

Tree Phenology

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. 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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4. 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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5. Birot, Y. and C. Christophe. 1983. Genetic structures and expected genetic gains from multitrait selection in wild populations of Douglas fir and Sitka spruce. I. Genetic variation between and within populations. *Silvae-Genetica* 32(5/6): 141-151.

Keywords: genetic tree improvement
genetic relationships
growth
tree phenology
tree morphology

Abstract: For Douglas fir, 371 open-pollinated progenies from 26 provenances ranging from N. to S. along the western foothills of the Cascade Mts., Washington, were tested. For Sitka spruce, 292 open-pollinated progenies from 21 provenances ranging from S. British Columbia to middle-Oregon were tested. Observations were made on growth, phenology and form from the nursery stage up to age 12. Classical patterns of geographic variation were observed for both species. Heritability and genetic correlations varied from one provenance to another, especially for Douglas fir, and also changed over time. Sitka spruce showed high additive effects, offering good prospects of future genetic gains. It was concluded that preliminary investigations on genetic parameters were necessary before setting up a breeding strategy.

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6. Blake, J.I., R. Linderman and D. Lavender. 1988b. Seedling vigor of Douglas fir and western hemlock in relation to ethylene exposure levels and ethane production during cold storage. *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. 235-242.

Keywords: nursery operations
tree morphology
tree phenology
tree/stand health

Abstract: The effects were examined of ethylene treatment on *Pseudotsuga menziesii* and *Tsuga heterophylla* 2-yr-old bare root seedlings lifted in October or December (in a nursery in Washington) and stored for 2 and 7 days. Seedlings exposed to 0.5 p.p.m. ethylene at +1 degrees C for 7 days exhibited reduced bud and root activity. These effects were apparently reversed at 5.0 p.p.m. In a second experiment, reducing ethylene concentrations with KMnO₄ during storage at +1 or +10 degrees C for 30 days did not affect foliage colour, but root and bud activity were generally enhanced. Ethylene concentrations in control bags ranged from 0.80 to 2.24 p.p.m. in October-lifted seedling bags and from 0.10 to 1.3 p.p.m. in December-lifted samples. The quantity of ethane in stored bags of *P. menziesii* seedlings was closely related to an increase in foliage discoloration. Little or no ethane was measured in *T. heterophylla* storage bags.

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7. Blake, J.I. and R.G. Linderman. 1992. A note on root development, bud activity, and survival of Douglas-fir, and survival of western hemlock and noble-fir seedlings, following exposure to ethylene during cold storage. *Canadian-Journal-of-Forest-Research* 22(8): 1195-1200.

Keywords: nursery operations
tree morphology
tree phenology
tree/stand health

Abstract: Three cold storage experiments were conducted with bare-root (2+0) Douglas fir (*Pseudotsuga menziesii*) seedlings from coastal Oregon and eastern Washington Cascade sources. The objectives were to determine the effects of ethylene at ambient and below-ambient (absorbed by KMnO₄ pellets) concentrations, and at 0.5 and 5 p.p.m. ethylene, during short-term storage on subsequent root development and bud activity, and to relate these results to survival in the field at sites in Washington and Oregon, after prolonged cold storage. Root numbers and lengths were measured 28 days after a 7-day storage period after lifting seedlings on 27 September and 1 December. In the coastal source, root numbers and lengths in the 5 p.p.m. ethylene treatment were, respectively, 46 and 49% greater in September, and 22 and 13% greater in December, than the controls. No comparable treatment effects were found for the Cascade source. Neither the KMnO₄ nor the 0.5 p.p.m. ethylene treatments affected root development in either seed source. For terminal buds in the controls, the number of days to 50% bud break was increased 2-8 days by a 30-day cold storage period compared with a 7-day period. For the coastal source, no increase in the time to 50% bud break was observed in the 5 p.p.m. ethylene treatment. Seedling survival was evaluated in the field for the same treatments following 4 months cold storage for the Douglas fir sources, coastal western hemlock (*Tsuga heterophylla*), and noble fir (*Abies procera*). Survival for the 5 p.p.m. ethylene treatment compared with the control was increased by 55% in the coastal Douglas fir source and by 13% in western hemlock. These results suggest that stimulated root development and bud activity may be partially responsible for the observed survival increase following cold storage at elevated ethylene levels.

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8. Childs, S.W. and L.E. Flint. 1987. Effect of shadecards, 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 shade cards 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 shade cards 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. Shade cards 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. Shade cards did not significantly affect seedling stomatal resistance. Differences in seedling survival caused by shade cards 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. Shade cards modify the soil temp. less extensively and so have less effect on seedling survival.

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9. Copes, D.L. 1983. Failure of grafted Douglas-fir planted at Monterey, Calif. *Tree-Planters' Notes* 34(3): 9-10.

Keywords: genetic tree improvement
tree grafting
growth
tree/stand health
tree phenology

Abstract: Trees were grafted onto established rootstocks (grown from rooted cuttings from Oregon or seedlings from California) in Oregon in April 1979, and in Dec. 109 of these were transplanted to a site on the Monterey Peninsula, California. Grafts were examined in July 1981. More than 30% of the transplanted grafts had died of early incompatibility and the cumulative 1980 and 1981 leader growth of the survivors averaged 12 cm. Identical grafts in Oregon showed 2-10% death due to incompatibility and av. leader growth of 1-2 m. It is suggested that the atypical unreliable budflush and reduced leader elongation in Monterey was due to winter temperatures that were not cool enough to satisfy bud dormancy requirements. It had been hoped to establish seed orchards out of range of pollen contamination from local Douglas fir stands.

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10. Copes, D.L. and R.A. Sniezko. 1991. The influence of floral bud phenology on the potential mating system of a wind pollinated Douglas-fir orchard. *Canadian Journal of Forest Research* 21(6): 813-820.

Keywords: genetic tree improvement
tree phenology
reproduction
genetic relationships

Abstract: Reproductive bud phenology was recorded from 1983 to 1989 in a Douglas fir (*Pseudotsuga menziesii*) clonal orchard near Monmouth, Oregon. Potential outcross efficiency was calculated for 20 clones from dates of male and female bud opening and pollination mechanism information. Potential outcross efficiency was limited to a maximum of 58% (1983) to 87% (1987). Cool weather before bud opening of the earliest clones delayed and compressed the breeding period and resulted in a greater percentage of trees having synchronous periods of pollen release and receptive seed strobili. Length of breeding season among years averaged 20 days and ranged from 16 to 27 days. Differences in phenology significantly affected the breeding system because the overall breeding period of the orchard clones exceeded the 8-day receptive period of individual clones by two or three times, and often prohibited or limited potential outcrossing between the earliest and latest clones. Outcrossing was greatest in clones with intermediate phenology and least in the earliest clones. The breeding system appears to be an almost continuous series of overlapping breeding subpopulations. Each year's breeding subpopulations were different from those of other years because of (1) large shifts in rank order of bud opening by 10 to 20% of the clones and (2) differences in the length of breeding season. Average temperature during March was linearly associated with time of floral bud opening. Geneticists may be able to use average temperature of the 4-week periods prior to opening of the earliest floral buds as a tool to identify seed crops formed during years with compressed breeding seasons. Such seed crops are potentially more diverse than seed crops produced during years with extended breeding seasons.

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11. Copes, D.L. 1999. Breeding graft-compatible Douglas-fir rootstocks (*Pseudotsuga menziesii* (MIRB.) FRANCO). *Silvae-Genetica* 48(3/4): 188-193.

Keywords: genetic tree improvement
tree grafting
tree/stand protection
growth
tree phenology
tree/stand health
genetic relationships

Abstract: A study encompassing 24 years was conducted to determine if a breeding programme could produce highly graft-compatible rootstocks for *P. menziesii*. A total of 27 trees of apparent high graft compatibility were selected and crossed to produce 226 control-pollinated families. Seedlings were grown, field planted and grafted with test scions. Graft unions from field tests were evaluated anatomically for internal symptoms of incompatibility. Average compatibility of progeny from the 226 crosses was 90.6%, compared with 65% in native populations. Breeding values were calculated for each parent by the best linear prediction (BLP) procedure. Average compatibility resulting from crossing among the top 10 parents was estimated by breeding values as 95.4%. Field-test results of progeny from 34 crosses among the 10 most compatible parents showed 96% compatibility. In addition to field-tests for graft compatibility, nursery tests of seedlings from 124 crosses were evaluated for second-year vegetative bud flush and seedling height. It was possible, while maintaining adequately high levels of graft compatibility, to breed both for resistance to spring frost damage and for increased seedling height.

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12. Dunsworth, B.G. 1988. Douglas-fir fall root phenology: a bioassay approach to defining planting windows. 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. 295-307.

Keywords: planting operations
growth
tree/stand health
tree phenology

Abstract: Natural seedling root phenology during the autumn and spring was observed in Douglas fir [*Pseudotsuga menziesii*] and western hemlock [*Tsuga heterophylla*] over several seasons on Vancouver Island, British Columbia. These observations were used to determine the soil climate conditions under which peak activity occurred. Mitotic indexing and total root tip counts were used to quantify root activity. Peak activity for both spring and autumn in both species could be reasonably bracketed by soil climate conditions of -1 bar soil tension and 4 degrees C. The hypothetical planting window defined by these soil climate conditions was then tested with a series of timing of planting studies for Douglas fir (autumn) and western hemlock (spring) containerized stock. The results indicated that although quality of planting stock and the season following planting are influential, a 10 to 15% survival and growth advantage can be gained by planting within the hypothetical window.

[Non-OSU Link](#)

13. Duryea, M.L. and S.K. Omi. 1987. Top pruning Douglas-fir seedlings: morphology, physiology, and field performance. *Canadian-Journal-of-Forest-Research* 17(11): 1371-1378.

Keywords: nursery operations
nursery pruning
tree phenology
tree/stand health
growth
yield

Abstract: Seedlings from 9 seed sources at 6 nurseries in Washington, Oregon and California were treated with various pruning treatments including tall and short ht. (25 and 15 cm, respectively), early and late timing (6 wk after bud burst or 6 wk after bud set, respectively), pruning twice or no pruning. Seedlings were evaluated for phenology and quality, and graded in the nursery. For each seed source, seedlings were planted at field sites in their own zone and on one common site. Seedlings pruned tall and early began growing again within 5 wk and set buds 2 wk later than unpruned seedlings. Shippable yield of seedlings pruned tall and early and of unpruned seedlings were n.s.d, although more pruned seedlings had multiple leaders. Pruned seedlings were smaller than unpruned seedlings at the time of planting. Survival and growth were the same for pruned and unpruned seedlings in the 1st year after planting. Pruned seedlings grew more than unpruned seedlings in the 2nd year, but were still shorter after 2 yr. Field growth was greater in seedlings pruned tall or early than in seedlings pruned short or

late. It is concluded that pruning should be continued as a cultural practice if it benefits nurseries, but that late short pruning should be avoided.

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14. Edwards, D.G.W. and Y.A. El-Kassaby. 1988. Effect of flowering phenology, date of cone collection, cone-storage treatment and seed pretreatment on yield and germination of seeds from a Douglas-fir seed orchard. *Forest-Ecology-and-Management* 25(1): 17-29.

Keywords: seed orchard management
reproduction
tree phenology

Abstract: The effects were studied of reproductive phenology, date of cone harvest, cone storage and seed pretreatment on yield and germination of seeds from a Douglas fir seed orchard in Victoria, BC, Canada. Flowering phenology (early, intermediate or late) had no discernible effect on seed maturation. Higher germination and yields of filled seeds were obtained from cones collected in mid-Aug., approximately 2 wk prior to cone opening, than from cones collected just as they began to open. Seeds extracted immediately following harvest germinated better than those from cones stored for 2 months. Seeds from all treatments were dormant and responded to prechilling by exhibiting increased germination rates. The implications of these findings for cone-crop management are discussed.

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15. El Kassaby, Y.A., D.G.W. Edwards and D.W. Taylor. 1990b. Effect of water-spray cooling treatment in a Douglas-fir seed orchard on seed germination. *New-Forests* 4(2): 137-146.

Keywords: seed orchard management
reproduction
tree phenology

Abstract: As part of an assessment of seed orchard crop management practices, results are given of an experiment undertaken to test the effect of cooling treatment on germination in a 13-year-old full-sib Douglas fir (*Pseudotsuga menziesii*) seedling seed orchard at Saanichton, British Columbia, Canada. Overhead cooling by sprinklers during February-March, used in order to delay flowering, produced non-significant effects on germination capacity, germination rate, germination value, and abnormal germination of seeds. The percentage of variation accounted for by cooling treatment ranged from 0.0 to 1.0%. In contrast, variation among trees within each treatment (i.e. cooled or not cooled) ranged from 28 to 46%. These effects were significant, indicating that each tree has an individual germination pattern. The temporal delay of reproductive phenology caused by temperature manipulation as a result of the cooling treatment was judged to be within the species' biological limits.

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16. El Kassaby, Y.A., A.M.K. Fashler and O. Sziklai. 1984. Reproductive phenology and its impact on genetically improved seed production in a Douglas-fir seed orchard. *Silvae-Genetica* 33(4/5): 120-125.

Keywords: seed orchard management
tree phenology
reproduction

Abstract: Reproductive phenology of buds was monitored for 2 yr in a Douglas fir seed orchard to determine the validity of the theory of panmictic equilibrium. There was a significant variation within clones and families in dates of seed-cone and pollen-cone bud burst, suggesting a major deviation from panmictic equilibrium. This would reduce the size of the breeding population and reduce seed yield. This effect could be reduced, and seed production maximized, either by the use of an irrigation mist system to delay bud development, or by the intensive application of booster pollination.

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17. El Kassaby, Y.A. and Y.S. Park. 1993. Genetic variation and correlation in growth, biomass, and phenology of Douglas-fir diallel progeny at different spacings. *Silvae-Genetica* 42(6): 289-297.

Keywords: genetic tree improvement
nursery operations
genetic relationships
growth
carbon allocation
tree phenology

Abstract: Parents of coastal Douglas fir (*Pseudotsuga menziesii*) selected from natural stands on sites ranging from 0 to 450 m altitude on Vancouver Island and in southeastern British Columbia were crossed and the resulting 104 full-sib families evaluated for 3 years after germination. The full-sib families were produced by a disconnected diallel mating scheme, consisting of 7 sets of 6-parent partial diallels, grown under 2 spacing treatments in a nursery. The objectives of the study were to determine the extent of genetic control of growth traits, biomass distribution and allocation strategies, and vegetative phenology. Spacing had a significant effect on 6 of the 11 traits studied. Significant GCA variance was found for all traits except 1-year height. Individual tree narrow-sense heritability varied from 0.06 to 0.69 for root dry weight and vegetative phenology, respectively. Spacing x family interaction variance was significant for only 2 traits. Two harvest indices, based on total and above-ground dry weights, were used to assess dry matter allocation strategy and to explore potential usefulness in tree breeding. Both indices had similar heritability estimates and their genetic correlation was high (0.91), indicating that use of an index based on above ground dry weight is a good surrogate for that based on total dry weight. Genetic correlations among growth and biomass traits were generally high, while those correlations with the harvest indices were variable.

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18. El Kassaby, Y.A. and K. Ritland. 1986. The relation of outcrossing and contamination to reproductive phenology and supplemental mass pollination in a Douglas-fir seed orchard. *Silvae-Genetica* 35(5/6): 240-244.

Keywords: genetic tree improvement
seed orchard management
tree phenology
genetic relationships
economics
reproduction

Abstract: A study was made using allozyme markers of outcrossing and contamination rates in relation to reproductive phenology and supplemental mass pollination in a Douglas fir seed orchard in British Columbia, Canada. Supplemental mass pollination was applied only to the intermediate reproductive phenology class, which showed a high outcrossing rate and no contamination. Both early and late reproductive phenology classes showed significant contamination, but the outcrossing rate for the former was significantly higher than for the latter. These results show that interpretation of seed crop genetic quality based on outcrossing alone could be misleading. The rate and source of contamination, reproductive phenology and crop size should also be considered. The practicability and economics of supplemental mass pollination in avoiding both selfing and contamination are discussed. It was concluded that waterspray cooling and/or supplemental mass pollination of early and late reproductive phenology classes in moderate or good cone-crop years would be an effective management practice. The option of aborting small cone crops in mature orchards is also discussed.

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19. Folk, R.S., S.C. Grossnickle, P. Axelrood and D. Trotter. 1999. Seed lot, nursery, and bud dormancy effects on root electrolyte leakage of Douglas-fir (*Pseudotsuga menziesii*) seedlings. *Canadian-Journal-of-Forest-Research* 29(8): 1269-1281.

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

Abstract: The effects of seed lot, nursery culture, and seedling bud dormancy status on root electrolyte leakage (REL) of Douglas-fir (*Pseudotsuga menziesii*) seedlings were assessed to determine if these factors should be considered when interpreting REL for seedling quality. The relationships of REL to survival, net photosynthesis (Pn), stomatal conductance (gwv) mid-day shoot water potential (Psi mid), root growth capacity (RGC), and relative height growth were determined for each factor in experiments in 1994-95 in nurseries in British Columbia. Nursery culture had no effect on the relationship between REL and all other measured attributes. Seed lot affected the relationship between REL and Pn, Psi mid, and survival. However, critical REL (i.e., lowest value associated with detectable root damage) and PS80 REL (i.e., level associated with an 80% probability for survival) were similar between seed lots. Bud dormancy status affected the relationship between REL and survival, RGC, and relative height growth.

Control levels of REL, critical REL, and PS80 REL decreased as the number of days required for 50% terminal bud break declined. Thus, terminal bud dormancy status must be known before REL can be used to assess seedling quality. If the bud dormancy status of Douglas-fir populations is known, then critical and PS80 REL levels may be useful as indices of root damage.

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20. Jermstad, K.D., D.L. Bassoni, K.S. Jech, N.C. Wheeler and D.B. Neale. 2001a. Mapping of quantitative trait loci controlling adaptive traits in coastal Douglas-fir. I. Timing of vegetative bud flush. *Theoretical-and-Applied-Genetics* 102(8): 1142-1151.

Keywords: genetic tree improvement
tree phenology

Abstract: Thirty-three unique quantitative trait loci (QTLs) affecting the timing of spring bud flush have been identified in an intraspecific mapping population of coastal Douglas-fir (*Pseudotsuga menziesii* var. *menziesii*) in a field experiment conducted in several sites in Washington and Oregon, USA, during 1995-98. Both terminal and lateral bud flush were measured over a 4-year period on clonal replicates at two test sites, allowing for the repeated estimation of QTLs. QTLs were detected on 12 linkage groups and, in general, each explained a small proportion of the total phenotypic variance and were additive in effect. Several QTLs influenced the timing of bud flush over multiple years, supporting earlier evidence that the timing of bud flush through developmental stages was under moderate to strong genetic control by the same suite of genes through developmental stages. However, only a few QTLs controlling the timing of bud flush were detected at both test sites, suggesting that geographic location plays a major role in the phenology of spring growth. A small number of QTLs with year and site interactions were also estimated.

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21. 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.

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22. Kaya, Z. 1992. The effects of test environments on estimation of genetic parameters for seedling traits in 2-year-old Douglas-fir. *Scandinavian-Journal-of-Forest-Research* 7(3): 287-296.

Keywords: genetic tree improvement
nursery operations
genetic relationships
growth
tree phenology

Abstract: The effects of test environments (dry versus wet) on the estimation of genetic parameters in seedling traits were studied in 160 open-pollinated families of Douglas fir (*Pseudotsuga menziesii*) from southwestern Oregon. Seedlings from four populations were grown in two test nursery environments between which a water potential difference of -9 bars was created over two growing seasons, by withholding water for 4 and 8 wk, respectively. Estimated genetic variances in most growth and phenology traits were considerably higher for seedlings grown in the wet environment than for those in the dry. Estimated genetic correlations between the same traits measured in different test environments indicated that most seedling traits studied for two growing seasons were genetically stable in both environments, suggesting that genotype environment interaction in these traits are weak. However, it is emphasized that the effect of test environment on estimation of genetic parameters in seedling traits, especially in adaptive seedling traits, should be evaluated very carefully when early evaluation of genetic entries is practised in Douglas-fir, since these traits (budburst timing, lammas growth and free growth) appear to be plastic in character.

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23. Kaya, Z., R.K. Campbell and W.T. Adams. 1989. Correlated responses of height increment and components of increment in 2-year-old Douglas fir. *Canadian-Journal-of-Forest-Research* 19(9): 1124-1130.

Keywords: genetic tree improvement
tree phenology
growth
genetic relationships

Abstract: The consequences for growth and phenology of early selection for height or its growth components were evaluated in 160 open-pollinated families of Douglas fir (*Pseudotsuga menziesii*) from SW Oregon. Seedlings from 2 inland and 2 coastal populations (40 families each) were grown for 2 growing seasons in a 'moist' and 'dry' nursery environment. Predicted response to selection suggests that risk of low juvenile-mature correlation and maladaptation with early selection would be less in the inland than in the coastal region. Early bud set in the 1st yr was genetically correlated with larger overwintering buds in seedlings from both inland and coastal regions. These larger buds yielded a large increment of predetermined growth in the 2nd yr, followed by little or no free growth and early bud set. Seedlings with late bud set in the 1st yr had the converse pattern. Inland seedlings set buds much earlier on av. than coastal seedlings, hence seedlings from the 2 regions had different growth patterns. Risks that can attend early selection for ht. generally would be decreased in both regions by selecting for predetermined growth, but several qualifications are discussed.

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[Non-OSU Link](#)

24. 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.

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25. 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.

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26. Li, P. and W.T. Adams. 1993. Genetic control of bud phenology in pole-size trees and seedlings of coastal Douglas-fir. *Canadian-Journal-of-Forest-Research* 23(6): 1043-1051.

Keywords: genetic tree improvement
genetic relationships
tree phenology
growth

Abstract: The extent to which bud phenology is genetically controlled and related to growth traits was examined in seedlings and pole-size trees of coastal Douglas-fir (*Pseudotsuga menziesii* var. *menziesii*). Data on bud burst, bud set, and stem growth were collected from pole-size trees of 60 open-pollinated families growing in four plantations in Oregon, and from seedlings of 45 of these same families growing in a bare-root trial in Washington, and greenhouse and transplant trials in Washington and Oregon. In both age-classes, bud burst was under moderate to strong genetic control ($r^2 \geq 0.44$) and family breeding values were stable across test environments, indicating that this trait could be readily altered in breeding programmes. Bud set was inherited strongly in pole-size trees ($r^2 = 0.81$) but weakly in seedlings ($r^2 \leq 0.30$). Both bud burst and bud set were positively correlated with growth in seedlings and pole-size trees. Thus, selection for greater growth at either age-class is expected to delay bud burst and bud set. An evaluation was made of the accuracy of two alternatives for assessing bud burst phenology in pole-size trees compared with the traditional method. It was shown that bud-burst date on lateral branches can be used to rank accurately both individuals and families for bud-burst date on less accessible leader shoots. In addition, it was found that families can be ranked for mean bud-burst date by the proportion of trees per family that have flushed on a given scoring day. This method is only effective, however, when between 25 and 75% of all trees in the test have flushed at the time of scoring.

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27. Li, P. and W.T. Adams. 1994. Genetic variation in cambial phenology of coastal Douglas-fir. *Canadian-Journal-of-Forest-Research* 24(9): 1864-1870.

Keywords: genetic tree improvement
genetic relationships
tree phenology
growth

Abstract: The objectives of this study were to (i) determine the extent of genetic variation and genetic control of cambial phenology in coastal Douglas fir (*Pseudotsuga menziesii* var. *menziesii*), (ii) assess the degree to which cambial phenology is genetically related to bud-burst timing, (iii) examine genetic relationships between cambial phenology and growth traits, and (iv) evaluate the potential for indirectly altering cambial phenology in breeding programmes when selection is for stem volume. Dates of diameter-growth initiation and cessation, and duration of diameter growth (i.e., cambial phenology traits), as well as diameter increment for the 1987 growing season (15-yr-old), were estimated from cumulative diameter growth curves of individual trees of 60 open-pollinated families growing in one plantation in Oregon. Data on stem height and diameter at breast height (d.b.h.), and date of bud burst in 1987 were also collected. Dates of diameter-growth initiation and cessation differed significantly among families, but had lower estimated individual heritabilities (≤ 0.23) than date of bud burst (0.87). Weak genetic correlations between date of bud burst and dates of diameter-growth initiation and cessation (range -0.09 to 0.26) indicate that timing of diameter growth cannot be reliably predicted from observations of the more easily measured bud burst. Cambial phenology traits were weakly correlated with 1987 diameter increment and moderately correlated with 15-year d.b.h. and volume. Selection of parents in this study for stem volume at age 15 and subsequent crosses among them, would be expected to lead to earlier initiation of diameter growth in the offspring, and possibly later cessation as well. The practical implications of these indirect responses in terms of increased risk of frost damage are unclear, since projected changes are small (i.e., a few days).

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28. 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*), lodgepolepine (*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.

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29. MacDonald, J.E. 1996. Early development of bud dormancy in conifer seedlings. *In* Plant dormancy: physiology, biochemistry and molecular biology. *Ed.* G.A. Lang. Wallingford, UK: CAB INTERNATIONAL. pp. 193-199.

Keywords: nursery operations
tree phenology

Abstract: A study is reported on 1-yr-old coastal Douglas fir (*Pseudotsuga menziesii* var. *menziesii*) nursery seedlings on Vancouver Island, British Columbia, with the aim of determining whether there was a difference in dormancy development in response to short-day or moderate moisture stress treatments. Successful dormancy induction was obtained during the first week of both types of treatment, but the phenology of dormancy development was different, being earlier in the short-day treatment. Of the short-day treatments tested (3-6 wk), dormancy development was earliest for the 4-wk duration.

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30. 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.

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31. McCreary, D.D., D.P. Lavender and R.K. Hermann. 1990. Predicted global warming and Douglas-fir chilling requirements. *Annales-des-Sciences-Forestieres* 47(4): 325-330.

Keywords: genetic tree improvement
nursery operations
tree phenology
growth

Abstract: Containerized Douglas fir (*Pseudotsuga menziesii*) seedlings from warm coastal and cool mountainous Oregon seed sources, grown under natural conditions, were chilled at constant temperatures of 5, 7 or 9 degrees C for 9, 11, 13 or 15 weeks beginning in mid-October. After a growth period of 9 weeks following chilling, degree of budbreak and dry weight of new shoot growth were measured. The longest and coldest chilling treatment produced the greatest growth response for all seed sources. Results are discussed with reference to predicted global warming, in particular the potential difficulty of reducing Douglas fir chilling requirements through tree breeding programmes.

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32. 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.

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33. Miller, G.E. 1983a. Evaluation of the effectiveness of cold-water misting of trees in seed orchards for control of Douglas-fir cone gall midge (Diptera: Cecidomyiidae). *Journal-of-Economic-Entomology* 76(4): 916-919.

Keywords: seed orchard management
tree/stand protection
tree/stand health
tree phenology

Abstract: The effectiveness of misting trees with cold water in delaying reproductive bud burst of Douglas fir (*Pseudotsuga menziesii*) and consequently controlling *Contarinia oregonensis* Foote was evaluated in tests in seed orchards in British Columbia in 1978-80. The misting treatment reduced the amount of damage to the same degree as was achieved with sprays of dimethoate when a 10-day delay in seed-cone bud burst coincided with the earliest 'flowering' trees being the most heavily attacked. Gall midge damage was not reduced to an acceptable level with less than a 10-day delay or when later-flowering trees were the most heavily attacked. It was not possible to determine the likely effectiveness of cold-water misting before bud burst in a given year, because the period of bud-burst delay varied with weather and because synchrony between presence of adult midges and susceptible host-tree stage was not consistent.

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34. O'Neill, G.A., S.N. Aitken and W.T. Adams. 2000. Genetic selection for cold hardiness in coastal Douglas-fir seedlings and saplings. *Canadian-Journal-of-Forest-Research* 30(11): 1799-1807.

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

Abstract: Genetic control of cold hardiness in two-year-old seedlings in a nursery in Oregon, USA, was compared with that in 7-year-old field saplings, for 40 open-pollinated families in each of two low-altitude breeding populations (Coast and Cascade) of coastal Douglas fir (*Pseudotsuga menziesii* var. *menziesii*) from western Oregon. The field trials were also in the Coast and Cascade breeding zones of Oregon (7 and 6 sites, respectively). In addition, the efficacy of bud phenology traits as predictors of cold hardiness at the two stages was explored. Autumn and spring cold hardiness were assessed using artificial freeze testing. Similar genetic control of cold hardiness in seedlings and saplings is suggested by strong type-B genetic correlations (r_B) between the two ages for autumn and spring cold injury traits ($r_B < \text{more or } \Rightarrow 0.78$) and by similar trends in individual tree heritability estimates (h^2), e.g., h^2 was greater in spring (mean 0.73) than in autumn (mean 0.36) and greater in the Coast population (0.69) than in the Cascade population (0.40) at both ages. Strong responses to direct selection are expected for spring cold hardiness at both ages and for autumn cold hardiness in seedlings, even under mild selection intensities. Similar heritabilities in seedlings and saplings, and strong genetic correlations between ages for cold-hardiness traits, ensure that selection at one age will produce similar gains at the other age. Type-A genetic correlations (r_A) between autumn and spring cold hardiness were near zero in the Cascade population (0.08 and -0.14 at ages 2 and 7, respectively) but were moderate and negative in the Coast population (-0.54 and -0.36, respectively).

Bud-burst timing appears to be a suitable surrogate to artificial freeze testing for assessing spring cold hardiness in both seedlings and saplings, as is bud set timing for assessing fall cold hardiness in seedlings, but bud set timing is a poor predictor of fall cold hardiness in saplings.

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35. 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.

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36. 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 gibberellinA4 + 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.

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37. 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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38. Riitters, K.H. and D.A. Perry. 1987. Early genetic evaluation of open-pollinated Douglas-fir families. *Forest-Science* 33(2): 577-582.

Keywords: genetic tree improvement
genetic relationships
growth

tree phenology

Abstract: A summary is given of experiments to determine the correlation of seed wt. and growth and phenology of seedlings of 14 families in a cold frame with ht. of saplings from earlier seed crops of the same families in 5 plantations at 9, 12 and 15 yr old. With some exceptions, correlations of seedling variables with field ht. were poor. Highest correlations with 15-yr ht. were for budset at 117 days, ht. and branching index of seedlings. Seedling growth and phenology values were generally poorly correlated with seed wt. Seedling/sapling correlations, however, were related to seedling/seed wt. correlations. Seedling/sapling correlations improved between 9 and 15 yr old.

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39. Ritchie, G.A. 1984. Effect of freezer storage on bud dormancy release in Douglas-fir seedlings. *Canadian-Journal-of-Forest-Research* 14(2): 186-190.

Keywords: nursery operations
tree phenology
tree/stand health

Abstract: Two-yr-old seedlings from 4 western Washington and Oregon provenances were lifted from the nursery on Dec. 11, 1979 and Jan. 21, Feb. 13 and March 11, 1980, following the accumulation of about 600, 1170, 1550, and 1800 chilling hours (temp. less than 5 degrees C), respectively. They were tested for bud dormancy intensity and vigour immediately after lifting and following 2 and 6 months in freezer (-1 degrees C) storage. Dormancy weakened exponentially with accumulated nursery chilling, with seedlings from all 4 provenances responding similarly. The rate of dormancy release was substantially retarded by freezer storage, so that by late March stored seedlings were more dormant than those remaining in the nursery beds. Dormancy weakened in storage more rapidly in high-altitude provenances than in provenances from lower altitudes. Early-lifted seedlings lost dormancy more rapidly in storage than did late-lifted seedlings. Vigour following a 6-wk greenhouse trial was good or excellent in all but the Dec.-lifted unstored seedlings and the March-lifted unstored and 6-month stored seedlings.

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40. Ritchie, G.A. 1986. Relationships among bud dormancy status, cold hardiness, and stress resistance in 2+0 Douglas-fir. *New-Forests* 1(1): 29-42.

Keywords: nursery operations
tree/stand protection
growth
tree/stand health
tree phenology
carbon allocation

Abstract: Seedlings were lifted from a western Washington nursery on six dates spanning the 1980-81 lifting season. On each date samples of seedlings were subjected to the following treatment: tumbling

for 5 min, desiccation of roots for 30 min at 30 degrees C and 2.1kPa vapour deficit, exposure of shoots to temp. of -10 degrees C, -15 degrees C or -20 degrees C for 2 h, and unstressed control. On two lift dates sub-samples of seedlings were placed into -1 degrees C storage and held for 2 months before the above treatments were administered. Bud dormancy status was determined, using a bud break test, on seedlings from each lift date before and after storage. After one growing season in the field, percent survival, vigour, height growth and shoot and root weight were determined on stressed and unstressed seedlings. Survival and vigour were less affected by treatments than were height and weight. Severity of stress was in the order -20 degrees C>-15 degrees C>desiccation> handling>-10 degrees C. Degree of cold injury was directly related to seedling dormancy status whether dormancy status had been attained in the nursery from natural chilling or in frozen storage. Seedlings in a mid-range of dormancy release (between deep rest and quiescence) were most resistant to all imposed stresses.

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41. 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](#)

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42. 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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43. Schermann, N., W.T. Adams, S.N. Aitken and J.C. Bastien. 1997. Genetic parameters of stem form traits in a 9-year-old coastal Douglas-fir progeny test in Washington. *Silvae-Genetica* 46(2/3): 166-170.

Keywords: genetic tree improvement
growth
wood quality
genetic relationships
tree phenology

Abstract: The genetic control of stem form traits was investigated in a 9-year-old progeny test comparing 80 open-pollinated families of *Pseudotsuga menziesii*, located in a fertile Pacific coast site in Washington, USA. In addition to stem form traits (internode sinuosity, and number of forks and ramicornes per tree), stem volume (height and DBH), bud phenology (earliness of budburst and budset), and occurrence of second flushing on the leader shoot (9th growing season) were measured. Trees with at least one fork or ramicorn were frequent (26% and 46%, respectively), as were trees with second flushing (26%). Most of the trees exhibited sinuosity of limited magnitude. Due to strong differences among family means and at least modest family heritabilities (0.35 to 0.66), all traits were found to be amenable to genetic improvement. The estimated genetic correlation (r_A) between

numbers of forks and ramicorns was relatively strong (0.54), and both forking defects traits exhibited similar genetic associations with other traits. Forking defects were strongly and positively associated with frequency of second flushing, a trait which in turn is positively and moderately correlated with both DBH (0.32) and earliness of budburst (0.39). These results are consistent with previous findings. Breeding consequences for simultaneous improvement of both stem volume and form are discussed.

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[Non-OSU Link](#)

44. 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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45. Sorensen, F.C. 1996. Effects of length of seed chilling period and sowing date on family performance and genetic variances of Douglas-fir seedlings in the nursery. *New-Forests* 12(3): 187-202.

Keywords: nursery operations
tree phenology
growth
tree/stand health

Abstract: Seeds of four full-sibling Douglas fir (*Pseudotsuga menziesii*) families (F) - randomly chosen from about 30 control-pollinated crosses in a second-growth stand in the central Oregon Cascade Range (USA) - were moist chilled (C) for 14, 33, and 77 days and sown (S) 29 March, 26 April, and 24 May at two densities (D = 111 and 200 seeds/m²), grown for 2 years in nursery beds and phenology and size traits recorded. The study was analysed in two parts: part I evaluated seed treatment effects and their interactions with families; and part II investigated the effect of treatments

on genetic variances, particularly among-family (σ^2_F) and within-plot (σ^2_w) components and the intraclass correlation for families (tf). In part I there were large and highly significant differences associated with C and S and among F for all traits. Early S combined with long C resulted in early emergence and gave large seedlings with little loss and damage. Many interactions between C and F, and S and F, were significant. Interactions involved rank changes for size but not for phenology traits, and were larger for CxF than for SxF. Seedling density affected seedling size but not phenology, did not interact with seed treatments, and interacted significantly but weakly with families. In part II, C and S, but not D, had significant effects on σ^2_F , σ^2_w , and tf, but not in a predictable manner. Because of significant interactions, it is recommended that standardized seed treatments be used in family nursery tests. This should help to keep the results from these tests as repeatable as possible. Long chilling and sowing as early as practicable are recommended to minimize disease losses and winter damages and to provide good nursery stock.

[OSU Link](#)

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46. Sorensen, F.C. 1997. Effects of sib mating and wind pollination on nursery seedling size, growth components, and phenology of Douglas-fir seed-orchard progenies. *Canadian-Journal-of-Forest-Research* 27(4): 557-566.

Keywords: genetic tree improvement
nursery operations
growth
tree/stand health
tree morphology
tree phenology

Abstract: Polymix outcross (X), full-sib (FS), and wind-pollination (WP) families were produced on 25 seed trees and 10 half-sib families on 10 of the same trees in a *Pseudotsuga menziesii* var. *menziesii* seedling seed orchard in Oregon. Seedlings were raised at 2 sowing densities for 2 years in the nursery, and inbreeding depression (ID) in seedling size related to inbreeding effect on growing season length and growth rate. Seedling mortality was light and not affected by inbreeding. Mean ID for 2-year size traits was 6% (height) and about 8% (diameter) per 10% increase in F, the inbreeding coefficient, and was linear with the increase in F over the range of F used. Both amount of ID and its fit to linearity differed greatly among seed trees. Elongation season was significantly and slightly shorter for FS than for X families; second-year relative elongation rate was nonsignificantly larger for FS than for X families. Inbred families had nonsignificantly larger within-plot variance and significantly larger coefficients of within-plot variance than X families. Sowing density was not a significant factor except in diameter and height/diameter ratio. Results are discussed in terms of plant growth habit and possible gene action. WP compared with X families were significantly shorter by 3.8% and significantly smaller in diameter by 4.6%, with much variation among family groups. About half of the height difference could be explained by seed weight; the remainder could have been due to pollen contamination or natural inbreeding. Progenies of the two pollen types did not differ for phenological traits, even though the seed orchard was in a drier, more inland location than the parent-tree locations. Progenies of WP had nonsignificantly larger within-plot variance than X progenies.

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47. St-Clair, J.B. and R.A. Snieszko. 1999. Genetic variation in response to shade in coastal Douglas-fir. *Canadian-Journal-of-Forest-Research* 29(11): 1751-1763.

Keywords: genetic tree improvement
growth
tree morphology
carbon allocation
tree phenology

Abstract: Tree improvement programmes have generally relied on testing families in open light environments. With increased interest in multiaged silvicultural systems, some people have questioned whether families selected in the open are appropriate for planting in the shade. Douglas-fir (*Pseudotsuga menziesii* var. *menziesii*) families from two climatically distinct seed sources in the Coast Range (NW Oregon) and Siskiyou Mountains (SW Oregon) were grown for 2 years under four levels of shade. The response to shade differed for several traits between the two populations and among families within populations. The magnitude of variation associated with the interaction, however, was small compared with the overall effects of genetic selection or of shade. Families selected based on performance in an open light environment resulted in nearly the same response to selection when grown under shade as families selected based on performance in the shade. It is concluded that seedlings from families selected in an open light environment are appropriate for use in the low-light environments of alternative silvicultural systems and that use of such genetically selected stock may compensate for the less favourable growing conditions. Genetic selection may contribute importantly to meeting multiple objectives, including the production of significant amounts of wood as well as the efficient and timely creation of large stand structures needed for other forest values.

[OSU Link](#)

[Non-OSU Link](#)

48. Stevenson, J.F., B.J. Hawkins and J.H. Woods. 1999. Spring and fall cold hardiness in wild and selected seed sources of coastal Douglas-fir. *Silvae-Genetica* 48(1): 29-34.

Keywords: genetic tree improvement
tree/stand protection
tree/stand health
tree phenology
growth

Abstract: Breeding for increased growth in coastal Douglas fir (*Pseudotsuga menziesii*) could affect the level of cold hardiness of seedlings used for reforestation. If increased growth is achieved by initiating growth earlier in the spring or prolonging growth later into autumn, cold hardiness could be reduced during these seasons. Cold hardiness was measured in top-cross and first generation seed orchard trees selected for increased growth rates, and wild stand trees on Vancouver Island and near Mission, BC, throughout one growing season by visual assessment of artificial freeze tests. Significant differences in freezing damage between genetically selected and wild stand trees were found during both spring and autumn. In April, LT50 of top-cross trees was 0.7-2.4 degrees C below that of wild stand trees, while in October, LT50 of wild stand trees was 1.9-3.4 degrees C below that of top-cross trees. Mitotic index was investigated as an indicator of dormancy, and a negative correlation between mitotic index and cold hardiness was found. A significant difference in mitotic index between the genetic groups was found

once in March when mitotic index in wild stand and seed orchard trees was 1.4% and mitotic index in top-cross trees was 0.9%. There were no significant differences in mitotic index at any other times during the year. Date of bud burst and rates of shoot extension were related to levels of cold hardiness in the three groups of seedlings. The stage of bud burst in May was significantly correlated with levels of hardiness found earlier in March and April. Trees that completed shoot extension earlier in the season were significantly more hardy in autumn. Top-cross trees may extend their growing season later into the fall, thereby gaining a height advantage over wild stand seedlings. These top-cross families do not have an increased mid to late autumn frost damage risk, and in fact may have reduced risk of critical spring frost damage due to delayed deacclimation.

[OSU Link](#)

[Non-OSU Link](#)

49. Stonecypher, R.W., R.F. Piesch, G.G. Helland, J.G. Chapman and H.J. Reno. 1996. Results from genetic tests of selected parents of Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) in an applied tree improvement program. *Forest-Science-Monograph* (32): 35.

Keywords: genetic tree improvement
planting operations
growth
tree phenology
genetic relationships

Abstract: Results from genetic tests, and genotype x environment interaction studies in six low-elevation breeding zones of Weyerhaeuser Company's Western Washington and Oregon Douglas fir (*Pseudotsuga menziesii*) tree improvement programme are summarized. Phenotypic selection in natural stands resulted in a 5% improvement in juvenile height over nonselect seed lots. Comparisons with nonselect sources, of offspring from parents in the top 50% performers in tests, indicated a 10% increase for the same trait. Seed produced in a 50% rogued seed orchard is thus expected to provide improved planting stock with a gain of 10% in juvenile height growth. Several select parents are producing offspring that are consistently performing in excess of 10% over nonselects. Estimates of breeding zone, breeding zone by location, and family by location interaction effects are small relative to family and planting location effects. Tests of families established on environmentally diverse sites indicate a striking lack of large family by planting location interaction. In tests showing statistically significant interactions, such interactions are caused by a relatively small number of families. Earlier budbreak and a higher spring frost susceptibility of Oregon sources established on Washington sites were observed. It is concluded that allocation and utilization of select families within Weyerhaeuser's Oregon and Washington ownership should not be constrained by the currently defined breeding zone boundaries, but based on parental performance and stability for growth and adaptive traits in general. It is suggested that the necessity for maintaining separate breeding zones, within Washington and Oregon, in subsequent cycles of recurrent selection is questionable. Average individual tree heritability, from 65 6-parent disconnected diallels, is 0.13 for age 6 and age 8 height. Dominance genetic variance is estimated to be one-half that of additive genetic variance for the same traits.

[OSU Link](#)

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50. Tung, C.H., L. Wisniewski and D.R. DeYoe. 1986b. Effects of prolonged cold storage on phenology and performance of Douglas-fir and noble fir 2+0 seedlings from high-elevation sources. *Canadian-Journal-of-Forest-Research* 16(3): 471-475.

Keywords: nursery operations
tree phenology
tree/stand health
growth
carbon allocation

Abstract: Seedlings of Douglas fir and noble fir (*Abies procera*) were lifted on 7 Nov. 1981 and 1 Mar. 1982 at Wind River Nursery, Washington, and stored at 1-2 degrees C until planting during the third week of June 1982 at 1500 m alt. in the Oregon Cascade Range. There was no difference in survival of Douglas fir attributable to storage treatment during the first two growing seasons. Noble fir seedlings stored for 7 months survived better during the first season than seedlings stored for 3 months, but no difference was evident after the second growing season. Time of bud burst did not differ between treatments for either species and no difference between treatments in rate of bud burst was seen in Douglas fir. Rate of bud burst was significantly greater in noble fir seedlings stored for 7 months than in those stored for 3 months. Shoot/root ratio decreased significantly during the first season for both species and treatments, but stabilized during the second season. Regardless of species, no differences were found in ht. growth and diam. increment between storage treatments. Results suggest that seedlings of these species originating from high alt. sources can be lifted in autumn and cold-stored for 7 months without adverse effects on performance after planting.

[OSU Link](#)

[Non-OSU Link](#)

51. 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.

[OSU Link](#)

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52. Vargas-Hernandez, J. and W.T. Adams. 1994. Genetic relationships between wood density components and cambial growth rhythm in young coastal Douglas-fir. *Canadian-Journal-of-Forest-Research* 24(9): 1871-1876.

Keywords: genetic tree improvement
genetic relationships
wood quality
tree phenology
growth

Abstract: Genetic relationships of wood density, and its components, with cambial growth rhythm traits were examined in a 15-year-old progeny test of coastal Douglas fir (*Pseudotsuga menziesii* var. *menziesii*) in Oregon, in an attempt to better understand the genetic control of wood formation, and to assess the potential effect of selecting for increased wood density on adaptation of trees. Timing of diameter growth during the 1987 growing season was determined in an earlier study, and wood formation traits were estimated by X-ray densitometry of increment core samples. Wood formation traits were under weak genetic control ($r^2 < 0.20$). Duration of earlywood and latewood formation were mostly determined by the timing of latewood transition. Overall core density was negatively correlated with the dates of cambial growth initiation ($r_A = -0.41$) and latewood transition ($r_A = -0.62$), and positively correlated with the date of cambial growth cessation ($r_A = 0.40$). As a result of these relationships, higher wood density was associated with a longer duration of cambial growth ($r_A = 0.67$) and a slower rate of wood formation ($r_A = -0.37$). All density components showed similar relationships with cambial phenology and wood formation traits. Selection for increased wood density is expected to cause only a slight extension of the cambial growth period, but it would also cause an earlier transition to latewood formation, negatively affecting growth rate.

[OSU Link](#)

[Non-OSU Link](#)

53. White, T.L. 1987. Drought tolerance of southwestern Oregon Douglas-fir. *Forest-Science* 33(2): 283-293.

Keywords: genetic tree improvement
tree/stand protection
tree phenology
tree/stand health

Abstract: Seedlings of 2 open-pollinated families from each of 36 seed sources were tested for their ability to survive simulated drought in a growth room, greenhouse and cold frame. Generally, seedlings of sources from higher alt. and, to a lesser extent, drier sites were more drought tolerant. Seedlings

from drought-tolerant sources tended to have earlier bud set, smaller initial ht. and less winter injury (needle mortality). The main selective force leading to earlier bud set and smaller ht. growth appeared to be the colder temp. regime at higher alt. Seedlings from higher alt. entered dormancy sooner and were better able to survive drought.

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