and translocation. This mechanism may have a significant role in plant nutrition when conditions favourable to  $\text{NH}_3$  volatilization follow urea fertilization.

[OSU Link](#)

[Non-OSU Link](#)

**82.** Newton, M. and D.S. Preest. 1988. Growth and water relations of Douglas fir (*Pseudotsuga menziesii*) seedlings under different weed control regimes. *Weed-Science* 36(5): 653-662.

**Keywords:** release treatments  
chemical release  
growth  
soil properties  
tree physiology

**Abstract:** Growth of Douglas fir (*P. menziesii*) was increased by controlling grasses and broadleaved weeds with combinations of 4.4 kg atrazine/ha and 2.2 kg 2,4-D or 2,4,5-T during the first 3 years after planting on a well-drained moist site in the Oregon Coast Range. The greatest growth occurred if weeds were controlled in the same growing season that tree seedlings were transplanted to the field; smaller increments came from second- and third-year weed control. Growth increases attributable to early weed control continued through the fifth year, indicating that conditions during establishment strongly influenced later growth. Plots with no herbaceous vegetation had more available soil water than those with competing vegetation, and tree seedlings on these plots experienced less water stress. Irrigation in the third year increased stem diameter of seedlings in that year but had no effect thereafter. Increases in average seedling stem volume at 5 years after transplanting were linearly related to the difference in observed xylem potential during the first three seasons after transplanting and the xylem potential at which photosynthesis ceased, -2 MPa.

[OSU Link](#)

[Non-OSU Link](#)

**83.** Newton, M., D.S. Preest and D.E. White. 1987. Effect of relieving moisture stress with extended weed control in Douglas-fir. *Proceedings-of-the-Western-Society-of-Weed-Science* (Vol.40): 129-130.

**Keywords:** release treatments  
chemical release  
growth  
tree physiology  
soil properties  
photosynthesis

**Abstract:** The growth of Douglas fir *Pseudotsuga menziesii* seedlings was increased during the first 5 years by controlling grasses and forbs in 7 herbicide regimes during the 1st 3 years, the effect diminishing with time after planting. Devegetated plots had more available moisture through the growing season than those with *Agrostis tenuis* or mixed mixed grass/forb cover dominated by *A. tenuis* or *Hypochaeris radicata*. Tree moisture stress followed soil moisture but only after allowing for large fluctuations of diurnal stress. Weed control relieved moisture stress in trees. *P. menziesii* photosynthesis tended to shut down in the region of -2.0 MPa moisture stress. For the 1st 3 years in a favourable coastal environment approx. 1700 MPa-h above -2.0 MPa was estimated to be required for survival. Increments of moisture beyond that would contribute significantly to growth.

[OSU Link](#)

[Non-OSU Link](#)

**84.** Owens, J.N. 1987. Development of Douglas-fir apices under natural and cone-inducing conditions. *Forest-Ecology-and-Management* 19(1-4): 85-97.

**Keywords:** seed orchard management  
tree physiology

**Abstract:** The anatomy, mitotic frequency (MF), size and total insoluble carbohydrate histochemistry were studied in axillary apices from 9- and 10-year-old Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) trees after cone induction treatments of rootpruning (RP) and (or) stem injections of a gibberellin A4 and A7 mixture (GA). Axillary buds were initiated at the time of RP but RP had no effect on axillary bud initiation. Axillary apices from control and GA-treated trees were similar and followed the normal sequence of bud-scale initiation, differentiation and leaf initiation described previously and no cone buds differentiated. Early development of axillary apices from RP and RP + GA treated trees was normal but development became retarded near the time of vegetative bud flush. Retarded apices were small with low MF and developed many features characteristic of latent apices. The ultrastructure of cells at the base of retarded apices showed dense cytoplasm and some unusual features. Apical retardation continued until mid-July when normal development resumed and apices differentiated into cone or vegetative buds or became latent. The trees in which the greatest retardation of apical development occurred during lateral shoot elongation produced the most cone buds. These results are discussed in relation to hypotheses proposed to explain how cultural and GA treatments affect cone induction in the Pinaceae.

[OSU Link](#)

[Non-OSU Link](#)

**85.** Owens, J.N., J.E. Webber, S.D. Ross and R.P. Pharis. 1985. Interaction between gibberellin A4/7 and root-pruning on the reproductive and vegetative processes in Douglas-fir. III. Effects on anatomy of shoot elongation and terminal bud development. *Canadian-Journal-of-Forest-Research* 15(2): 354-364.

**Keywords:** seed orchard management  
tree physiology  
tree phenology  
growth

**Abstract:** The relative importance of cell division and cell elongation to shoot elongation and the anatomical changes in vegetative terminal apices were assessed for 9- and 10-yr-old seedlings in a seed orchard in British Columbia after two effective cone-induction treatments, gibberellin A4/7 (GA4/7) and root-pruning (RP). Root-pruning was done in mid-April 1981 at the start of vegetative bud swelling and GA treatments were begun at vegetative bud flushing in mid-May and continued until early July. Shoot elongation before flushing resulted primarily from cell divisions and was not affected by the RP treatment. Shoot elongation after flushing resulted primarily from cell expansion which was reduced by RP treatments. Root-pruning significantly slowed mitotic activity, apical growth, and development of vegetative terminal buds from mid-June to mid-July. Apical growth then resumed during leaf initiation and the final number of leaf primordia initiated was not affected. This resulted in a delay of 2-4 wk in the transition from bud-scale to leaf initiation. Retarded terminal vegetative apices anatomically

resembled latent axillary apices but were never completely inhibited. GA + RP had the same effect as RP. GA4/7 alone had no effect on shoot or apical development. These results show that RP and GA + RP significantly retard shoot elongation and terminal bud development but still allow normal development of vegetative terminal buds. Retardation of bud development by a few weeks shifts the critical morphogenetic phase of transition from bud scale to leaf initiation to a later time when endogenous and environmental conditions may differ from the normal.

[OSU Link](#)

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**86.** Owens, J.N., J.E. Webber, S.D. Ross and R.P. Pharis. 1986. Interaction between gibberellin A4/7 and root-pruning on the reproductive and vegetative processes in Douglas-fir. IV. Effects on lateral bud development. *Canadian-Journal-of-Forest-Research* 16(2): 211-221.

**Keywords:** seed orchard management  
tree phenology  
tree physiology

**Abstract:** The anatomy, mitotic frequency, size and total insoluble carbohydrate histochemistry were studied in axillary apices from 9- and 10-yr-old trees [in a seed orchard in British Columbia] after cone induction by root-pruning (RP) and/or stem injections of a gibberellin A4 + A7 (GA4/7) mixture. Axillary buds were initiated at the time of root-pruning, but RP treatment had no effect on time or number of axillary buds initiated. Axillary apices from control and GA treated trees were similar and followed the normal sequence of bud-scale initiation, differentiation and leaf initiation and no cone buds differentiated. Early development of axillary apices from RP and RP+GA treatments was normal, but development became retarded near the time of vegetative bud flush. Retarded apices were small with low mitotic frequency and developed many features characteristic of latent apices. Retardation of axillary apices continued until mid-July when normal development resumed and apices became latent or differentiated into reproductive or vegetative buds. Trees which had the greatest retardation of apical development during lateral shoot elongation produced the most cone buds. Results are discussed in relation to 4 hypotheses on effects of cultural and gibberellin treatments on cone induction in the Pinaceae.

[OSU Link](#)

[Non-OSU Link](#)

**87.** Pabst, R.J., J.C. Tappeiner, II and M. Newton. 1990. Varying densities of Pacific madrone in a young stand in Oregon alter soil water potential, plant moisture stress, and growth of Douglas fir. *Forest-Ecology-and-Management* 37(4): 267-283.

**Keywords:** release treatments  
manual release  
soil properties  
tree physiology  
growth

**Abstract:** In a study to evaluate the effects of mixed conifer/broadleaf stands on soil water potential, and Douglas fir (*Pseudotsuga menziesii*) moisture stress and growth, Pacific madrone (*Arbutus menziesii*) and associated shrub and herbaceous vegetation were thinned to represent the following range of conditions: high-density madrone (H) with associated shrubs and herbs controlled; medium-density madrone (M), shrubs and herbs controlled; low-density madrone (L), shrubs and herbs controlled; no madrone (N), shrubs and herbs controlled; and no madrone (U), shrubs and herbs predominate. The study was carried out in 1985 and 1987 at a 2-ha droughty site in the Klamath Mountains, SW Oregon, planted in 1979 with 2+0 Douglas fir. Soil water-potential (psi) at a depth of 0-30 cm was consistently higher in treatment N than in all other treatments; in 1987 this difference was significant ( $P < 0.025$ ). Average psi in treatment U reached -1.5 MPa (permanent wilting point) between June and July in both years of the study, whereas in the other treatments that level was never reached. Soil water conditions were also relatively severe in treatment H. Predawn plant moisture stress (PMS) of Douglas fir was significantly ( $P = 0.0001$ ) less in treatment N than in all other treatments. Seasonal moisture-stress relief (SMSR) of Douglas fir was significantly related to madrone leaf area index (LAI) and was greatest in treatment N. Seasonal moisture stress relief of madrone was also significantly correlated with LAI. There were highly significant linear relationships between both predawn and midday PMS and soil water potential for Douglas fir and madrone. Results clearly show that conditions for maximum Douglas fir growth occurred in treatment N. Average diameter growth of Douglas fir was greatest in treatment N, although not significantly different from that in treatment U, and least in treatment H. In 1987, Douglas fir growth in diameter, stem basal area, and stem volume was strongly related to SMSR and madrone LAI, and to a lesser extent, seasonal soil tension relief.

[OSU Link](#)

[Non-OSU Link](#)

88. Parke, J.L., R.G. Linderman and C.H. Black. 1983a. The role of ectomycorrhizas in drought tolerance of Douglas-fir seedlings. *New-Phytologist* 95(1): 83-95.

**Keywords:** nursery operations  
tree/stand protection  
photosynthesis  
tree physiology  
mycorrhizal response

**Abstract:** *Pseudotsuga menziesii* seedlings were watered daily or conditioned to cyclic drying and re-wetting of the soil. Net photosynthesis rates of mycorrhizal and non-mycorrhizal seedlings watered daily were similar but drought-stressed mycorrhizal seedlings fixed CO<sub>2</sub> at a rate 10 times that of non-mycorrhizal ones. Total leaf water potentials of mycorrhizal plants were lower than those of non-mycorrhizal plants but they recovered more rapidly. Non-mycorrhizal seedlings and those inoculated with 4 ectomycorrhizal fungi were allowed to dry, then re-watered and compared for their ability to tolerate and recover from drought. Those inoculated with *Rhizopogon vinicolor* were the least affected by drought. Net photosynthetic rate of R.-inoculated seedlings 24 h after re-watering was 7 times greater than that of non-mycorrhizal seedlings. The transpiration rate of R.-inoculated seedlings was low before desiccation, declined rapidly during the drought period and, after re-watering, quickly resumed a rate higher than that for other treatments.

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89. Petersen, T.D., M. Newton and S.M. Zedaker. 1988. Influence of *Ceanothus velutinus* and associated forbs on the water stress and stemwood production of Douglas-fir. *Forest-Science* 34(2): 333-343.

**Keywords:** release treatments  
chemical release  
tree physiology  
soil properties  
growth

**Abstract:** In studies in the central Cascade Mts., Oregon, three regimes were established in 1978 around individual trees in four 5-yr-old and four 10-yr-old stands, viz. no treatment (control), elimination of *C. velutinus* with 2,4-D or elimination of *C. velutinus* and forbs with 2,4-D and glyphosate. Seasonal and diurnal variation in stem and soil water potentials were measured during 1979. Soil water potential during late summer was  $<-1.5$  MPa at depths of 10, 40 and 100 cm on control plots and at depths of 10 and 40 cm in 5-yr-old stands and 10 cm in 10-yr-old stands in plots where only *C. velutinus* was eliminated. In the absence of shrubs and forbs, soil water potential at 100 cm was near field capacity throughout the season. Predawn stem water potential during late summer was significantly lower on control plots than on the treatment plots for all 5-yr-old stands and for two of the 10-yr-old stands. By 1986, tree stems were 2-6 cm larger in basal diam. and 1-2 m taller in the absence of competitors. The increase in stem size was greater in the stand treated at 5 yr old than in that treated at 10 yr old. The correlation between growth and water stress suggests that interspecific competition for soil water during summer drought is a limiting factor in stemwood production.

[OSU Link](#)

[Non-OSU Link](#)

90. Price, D.T., T.A. Black and F.M. Kelliher. 1986. Effects of salal understory removal on photosynthetic rate and stomatal conductance of young Douglas-fir trees. *Canadian-Journal-of-Forest-Research* 16(1): 90-97.

**Keywords:** release treatments  
manual release  
photosynthesis  
tree physiology  
soil properties  
growth

**Abstract:** Studies were made in a thinned 32-yr-old Douglas fir stand on a drought-prone site on the E. coast of Vancouver Island. Four pairs of similar trees were selected and the salal (*Gaultheria shallon*) understory was removed completely from around one of each pair. The root zones of each tree were isolated using plastic sheeting buried to bedrock. Photosynthesis, stomatal conductance, soil water potential and canopy microclimate were measured intensively in one pair on 4 clear days during an extended dry period in June 1982. B.a. increment of the four pairs of trees was measured over 3 growing seasons. To determine the effect of soil water potential on tree photosynthesis, the same variables were measured for 3 consecutive days in Aug. 1982 for another tree initially subjected to a soil water potential of approx.  $-1.6$  MPa, but irrigated to approx.  $-0.02$  MPa between days 1 and 2. Solar irradiance decreased markedly between days 2 and 3, thus creating a unique data set. Results showed that removal of the understory significantly increased rates of photosynthesis in Douglas fir, both diurnally

and seasonally. Photosynthesis was not generally limited by stomatal conductance unless vapour pressure deficit was high and photon flux density was saturating. Improved tree growth after understorey removal was due to the increased soil water potential that increased both photosynthetic capacity and stomatal conductance.

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[Non-OSU Link](#)

91. Puttonen, P. 1987. Abscisic acid concentration in Douglas-fir needles in relation to lifting date, cold storage, and postplanting vigor of seedlings. *Canadian-Journal-of-Forest-Research* 17(5): 383-387.

**Keywords:** nursery operations  
growth  
tree/stand health  
tree physiology  
tree phenology

**Abstract:** Spring-lifted seedlings (2+0) were grown outside in pots at Corvallis, Oregon, in 1982. In late July pots were watered weekly to induce dormancy. From early Sep., plants received either a natural photoperiod or an extended (16 h) photoperiod for 6 wk. In mid-Nov. 1982 or mid-Jan. 1983, the plants were lifted and stored in a cold room (4 degrees C) for 25 days, bare rooted in polyethylene bags in the dark, or in pots in the dark or with an 8 h photoperiod. After storage, seedlings were planted in a cold frame or in pots in a growth room with 16-h photoperiod and day/night temp. of 21/16 degrees . In Sep. 1983, seedling ht., length of leader for 1982 and 1983, root collar diam. and survival were recorded. ABA concn. in needles was analysed after 48h and 25 days in storage, after 48h in a cold frame or growth room and at bud break. Lifting times and storage treatments did not have a significant effect on ABA concn. Seedling vigour was not indicated by ABA concn. There were treatment differences in performance after storage. Compared with seedlings lifted in mid-Jan., those lifted in mid-Nov. had reduced survival and more days to bud burst.

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92. Radwan, M.A. 1992. Effect of forest floor on growth and nutrition of Douglas-fir and western hemlock seedlings with and without fertilizer. *Canadian-Journal-of-Forest-Research* 22(9): 1222-1229.

**Keywords:** nursery operations  
nursery fertilization  
growth  
tree physiology

**Abstract:** Experiments were conducted to determine the effects of four different forest soils from western Washington, USA, on growth and shoot nutrients of potted Douglas fir (*Pseudotsuga menziesii*) and western hemlock (*Tsuga heterophylla*) seedlings, in the absence and presence of forest floor, and with and without N and P fertilizers. Nine-month-old seedlings from low-altitude seed sources were used, and seedlings were grown for 2 years in a roofed lathhouse. Soils were of the Klone, Vesta, Bunker, and Shelton series; samples of Klone and Vesta soils, and of Bunker and Shelton soils (to 20 cm

depth), were collected from western hemlock and Douglas fir stands, respectively. Forest floor samples were collected from the same sites. Fertilizer was added as ammonium nitrate at 100 kg N/ha and triple superphosphate at 226 kg P/ha. The forest floor, at 70 g/7.6-litre pot, and the N and P fertilizers were added to the top of the planting pots without mixing. The P, N, K, Ca and Mg contents of the forest floor, mineral soils and shoots were measured. The forest floors and mineral soils differed by source in many of the chemical characteristics determined. Overall, seedling growth of Douglas fir and western hemlock was better in the Klone and Shelton soils than in the Bunker and Vesta soils. Seedlings, especially those of western hemlock, grew better in soils with forest floor than without forest floor. The N fertilizer reduced seedling growth of both species and, in some soils, reductions were more in soils with forest floor. The P fertilizer improved seedling growth of both species in all soils, and with one exception, growth was much greater in the presence than in the absence of the forest floor. With both species, soil, forest-floor, and fertilizer treatments affected concentrations and contents of the various shoot nutrients determined. The nutritional changes observed varied by nutrient and reflected differences in uptake of native and fertilizer nutrients, as well as changes in shoot dry weight. The results demonstrate the importance of the forest floor to growth and nutrition of Douglas fir and western hemlock seedlings, especially when fertilizers are used.

[OSU Link](#)

[Non-OSU Link](#)

**93.** Radwan, M.A., J.S. Shumway, D.S. DeBell and J.M. Kraft. 1991. Variance in response of pole-size trees and seedlings of Douglas-fir and western hemlock to nitrogen and phosphorus fertilizers. *Canadian-Journal-of-Forest-Research* 21(10): 1431-1438.

**Keywords:** nursery operations  
nursery fertilization  
fertilization  
tree physiology  
growth

**Abstract:** A study was made of the effects of N, P and NP fertilizer treatments on plant nutrients and growth of Douglas fir (*Pseudotsuga menziesii*) and western hemlock (*Tsuga heterophylla*). Three trials were conducted, (1) and (2) on pole-size trees at two different sites in Washington and (3) on potted seedlings in a lathhouse; only *T. heterophylla* was studied in (2). Soil series were Bunker for Douglas fir and Klone for western hemlock in trials 1 and 3, and Vesta in trial 2. Nitrogen fertilizers used were urea in trial 1 and ammonium nitrate in the other two trials; P was applied as triple superphosphate in all three trials. For each species in trial (1), P was applied at 0, 100, 300 and 500 kg P/ha and N was applied at 0 and 224 kg N/ha in a factorial design. In trial (2), P was applied at 0, 100 and 300 kg P/ha and N was applied at 0 and 112 kg N/ha in a factorial design. In trial (3), N and P were applied individually to seedlings at a rate of 100 kg N/ha and 226 kg P/ha. In general, fertilizer treatments changed the levels of some plant-tissue nutrients of the pole-size trees and potted seedlings. Neither height nor basal area growth of the trees were significantly affected by any of the treatments in the first two trials. Seedling growth of both Douglas fir and western hemlock was improved by P fertilizer, but was negatively affected by N fertilizer. The results clearly show differences between pole-size trees and seedlings in response to N and P fertilizers. It is concluded that N should not be applied where soils are high in N and low in P, and that P applications should be confined to sites with low-P soils, when trees are young, before canopy closure.

[OSU Link](#)

[Non-OSU Link](#)

94. Ritchie, G.A., Y. Tanaka and S.D. Duke. 1992. Physiology and morphology of Douglas-fir rooted cuttings compared to seedlings and transplants. *Tree-Physiology* 10(2): 179-194.

**Keywords:** nursery operations  
tree phenology  
tree physiology  
growth  
tree morphology  
carbon allocation

**Abstract:** Cuttings of Douglas fir (*Pseudotsuga menziesii*) from three open-pollinated families were rooted in two types of tray and then grown for 1.5 years in a nursery in Washington State. During their second winter they were sampled periodically and tested for cold hardiness, dormancy status, root growth potential and various morphological characteristics. Two-year-old seedlings and transplants were tested concurrently for comparison. Rooted cuttings, seedlings and transplants cold hardened at similar rates during early winter, achieving the same level of midwinter hardiness (LT50 = -18 degrees C) in early January. However, rooted cuttings remained hardier later into spring than did seedlings or transplants. Rooted cuttings exhibited deeper dormancy in early winter than seedlings or transplants but these differences disappeared after January. Root growth potentials of all three stock types remained above threshold values established for transplants throughout winter. Rooted cuttings had greater stem diameter, higher stem diameter : height ratio, and greater root weight than either seedlings or transplants. This may reflect lower growing densities for rooted cuttings. Root : shoot ratios of rooted cuttings were greater than for seedlings and similar to those of transplants. Rooted cuttings also had deeper and coarser root systems, which probably reflected lack of wrenching at the nursery.

[OSU Link](#)

[Non-OSU Link](#)

95. Roberts, S.D., C.A. Harrington and T.A. Terry. 2005. Harvest residue and competing vegetation affect soil moisture, soil temperature, N availability, and Douglas-fir seedling growth. *Forest-Ecology-and-Management* 205(1/3): 333-350.

**Keywords:** site preparation  
chemical preparation  
release treatments  
chemical release  
soil properties  
growth  
tree physiology

**Abstract:** Decisions made during stand regeneration that affect subsequent levels of competing vegetation and residual biomass can have important short-term consequences for early stand growth, and may affect long-term site productivity. Competing vegetation clearly affects the availability of site resources such as soil moisture and nutrients. Harvest residues can also affect the availability of site

resources. We examined second and third year seedling performance of a Douglas fir (*Pseudotsuga menziesii*) plantation with different vegetation control and biomass retention treatments on a highly productive site in the coast range of Washington, USA. Treatments included a bole-only harvest without vegetation control (BO-VC), a bole-only harvest with complete vegetation control (BO+VC), and a total tree harvest with complete vegetation control that also included removal of all coarse woody debris and harvest residues (TTP+VC). The VC treatment involved: (a) in the first year, broadcast application of Oust and Accord concentrate applied with a surfactant 2 weeks before planting; (b) in the second year, a March broadcast application of Atrazine and a directed spot-spray of Accord Concentrate on the vegetation between rows in April-May; and (c) in the third year, a March broadcast application of Atrazine and Oust, a direct spot-spray application of Accord Concentrate, and a spot-spray of Transline with surfactant on April-May to control persistent shrub species. The study was conducted to determine if vegetation control and residue retention treatments affected soil moisture, soil temperature, and apparent nitrogen (N) availability, and whether these differences in site resources were correlated with seedling size and growth. In both second and third growing seasons, volumetric soil moisture at 0-20 cm depth was lowest on plots that did not receive vegetation control (BO-VC). Seedlings on these plots also had the lowest diameter and volume growth. In year 2, which was fairly moist, volume growth on TTP+VC plots was slightly higher than on BO+VC plots. TTP+VC plots did have lower soil moisture, but soil temperatures were slightly warmer. In year 3, a drier year, growth was greatest on BO+VC plots, which had consistently higher soil moisture levels. Apparent N availability in year 3 also varied with vegetation control. Douglas fir foliar N concentrations averaged 2.3% on the plots where competing vegetation was eliminated, compared to 1.8% on plots where competing vegetation was not controlled. Douglas fir foliar N concentrations did not differ between residue retention treatments, although N concentrations of competing vegetation were higher where residual biomass was retained. Higher apparent N availability was correlated with greater seedling growth. Based on the results from years 2 and 3, it appears that soil moisture, particularly late in the growing season, had the greatest effect on seedling growth in both years. Available N may also have played a role, although the effects of N cannot be completely separated from those of soil moisture. When soil moisture is adequate, it appears that available N and soil temperature exert greater influence on growth. Vegetation control and residue retention can influence all 3 of these factors. The relative importance of each factor may depend on the year-to-year variation in environmental conditions.

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96. Rollwagen, B.A. 1983. Effects of ammonium and nitrate application on rhizosphere pH, growth and nutrient uptake by Douglas-fir, Sitka spruce and western hemlock. *Forestry-Abstracts* 44(11): 699.

**Keywords:** fertilization  
soil properties  
growth  
tree physiology

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97. Rose, R., J.F. Gleason and M. Atkinson. 1993. Morphological and water-stress characteristics of three Douglas-fir stocktypes in relation to seedling performance under different soil moisture conditions. *New-Forests* 7(1): 1-17.

**Keywords:** nursery operations  
tree phenology  
tree physiology  
growth  
tree morphology

**Abstract:** Phenology, morphology, frost hardiness and response to moisture stress were examined for three Douglas fir (*Pseudotsuga menziesii*) stocktypes grown from the same seed lot in a nursery near Olympia, Washington, USA. The types were mini-plugReg. transplants(MPT), 1+1 bareroot transplants (1+1), and 2+0 bareroot seedlings (2+0). In the late summer and autumn before lifting, 2+0 seedlings set bud before 1+1 seedlings and 1+1 seedlings before MPT seedlings. The 2+0 seedlings appeared slowest to acquire frost hardiness and seemed to deharden most rapidly in spring. Although 2+0 seedlings were taller than the MPT stocktype, MPT and 2+0 seedlings were relatively similar in other morphological respects, but 1+1 seedlings were much larger. All stocktypes were potted on 20 January 1989, placed in a greenhouse, and subjected to 39%, 18%, 16%, or 6% soil water-content (% dry weight) until the end of the experiment in mid-July 1990. The largest decrease in pre-dawn xylem water potential occurred with 16% and 6% soil water content; pre-dawn xylem water potential averaged over the three stocktypes generally declined 219% from low to high soil moisture stress. The 1+1 seedlings used more water than the other two stocktypes, and at maximum soil moisture stress, plant moisture stress increased in the order MPT < 2+0 < 1+1. During the 6-month greenhouse experiment, the larger 1+1 stocktype showed the most absolute growth, but the smaller stocktypes grew more on a relative scale. Growth of the stocktypes appeared to be related to differences in morphology and water-use patterns as the seedlings competed for available water within each pot. The results show that MPT seedlings, a new stocktype, performed as well as the more traditionally used 2+0 and 1+1 seedlings and that stocktype selection is important in reforestation efforts.

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98. Rose, R. and D.L. Haase. 2000. The use of coir as a containerized growing medium for Douglas-fir seedlings. *Native-Plants-Journal* 1(2): 107-111.

**Keywords:** nursery operations  
growth  
carbon allocation  
tree physiology  
tree morphology  
soil properties

**Abstract:** In response to environmental concerns and the need for peatland conservation, alternative growing media for conifer seedling production must be investigated. Douglas-fir (*Pseudotsuga menziesii*) seedlings were grown in 6 media; components included peat moss, peat moss amended with sawdust, and 2 sources of coir (coconut fibre) mixed with and without peat moss. Coir had higher pH, P, K, and Na and lower Ca and N than peat moss and a peat moss-sawdust mixture. Bulk densities of coir and coir-based media were lower than those in peat moss and a peat moss-sawdust mixture. After 21 weeks, seedlings grown in coir-based media were significantly smaller and had lower foliar N and Ca than those grown in peat moss. Because of coir's many favourable qualities, further research is recommended using culturing regimes specific to the substrate's nutrient properties.

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99. Rose, R. and J.S. Ketchum. 2002. Interaction of vegetation control and fertilization on conifer species across the Pacific Northwest. *Canadian-Journal-of-Forest-Research* 32(1): 136-152.

**Keywords:** fertilization  
release treatments  
chemical release  
growth  
tree/stand health  
tree physiology  
stand conditions

**Abstract:** An experiment evaluating three levels of vegetation competition control (no control, 1.5 m<sup>2</sup> of vegetation control, and 3.3 m<sup>2</sup> of vegetation control), each with two fertilizer application treatments (fertilizer application at the time of planting with complete slow-release fertilizer (WoodaceReg. IBDU), or no fertilizer application), was installed at five sites. Two of these sites were planted with Douglas-fir (*Pseudotsuga menziesii*) in the Oregon Coast Range, one with ponderosa pine (*Pinus ponderosa*) in eastern Washington, one with western hemlock (*Tsuga heterophylla*) in the coastal hemlock zone in Oregon, and one with coastal redwood (*Sequoia sempervirens*) in northern California, USA. At four of the five sites, mean stem volume, basal diameter, and height of seedlings increased significantly with increasing area of weed control, and the magnitude of difference between treatments increased with time. Fertilizer application significantly increased seedling size only at the two sites with adequate soil moisture; increases were marginally significant at a third. Response to fertilizer application was less than from weed control and impacted growth for only the first year, whereas the influence of weed control continued to influence growth the entire length of the study (4 years). Area of vegetation control and fertilizer application did not interact significantly at any site.

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100. Roth, B.E. and M. Newton. 1996b. Survival and growth of Douglas-fir relating to weeding, fertilization, and seed source. *Western-Journal-of-Applied-Forestry* 11(2): 62-69.

**Keywords:** planting operations  
fertilization  
release treatments  
chemical release  
growth  
tree physiology  
tree morphology  
tree/stand health

**Abstract:** The goal of this study was to quantitatively evaluate the individual and interactive effects of weed control, nitrogen fertilizer, and seed source on Douglas fir (*Pseudotsuga menziesii*) survival and growth in plantations on a range of sites and growing conditions in western Oregon. Weed control with

hexazinone (broadcast application after planting) was the dominant factor influencing seedling survival and growth and accounted for 49% of the explained variation in seedling volume after 2 years. Nitrogen fertilizer (urea) had no effect when used in conjunction with weed control and a negative effect when used without weed control. Seedlings from a seed orchard source were significantly larger in diameter and volume than those from a wild local source after two growing seasons, but second-year heights were similar for the two seedling types. Initial seedling size was positively correlated with growth rate.

[OSU Link](#)

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**101.** Sachs, D. and J.A. Trofymow. 1991. Testing the performance of FORCYTE-11 against results from the Shawnigan Lake thinning and fertilization trials on Douglas-fir. Canadian-Forest-Service, Pacific and Yukon Region Information-Report BC-X-324. viii + 58 p.

**Keywords:** fertilization  
thinning  
precommercial thinning  
growth  
yield  
tree physiology  
carbon allocation  
tree/stand health  
computer modeling

**Abstract:** FORCYTE-11 is an ecosystem-based forest growth simulation model. Its performance was evaluated with data on stand and tree biomass, height, stocking (mortality) and foliar assimilation and loss rates for Douglas fir (*Pseudotsuga menziesii*) in thinning/fertilizer trials in British Columbia.

[OSU Link](#)

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**102.** Schuch, U.K., M.L. Duryea and L.H. Fuchigami. 1989. Dehardening and budburst of Douglas-fir seedlings raised in three Pacific Northwest nurseries. Canadian-Journal-of-Forest-Research 19(2): 198-203.

**Keywords:** nursery operations  
tree phenology  
tree physiology

**Abstract:** Two-yr-old Douglas fir (*Pseudotsuga menziesii*) seedlings from 2 seed sources raised in 3 nurseries in Oregon and Washington were tested to see how nursery location affected dehardening (the seasonal transition from a frost-resistant to a frost-susceptible condition) and budburst between Jan. and Mar. 1986. The seedlings were measured with a whole-plant freezing test. In general, seedlings raised at the nursery at the highest alt., and in a few cases trees from the most northerly nursery, were more frost resistant than trees from a coastal nursery. From Jan. to Mar., seedlings from the highest (975 m) seed source had less hardy stem tissue than seedlings from the coastal source (450 m). A growth-chamber experiment confirmed the outdoor dehardening studies. A constant temp. of + 5



degrees C with a 16-h photoperiod maintained cold hardiness, whereas +10 and 15 degrees C with a 16-h photoperiod promoted rapid dehardening after 20 d. The nursery environment influenced budburst; trees raised in the coastal nursery burst bud significantly earlier than trees from the other 2 nurseries. Trees of different provenances from the same nursery burst terminal buds only 2 d apart.

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**103.** Shainsky, L.J., M. Newton and S.R. Radosevich. 1992. Effects of intra- and inter-specific competition on root and shoot biomass of young Douglas-fir and red alder. *Canadian-Journal-of-Forest-Research* 22(1): 101-110.

**Keywords:** planting operations  
growth  
tree morphology  
carbon allocation  
tree physiology

**Abstract:** Two-year-old seedlings of Douglas fir (*Pseudotsuga menziesii*) and red alder (*Alnus rubra*) were planted in Oregon in 1985 at densities of 1, 2, 4, 8 and 16 trees/m<sup>2</sup> in a two-way density matrix composed of 5 monoculture densities and 25 mixtures of all possible pairwise combinations of monoculture densities. Roots and shoots were harvested after the fourth growing season. Response surfaces for root, shoot and total biomass per tree were generated within the matrix. Regression analysis quantified the effect of each species' density on biomass components. Alder overtopped the Douglas fir in all mixed stands. Alder density influenced the root and shoot biomass of both species more than Douglas fir density did, the greatest reduction in root biomass of Douglas fir taking place at an alder density of  $\leq 1$  tree/m<sup>2</sup>. Douglas fir density interacted with red alder density to influence all biomass components. Douglas fir density effects were inconsistently significant across alder densities. While increasing the density of each species reduced root and shoot biomass per tree, allocation of biomass to roots and shoot was not affected by competition, nor were the allometric equations relating biomass to stem diameter and stem volume index. Foliar concentrations of N and P in the Douglas fir understory are reported.

[OSU Link](#)

[Non-OSU Link](#)

**104.** Simpson, D.G. 1984. Filmforming antitranspirants: their effects on root growth capacity, storability, moisture stress avoidance, and field performance of containerized conifer seedlings. *Forestry-Chronicle* 60(6): 335-339.

**Keywords:** nursery operations  
tree physiology  
growth  
tree/stand health

**Abstract:** One of 6 antitranspirants was sprayed on *Pinus contorta*, *Picea glauca*, *Tsuga heterophylla* and *Pseudotsuga menziesii* seedlings before or after a 12-wk storage period at 2 degrees C. Root growth

capacity and pre-dawn water potential were measured immediately after treatment or after storage. Sample seedlings were planted out in British Columbia in April and May 1981 and survival and growth recorded after one season (Sept.). XEF-4-3561-A, Wilt Pruf, Folicote and Vapor Gard increased moisture stress avoidance (water potential) in all species. Plantgard and Clear Spray increased it only in *T. heterophylla*. Root growth capacity was reduced by Folicote and Vapor Gard in *Pinus contorta*, and by XEF, Wilt Pruf and Vapor Gard in *Pseudotsuga menziesii*. Growth in the first season was reduced by XEF and Wilt Pruf in *P. menziesii*, *T. heterophylla* and *Picea glauca*, and by Vapor Gard in *T. heterophylla* and *Pseudotsuga menziesii*. Growth in *Pinus contorta* was significantly increased by Wilt Pruf and unaffected by the others. Further trials of Wilt Pruf and XEF on *Pinus contorta* are recommended.

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**105.** Simpson, D.G. 1990. Frost hardiness, root growth capacity, and field performance relationships in interior spruce, lodgepole pine, Douglas-fir, and western hemlock seedlings. *Canadian-Journal-of-Forest-Research* 20(5): 566-572.

**Keywords:** nursery operations  
tree/stand protection  
tree physiology  
tree/stand health  
growth

**Abstract:** Interior spruce (*Picea glauca*-*P. engelmannii* complex), lodgepole pine (*Pinus contorta*), interior and coastal Douglas fir (*Pseudotsuga menziesii*) and western hemlock (*Tsuga heterophylla*) were grown from seed for 20 wk in containers in a greenhouse, with 18-h photoperiods. Seedlings were then acclimatized under natural daylength and temperature conditions at Vernon, British Columbia, for up to 12 wk (7 September-1 December). To create planting stock batches of varying quality, at 2-wk intervals during the acclimatization period separate samples of seedlings were taken (1) for immediate measurement of foliage frost hardiness or (2) for overwinter storage at 2 degrees C (western hemlock and coastal Douglas fir) or -2 degrees C (interior spruce, lodgepole pine and coastal Douglas fir). After storage, samples were used either for root growth capacity (RGC) measurement or for outplanting at various forest sites in British Columbia. In all species, frost hardiness and RGC increased with increasing weeks of acclimatization. Frost hardiness and RGC were correlated with each other in western hemlock, lodgepole pine and Douglas fir, and with field performance (survival or growth) in interior spruce, lodgepole pine and Douglas fir.

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**106.** Stjernberg, E.I. 1997. Mechanical shock during transportation: effects on seedling performance. *New-Forests* 13(1/3): 401-420.

**Keywords:** nursery operations  
tree physiology  
tree/stand health  
growth

**Abstract:** A study was carried out to monitor shocks to seedling planting stock during transport from nursery to the planting site in normal commercial reforestation operations. Size and exact time of mechanical shocks were measured by a recorder placed inside seedling boxes. Seedling shipments by refrigerated semi-trailer, 5-t truck, pickup truck, small trailer and all-terrain vehicles were monitored in Alberta and British Columbia. Number of shocks, peak acceleration and average drop height were tabulated for travel on both paved and gravel roads. Twenty-two trials involving 7 conifer species (Douglas fir, *Pseudotsuga menziesii*; western hemlock [*Tsuga heterophylla*]; western red cedar [*Thuja plicata*]; amabilis fir [*Abies amabilis*]; white spruce, *Picea glauca*; lodgepole pine, *Pinus contorta*; Engelmann spruce, *Picea engelmannii*) were established at nurseries and field locations covering several ecological zones in both provinces. Frozen-stored, cool-stored, and freshly lifted seedlings were used in the trials. Seedlings were given 2 mechanical stress treatments by dropping them 30 times from 0.5 or 1 m height. Control seedlings were not dropped. Treatments were applied to nursery-trial seedlings not exposed to normal handling and transport, and to field-trial seedlings after transport to the planting site. Six root growth potential tests were made with treated and control seedlings in conjunction with the nursery trials. Seedling survival and volume growth were recorded for two growing seasons and the results are statistically analysed. They indicated that seedlings should not be affected by normal transport and handling activities - some of the shock treatments tested were much more stressful than those resulting from normal procedures. There was some evidence that mechanical shocks could reduce the growth and survival of bare rooted stock, but normal mechanical stresses had no effect on containerized stock. However, it is recommended that care be taken to reduce extreme mechanical shocks during planting stock transportation.

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[Non-OSU Link](#)

107. Turner, J. 1982. The mass flow component of nutrient supply in three western Washington forest types. *Acta Oecologica Oecologia Plantarum* 3(4): 323-329.

**Keywords:** fertilization  
soil properties  
growth  
tree physiology

**Abstract:** [See FA 37, 7318; 38, 5185; 39, 1857; 41, 3566; 44, 4913] The mass flow component of nutrient uptake, defined as the product of bulk soil sol. concn. and water uptake was calculated for a series of forest stands from previously published data. Stands were of Douglas fir of varying ages and nutrient status (both undisturbed and fertilized), red alder (*Alnus rubra*), Pacific silver fir (*Abies amabilis*) and beech (*Fagus sylvatica*). Uptake of N, P, K, and Mg increased, and Ca uptake remained stable as stands matured; the proportion of nutrient uptake fulfilled by mass flow tended to increase with stand age. Fertilizer application gave various results related to changes in soil sol. nutrient concn. and tree growth. The stands of red alder and silver fir showed variable patterns between nutrients and these are discussed in relation to soil nutrients, productivity and previously unpublished data.

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[Non-OSU Link](#)

108. Turner, J., M.J. Lambert and S.P. Gessel. 1988. Nitrogen requirements in young Douglas-fir of the Pacific Northwest. *Fertilizer-Research* 15(2): 173-179.

**Keywords:** fertilization  
growth  
tree physiology

**Abstract:** A series of fourteen Pacific Northwest Douglas-fir installations, ranging in age from 6 to 26 years were analysed with respect to site factors, foliage nutrients, and growth response to applied fertilizer. Unfertilized basal area increment ranged from 1.2 to 3.1  $\text{m}^2 \text{ha}^{-1} \text{yr}^{-1}$  with no apparent relationship with soil, stand age or site index. Basal area increment was correlated with foliage N and a critical level of N was calculated as 1.7%. Applications of 220 kg N  $\text{ha}^{-1}$  as urea increased growth between 0 and 95% of the unfertilized basal area growth, with an average of 24.9%. Response could be predicted from foliage N and unfertilized basal area increment. When the same relationships were applied to previously older stand data, results were more variable as elements such as B and S showed evidence of being limiting.

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109. Turner, J. and S.J. Mitchell. 2003. The effect of short day treatments on containerized Douglas-fir morphology, physiology and phenology. *New-Forests* 26(3): 279-295.

**Keywords:** nursery operations  
growth  
tree morphology  
tree physiology  
photosynthesis  
tree phenology

**Abstract:** The effect of short day treatments ('blackout') on Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) container seedlings at the time of lift and following cold storage was investigated. Variables measured included height, root collar diameter (RCD), root growth capacity (RGC), photosynthetic efficiency after -18 degrees C freezing (PEF), and days to terminal bud break (DBB). From one to four blackout dormancy induction treatments were started on three dates (July 12, July 26, and August 10) with 10 or 20 d between multiple blackouts. Increasing the number of blackout treatments resulted in lower RCD, lower DBB in the late winter/early spring, and higher PEF in the early fall. Later blackout start dates decreased PEF in the early fall, and increased overall height and late fall RGC as compared to earlier blackout start dates. Nurseries growing Douglas-fir seedlings from coastal Pacific Northwest provenances should be aware that blackout regimes can decrease RGC in the late fall, and cause quicker dormancy release in the early spring. Coastal Douglas-fir can be lifted and planted in the early fall, when RGC and DBB are relatively high. If planting between February and April is necessary, seedlings given blackout should be cold stored in January to maintain an adequate level of dormancy, RGC and PEF.

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[Non-OSU Link](#)

110. Velazquez-Martinez, A., D.A. Perry and T.E. Bell. 1992. Response of aboveground biomass increment, growth efficiency, and foliar nutrients to thinning, fertilization, and pruning in young

Douglas-fir plantations in the central Oregon Cascades. *Canadian-Journal-of-Forest-Research* 22(9): 1278-1289.

**Keywords:** fertilization  
thinning  
pruning  
growth  
carbon allocation  
tree physiology  
tree morphology

**Abstract:** The effect of thinning and silvicultural practices (multinutrient fertilization and/or pruning) on total aboveground biomass increment and growth efficiency was studied over three consecutive 2-year periods (1981-1987) in young Douglas fir (*Pseudotsuga menziesii*) plantations in the central Oregon Cascades. Plantations were 21-27 yr old in 1987. Plots were heavily thinned (leaving 300 trees/ha), moderately thinned (leaving 604 trees/ha) or left unthinned (leaving 3459 trees/ha) in 1981. Fertilizer (N, P, K, Ca, S and Fe) was applied with slow-release tabs. Net above-ground biomass annual increment over the 6-year period averaged 14.5, 7.8, and 5.5 t/ha for the high-, medium-, and low-density plots, respectively. Growth efficiency, after dropping sharply between leaf area indexes (LAI) of 1 and 6, remained relatively constant up to the highest measured LAI of 17. Consequently, above-ground biomass increment continued to increase at LAIs well above that at which the Beer-Lambert law predicts maximum light should be absorbed. Foliage analyses indicated that thinning improved N, K and Mg nutrition and increased the translocation of K from 1-yr-old foliage to support new growth. However, fertilizer application increased foliar N and P contents only when coupled with pruning, suggesting that trees favour total leaf area over individual needle nutrition. Indications of K and Mg limitations in this study are supported by other recent studies of Douglas fir.

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**111.** Vihnanek, R.E. 1987. The effects of prescribed burning on the growth and nutrition of young Douglas-fir plantations in some salal [*Gaultheria shallon*]-dominated ecosystems [in British Columbia, Canada]. *Forestry-Abstracts* 48(11): 641.

**Keywords:** site preparation  
prescribed fire  
growth  
tree physiology

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**112.** Vihnanek, R.E. and T.M. Ballard. 1988. Slashburning effects on stocking, growth, and nutrition of young Douglas-fir plantations in salal-dominated ecosystems of eastern Vancouver Island. *Canadian-Journal-of-Forest-Research* 18(6): 718-722.

**Keywords:** site preparation  
prescribed fire  
growth  
tree physiology  
stand conditions

**Abstract:** Stocking, ht. growth, basal diam. growth, and foliar nutrient concn. of 5- to 15-yr-old Douglas fir (*Pseudotsuga menziesii*) were evaluated on burned and unburned areas within each of 20 sites on eastern Vancouver Island, which were characterized by ecosystems dominated by salal (*Gaultheria shallon*). Burning significantly reduced salal ht. and cover and significantly increased Douglas fir stocking, ht. growth, basal diam. and foliar P, K, Ca, Fe, and B concn. Foliar concn. of N, Mg, S, Zn and Cu were not significantly affected. Foliar Mn concn. were significantly reduced but remained very far above the deficiency threshold.

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**113.** Vogt, K.A., D.J. Vogt, E.E. Moore, W. Littke, C.C. Grier and L. Leney. 1985. Estimating Douglas-fir fine root biomass and production from living bark and starch. *Canadian-Journal-of-Forest-Research* 15(1): 177-179.

**Keywords:** fertilization  
tree morphology  
tree physiology

**Abstract:** A potential indirect technique for determining fine root biomass and production is reported. Data from 4 permanent Douglas fir plots in Washington State given different fertilizer treatments showed a direct correlation between the starch content of a 1-cm wide band of living bark at b.h. per hectare and fine root biomass per hectare ( $r^2 = 0.85$ ). Starch content was determined in bark samples from 5 trees in each plot and estimates of the volume of 1-cm wide bands of bark at b.h. were made from measurements of d.b.h. and total bark thickness of every tree in each plot. Fine root biomass was determined in soil cores obtained with a post hole digger (inner diam. 15.3 cm); traditional small core methods could not be used because of the high gravel and rock content of the soil.

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**114.** Walker, R.B., S.P. Gessel and R.E. Miller. 1994. Greenhouse and laboratory evaluation of two soils derived from volcanic ash. *Northwest-Science* 68(4): 250-258.

**Keywords:** fertilization  
growth  
tree/stand health  
carbon allocation  
tree morphology  
tree physiology

**Abstract:** This study assessed the mineral nutrient status of two soils derived from volcanic ash in SW Oregon. The study was initiated because conifers in some of the field plots on such soils had failed to give an expected yield response to the application of nitrogen fertilizer. Soil pot tests were carried out using both Romaine lettuce (*Lactuca sativa*) and Douglas fir (*Pseudotsuga menziesii*) seedlings, with a wide range of fertilizer treatments. Heavy phosphorus fertilization was necessary for satisfactory growth of lettuce, which also showed a 26% response to sulfur addition. With Douglas fir, pot tests showed no response to nitrogen alone, but gave a statistically significant response to phosphorus fertilization together with nitrogen (seedlings were non-mycorrhizal), and some suppression of yield with sulfur additions. There was a favourable effect of sulfur fertilization on foliar colour, and a chlorosis in younger foliage probably attributable to iron deficiency. Most of the tissue analyses showed low concentrations of magnesium (<0.05%), and also of calcium (<less or =>0.08%), iron (<70 mg/kg), boron (mostly 20 mg/kg) and copper (<less or =>2.6 mg/kg) in the younger foliage. Thus there is an implication from the field trials, and evidence from the greenhouse and laboratory study, that elements besides nitrogen need to be added to provide proper nutrition on these volcanic ash soils. The information can aid in guiding further fertilizer trials in forests on volcanic ash derived soil in SW Oregon and elsewhere.

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**115.** Weetman, G.F., C.E. Prescott, F.L. Kohlberger and R.M. Rournier. 1997. Ten-year growth response of coastal Douglas-fir on Vancouver Island to N and S fertilization in an optimum nutrition trial. Canadian-Journal-of-Forest-Research 27(9): 1478-1482.

**Keywords:** fertilization  
growth  
yield  
tree physiology

**Abstract:** A 27-year-old stand of coastal Douglas fir (*Pseudotsuga menziesii*) on Vancouver Island, British Columbia, was fertilized four times (1981, 1983, 1986 and 1988) with N as urea at six rates from 0 to 250 kg N/ha, with and without S coating (0-50 kg/ha). Current-year foliage was collected annually during 1981-85 and in 1990. Foliar N levels declined in the control plots over the 10-year period, but remained elevated in the fertilized plots. The increase in foliar N concentrations was commensurate with the amount of N added. Stand basal area response increased with increasing rates of N addition. The greatest response in relative basal area net increment was 4.52 m<sup>2</sup>/ha (40%) in plots that received a total of 1000 kg N/ha during the 10 years. Over a 60-year rotation, about 62 m<sup>3</sup> of extra wood would be produced under this regime. There was no additional response to S added in conjunction with N, so the N + S plots received only a single application of fertilizer. Mortality was confined to smaller suppressed stems, mostly of species other than Douglas fir. Foliar N concentrations and basal area increment declined steadily following cessation of fertilizer application in these plots, but remained greater than those in control plots for the 10-year measurement period. The results suggest that sustained increases in growth response of Douglas fir can be achieved through repeated additions of N that maintain elevated concentrations of N in foliage.

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116. Woodruff, D.R., B.J. Bond, G.A. Ritchie and W. Scott. 2002. Effects of stand density on the growth of young Douglas-fir trees. *Canadian-Journal-of-Forest-Research* 32(3): 420-427.

**Keywords:** planting operations  
growth  
photosynthesis  
tree physiology

**Abstract:** The objectives of this study were (i) to provide further evidence of a positive correlation of stand density with early growth of coastal Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*); (ii) to determine when after planting the positive growth response occurs and how long it lasts; and (iii) to use stable isotopes of carbon to test whether the mechanism(s) responsible for the positive growth response to density are related to variables affecting photosynthesis, such as nutrient or moisture availability. We measured annual height (h) and diameter (d) growth (retrospectively) of 8- and 12-year-old trees in initial planting densities of 300, 1360, and 2960 trees/ha. Both height and diameter growth increased with density through the fifth year after planting and decreased with density by year 7. Diameter squared x height (d<sup>2</sup>h) was used as a volume index to assess increase in tree volume. Second-year increase in d<sup>2</sup>h for the high-density treatments was 300% of that in the low-density treatments. The delta 13C values of wood cellulose from annual rings of the second and third years after planting were not significantly different among densities, suggesting either (i) no significant differences in the effects of water availability, nutrient availability, or source air on photosynthesis in the three density treatments or (ii) differences that produced no net effect on delta 13C.

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117. Zhang, J.W., J.D. Marshall and B.C. Jaquish. 1993. Genetic differentiation in carbon isotope discrimination and gas exchange in *Pseudotsuga menziesii*. A common garden experiment. *Oecologia* 93(1): 80-87.

**Keywords:** genetic tree improvement  
photosynthesis  
tree physiology

**Abstract:** Seeds were collected in 1966 from 25 naturally regenerated Douglas fir (*Pseudotsuga menziesii*) stands across its range in the USA and Canada (from 33 degrees 30' N to 53 degrees 12' N), from 170 m to 2930 m altitude, and from coastal and interior sites. Seeds were sown in spring 1972, and at 3 yr old seedlings were transplanted to the Trinity Valley tree breeding site, British Columbia. Photosynthesis (A), stomatal conductance to water vapour (g) and the ratio of intercellular to ambient CO<sub>2</sub> (ci/ca) were measured between 09.00 and 16.00 h on 30 May, 18 July and 1 September 1990. Light levels were above saturation for photosynthesis on these days. The relative abundance of 13C and 12C (carbon isotope discrimination; Delta ) ranged from 19.7‰ to 22.43‰ and was closely related to geographic location of seed source. There were no significant differences in Delta between the coastal and interior varieties. Most variation occurred within the interior variety; populations from the southern Rocky Mountains had the greatest discrimination (21.53%) and the lowest water use efficiency. Delta , g, ci/ca and intrinsic water use efficiency (A/g) were all correlated with altitude of origin and height and diameter at 15 yr. Observed patterns in the common garden did not conform to



expectations of higher water use efficiency (measured by both  $A/g$  and  $\Delta$ ) in trees from the drier habitats of the interior, nor did they agree with published in situ observations of decreasing  $g$  and  $\Delta$  with altitude. The genetic effect counteracts the altitudinal effect, leading to some degree of homeostasis in physiological characteristics in situ.

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