Nursery Fertilization

1. 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 (NH4NO3+K2SO4 and (NH4)2SO4+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 NH4NO3+K2SO4. 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 outplantingperformance after one growing season.

OSU Link
Non-OSU Link

2. 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 CO2 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.

OSU Link
Non-OSU Link

3. 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 ofmycorrhiza.

OSU Link
Non-OSU Link

4. 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.

OSU Link
Non-OSU Link

5. 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 ectomycorrhizalfungi 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 substanceconcn. 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 Thelephoraseedlings. 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 inectomycorrhizal Douglas fir, despite lower zeatin riboside concentrations for Laccaria-inoculated plants.

OSU Link
Non-OSU Link

6. Donald, D.G.M. and D.G. Simpson. 1985. Shallow conditioning and late fertilizer application effects on the quality of conifer nursery stock in British Columbia. B.C.-Ministry-of-Forests Research-Note 99. viii + 36 p.

Keywords: nursery operations
nursery fertilization
tree/stand protection
tree morphology
tree/stand health

growth

Abstract: Eight trials on 2+0 stock of Picea engelmannii, P. glauca,
P. sitchensis, Pinus contorta and Pseudotsuga menziesii (var. glauca and var. menziesii) in 4 nurseries were conducted to compare the effects of shallow conditioning (undercutting and wrenching at 10 cm deep) with those of the standard conditioning regime (undercutting and wrenching at 20 cm) on nursery performance, storage and field performance. The application of a complete NPK fertilizer 50 days before lifting was also evaluated. Shallow conditioning and late fertilizer application improved the root growth capacity at lifting, but could not replace cold exposure for hardening Pseudotsuga menziesii. Shallow conditioning had little effect on survival after planting and reduced initial ht. increment of all species. Application of fertilizer just before lifting improved the early growth of the trees without adversely affecting survival. Planting seedlings some 5 cm deeper than they stood in the nursery improved establishment.

7. 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 unirrigatedloam 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 capcity. Cold hardiness (measured by electrical impedance) was correlated with survival of cold-stored trees after planting (rsuperscript 2 = 0.82). Root growth capacity, averaged over all fertilizer treatments was closely correlated with survival of stored

and freshly lifted trees (rsuperscript 2 = 0.93). Foliar nutrient concn. were reduced by wrenching, but fertilizing increased nutrient reserves within the seedling.

OSU Link
Non-OSU Link

8. 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.

OSU Link
Non-OSU Link

9. 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, ammoniumsulphate 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 NO3 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.

OSU Link
Non-OSU Link

10. 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.

OSU Link
Non-OSU Link

11. Driessche, R.v.-d. 1992b. Changes in drought resistance and rootgrowth 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.

OSU Link
Non-OSU Link

12. Dunsworth, B.G. 1985. Three-yr survival and height growth of 2+0 bareroot Douglas-fir seedlings treated with a Symbex root dip. Tree-Planters' Notes 36(1): 24-25.

Keywords: nursery operations
nursery fertilization
growth
tree/stand health

Abstract: Seedling roots were dipped in a sol. of Symbex [a stimulant containing fertilizer and microorganisms?] diluted 40:1 with water, or water before planting out in May 1980 on Vancouver

Island, British Columbia. Although the ht. growth of Symbex-treated trees was significantly greater in 1981, there were n.s.d. in total ht., ht. growth or survival after 3 growing seasons.

OSU Link
Non-OSU Link

13. Gagnon, J., C.G. Langlois, D. Bouchard, F.l. 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.

OSU Link
Non-OSU Link

14. 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 NO3- (and total N) and assigned to one of four treatments: unamended control; amendment with 60 mg kg-1 (NH4)2SO4; amendment with 15 mg kg-1 of the nitrification inhibitor dicyandiamide (DCD) or amendment with both (NH4)2SO4 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 (Loge(DMfinal) - Loge(DMinitial); RDMI) and relative N increment (Loge(Nfinal) - Loge(Ninitial); 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.

OSU Link
Non-OSU Link

15. 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.

16. 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 ofPopulus deltoides X P. trichocarpa. Each sludge and the unamended soil were analysed for total solids, total C, P and K, total N and NH4-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 morefavourable 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

17. Henry, C.L., D.W. Cole, T.M. Hinckley and R.B. Harrison. 1993. The use of municipal and pulp and paper sludges to increase production in forestry. Journal-of-Sustainable-Forestry 1(3): 41-55.

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

Abstract: Because of their high nutritional content and soil conditioning properties, municipal and pulp and paper (P&P) sludges (biosolids) can serve as soil amendments for nutritionally deprived or organically poor soils on forest sites. Studies conducted over the past 20 years at an experimental forest site in Western Washington, USA, have largely confirmed the potential of biosolids to increase the productivity of many forest lands. These studies clearly demonstrated that application of biosolids at environmentally acceptable rates will result in growth responses for both young seedlings as well as established stands. Municipal biosolids have been applied to a number of Douglas fir (Pseudotsuga menziesii) stands. Young stands treated with 47 t/ha showed an average of 72, 14 and 2% height responses for Site Class IV, III and II, respectively, over a 10 year period. Thinned versus unthinned 55-year-old Douglas fir treated with 142 dry t/ha averaged 43 and 48%, respectively, for the 12 year period greater than controls. Average growth responses of 65 and 40% occurred in the 65-year-old stand for the Site Class IV and II, respectively, from a 47 dry t/ha application. Growth response resulting from application of P&P biosolids to a number of tree species (Douglas fir, Pinus monticola and Abies procera in nursery beds, and plots of Populusdeltoides x P. trichocarpa rooted cuttings) has also been excellent. When properly applied, biosolids can provide an excellent alternative to chemical fertilizers as a means of enhancing forest production. Growth response is typically greater and lasts longer when compared with chemical fertilizers.

OSU Link
Non-OSU Link

18. Hildebrand, D.M., J.K. Stone, R.L. James and S.J. Frankel. 2004. Alternatives to preplant soil fumigation for Western forest nurseries. Pacific-Northwest-Research-Station,-USDA-Forest-Service General-Technical-Report PNW-GTR-608. ii + 27 p.

Keywords: nursery operations
nursery fertilization
tree/stand protection
tree/stand health
growth

Abstract: Field trials were conducted at six bare-root forest tree (Pinus ponderosa, Pseudotsuga menziesii, Pinus contorta and Abies magnifica var. shastensis) nurseries in the Western United States: Bend Pine Nursery in Bend and J. Herbert Stone Nursery in Central Point (Oregon), Coeur d'Alene Nursery and Lucky Peak Nursery in Idaho, and Humboldt Nursery near McKinleyville and Placerville Nursery near Camino (California). These field experiments compared cultural treatments including timing and depth of sowing; bare fallow (with and without periodic tilling); organic amendments including sawdust, composts, and cover crops; mulches including pine needles, sawdust, and rice straw; and fumigation with methyl bromide/chloropicrin or dazomet. Measured effects included population levels of potential soil-borne pathogens (species of Fusarium and Pythium), disease incidence, seedbed density, and sizes of conifer seedlings. Several non-fumigation treatments resulted in production of seedlings with densities and sizes similar to or better than those produced in beds treated with chemical fumigation. Results varied within the nurseries depending on conifer species, field history, and disease presence. Beneficial cultural practices included: (1) incorporation of slowly decomposing organic soil amendments, e.g., aged sawdust with additional nitrogen provided later to seedlings; (2) bare fallowing with periodic tilling, and bare fallowing without periodic tilling plus supplemental weed control; and (3) sowing of conifer seed earlier and more shallow than sown conventionally, and covering seed with a nonsoil mulch such as aged sawdust or hydromulch.

OSU Link
Non-OSU Link

19. 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 cm3 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
Non-OSU Link

20. 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 O2 became hypoxic faster and synthesized more ethanol than less active tissues, such as needles. All tissues that were incubated for 4 h in N2 synthesized ethanol. Needles incubated in N2 and light had much lower quantities of ethanol than needles in N2 and dark, suggesting that O2 from photosynthesis limited internal anoxia. Most tissues from +N seedlings synthesized greater quantities of ethanol in N2 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 N2-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

21. 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 (preformed) and wound-induced rates of monoterpene synthesis and pool sizes in trees grown under ambient and elevated (ambient +200 micro mol mol-1) CO2, 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-1 N by weight). Monoterpene pool size decreased at elevated CO2, 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.

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22. 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 CO2 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.

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23. 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.

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24. 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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25. Molina, R. and J. Chamard. 1984. Use of the ectomycorrhizal fungus Laccaria laccata in forestry. II. Effects of fertilizer forms and levels on ectomycorrhizal development and growth of container-grown Douglas-fir and ponderosa pine seedlings. Canadian-Journal-of-Forest-Research 13(1): 89-95.

Keywords: nursery operations
nursery fertilization
mycorrhizal response
growth

Abstract: [See FA 44, 2464] Seedlings were grown in peat/vermiculite medium with or without pre-germination inoculation with L. laccata, using three rates of soluble NPK fertilizer (low, high, and a combination of low changed to high) or full or half strength of a slow-release fertilizer. Ectomycorrhizal development was excellent for both hosts regardless of fertilizer treatment; ectomycorrhizal short roots averaged 93.6% for Douglas fir and 94.5% for ponderosa pine. Inoculation did not affect the size of Douglas fir but significantly reduced growth of ponderosa pine at low fertility.

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26. 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 Kloneand 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

triplesuperphosphate 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.

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27. 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 inWashington 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.

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28. Thompson, G. 1995. Nitrogen fertilization requirements of Douglas-fir container seedlings vary by seed source. Tree-Planters' Notes 46(1): 15-18.

Keywords: nursery operations
nursery fertilization
growth
carbon allocation
tree morphology

Abstract: Growth of container-grown Douglas fir (Pseudotsuga menziesii) from different seed sources from western Washington, northern Idaho and western Montana was evaluated following application of 100, 150, or 200 p.p.m. nitrogen during the rapid growth phase. The optimum level of N varied between seed sources for height, stem diameter, and bud growth, as well as for root shoot ratio. Target seedling specifications were met adequately for the westernmost sources at 100 and 150 p.p.m. N, whereas eastern sources required 150 or 200 p.p.m. Nitrogen levels should thus be tailored to individual Douglas fir seed sources to maximize the number of shippable seedlings per lot.

OSU Link
Non-OSU Link

29. Wang, X. and D. Zabowski. 1998. Nutrient composition of Douglas-fir rhizosphere and bulk soil solutions. Plant-and-Soil 200(1): 13-20.

Keywords: nursery operations
nursery fertilization
soil properties

Abstract: A study was conducted during 1995-96 at Weyerhaeuser Rochester Seedling Nursery and the White River District of the Weyerhaeuser Tree Farm, Washington, to investigate the nutrient composition of Douglas-fir [Pseudotsuga menziesii] rhizosphere soil solution in soils belonging to the Nisqually and Pitcher soil series, respectively, and to compare rhizosphere solution with that of bulk soil solution. Fertilized (urea, ammonium sulfate, calcium nitrate, and triple superphosphate) and unfertilized Nisqually soils were also compared. Soil solutions were collected using centrifugation. Nutrient concentrations in the rhizosphere solutions were typically higher than that of bulk soil solutions when no fertilizer was applied, but differences in the concentrations of nutrients between the rhizosphere and bulk soil solutions were masked by the addition of fertilizers. With a higher concentration of NH4 relative to NO3 in the rhizosphere soil solution, the solution pH of the rhizosphere was lower than that of the bulk soil, but with a lower concentration of NH4 relative to NO3, the solution pH of the rhizosphere was higher than that of the bulk soil solution.

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