

Soil Properties

1. Amaranthus, M.P., C.Y. Li and D.A. Perry. 1990. Influence of vegetation type and madrone soil inoculum on associative nitrogen fixation in Douglas-fir rhizospheres. *Canadian-Journal-of-Forest-Research* 20(3): 368-371.

Keywords: planting operations
soil properties

Abstract: In studies in SW Oregon in 1985, Douglas fir (*Pseudotsuga menziesii*) seedlings grown at a site cleared of whiteleaf manzanita (*Arctostaphylos viscida*) and an adjacent, cleared, annual grass meadow were either inoculated with 100-120 ml per seedling of pasteurized or unpasteurized soil from a nearby Pacific madrone (*Arbutus menziesii*) stand, or left uninoculated. After one growing season, Douglas fir seedling whole-plant soil systems were assayed for nitrogenase activity by the acetylene reduction method. The rate of acetylene reduction in rhizospheres of uninoculated seedlings from the manzanita site (1.40 ± 0.44 nmol/h) was significantly greater than that of uninoculated seedlings from the meadow site (0.67 ± 0.15 nmol/h). Unpasteurized madrone soil increased the rate of acetylene reduction by >500% for inoculated seedlings grown on the manzanita site, but decreased it by 80% for those grown on the meadow site. The influence of madrone soil was apparently biotic: pasteurized madrone soil did not have a significant effect. No acetylene was reduced in soil without seedlings. *Azospirillum* sp., a microaerophilic nitrogen (N₂) fixing bacterium, was isolated from within the mycorrhizas of inoculated seedlings harvested from the manzanita site. These results suggest that early successional ectomycorrhizal shrubs and broadleaved trees may be important in maintaining mycorrhizal fungi and associated N₂ fixers after severe disturbance.

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2. Bailey, V.L., J.L. Smith and H. Bolton, Jr. 2002. Fungal-to-bacterial ratios in soils investigated for enhanced C sequestration. *Soil-Biology-and-Biochemistry* 34(7): 997-1007.

Keywords: fertilization
soil properties

Abstract: Fungi and bacteria govern most of the transformations and ensuing long-term storage of organic C in soils. We assessed the relative contributions of these two groups of organisms to the microbial biomass and activity of soils from five different ecosystems with treatments hypothesized to enhance soil C sequestration: (1) desert (an elevation gradient allowed comparison of soil developed in a cooler, wetter climate with soil developed in a warmer, drier climate), (2) restored tallgrass prairie (land reverted to native prairie in 1979 and neighbouring land farmed to row crops for ~100 year), (3,4) two forest types (Douglas fir [*Pseudotsuga menziesii*] and loblolly pine [*Pinus taeda*], unfertilized control and N-fertilized plots), and (5) agricultural land (conventional- and no-till management systems). The selective inhibition technique, using captan (fungicide) and oxytetracycline hydrochloride (bactericide), was used to determine the activities (respiration) of fungi and bacteria in each of these soils and substrate-induced respiration was used to measure total active soil microbial biomass. C. Phospholipid fatty acid analysis was used to determine the composition of the soil microbial biomass and determine if the activities and structure of the microbial communities were related. Differences in

fungus-to-bacterial (F:B) activities between treatments at a site were greatest at the prairie sites. The restored prairie had the highest F:B (13.5) and high total C (49.9 g C kg⁻¹ soil); neighbouring soil farmed to maize had an F:B of 0.85 and total C of 36.0 g C kg⁻¹ soil. Within the pairs of study soils, those that were tilled had lower fungal activities and stored C than those that were managed to native or no-till systems. In all pairs of soils, soils that had higher absolute fungal activities also had more total soil C and when two extreme cases were removed fungal activity was correlated with total soil C (R²=0.85). Thus, in this small set of diverse soils, increased fungal activities, more than F:B ratios, were associated with increased soil C. Practices that involved invasive land management decreased fungal activity and stored soil C compared to similar soils that were less intrusively managed.

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

Keywords: fertilization
growth
tree physiology
soil properties

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

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4. Blake, J., S.R. Webster and S.P. Gessel. 1988a. Soil sulfate-sulfur and growth responses of nitrogen-fertilized Douglas-fir to sulfur. *Soil-Science-Society-of-America-Journal* 52(4): 1141-1147.

Keywords: fertilization
soil properties
growth

Abstract: Two studies were conducted to determine the growth response of N-fertilized Douglas fir [*Pseudotsuga menziesii* (Mirb.) Franco] to S supplements. The relationship between response and soil SO₄-S extracted with Morgan's solution, 1.22 M NaOAc + 0.53 MHOAc (pH 4.8), was used to establish critical levels for S. Douglas fir seedlings were grown in the greenhouse in the surface mineral layer (0 to

0.15 m) of 20 forest soils from western Washington and Oregon. On the average, significant increases in total dry weight (17.5%), stem diameter (10.1%), and height (6.9%) occurred when soils were fertilized with N and S in comparison to N alone. Using the Cate-Nelson procedure, growth responses to N and S were most likely to occur when soil SO₄-S was below 14 mg S kg⁻¹. Twenty eight installations were established in the field containing five treatments, three rates of N as urea, and one plot of 336 kg N ha⁻¹ with P, K, Ca, and S. Differences in percent basal area growth between N alone and N with P, K, Ca, and S were significantly related to soil SO₄-S. Over the initial 5-yr period, response over N alone was improved by 74% when soil SO₄-S was <20 mg S kg⁻¹. When the N with P, K, Ca, and S plots were retreated with only N and S, response over the next 3 yr was more than doubled compared with N alone. Identification of S responsive stands was improved by the inclusion of stand age weighted subsoil SO₄-S concentrations.

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

Keywords: thinning
fertilization
soil properties
tree physiology

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

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6. Busse, M.D., G.O. Fiddler and A.W. Ratcliff. 2004. Ectomycorrhizal formation in herbicide-treated soils of differing clay and organic matter content. *Water, Air, and Soil Pollution* 152:23-34.

Keywords: release treatments
chemical release
growth
tree morphology
tree/stand health
soil properties
mycorrhizal response

Abstract: Herbicides are commonly used on private timberlands in the western United States for site preparation and control of competing vegetation. How non-target soil biota respond to herbicide applications, however, is not thoroughly understood. We tested the effects of triclopyr, imazapyr, and sulfometuron methyl on ectomycorrhizal formation in a greenhouse study. Ponderosa pine, Douglas-fir, and white fir seedlings were grown in four forest soils ranging in clay content from 9 to 33% and organic matter content from 3 to 17%, and treated with commercial formulations of each herbicide at 0, 1.0, and 2.0 times the recommended field rate. Many of the possible herbicide-soil combinations resulted in reduced seedling growth. Root development was particularly sensitive to the three herbicides, with an average of 51% fewer root tips compared to the control treatment. The ability of mycorrhizal fungi to infect the remaining root tips, however, was uninhibited. Mycorrhizal formation was high, averaging 91% of all root tips, regardless of herbicide, application rate, soil type, or conifer species. In agreement, soil microbial biomass and respiratory activity were unaffected by the herbicide treatments. The results show that these herbicides do not alter the capability of mycorrhizal fungi to infect roots, even at concentrations detrimental to seedling growth.

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

Keywords: site preparation
fertilization
tree physiology
growth
soil properties

Abstract: The use of green fallowing was studied at 2 sites, viz. (a) a coastal site at Koksilah, 15 km NW of Shawnigan Lake, British Columbia, where extensive subsoil exposure had resulted from roading operations in a highly productive Douglas fir (*Pseudotsuga menziesii*) and western hemlock (*Tsuga heterophylla*) stand, and (b) an inland site 30 km S. of Vanderhook including several landings and skid roads which had been deep-ripped to a depth of 50 cm, reducing soil density to 1350 kg/m³. Plots at (a) were seeded in 1976 at 100 kg/ha with a grass/legume mixture including 3 spp. of *Trifolium* and *Lotus corniculatus*, and received NPK (10:30:10) at 450 kg/ha. Site nutrient levels improved substantially over 5 yr with N showing the greatest gains, and Douglas fir seedlings (1+2) planted in 1977 responded with increased foliar N and K contents and 300% greater ht. growth. Plots at (b) were seeded in 1981 at 40 kg/ha with a legume mixture of 3 spp. of *Trifolium*, *Medicago sativa* and *L. corniculatus*, and received NPK (19:19:19) at 300 kg/ha. Nutrient gains were found after 2 yr for P, K and especially N, and although foliar nutrient contents and growth of lodgepole pine (*Pinus contorta*) seedlings showed no increase, the enhancement of site nutrient capital is considered to be a gain likely to benefit commercial forestry production.

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8. Carter, R. and K. Klinka. 1992. Use of ecological site classification in the prediction of forest productivity and response to fertilisation. *South-African-Forestry-Journal* (160): 19-23.

Keywords: fertilization
growth
soil properties

Abstract: The results are presented of two related studies in southern coastal British Columbia. A total of 149 study plots in even-aged immature Douglas fir (*Pseudotsuga menziesii*) stands were categorized into 6 ecologically similar site associations (indicated best by climax plant communities) and into 15 soil moisture and soil nutrient combinations, for the prediction of site index. Fifty-one of these plots were used to predict basal area growth response to nitrogen fertilizer (225 kg N/ha as urea). Regression models indicated strong correlations between Douglas fir site index (m (height)/50 yr) and both indirect and direct measures of soil moisture and nutrient regimes ($R^2 > 0.72$; $p < 0.01$). Third-year basal area response to N fertilizer varied significantly among site associations ($R^2 = 0.60$; $p < 0.01$). Site index also showed a significant relation with third-year basal area response ($R^2 = 0.52$; $p < 0.01$), while the best predictive model included site associations and pretreatment foliar N and sulfate-S ($R^2 = 0.64$; $p < 0.01$). It is suggested that the approach and methods of the study are applicable to predicting site-specific growth performance and response to fertilization of other tree species, including eucalypts.

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9. Carter, R.E., E.R.G. McWilliams and K. Klinka. 1998. Predicting response of coastal Douglas-fir to fertilizer treatments. *Forest-Ecology-and-Management* 107(1/3): 275-289.

Keywords: fertilization
growth
soil properties

Abstract: A broadly-based, intensive Douglas-fir (*Pseudotsuga menziesii*) fertilizer experiment throughout southern coastal British Columbia (48 sites) was used to examine 3- and 6-yr crop tree growth responses to prescribed fertilizer applications (N alone, and N + additional nutrients identified as potentially deficient by foliar analysis). Absolute and relative basal area responses were evaluated in relation to site associations of the provincial ecosystem classification system, site index (SI), and a large number of site and stand chemical and physical properties. Few of the site and stand variables examined as possible response prediction criteria appeared to have any real utility. The strongest relationships found were between relative basal area response and (1) site index (R^2 0.46 for both 3- and 6-yr responses), (2) mineral soil mineralizable-N (R^2 0.50 and 0.46 for yr 3 and 6 responses, respectively), and (3) total mineralizable-N (R^2 0.47 and 0.50 for yr 3 and 6 responses, respectively). In all cases average relative response declined with increasing site quality. However, there were highly productive sites ($SI_{50} < \text{more or } \geq 35$ m) characterized by an absence of growing-season water deficits and relatively low foliar N concentrations (12-13 g/kg) which showed significant fertilizer responses. These sites are where the greatest financial returns from fertilizing may be realized. Relationships identified between site and stand variables and basal area responses were, in many cases, different from those found by other researchers for coastal Douglas fir. This brings the portability of identified relationships into question.

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10. Chappell, H.N., D.W. Cole, S.P. Gessel and R.B. Walker. 1991. Forest fertilization research and practice in the Pacific Northwest. *Fertilizer-Research* 27(1): 129-140.

Keywords: fertilization
soil properties

Abstract: A review showed that most Pacific Northwest USA Douglas-fir (*Pseudotsuga menziesii*) forest sites are nitrogen deficient. Mineral cycling research has shown high C:N ratios and low nitrification rates for soils in the region. Research and development projects in the Pacific Northwest have produced an information base that is used to select sites and stands for fertilization and to forecast growth after treatment. Much of the basis for operational fertilization programmes in western Oregon and Washington comes from cooperative research; current activities for these programmes are directed toward improving site-specific response information. Forest fertilization in the Pacific Northwest has become a major silvicultural practice over the past two decades. Forest industry and government organizations managing forest lands in western Oregon and Washington apply nitrogen fertilizer to Douglas-fir stands over a range of soil and stand types. About 50 000 to 55 000 ha are fertilized each year, and future programmes will probably be of similar magnitude. Most current plans for management regimes including fertilization require multiple applications.

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11. Chappell, H.N., C.E. Prescott and L. Vesterdal. 1999. Long-term effects of nitrogen fertilization on nitrogen availability in coastal Douglas-fir forest floors. *Soil-Science-Society-of-America-Journal* 63(5): 1448-1454.

Keywords: fertilization
soil properties

Abstract: The aim of this study was to determine if N availability was elevated 8 to 12 years after repeated N fertilization, and if the effects of N fertilization were related to the soil N capital. Rates of N cycling in control and fertilized plots of Douglas-fir (*Pseudotsugamenziesii*) in Oregon, USA, were compared by measuring net N mineralization rates in forest floors and by estimating rates of N turnover from the litterfall/forest floor ratio. Litterfall N contents, litter N concentrations, and rates of N turnover increased along the gradient in soil N capital in both control and fertilized stands. Fertilization did not affect litterfall N content, but C:N ratios of litter and forest floors were significantly lower in fertilized stands along the gradient. Turnover rates of N in the forest floors were not higher in fertilized plots than in control plots, nor were rates of net N mineralization affected by fertilization. Net nitrification rates were higher in some of the plots that received 1120 kg N ha⁻¹ than in control plots. Nitrogen fertilization did not result in a sustained increase in N cycling and N availability analogous to a higher site N capital, and the effect of N fertilization was not related to the initial soil N capital of these sites.

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

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

Abstract: A comparison was made of two common techniques used to improve seedling survival on hot, dry reforestation sites. Adjacent shelterwood and clearcut sites in SW Oregon, USA, planted with 2+0 Douglas fir, were located and instrumented to compare temp. and moisture. In addition, cardboard shadeboards 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 shadeboards 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. Shadeboards 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. Shadeboards did not significantly affect seedling stomatal resistance. Differences in seedling survival caused by shadeboards 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. Shadeboards modify the soil temp. less extensively and so have less effect on seedling survival.

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13. Childs, S.W., H.R. Holbo and E.L. Miller. 1985. Shadeboard and shelterwood modification of the soil temperature environment. *Soil-Science-Society-of-America-Journal* 49(4): 1018-1023.

Keywords: planting operations
soil properties

Abstract: A study was conducted on steep, south-facing slopes in southwest Oregon to assess the effect of two common reforestation practices on the soil thermal environment. Three clearcut sites and three shelterwood sites were instrumented to measure soil temperature at five depths in the vicinity of shaded and unshaded Douglas-fir seedlings. Since the soils studied were skeletal, heat capacities of both fine and coarse soil fractions were determined for each site. These data were used to estimate soil heat fluxes. Shelterwoods decrease soil temperatures approximately 6 K when compared with clearcuts. This result holds at both 20- and 320-mm depths. Shelterwoods also decrease the depth of diurnal heating and decrease maximum hourly heat loss and gain values by 73 and 80 W/m², respectively. Shadeboards, cardboard rectangles placed to the southwest of seedlings, generally have little effect on the soil temperature regime of skeletal soils but are effective in reducing daily heat flux. The dominant shadeboard effect is a decrease in average daytime heat flux by 22 W/m², but shadeboards also decrease average nighttime fluxes. Shelterwoods ameliorate seasonal soil temperature conditions significantly and may be an appropriate technique in situations where

cumulative soil heating limits reforestation success. Shadecards should be useful in situations where heat stress events of only a few days are a problem. Over a season, shadecards exert little control, and their influence on stress is limited. Since all soils studied had high heat capacities due to large rock fragment content the conclusions of this study may be limited to soils with large soil heat capacity.

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14. Colinas, C., R. Molina, J. Trappe and D.

Perry. 1994a. Ectomycorrhizas and rhizosphere microorganisms of seedlings of *Pseudotsuga menziesii* (Mirb.) Franco planted on a degraded site and inoculated with forest soils pretreated with selective biocides. *New-Phytologist* 127(3): 529-537.

Keywords: planting operations
fertilization
soil properties
mycorrhizal response

Abstract: Inoculation of planting holes with small amounts of soil from a mature forest or a plantation can improve formation of ectomycorrhizas on *Pseudotsuga menziesii* seedlings in degraded clearcuts in southwestern Oregon. To determine the component(s) of transferred soil responsible for increased ectomycorrhiza formation, soil from a clearcut, a mature forest and a plantation was treated with one of the following: (1) fertilizer to test for the effect of nutrients, (2) dimethoate and carbofuran to test for the effect on microarthropods or nematodes, (3) fumagillin to test for the effect on protozoa, (4) captan to test for the effect on fungi, (5) penicillin and oxytetracycline to test for the effect on bacteria, (6) pasteurization to test for the effect of active forms of organisms, (7) Tyndallization to test for the effect of resting forms of organisms, or (8) water as a control. The effect was studied of inoculation with soil subjected to these treatments on number and types of ectomycorrhizas, on length of active mycelium, and on number of active bacteria in the rhizosphere. Inoculation with untreated forest or plantation soils increased the number of ectomycorrhizas but did not change the mycorrhizal types present. Most agents had different effects in different soils. Inoculation with pasteurized and Tyndallized clearcut and plantation soils increased the number of Rhizopogon- and Thelephora-type ectomycorrhizas and decreased the number of active bacteria, as did untreated forest soil. It is hypothesized that the role of the soil transfer is to provide a rhizosphere environment free from a deleterious organism present in the clearcut. In this environment, beneficial organisms present in the clearcut or brought in with the seedling from the nursery can proliferate.

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15. Curtis, R.O., D.D. Marshall and D.S. DeBell. 2004. Silvicultural options for young-growth Douglas-fir forests: the Capitol Forest study - establishment and first results. Pacific Northwest-Research-Station,- USDA-Forest-Service General-Technical-Report PNW-GTR-598. xi + 110 p.

Keywords: thinning
commercial thinning

economics
soil properties

Abstract: This report describes the origin, design, establishment and measurement procedures and first results of a large long term cooperative study comparing a number of widely different silvicultural regimes applied to young-growth Douglas-fir (*Pseudotsuga menziesii*) stands managed for multiple objectives. Regimes consist of (1) conventional clear felling followed by intermediate thinning; (2) retention of reserve trees to create a two-aged stand; (3) small patch cuts dispersed within a thinned matrix, repeated at approximately 15-year intervals to create a mosaic of age classes; (4) group selection within a thinned matrix on an approximate 15-year cycle; (5) continued thinning on an extended rotation; and (6) an untreated control. Each of these regimes is on operation-size units (approximately 30 to 70 acres each). A LIDAR system was used to scan the surface of the 2 miles² that encompass the Blue Ridge study site on the Capitol State Forest, near Olympia, Washington, USA. This measurement technology emits laser pulses that are reflected by vegetation, buildings, or the ground surface. Output variables from the study to be evaluated include conventional timber growth and yield statistics, harvest costs, sale layout and administration costs, aesthetic effects and public acceptance, soil disturbance, bird populations, and economic aspects. Descriptive statistics and some initial results are presented for the first replicate, established in 1997-98.

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16. Donegan, K.K., L.S. Watrud, R.J. Seidler, S.P. Maggard, T. Shiroyama, L.A. Porteous and G. DiGiovanni. 2001. Soil and litter organisms in Pacific Northwest forests under different management practices. *Applied Soil Ecology* 18:159-175.

Keywords: planting operations
site preparation
prescribed fire
soil properties

Abstract: Soil and litter organisms were monitored for their response to different forest management practices. Litter and soil cores (0-10, 10-20 cm) were collected at approximately 8-week intervals over a 19-month period from a low elevation 110-140-year-old Douglas fir (*Pseudotsuga menziesii*) forest and adjacent 8-year-old clearcut in the Oregon Cascades, and from a high elevation 200-250-year-old Douglas fir forest and adjacent 5-year-old clearcut in the McKenzie River drainage. The low elevation clearcut had been broadcast burned and replanted with Douglas fir trees and a grass (*Dactylis* and *Lolium*)-legume (*Trifolium* and *Lotus*) mixture whereas the high elevation clearcut was not burned, large woody debris was left, and it was replanted with Douglas fir, Noble fir [*Abies procera*], Grand fir [*Abies grandis*], and western white pine [*Pinus monticola*]. The litter and soil cores were analysed for types of microarthropods and numbers of nematodes, fungi, culturable, aerobic bacteria, spore-forming bacteria, and chitin-degrading bacteria. Microbial community metabolic profiles, using the Biolog method, were also generated for the 0-10 cm soil samples. Populations of *Pseudomonas* spp. were analysed in the litter and soil samples using 16S rDNA fingerprints. Plant surveys were conducted to identify potential relationships of soil organisms to plant community composition. At both elevational field sites, there were significantly ($P < 0.05$) higher levels of nematodes and microarthropods in litter and soil in forest plots than in clear felled plots. Bacterial and fungal populations were also significantly higher in litter in forest plots than in clear felled plots at the

high elevation site. In the litter and soil at the low elevation site and the soil at the high elevation site, however, microbial levels were higher in clear felled plots than in forest plots. The *Pseudomonas* spp. populations and the microbial community metabolic profiles in the 0-10 cm soil differed significantly between the forest and clear felled plots at the low elevation site but not at the high elevation site. At both elevational field sites, the plant cover (%) and plant density were significantly higher in clear felled plots than in forest plots. These observed differences in the population size and composition of organisms between mature forests and both low management and high management clearcuts demonstrated the impacts forest management practices may have on the soil ecosystem.

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17. Edmonds, R.L. and T. Hsiang. 1987. Forest floor and soil influence on response of Douglas-fir to urea. *Soil-Science-Society-of-America-Journal* 51(5): 1332-1337.

Keywords: fertilization
thinning
growth
soil properties

Abstract: Data from the Regional Forest Nutrition Research Project (RFNRP) in Washington and Oregon were analyzed to improve stand-specific prediction of Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco] response to urea fertilization. The response variable (relative difference in volume growth between fertilized and control plots 4 yr after fertilization with 448 kg N/ha) was regressed against 28 stand and site variables (e.g., age, elevation, forest floor C/N ratio, soil cation exchange capacity, etc.) using stepwise multiple regression analysis. Data from 120 installations were stratified by thinning level (thinned or unthinned), geographic location (provinces), and site quality (site index and class). Forest floor C/N ratio was the dominant variable related to response. In thinned installations of high site quality (site classes 1 and 2), 60% of variation in response was explained by the forest floor C/N, and 75% of the variation in response was explained with inclusion of surface soil exchangeable K. In thinned, low site quality stands, response was not as well related to forest floor C/N. Analysis of the data by province indicated that S may be limiting in southwest Oregon and P in coastal Washington.

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[Non-OSU Link](#)

18. Feller, M.C. 1988. Relationships between fuel properties and slashburning-induced nutrient losses. *Forest-Science* 34(4): 998-1015.

Keywords: site preparation
prescribed fire
soil properties

Abstract: The relations between slash load, slash and forest floor consumption variables, and species origin of slash (slash type) on one hand and nutrient (N, P, S, K, Na, Mg and Ca) losses to the atmosphere

during slashburning on the other were studied by burning 50 plots, each 2.25 m² in area. The plots contained known amounts of slash materials derived from four major southwestern British Columbia tree species (Tsuga heterophylla, Thuja plicata, Chamaecyparis nootkatensis and Pseudotsuga menziesii) and were burned under different weather conditions. Nutrient losses (g/m²) decreased in the order N > Ca > S > K > Mg > P > Na and were generally within the range of such losses recorded for operational prescribed burns in western North America. Losses of all nutrients except Na were positively correlated with fuel consumption. Nitrogen and S exhibited the best correlations, whereas no correlations were found for Na. Of the fuel consumption variables considered, depth of forest floor consumed, then total slash consumption, were best correlated with nutrient loss. Losses of most nutrients generally increased with slash load and as slash type changed from Tsuga to Pseudotsuga to Thuja/Chamaecyparis. This was partly due to the effects of slash load and slash type on fuel consumption, and partly due to their effects on burning-caused changes in nutrient concn. in slash materials. The study suggests that nutrient losses to the atmosphere during operational slashburns can be minimized by minimizing forest floor and large diameter slash consumption during burning.

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19. Feller, M.C. 1990. Herbicide application followed by prescribed fire to convert a brushfield into a conifer plantation in south coastal B.C.: a combination of the initial effects of two treatments. B.C. Ministry of Forests FRDA Report 146. 40 p.

Keywords: site preparation
chemical preparation
prescribed fire
growth
tree/stand health
soil properties
stand conditions

Abstract: A field study was carried out in Pseudotsuga menziesii stands in British Columbia, Canada, to investigate the effects on vegetation of glyphosate applications in September 1987 or July 1988, followed by burning in October 1988. Results did only show slight differences between treatments.

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20. Feller, M.C., J.P. Kimmins and K.A. Scoullar. 1983. FORCYTE-10: calibration data and simulation of potential long-term effects of intensive forest management on site productivity, economic performance, and energy benefit/cost ratio. *In* I.U.F.R.B. Symposium on Forest Site and Continuous Productivity; Seattle, Washington; August 22-28, 1982. *Eds.* R. Ballard and S.P. Gessel. Pacific-Northwest Forest-and-Range-Experiment-Station, USDA-Forest-Service General-Technical-Report PNW-GTR-163 Part B. 179-200 pp.

Keywords: thinning
fertilization

soil properties
economics
computer modeling

Abstract: FORCYTE (FORest nutrient Cycling and Yield Trend Evaluator) is a computer simulation model of forest plant biomass production, litterfall, and decomposition, complete with nutrient cycling, nutrient limitation on growth, and a variety of management interventions. The model is a computerized approach to the estimation of the effects of varying thinning and fertilizer regimes, utilization level, and rotation length on site nutrient budgets, stand productivity, and the economic performance and energy efficiency of management. The model has evolved over 5 years to its present version FORCYTE-10, which is briefly described. Accompanying the development of FORCYTE, there has been a series of field research projects. Detailed biomass and biogeochemical descriptions of age sequences of Douglas-fir stands on both good and poor sites have been prepared for purposes of model calibration and testing. The present report summarizes some of the results of the FORCYTE-10 field studies on Vancouver Island, British Columbia, and presents some examples of the use of the model when calibrated with these data.

[OSU Link](#)

[Non-OSU Link](#)

21. Flint, L.E. and S.W. Childs. 1987. Effect of shading, mulching, and vegetation control on Douglas-fir seedling growth and soil water supply. *Forest-Ecology-and-Management* 18(3): 189-203.

Keywords: release treatments
chemical release
manual release
growth
soil properties

Abstract: Harsh environments on many harvested sites in SW Oregon necessitate site modifications for successful regeneration of Douglas fir. A 2-yr study was made with 350 seedlings to assess the effects of 12 soil-surface shading, mulching, and vegetation control techniques on seedling growth and soil temp. and moisture environments. Major effects of treatments were to lower soil surface temp., reduce soil surface evaporation, and reduce vegetative competition for soil water. These affected seedlings by adjusting the timing of seedling growth and reducing soil water loss to increase available water for seedling use. Final seedling shoot vol. and stem diam. both differed among treatments. Seedlings in treatments where competing vegetation was controlled showed significantly greater growth than seedlings in other treatments. Soil water loss in treatments where either soil surface evaporation was controlled by mulching, or where competing vegetation was controlled, was significantly less than water loss from the shaded and control treatments. Soil water loss in treatments with vegetation controlled by herbicide was significantly less than in treatments with vegetation controlled by scalping. Seedlings showed greatest growth with treatments that elicited the most efficient use of available microsite water either by reducing soil surface evaporation or vegetation competition.

[OSU Link](#)

[Non-OSU Link](#)

22. Fox, T.R. 2004. Nitrogen mineralization following fertilization of Douglas-fir forests with urea in Western Washington. *Soil-Science-Society-of-America-Journal* 68(5): 1720-1728.

Keywords: fertilization
soil properties

Abstract: Nitrogen mineralization following repeated applications of urea fertilizer was determined in the A horizon soil from two stands of Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco] in the Cascade Mountains of Washington. Repeated applications of urea at rates ranging from 0 to 600 kg N ha⁻¹ were made at annual and 5-yr intervals over a 6-yr period. Nitrogen fertilization increased N mineralization potential in these soils. However, soil N mineralization followed a quadratic relationship with the total amount of N applied in fertilizer over the 6-yr treatment period, increasing up to total application rates of 450 kg N ha⁻¹ and then declining at higher rates. The decrease in N mineralization rates at the high N fertilization rates may be due to changes in the quality of soil organic matter, which reduced the effectiveness of extracellular enzymes and decreases the rate of decomposition and mineralization. Soil pH dropped following urea fertilization, with greater declines observed in the highest rates of urea fertilizer. Decreases in extractable Ca and Mg levels in the soil accompanied the decline in soil pH. These results suggest that high rates of nitrification occurred and that nitrate leaching was stripping Ca and Mg from the cation-exchange complex in these soils. It appears that repeated applications of urea fertilizer at low to intermediate rates may increase long-term N availability and thus improve soil quality. However, annual applications of high rates of urea may decrease soil quality because under these circumstances N mineralization did not increase and there was a loss of cations from the soil.

[OSU Link](#)

[Non-OSU Link](#)

23. Frey Klett, P., J.L. Churin, J.C. Pierrat and J. Garbaye. 1999. Dose effect in the dual inoculation of an ectomycorrhizal fungus and a mycorrhiza helper bacterium in two forest nurseries. *Soil Biology and Biochemistry* 31:1555-1562.

Keywords: nursery operations
growth
carbon allocation
mycorrhizal response
soil properties

Abstract: Disinfected soil at two Douglas-fir (*Pseudotsuga menziesii*) bare-root forest nurseries was inoculated with three doses (8 X10⁵, 8 X10⁷ and 8 X10⁹ cfu [colony forming units]/m²) of the rifampicin-resistant mycorrhiza helper bacterium *Pseudomonas fluorescens* strain BBc6R8 and the ectomycorrhizal fungus *Laccaria bicolor* strain S238N. In one of the two nurseries, two doses of fungal inoculum (50 and 100 mg/m² dry weight (DW) mycelium entrapped in alginate beads at the constant dose of 1 litre/m²) were tested. For all bacterial treatments the density of *P. fluorescens* BBc6R8 in the soil, determined by dilution plating, dropped below the detection limit (10⁻² cfu/g DW soil) 2 weeks after inoculation. Fifteen weeks after inoculation, the introduced bacterium was detected by enrichment only in the treatments inoculated with the highest bacterial dose. Two years after inoculation, *P. fluorescens* BBc6R8 was not detected in the soil of any of the bacterial treatments. Five months after inoculation and sowing, bacterial inoculation significantly increased the percentage of mycorrhizal short roots on plants inoculated with either low or high amounts of *L. bicolor*,

in one of the nurseries. The lowest bacterial dose increased mycorrhizal colonization from 45 to 70% in plants inoculated with the low amount of fungal inoculum, and from 64 to 77% in plants inoculated with the high amount of fungal inoculum. The lowest bacterial dose increased mycorrhizal colonization more than the highest bacterial dose. The same *L. bicolor* mycorrhizal index (70%) was obtained with 50 mg/m² DW mycelium plus the bacterium than with twice this fungal dose and no bacterium (64%). Two years after inoculation, the height of the mycorrhizal Douglas-firs in the other nursery was significantly increased by the lowest bacterial dose (from 40.7 to 42.6 cm). It was indicated that co-inoculating a helper bacterium together with an ectomycorrhizal fungus is an efficient way to optimize controlled mycorrhization techniques for the production of high-quality Douglas-fir planting stocks. It was confirmed that BBc6R8 acts at a low population density (less than 10² cfu/g soil), this contrasts with most PGPR [plant growth promoting rhizobacteria?] effects where the minimal inoculation dose of 10⁵ cfu/g soil is required to obtain the beneficial effect.

[OSU Link](#)

[Non-OSU Link](#)

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

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

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

words, a total seedling N concentration of 1.6% and a substrate fertility of 52 p.p.m. N are appropriate to optimize both the ectomycorrhizal development and the growth of Douglas fir seedlings.

[OSU Link](#)

[Non-OSU Link](#)

25. Gessel, S.P., R.E. Miller and D.W. Cole. 1990. Relative importance of water and nutrients on the growth of coast Douglas fir in the Pacific Northwest. *Forest-Ecology-and-Management* 30(1-4): 327-340.

Keywords: fertilization
growth
soil properties

Abstract: The Douglas-fir region in northwestern North America is characterized by abundant moisture supply during winter, extended dry periods during the growing season and significant differences in water availability. Many soils have low fertility and indigenous tree species respond to nitrogen fertilization, especially Douglas fir (*Pseudotsuga menziesii*). Although irrigation of commercial forests in this region is currently impractical, questions arising about the relative importance of water and nutrients were examined using long-term growth data from three studies. At Pack Forest (Washington), fertilization without irrigation doubled growth rates, and no positive growth responses were measured from irrigation. Short-term (5 yr) irrigation with sewage effluent containing many nutrients resulted in a six-fold increase in biomass production for poplar and three-fold for Douglas fir as compared to irrigation with equal volumes of river water. Volume growth in 12- to 65-yr-old stands in southwestern Oregon was increased by fertilization at about 70% of the locations; annual gain averaged 2.73 m³/ha for 5-12 yr. Response was not related to annual precipitation, which ranged from 81 to 279 cm, nor other moisture-related variables. Absolute and relative volume response showed highest correlation with soil carbon : nitrogen ratio. Compared with nutrition, moisture does not seem to be a major limiting factor for growth in the Douglas fir region of the Pacific Northwest.

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[Non-OSU Link](#)

26. Harrison, R., D.S. Xue, C. Henry and D.W. Cole. 1994a. Long-term effects of heavy applications of biosolids on organic matter and nutrient content of a coarse-textured forest soil. *Forest-Ecology-and-Management* 66(1/3): 165-177.

Keywords: fertilization
soil properties

Abstract: Long-term changes in soil properties due to a single heavy application of municipal biosolids (municipal sewage sludge) on a coarse-textured glacial outwash soil were evaluated. Study sites, located at the Pack Experimental Forest, 100 km S. of Seattle, Washington, were clearcut, cleared, fertilized with 500 t/ha of municipal biosolids and planted with either Lombardy poplar (*Populus nigra* var. *italica*), Douglas fir (*Pseudotsuga menziesii*) or ponderosa pine (*Pinus ponderosa*) in 1975. Soil samples were taken in 1990 from treated stands and from adjacent (unamended) control sites by horizon to a depth of 185 cm. Biosolids-amended samples had greater amounts (mg/g) of C (139 vs. 67), N (12 vs 3.4), P (14 vs. 2.2) and S (2.5 vs. 0.4) contents in 0-7 cm mineral soil and other surface soil

horizons, compared with control soil horizons, but showed no significant differences below 25 cm. Soil pH ranged from 0.4 to 1.0 units lower in biosolids-amended vs. unamended soil throughout the sampled soil horizon. Soil cation exchange capacity was higher in the surface soil horizons of treated plots (30 vs. 18 mmolc kg⁻¹ in 0-7 cm soil), but there were no significant differences below 50 cm. Biosolids-amended samples had greater amounts (mg/g) of total Ca (13 vs. 6.1 in 0-7 cm soil) and K (1.9 vs. 1.5 in 0-7 cm soil) throughout the sampled soil profile. Total Mg was relatively constant (2.0-3.0) throughout the sampled soil profile. Study results indicate that one of the primary objectives of the original biosolids application (increasing total nutrients in the rooting zone of the forest soil) extended at least 15 years from the application date.

[OSU Link](#)

[Non-OSU Link](#)

27. Harrison, R.B., S.P. Gessel, D. Zabowski, C.L. Henry, D.S. Xue, D.W. Cole and J.E. Compton. 1996. Mechanisms of negative impacts of three forest treatments on nutrient availability. *Soil-Science-Society-of-America-Journal* 60(6): 1622-1628.

Keywords: fertilization
growth
soil properties
tree/stand health

Abstract: Many forest management treatments are directly aimed at maintaining or enhancing forest productivity. There may also be secondary effects that detract from this goal. Three case studies in Washington state, USA, are discussed in which several mechanisms may have led to adverse secondary impacts. In the first study, pulp and paper (PIT) sludges were mixed into soil and growth of Douglas-fir (*Pseudotsuga menziesii*), noble fir (*Abies procera*) and western white pine (*Pinus monticola*) was monitored. There was a significant negative correlation of height and diameter growth and C:N ratio for Douglas-fir and western white pine. In a second study, effects of 50 years of red alder (*Alnus rubra*) and Douglas-fir growth on soil chemistry and stand productivity were compared. When the 50-year-old stands were cut and red alder was established by planting into the soil of the former Douglas-fir and red alder forests, a reduction in available P in the soil of the previous red alder stand was observed. In a third study, high rates of low C:N ratio organic matter (300 t/ha) were added in municipal biosolids (~8000 kg N/ha) to Douglas-fir and grand fir (*Abies grandis*) plantations. Excess organic N in the biosolids apparently mineralized, nitrified, and contributed to soil acidification and accelerated cation leaching. Severe Mg deficiency (0.25 g/kg in biosolids-treated vs. 0.93 g/kg in untreated areas) might be the cause of observed foliar chlorosis and poor growth rates.

[OSU Link](#)

[Non-OSU Link](#)

28. Harrison, R.B., C.L. Henry, D.W. Cole and D. Xue. 1995. Long-term changes in organic matter in soils receiving applications of municipal biosolids. *In Carbon forms and functions in forest soils*. Eds. W.W. McFee and J.M. Kelly. Soil Science Society of America Inc., Madison WI. pp. 139-153.

Keywords: fertilization
soil properties

Abstract: Soil concn of C, N, P, Ca, Mg, K, pH, and CEC were compared at two forest sites of contrasting mineralogy and management in Washington, U.S.A., after the application of municipal biosolids. The soil on the Pack forest site was an extremely coarse-textured outwash soil whilst that of the Mt. Pilchuck Tree Farm was a sandy outwash soil. The Pack forest was characterized by 80-yr-old second growth Douglas fir (*Pseudotsuga menziesii*) with an understory of salal (*Gaultheria shallon*). The Mt. Pilchuck Tree Farm site was characterized by 60-yr-old second growth Douglas fir with an understory of salal. Both sites were harvested and cleared prior to the initiation of the studies. The forest floors were different in the biosolids-amended soils compared with the unamended soils, with more highlyhumified material and fewer fine roots. Large increases in C, N, and P concn in the amended plots were restricted to the top 27 cm of soil. Ca and Mg increases were observed at the Pack Forest amended site but not at the Mt. Pilchuck Tree Farm site. At both sites the pH was lower in the amended plots. The differences between the sites are discussed with reference to soil type and management practices. Implications for long-term nutrient retention are considered.

[Non-OSU Link](#)

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

Keywords: fertilization
tree/stand health
tree physiology
soil properties

Abstract: Soil and plant samples were collected from chlorotic plantations of grand fir (*Abies grandis*) and Douglas fir (*Pseudotsuga menziesii*) near Seattle, Washington state, USA, in winter 1989. The soils had been amended in 1981 with an average of 300 dry t/ha of municipal sewage sludge. The sludge amendment resulted in an N application rate of approximately 8000 kg/ha. Foliage analysis indicated that a severe Mg deficiency (0.25 g/kg in sludge-treated vs. 0.93 g/kg in untreated areas) might be the cause of chlorosis. No other nutrient showed concentrations in the deficient or toxic ranges. Trace metal levels in foliage were increased significantly for Ni, Cd and Cr at sludge-treated sites, but were not at toxic levels. Soil samples taken to a depth of 1.4 m indicated the potential for soil acidification (up to 0.9 pH unit) in soil surface horizons. In addition, exchangeable Ca, Mg and K may have been depleted in surface horizons. Exchangeable Al and Fe were greater in the surface of sludge-treated sites. These observations, and the loss of much of the nitrogen added during the sludge amendment, indicated that nitrification and cation leaching were the most likely mechanism for acidification and depletion of exchangeable cations. Fertilizing the plantation with MgSO₄ or dolomitic limestone was carried out in spring 1990. New foliage collected in June 1990 was non-chlorotic and significantly higher in Mg concentration than unfertilized foliage (1.1. vs. 0.7 g/kg, respectively). The results of this study indicate that it is important to assess the potential for initiating a nutrient deficiency due to secondary effects of sludge application in forest systems.

[OSU Link](#)

[Non-OSU Link](#)

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

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

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

[OSU Link](#)

[Non-OSU Link](#)

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

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

Abstract: Four nursery beds at the University of Washington Charles Lathrop Pack Demonstration Forest were each divided into plots that received 8 sludge treatments before being planted with seedlings of Douglas fir, *Abies procera* or *Pinus monticola*, or cuttings of *Populus deltoides* X *P. trichocarpa*. Each sludge and the unamended soil were analysed for total solids, total C, P and K, total N and 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 more favourable than that of untreated soil, but av. response was negative when soil was treated with primary pulp and paper

sludge with a very high C : N ratio. Treatments that produced the greatest growth also increased seedling mortality.

[Non-OSU Link](#)

32. Henry, C.L., D.W. Cole and R.B. Harrison. 1994. Use of municipal sludge to restore and improve site productivity in forestry: The Pack Forest Sludge Research Program. *Forest-Ecology-and-Management* 66(1/3): 137-149.

Keywords: fertilization
growth
soil properties
stand conditions

Abstract: Municipal wastewater residuals - sludge or biosolids - represent a major waste by-product from society that must be managed in responsible ways. Because of its high nutrient and organic matter content, sludge can be beneficially recycled into forest sites for site improvement purposes. This paper reviews the opportunities and problems that have been encountered during 20 yr of research into sludge application in forests, based on data from studies carried out in the Pack Demonstration Forest, Washington, on a variety of sites - including clear-felled, young or mature Douglas fir [*Pseudotsuga menziesii*] stands, and rights-of-way. Research to date on forest application of sludge has been very encouraging, clearly demonstrating the validity of this management technique. Forest sites typically display benefits in two ways: (1) an immediate growth response by both overstorey and understorey species; (2) a long-term improvement to the productivity of the site. However, for this practice to have broad utility and acceptance, it is critical that the concerns of the regulatory agencies and general public be addressed regarding public health and environmental issues through continued research. These concerns include the fate of trace metals, including movement, uptake and potential phytotoxicity, and passage into wildlife and human food chains, the fate of pathogens, and leaching of nitrates into groundwater systems. Many concerns are a result of misconceptions or misunderstandings of the potential problems involved and require working with these agencies and the general public through education and demonstration programmes.

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[Non-OSU Link](#)

33. 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 *Populus deltoides* 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.

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[Non-OSU Link](#)

34. Hetherington, E.D. 1985. Streamflow nitrogen loss following forest fertilization in a southern Vancouver Island watershed. *Canadian-Journal-of-Forest-Research* 15(1): 34-41.

Keywords: fertilization
soil properties

Abstract: Water quality was monitored in the Lens Creek catchment to determine nitrogen loss following aerial application of 224 kg/ha N (as urea) to a second-growth Douglas-fir forest in Sept. 1974. Peak nitrogen concentrations measured in 2 small tributary streams were 14 mg/litre as urea (after 12 h), 1.9 mg/litre as ammonia (after 24 h), and 9.3 mg/litre as nitrate (after 7 wk). For the first 14 months, estimated nitrogen outputs in excess of background amounts were 5.9 and 14.5% respectively of the total nitrogen applied to the 2 subsidiary catchments which had 46 and 80% of their drainage areas fertilized. These losses were considerably higher than amounts of <1% previously reported for western North America. Increased amounts of urea N and ammonia N were short-lived, while nitrate N remained above background values for the duration of the study. Reasons for the high nitrogen loss include nitrification of the urea during 7 wk of mild, dry weather following fertilizing, the presence of alder and swampy areas adjacent to the streams, high soil permeability, steep slopes, and abundant, above average early winter rainfall. The catchments had been fertilized previously in 1967-68 and 1972 but any influence of this on nitrogen loss during the present study is unknown. Lens Creek water quality was not adversely affected by the fertilizing in terms of drinking water standards or toxicity to fish.

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35. Homann, P.S., B.A. Caldwell, H.N. Chappell, P. Sollins and C.W. Swanston. 2001. Douglas-fir soil C and N properties a decade after termination of urea fertilization. *Canadian-Journal-of-Forest-Research* 31(12): 2225-2236.

Keywords: fertilization
soil properties

Abstract: Chemical and microbial soil properties were assessed in paired unfertilized and urea fertilized (>89 g N/m²) plots in 13 second-growth Douglas fir (*Pseudotsuga menziesii*) stands distributed throughout western Washington and Oregon, USA. A decade following the termination of fertilizer application, fertilized plots averaged 28% higher total N in the O layer than unfertilized plots, 24% higher total N in surface (0-5 cm) mineral soil, and up to four times the amount of extractable ammonium and nitrate. Decreased pH (0.2 pH units) caused by fertilizer application may have been due to nitrification or enhanced cation uptake. In some soil layers, fertilizer application decreased cellulase activity and soil respiration but increased wood decomposition. There was no effect of fertilizer application on concentrations of light and heavy fractions, labile carbohydrates, and phosphatase [phosphoric monoester hydrolases] and xylanase activities. No increase in soil organic C was detected, although variability precluded observing an increase of less than ~15%. Lack of aregionwide fertilizer application influence on soil organic C contrasts with several site-specific forest and agricultural studies that have shown C increases resulting from fertilizer application. Overall, the results indicate a substantial residual influence on soil N a decade after urea fertilizer application but much more limited influence on soil C processes and pools.

[OSU Link](#)

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

Keywords: fertilization
growth
soil properties
tree physiology

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

[OSU Link](#)

[Non-OSU Link](#)

37. Murray, M.D. and R.E. Miller. 1986. Early survival and growth of planted Douglas-fir with red alder in four mixed regimes. Pacific-Northwest-Research-Station,-USDA-Forest-Service Research-Paper PNW-RP-366. ii + 13 p.

Keywords: planting operations
release treatments
growth
stand conditions

Abstract: To quantify interactions between species, the survival and growth of planted Douglas fir in association with volunteer or planted red alder (*Alnus rubra*) were studied at a site on the W. side of the Cascade Range, Washington. The planted alders were wildings taken either from a nearby site or from a distant coastal site and interplanted in a 3-yr-old Douglas fir plantation. The volunteer alders established during the first year and were cut when the plantation was 3 or 7 yr old. There was no apparent advantage in using non-local alder to reduce aboveground competition with Douglas fir. Survival of both sources of transplanted alder was high. Retaining about 1100 plants/ha of volunteer alders until plantation age 7 yr had no measurable effect on Douglas fir. It is recommended that, with alder densities of <1250/ha, alder control on most land of average or below average site quality can be delayed until 6-8 yr after planting Douglas fir. This will reduce alder sprouting and allow simultaneous control of alder and precommercial thinning of Douglas fir.

[OSU Link](#)

[Non-OSU Link](#)

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

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

Abstract: This experiment evaluated the influence of manure, peat, and vermiculite incorporated at low and high rates (0.0118 and 0.0236 m³/m²) and under two soil moisture regimes on Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) seedling (1+0 for 1+1) xylem water potential (Phi xylem), whole-plant growth, root architectural development, and subsequent field performance under fertilized and non-fertilized conditions. Trends in soil moisture retention were observed (high manure > high peat > control) but there were no differences in Phi xylem. Root length in the wetter soil moisture experiment was initially (three months) greatest for seedlings in high vermiculite and least in high manure but there were no differences among treatments at lifting (eight months). Mean height was greatest for seedlings grown in vermiculite and peat (wetter nursery experiment) after two field seasons. Field fertilization (35 g/seedling) with controlled-release fertilizer in the planting hole stimulated height growth initially, but decreased height and diameter growth during the second growing season. Dramatic improvements

associated with the use of nursery soil amendments were not realized, but the failure to identify negative effects, a potential reduction in disease incidence, and improvement of nursery soil physical and chemical properties may justify their use.

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39. Kabzems, R.D. and K. Klinka. 1987. Initial quantitative characterization of soil nutrient regimes. I. Soil properties. *Canadian-Journal-of-Forest-Research* 17(12): 1557-1564.

Keywords: fertilization
soil properties

Abstract: Data on properties of the forest floor and mineral soil were collected from 6 Douglas fir ecosystems on southern Vancouver Island. Data were analysed to determine whether soil properties reflecting nutrient status differed significantly from soil nutrient regimes assessed using selected vegetation, environmental and physiographic features. The sum of mineralizable N, total N and exchangeable Ca and Mg in mineral soil and forest floor were the properties that best characterized the soil nutrient regimes recognized in this study (poor, medium, rich, very rich). Previous application of N fertilizer did not appear to change soil N status sufficiently to alter the classification.

Both discriminant and cluster analyses consistently differentiated the soil nutrient regimes using exchangeable Mg and mineralizable N in forest floor plus mineral soil. The consistency of these groupings suggests that important differences between the nutrient regimes could be identified using soil properties alone.

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[Non-OSU Link](#)

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

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

Abstract: On conifer plantations, competitive understorey vegetation often retards growth and establishment of tree seedlings. Livestock grazing is one method of controlling the understorey vegetation and increasing the availability of site resources to tree seedlings. It was hypothesized that prescribed cattle grazing ameliorates water stress of young tree seedlings by reducing root growth of competing understorey species. On a Douglas-fir (*Pseudotsuga menziesii*) and ponderosa pine (*Pinus ponderosa*) plantation in SW Oregon planted in 1986, seedling water stress was evaluated using the pressure chamber technique and gravimetric soil water determinations in 1986-89. Root growth of orchardgrass (*Dactylis glomerata*), the major understorey competing species, was quantified in 1988 and 1989 using the root periscope/mini-rhizotron technique. Seedling water stress levels during spring and summer were similar in cattle-grazed areas and ungrazed areas in 1986 to 1988, but in

summer 1989, water stress was reduced significantly in the grazed area. Soil water content was higher in the grazed area in 1989, especially at the 10-20 cm soil depth. End of season (July) orchardgrass root growth in grazed plots was 18% less in 1988 and 15% less in 1989 than root growth in ungrazed plots. It is concluded that repeated cattle grazing of orchardgrass reduced transpirational surface area and root growth sufficiently to increase soil water availability to tree seedlings. Thus, prescribed cattle grazing on conifer plantations can enhance seedling physiological status by acting as a regulator of above- and belowground competition.

[OSU Link](#)

[Non-OSU Link](#)

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

Keywords: fertilization
tree physiology
soil properties
mycorrhizal response

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

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42. Little, S.N. and D.R. Waddell. 1987. Highly stocked coniferous stands on the Olympic Peninsula: chemical composition and implications for harvesting strategy. Pacific-Northwest-Research-Station,-USDA-Forest-Service Research-Paper PNW-RP-384. 29 p.

Keywords: site preparation
mechanical preparation
soil properties

Abstract: An assessment is presented of macronutrients and their distribution within highly stocked, stagnant stands of mixed conifers on the Quilcene Ranger District, Olympic National Forest, northwest Washington, USA. These stands consisted of predominantly three species: western hemlock (*Tsuga heterophylla*), coast Douglas fir (*Pseudotsuga menziesii* var. *menziesii*), and western redcedar (*Thuja plicata*). Preliminary investigation suggested that the living crown contained a small portion of the nutrient capital on the site. Extracting this material from the site during harvest or site preparation should not pose a threat to future production of biomass. Bioassays suggested that no

macronutrients were deficient for growth of Douglas fir seedlings. However, care should be taken during harvest and site treatment to protect the nutrient capital in dead material and in the forest floor.

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[Non-OSU Link](#)

43. Maguire, D.A. 1994. Branch mortality and potential litterfall from Douglas-fir trees in stands of varying density. *Forest-Ecology-and-Management* 70(1/3): 41-53.

Keywords: thinning
wood quality
soil properties

Abstract: Differential crown recession and crown development among stands of differing density suggest that an opportunity may exist to control the input of fine woody litter into the system by manipulating stand density. The objective of this study was to measure the rate of branch mortality among stands of differing density and to estimate the range in total per hectare necromass inputs. Although litter traps are reliable for estimating per hectare rates of litterfall, branch mortality dating on sectioned stems uniquely allows assessment of several other litterfall components: (1) individual tree contributions to total litterfall; (2) the amount of branch material released by mortality, regardless of whether the branches are shed to the forest floor; (3) the distribution of basal diameters characterizing the litterfall from a given tree and stand. Twenty-four trees were felled and sectioned on permanent plots that were part of a silvicultural study of Douglas fir (*Pseudotsuga menziesii*) stand density regimes, in Umpqua National Forest, near Tiller, Oregon. Whorl branches were dissected out of bole sections to determine the dates of mortality, and a branch biomass equation was applied to estimate potential rate of litterfall. Periodic annual rates were expressed in four ways: (1) number of branches per tree; (2) mass of branches per tree; (3) mass of branches per unit of crown projection area; (4) mass of branches per hectare. For the growth periods investigated, larger trees and trees growing on denser plots tended to release a greater necromass through branch mortality. Average branch basal diameter generally decreased with increasing stand density. Annual branch mortality ranged from 33 to 430 g m⁻² crown projection area for individual trees, and from 236 to 1035 kg ha⁻¹ for individual plots. These rates approached the low end of the range of previously published fine litterfall rates for Douglas fir. Rates on these plots were relatively low owing to the temporary delay in crown recession imposed by artificial thinning. A conceptual model of branch litter dynamics is presented to depict consistencies with crown development among stands managed under different density regimes.

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44. Miller, R.E., D.H. McNabb and J. Hazard. 1989. Predicting Douglas fir growth and response to nitrogen fertilization in western Oregon. *Soil-Science-Society-of-America-Journal* 53(5): 1552-1560.

Keywords: fertilization
growth
soil properties
stand conditions

Abstract: The objective of this study was to determine the efficacy of various stand (site index, age, and relative density), climatic (total precipitation, average daily solar radiation), site (elevation, soil depth, and available water-holding capacity), and soil-test variables (anaerobically mineralized N, total N, organic matter, and C:N ratio) to predict relative and absolute response of *Pseudotsuga menziesii* stands to a single application of 224 Kg/N ha as urea. The core equation with stand variables accounted for 70% of residual variation in average annual volume growth. Predicting response of fertilized stands proved much less precise. The best core equation explained 37% of the residual variation for average percentage response in volume growth and explained less variation in absolute response in both volume and basal area. Of the site, climatic, and soil-test variables, C:N ratio in the surface soil was the only one that significantly increased precision of the core equations. The best combined equation explained 46% of the variation in percent volume response. The anaerobic N mineralization test failed to make a significant contribution to the core equation and had a lower correlation with response than did the C:N ratio. Stand variables remain the most reliable predictors of fertilizer response in this region; any improvement from including soil data for N or organic matter is not justified because of their additional cost.

[OSU Link](#)

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45. Miller, R.E., E.L. Obermeyer and H.W. Anderson. 1999. Comparative effects of precommercial thinning, urea fertilizer, and red alder in a site II, coast Douglas-fir plantation. Pacific-Northwest-Research-Station,-USDA-Forest-Service Research-Paper PNW-RP-513.ii + 25 p.

Keywords: fertilization
thinning
precommercial thinning
growth
yield
tree/stand health
soil properties

Abstract: The number of red alder (*Alnus rubra*) trees retained with 300 Douglas-fir (*Pseudotsuga menziesii*) per acre was varied on a high-quality site in coastal Oregon. Alder densities of 0, 20, 40, and 80 per acre were tested. A fifth treatment eliminated nitrogen-fixing alder, but substituted nitrogen fertilizer. Treatment 6 had neither thinning nor alder control. Treatments were randomly assigned within each of three blocks in a 9-year-old plantation. Stand density was reduced within 15 of these 18 experimental units. Surplus conifers were cut, but surplus red alder were controlled by the "hack-and-squirt" method. Because numerous trees of other species regenerated naturally, combined density of all species before thinning ranged from 1400 to 5700 trees per acre. Subsequent 17-year change in number, average height, basal area, and volume of Douglas-fir were compared. Retaining 20, 40, or 80 alder per acre reduced numbers of associated Douglas-fir by about 10, 17, and 23 percent, respectively. In pure Douglas-fir plots, gross volume growth was similar for non-fertilized and fertilized plots, indicating no measurable benefits of additional nitrogen. In mixed stands, red alder reduced yield of associated Douglas-fir, but not yield of combined species. Similar comparisons are needed at other locations, especially those with known nitrogen deficiency.

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46. Miller, R.E., D.L. Reukema and H.W. Anderson. 2004. Tree growth and soil relations at the 1925 Wind River spacing test in coast Douglas-fir. Pacific-Northwest-Research-Station,-USDA-Forest-Service Research-Paper PNW-RP-558. iii + 41 p.

Keywords: planting operations
growth
soil properties

Abstract: The 1925 Wind River (Washington, USA) spacing test is the earliest field trial seeking to determine the most appropriate spacing for planting Douglas-fir (*Pseudotsuga menziesii*). Spacing treatments were not replicated, although individual spacings were subsampled by 2 to 4 tree-measurement plots. Previously, greater growth occurred at the wider spacings (10 and 12 ft) than at the closer spacings (4, 5, 6 and 8 ft). We considered three possible explanations: (1) close spacing eventually retarded growth, (2) soil quality may be better in the 10- and 12-ft spacings than at closer spacings, and (3) tree spacing and soil quality combined affected growth. To test these explanations, we measured and mapped several site factors (topographic relief, depth to bedrock, and soil properties), and related these factors to tree and stand growth. We infer from the strong correlation between spacing and soil variables that the influence of soil and spacing cannot be separated; differences in soil depth and available water capacity confound spacing effects and vice versa. Because soils in the wider spacings were generally deeper and had more available water capacity than do soils in the closer spacings, we conclude that some of the superior tree growth attained in the 10- and 12-ft spacings is due to more favourable soil conditions. Visual comparisons of tree size, however, suggest that spacing is probably the stronger factor affecting tree growth at this location.

[OSU Link](#)

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47. Minore, D. 1986a. Effects of site preparation on seedling growth: a preliminary comparison of broadcast burning and pile burning. Pacific-Northwest-Research-Station,-USDA-Forest-Service Research-Note PNW-RN-452. 12 p.

Keywords: site preparation
prescribed fire
growth
soil properties

Abstract: In studies in SW Oregon, measured and potential heights were similar for 5-yr-old planted seedlings of Douglas fir (*Pseudotsuga menziesii*) on areas that had been broadcast burned. Measured heights were less than potential heights on most of the pile-and-burn plantations, suggesting that site quality is damaged by this site preparation method.

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48. Minore, D. and H.G. Weatherly. 1990. Effects of site preparation on Douglas-fir seedling growth and survival. *Western-Journal-of-Applied-Forestry* 5(2): 49-51.

Keywords: site preparation
mechanical preparation
prescribed fire
growth
tree/stand health
soil properties

Abstract: The effects of 5 site preparation treatment combinations (A: cable yarding + broadcast burning - B: tractor yarding + broadcast burning - C: machine piling + broadcast burning - D: machine piling + off-site burning - and E: machine piling + off-site burning + tilling) on Douglas fir (*Pseudotsuga menziesii*) growth and survival were studied in 1984-87. Seedling height, potential seedling height, survival percentages, soil-penetration resistances, and occurrence of visible soil humus were evaluated on 149 progeny-test plantations in western Oregon. Survival was not improved by mechanical site preparation (survival at 5 years was 84.8% for treatment A, 73.7% for C and 78.1% for E). Seedlings grown on compacted soils with low humus, associated with piling slash off site, did not grow as tall during their first 5 years as seedlings grown on similar sites where slash had been broadcast-burned (height 77 cm for treatments D and E, compared to 93 cm for A). Mechanical site preparation was not essential for Douglas fir survival, as long as competing vegetation is controlled. Increased soil compaction, loss of humus, and reduced 5 year height growth associated with mechanized slash removal indicated detrimental effects on site quality as well as tree growth.

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

Keywords: fertilization
thinning
precommercial thinning
carbon allocation
tree physiology
growth
soil properties

Abstract: The effects of thinning (two-thirds of basal area removed) and N fertilizer (448 kg N/ha as urea) on biomass and nutrition of a 24-year-old Douglas fir (*Pseudotsuga menziesii*) stand at Shawnigan Lake, British Columbia, were studied over 18 years. At years 0, 9, and 18 after treatments, the aboveground biomass and N, P, K, Ca, and Mg contents of stemwood, stem bark, foliage, and dead and live branches were determined (kg/ha), and increments in these properties (kg/ha per year) were calculated for the 0-9 and 9-18 year periods. Foliar biomass was increased by both treatments during the first period and also by thinning in the second period. Aboveground net primary production (ANPP) per unit of foliage biomass (foliage efficiency) was increased by treatments in the 0-9 year period. The combined effects of increased foliage mass and foliage efficiency resulted in increased total biomass production. Thinning and fertilizer application increased the uptake of all elements except for P with fertilizer. This increase may have contributed to the long-term increase in stem growth. Retranslocation of elements before foliage shedding was important for tree nutrition, but was

not improved by fertilizer during the 9-18 year measurement period. The efficiency of N use in dry matter production (ANPP/unit of N uptake) was decreased by fertilizer. This implied that poor sites would respond to fertilizer better than rich sites.

[OSU Link](#)

[Non-OSU Link](#)

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

Keywords: fertilization
tree physiology
soil properties

Abstract: Seasonal effects on the volatilization and vegetal recapture of NH₃ following application of pelleted 15N urea at 200 kg N ha⁻¹ to a 40-yr-old Douglas-fir [*Pseudotsuga menziesii*] ecosystem were investigated. Volatilization totalled 14 and 0.7% of applied N in spring and autumn, respectively, and the difference appeared to be related to precipitation patterns following fertilization. Volatilization was generally enhanced by small spring rainfalls while depressed by larger autumn rains. The isotopic abundance of evolved NH₃ fluctuated from >90 to <10% of that of the fertilizer source. These fluctuations reflected the role of precipitation in the regulation of spatial heterogeneity of urea and urease in soil. Under spring conditions NH₃ was recaptured by potted Douglas-fir seedlings. Seedlings at 10 cm above the forest floor captured 16 times as much NH₃ as seedlings positioned at the 150-cm elevation. Labelled N was distributed among seedling tissues in the order: current foliage > 1-year-old foliage > roots which is consistent with anabolic incorporation and translocation. This mechanism may have a significant role in plant nutrition when conditions favourable to NH₃ volatilization follow urea fertilization.

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51. Nelson, E.E., M.G. McWilliams and W.G. Thies. 1994. Mortality and growth of urea-fertilized Douglas-fir on a *Phellinus weirii*-infested site in Oregon. *Western-Journal-of-Applied-Forestry* 9(2): 52-56.

Keywords: planting operations
fertilization
tree/stand protection
growth
tree/stand health
soil properties

Abstract: Twelve plots were established in 1972 in an 11-yr-old Douglas fir (*Pseudotsuga menziesii*) plantation infected with *Phellinus weirii*, the cause of laminated root rot. All plots were thinned and either interplanted with red alder (*Alnus rubra*) or fertilized at 5- to 10-yr intervals with urea to determine the effect of nitrogen on tree growth and mortality caused by *P. weirii*, or left

untreated. Interplanted alder, however, failed to survive. Mortality was assessed at intervals of 2 to 3 yr. Plots were inventoried (100% cruise) in 1978 and 1990. Growth over 12 yr appeared better on fertilized than nonfertilized plots, but the difference was not significant. Mortality caused by the preferential feeding of black bears [*Ursus americanus*] on the inner bark of fertilized trees reduced the overall gain. Mortality caused by laminated root rot did not differ significantly among treatments. Three months after the initial application of urea at 448 kg N/ha, soil sampled to a depth of 30 cm was higher in ammonium and nitrate forms of nitrogen on fertilized than nonfertilized plots, but increases were not significant. Numbers of soil bacteria were directly correlated with soil ammonium content ($P = 0.1092$). Numbers of aerobic actinomycetes were inversely correlated with soil nitrate content ($P = 0.0398$).

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

Keywords: release treatments
chemical release
growth
soil properties
tree physiology

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

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

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

Abstract: The growth of Douglas fir *Pseudotsuga menziesii* seedlings was increased during the first 5 years by controlling grasses and forbs in 7 herbicide regimes during the 1st 3 years, the effect diminishing with time after planting. Devegetated plots had more available moisture through the growing season than those with *Agrostis tenuis* or mixed mixed grass/forb cover dominated by *A. tenuis* or *Hypochaeris radicata*. Tree moisture stress followed soil moisture but only after allowing for large fluctuations of diurnal stress. Weed control relieved moisture stress in trees.

P. menziesii photosynthesis tended to shut down in the region of -2.0 MPa moisture stress. For the 1st 3 years in a favourable coastal environment approx. 1700 MPa-h above -2.0 MPa was estimated to be required for survival. Increments of moisture beyond that would contribute significantly to growth.

[OSU Link](#)

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

Keywords: release treatments
manual release
soil properties
tree physiology
growth

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

[OSU Link](#)

[Non-OSU Link](#)

55. Perry, D.A., C. Choquette and P. Schroeder. 1987. Nitrogen dynamics in conifer-dominated forests with and without hardwoods. *Canadian-Journal-of-Forest-Research* 17(11): 1434-1441.

Keywords: release treatments
soil properties
tree morphology

Abstract: In studies on the E. slopes of the Oregon Coast Range, contents of N and C in the surface 12 cm of mineral soil, N in leaf litterfall, anaerobic N mineralization rates in the soil and forest floor, and root and N accretion to sand traps placed in surface soil layers were studied in stands dominated by Douglas fir trees, from which the broadleaved component had been partially or completely removed during thinning 3 yr earlier. Contrary to expectations, stands without broadleaved species had more N in mineral soil, a greater rate of anaerobic soil N mineralization and a lower soil C : N ratio than stands with broadleaved species. These variables did not differ between thinned and unthinned mixed stands. From litterfall and sand trap data, it is suggested that N was redistributed in the coniferous system after removal of the broadleaved species.

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

Keywords: release treatments
chemical release
tree physiology
soil properties
growth

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

[OSU Link](#)

[Non-OSU Link](#)

57. Peterson, C.E., P.J. Ryan and S.P. Gessel. 1984. Response of northwest Douglas-fir stands to urea: correlations with forest soil properties. *Soil-Science-Society-of-America-Journal* 48(1): 162-169.

Keywords: fertilization
thinning
growth
soil properties

Abstract: Replicated forest floor and surface soil (0-15 cm) samples were obtained from control plots at 160 field installations in western Washington and Oregon. Six-year growth responses of thinned and unthinned Douglas-fir [*Pseudotsuga menziesii*] treated with 0, 224, and 448 of urea-N ha⁻¹ were correlated with 18 forest floor and surface soil properties of the control plots. Forest floor nitrogen properties were the most highly correlated with various estimates of response in both thinned and unthinned stands; these correlations were generally independent of methods used to estimate response. For unthinned stands, C/N ratios of both forest floor and surface soil were well correlated with growth response to fertilizer, whereas for thinned stands, N content (kilograms per hectare) of the forest floor was consistently correlated with response.

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[Non-OSU Link](#)

58. Piatek, K.B., C.A. Harrington and D.S. DeBell. 2003. Site preparation effects on 20 year survival and growth of Douglas-fir (*Pseudotsuga menziesii*) and on selected soil properties. *Western-Journal-of-Applied-Forestry* 18(1): 44-51.

Keywords: site preparation
mechanical preparation
prescribed fire
tree/stand health
growth
soil properties

Abstract: Long-term effects of site preparation on tree performance and soil properties are not well known. Five site preparation treatments were evaluated to determine how they affected survival and growth of Douglas-fir (*Pinus menziesii*) 3, 10, and 20 years after planting, and soil bulk density, C, N, P, and organic matter concentrations at 0 to 20 cm soil depth 21 years after planting. The site preparation treatments were imposed following logging of three harvest units of old-growth forest on a volcanic soil in southwestern Washington, USA; the units were logged to leave 17, 38, and 53 tonnes/ha of woody residue. The site preparation treatments were hand-pile-and-burn, machine-pile-and-burn, scarification, broadcast burn, and control. Mean survival ranged from 86% at age 3 to 70% at age 20, and average tree heights at 3, 10, and 20 years were 0.6, 4.1, and 11.7 m. The scarification treatment had the best growth; at age 20, its average tree was 21% taller, 26% larger in diameter, and 82% greater in volume than the control. The hand-pile-and-burn treatment did not differ from the control in tree growth; the machine-pile-and-burn and broadcast burn treatments were intermediate in their growth response. Average soil bulk density was 0.74 g/cm³, organic matter concentration was 118 g/kg, and C, N, and P concentrations were 49, 1.6, and 0.7 g/kg with no significant treatment effects. Site preparation may have benefited growth of the trees on these units by decreasing competition from invading and regrowing vegetation, increasing nutrient availability, or increasing soil temperature.

[OSU Link](#)

[Non-OSU Link](#)

59. Prescott, C.E. 1995. Does nitrogen availability control rates of litter decomposition in forests? *Plant-and-Soil* 168/169: 83-88.

Keywords: fertilization
soil properties

Abstract: The effects of increased exogenous N availability on rates of litter decomposition were assessed in several field fertilization trials. In a jack pine (*Pinus banksiana*) forest, needle litter decomposed at the same rate in the controls and those plots fertilized with urea and NH_4NO_3 at 1350 kg N/ha (+or-P and K). Mixed needle litter of western hemlock (*Tsuga heterophylla*), western red cedar (*Thuja plicata*), and Douglas-fir (*Pseudotsuga menziesii*) from plots amended with sewage sludge (500 kg N/ha) lost less weight than the controls. Forest floor material also decomposed more slowly after amendment with sewage sludge. Paper birch (*Betula papyrifera*) leaf litter treated with either sewage sludge (1000 kg N/ha), pulp sludge, or a sewage/pulp sludge-mixture decomposed at the same rate as the controls. Exogenous N availability therefore had little impact on litter decomposition rates. The influence of endogenous N availability on litter decomposition rates was studied with a microcosm. Lodgepole pine (*Pinus contorta* var. *latifolia*) needle litter collected from trees fertilized at 525 kg $\text{NH}_4\text{NO}_3\text{-N}$ /ha and green needles were both richer in N (1.56 and 1.9% N, resp.) than needles from control trees (0.33 and 0.88% N, resp.), although all the needles decomposed at the same rate. It was concluded that N availability alone, either exogenous or endogenous, did not control litter decomposition rates. Increased N availability, through fertilization or deposition, in the absence of changes in vegetation composition, was not considered sufficient to alter rates of litter decomposition in forests.

[Non-OSU Link](#)

60. Prescott, C.E., M.A. McDonald, S.P. Gessel and J.P. Kimmins. 1993b. Long-term effects of sewage sludge and inorganic fertilizers on nutrient turnover in litter in a coastal Douglas fir forest. *Forest-Ecology-and-Management* 59(1-2): 149-164.

Keywords: fertilization
soil properties

Abstract: Rates of litter input, decomposition, net N mineralization, and N and P supply on the forest floor were measured in a 70-yr-old second growth stand of Douglas fir (*Pseudotsuga menziesii*) on a poor site in western Washington state, approximately 10 yr after applications of sewage sludge and inorganic fertilizers. Sewage sludge was applied to three plots at the rate of 6000 kg N/ha, and nitrogenous fertilizers were applied to two plots at rates of 1082 and 1568 kg N/ha. The rate of each process in each treated plot was compared with that in an adjacent control plot. Amounts of N returned in needle litter during 1 yr were greater on sludged and fertilized plots relative to adjacent control plots. Decomposition of a standard needle litter was the same on all plots after a 2-h in situ incubation. Rates of N mineralization during aerobic incubations of forest floor material were similar in all plots in field incubations, but smaller rates were measured in material from sludged plots in laboratory incubations. Greenhouse bioassays with Douglas fir and Sitka spruce (*Picea sitchensis*) seedlings showed greater P

supply in forest floor material from sludged plots, but no differences in N supply between any treatments. Turnover of N in litter was not different 10 yr after fertilization of this forest with sewage sludge or N fertilizer. There was evidence of long-term enhancement of P turnover in litter plots treated with sewage sludge.

[OSU Link](#)

[Non-OSU Link](#)

61. Prescott, C.E. and L.M. Zabek. 1999. Decomposition and nitrogen mineralization in forests of British Columbia: effects of forest management practices. *In* Proceedings: Pacific Northwest forest and rangeland soil organism symposium; 1998 March 17-19; Corvallis, OR. Pacific-Northwest-Research-Station, USDA-Forest-Service General-Technical-Report PNW-GTR-461. Eds. R.T. Meurisse, W.G. Ypsilantis, and C. Seybold. 124-136 pp.

Keywords: planting operations
fertilization
soil properties

Abstract: The productivity of most forests in the Pacific Northwest is limited by the availability of nitrogen. Nitrogen availability is largely controlled by the rate at which N is recycled from organic matter, through the processes of decomposition and mineralization. These processes are controlled by the factors that limit the activities of the soil organisms involved, particularly temperature, moisture, and the physical and chemical nature of the organic matter. Forest management activities may influence each of these factors and thereby affect rates of decomposition, N mineralization and N availability. The influences of several common forest management activities on decomposition and N mineralization were examined in a suite of experiments across British Columbia, Canada. Rates of decomposition were compared in forests and adjacent clear felled areas at 22 sites, and rates were either the same or slower in the felled areas. Several sites had additional silvicultural treatments that provide a range of either opening size or removal intensity. Decomposition rates were not influenced by opening size, but rates of net N mineralization and nitrification were increased in openings greater than 0.1 ha. Tree species influences N mineralization in the forest floor, with highest rates occurring in Douglas-fir and broadleaf species and lowest rates in cedar and pines. The decomposition rates of foliar litters was best predicted by its lignin concentration. The influence of managing to maintain a component of broadleaf species was examined in decomposition experiments with pure and mixed litter of aspen and spruce, Douglas-fir and alder, and lodgepole pine, Douglas-fir and paper birch. There was no effect of mixing litters on their rates of decomposition. Likewise, N fertilization had no effect on decomposition rates in trials in coastal Douglas-fir and aspen.

[OSU Link](#)

[Non-OSU Link](#)

62. Preston, C.M., V.G. Marshall, K. McCullough and P.J. Mead. 1990. Fate of ¹⁵N-labelled fertilizer applied on snow at two forest sites in British Columbia. *Canadian-Journal-of-Forest-Research* 20(10): 1583-1592.

Keywords: fertilization
soil properties

Abstract: Fertilizer was applied on snow in January 1981 at 100 kg N/ha as (15N)urea, 15NH₄NO₃ or NH₄15NO₃ to 11-yr-old lodgepole pine (*Pinus contorta* var. *latifolia*) at Spillimacheen in the British Columbia interior and as (15N)urea (200 kg N/ha) to 13-yr-old Douglas fir (*Pseudotsuga menziesii*) at Green Mountain, a coastal site in British Columbia. Recovery of labelled N after one growing season was determined in soil and biomass at both sites, and it was also monitored during the growing season in snow and soil at Spillimacheen. At Green Mountain, 5.5% of urea N was recovered in tree biomass, 10.8% in understorey and 33.4% in soil organic N (total recovery 49.7%). Leaching may have contributed to N losses at Green Mountain, but was probably not a direct consequence of the application on snow. At Spillimacheen, total recovery of (15N)urea was 93.3%, with 10.1% in tree biomass, 2.4% in understorey and 80.8% in soil. For 15NH₄NO₃, recoveries were 5.3% in tree biomass, 2.9% in understorey and 87.0% in soil, for a total of 95.2%. For NH₄15NO₃, recoveries were 1.9% in tree biomass, 3.4% in understorey and 39.1% in soil, for a total of 44.4%. At Spillimacheen, the performance of 15NH₄NO₃ was comparable to that of urea in tree uptake and soil retention. There were large losses with the NH₄15NO₃ source, however, probably because of leaching and denitrification during snowmelt. For this reason, fertilization with nitrate on snow is not recommended because of nitrate's susceptibility to leaching, but urea and ammonium sources may be applied under these conditions.

[OSU Link](#)

[Non-OSU Link](#)

63. Preston, C.M. and R.H. Newman. 1995. A long-term effect of N fertilization on the ¹³C CPMAS NMR of de-ashed soil humin in second-growth Douglas-fir stand of coastal British Columbia. *Geoderma* 68(4): 229-241.

Keywords: fertilization
thinning
soil properties

Abstract: Carbon-13 CPMAS NMR spectroscopy was used to examine long-term effects of thinning and N fertilization on the humin fraction of soil organic matter in a second-growth Douglas-fir (*Pseudotsuga menziesii*) stand in coastal British Columbia, Canada. De-ashed OM-enriched humin fractions were prepared from three mineral soil horizons of four silvicultural treatments using 1.0M HF accompanied by removal of ferromagnetic iron particles, and a density separation. With some exceptions a higher proportion of mass was recovered in the denser, light-coloured fraction, and a higher proportion of C and N in the less-dense, dark fraction. In all cases, the less-dense fraction was enriched in total C compared to the original crude humin, and had a more favourable C:Fe ratio for NMR spectroscopy. The fraction of observable C was 33-37% for 8 of the samples, but as low as 7.6% for the remaining four. Carbon-13 CPMAS NMR spectra had typical features for humins (alkyl C, O-alkyl C, di-O-alkyl C, aromatic C, and carboxyl, ester and amide C). With fertilization, there was a small but consistent decrease in the ratio of alkyl to O-alkyl C, regardless of horizon or thinning, indicating a lower extent of decomposition. Carbon-13 subspectra based on proton spin relaxation time (T₁(1H)) were obtained for one fertilized and one unfertilized sample. Subspectra of the slowly-relaxing (long T₁(1H)) domain were dominated by long-chain alkyl C. For the fertilized sample, the subspectrum of the fast-relaxing (short T₁(1H)) domain had a higher proportion of O- and di-O-alkyl C, consistent with results from the normal CPMAS NMR spectra. Despite the uncertainties introduced by the de-ashing treatment and the low fraction of observable C, ¹³C CPMAS NMR showed that fertilization has a long-term effect which is reflected in this humin fraction.

[OSU Link](#)

[Non-OSU Link](#)

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

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

Abstract: Studies were made in a thinned 32-yr-old Douglas fir stand on a drought-prone site on the E. coast of Vancouver Island. Four pairs of similar trees were selected and the salal (*Gaultheria shallon*) understory was removed completely from around one of each pair. The root zones of each tree were isolated using plastic sheeting buried to bedrock. Photosynthesis, stomatal conductance, soil water potential and canopy microclimate were measured intensively in one pair on 4 clear days during an extended dry period in June 1982. B.a. increment of the four pairs of trees was measured over 3 growing seasons. To determine the effect of soil water potential on tree photosynthesis, the same variables were measured for 3 consecutive days in Aug. 1982 for another tree initially subjected to a soil water potential of approx. -1.6 MPa, but irrigated to approx. -0.02 MPa between days 1 and 2. Solar irradiance decreased markedly between days 2 and 3, thus creating a unique data set. Results showed that removal of the understory significantly increased rates of photosynthesis in Douglas fir, both diurnally and seasonally. Photosynthesis was not generally limited by stomatal conductance unless vapour pressure deficit was high and photon flux density was saturating. Improved tree growth after understory removal was due to the increased soil water potential that increased both photosynthetic capacity and stomatal conductance.

[OSU Link](#)

[Non-OSU Link](#)

65. Prietzel, J., G.L. Wagoner and R.B. Harrison. 2004. Long-term effects of repeated urea fertilization in Douglas-fir stands on forest floor nitrogen pools and nitrogen mineralization. *Forest-Ecology-and-Management* 193(3): 413-426.

Keywords: fertilization
soil properties

Abstract: In six Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco] stands in the Puget Sound Region in Western Washington/USA, forest floor C and N pools were quantified on control plots and on plots that had been fertilized repeatedly with urea 8-30 years ago (total amount of applied N 0.9-1.1 Mg ha⁻¹). Additionally, net N mineralization and nitrification rates were assessed in field and laboratory incubation experiments. Forest floor C/N ratios were decreased on the fertilized plots of all sites compared to the respective control plots. The decreases were particularly strong at sites with initial C/N ratios larger than 30. On sites with low productivity (site index at age 50: <33 m), N fertilization resulted in considerable

increases in forest floor N pools. Net N mineralization and nitrification during 12-week field incubation was negligible for the unfertilized and fertilized plots of all except one site (Pack Forest), where the stand had been clear-cut 2 years ago. The increases in N mineralization rates during 12-week laboratory incubation induced by repeated N fertilization showed an inverse relationship to the time elapsed since the last fertilizer application, and were generally larger at sites with initial forest floor C/N ratios >30. For the investigated sites, fertilization effects on net N mineralization sustained for at least 11 years after the last fertilizer application. Nitrification correlated strongly with the forest floor pH; significant formation of NO₃⁻ was observed only for O layers with a pH (H₂O) higher than 4.5.

[OSU Link](#)

[Non-OSU Link](#)

66. Radwan, M.A. and J.S. Shumway. 1984. Site index and selected soil properties in relation to response of Douglas-fir and western hemlock to nitrogen fertilizer. *In* Forest soils and treatment impacts: Proceedings of the Sixth North American Forest Soils Conference, Department of Forestry, Wildlife and Fisheries, University of Tennessee, Knoxville, TN, June 1983. *Ed.* E.L. Stone. pp. 89-104.

Keywords: fertilization
growth
soil properties

Abstract: Studies were made in 25 Douglas fir stands in Washington and Oregon and in 16 western hemlock stands in Washington. Site index, total and mineralizable soil N were the only variables correlated with growth response to N fertilizer by Douglas fir. Growth response of hemlock was correlated with extractable P/total N in the soil. Total N and mineralizable S in mineral soil were highly correlated and showed moderate negative correlations with growth response of hemlock, but site index was not correlated with response. Results suggest that site index and soil N seem promising indicators of the response of Douglas fir to N fertilizer, while extractable P and the P/N ratio may indicate the response of hemlock. Soil N appears to be more important than soil P in predicting the response of Douglas fir on the sites studied. Soil S did not appear to limit the response of either species to N fertilizer and does not seem promising for estimating the response to N.

[OSU Link](#)

[Non-OSU Link](#)

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

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

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

[OSU Link](#)

[Non-OSU Link](#)

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

Keywords: fertilization
soil properties
growth
tree physiology

[OSU Link](#)

[Non-OSU Link](#)

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

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

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

[OSU Link](#)

[Non-OSU Link](#)

70. Sachs, D. and P. Sollins. 1986. Potential effects of management practices on nitrogen nutrition and long-term productivity of western hemlock stands. *Forest-Ecology-and-Management* 17(1): 25-36.

Keywords: thinning
commercial thinning
yield
soil properties
computer modeling

Abstract: The FORCYTE-10 computer model, developed by J.P. Kimmins and K. Scoullar for Douglas-fir forests in British Columbia, was modified to simulate growth and nutrient cycling of coastal western hemlock stands in Oregon. Initial calibration indicated that predicted yield was extremely sensitive to the rate of mineralization of soil organic matter (SOM), variation in SOM C/N ratio with site quality, the soil extractable NO₃⁻/NH₄⁺ ratio, and the decomposition rate and N mineralization pattern of large and medium-size roots and woody debris. The predictions suggested that yield and SOM remain stable under a management system consisting of six successive 90-yr rotations. More intensive utilization (e.g., shorter rotations, whole-tree harvesting and commercial thinning) causes depletion of soil and forest floor nitrogen and a small decline in site productivity in later rotations.

[OSU Link](#)

[Non-OSU Link](#)

71. Shumway, J.S. and H.N. Chappell. 1995. Preliminary DRIS norms for coastal Douglas-fir soils in Washington and Oregon. *Canadian-Journal-of-Forest-Research* 25(2): 208-214.

Keywords: fertilization
thinning
growth
soil properties

Abstract: The Diagnosis and Recommendation Integrated System (DRIS) has been used successfully to evaluate interactions between nutrients and fertilizer response and for diagnosing nutrient deficiency in agricultural crops. This study used soil tests to develop DRIS norms and evaluate their effectiveness in coastal Douglas fir (*Pseudotsuga menziesii*) forests. DRIS norms for nitrogen, phosphorus, potassium, and calcium were developed using soil test and site index data from 72 soil series that commonly support Douglas fir in western Washington. The norms were tested using soil test and stand basal area growth response data from 20 thinned and 30 unthinned N fertilizer test sites in coastal Washington and Oregon. Response to urea fertilizer in thinned stands averaged 34% and 43% for 224 and 448 kg N.ha⁻¹, respectively, when N was identified as the most limiting nutrient. When N was not the most limiting nutrient, N response averaged 8% and 10% for 224 and 448 kg N.ha⁻¹, respectively. Results were similar in unthinned stands and thinned stands, although response to fertilizer appeared to be slightly less in unthinned stands when N was the most limiting nutrient. DRIS correctly classified 25 of the 33 sites (76%) where N fertilizer increased growth by more than 15%. More importantly, 13 of the 17 (76%) sites that responded by less than 15% were correctly identified by DRIS. The results clearly indicate that N fertilizer response is dependent on the interactions (balance) between soil nutrients at a given site. Future soil diagnostic work needs to focus on techniques, like DRIS, that provide an assessment of these interactions.

[OSU Link](#)

[Non-OSU Link](#)

72. Strader, R.H. and D. Binkley. 1989. Mineralization and immobilization of soil nitrogen in two Douglas-fir stands 15 and 22 years after nitrogen fertilization. *Canadian-Journal-of-Forest-Research* 19(6): 798-801.

Keywords: fertilization
growth
soil properties

Abstract: Additions of ¹⁵N-labelled NH₄Cl were used to examine the role of microbial immobilization in long-term growth response of Douglas fir (*Pseudotsuga menziesii*) plantations to N fertilizer treatment. Soil samples were collected in summer 1986 from fertilized (448 or 470 kg/ha N) and nonfertilized plots at previously established N fertilization experiments near Shawnigan Lake, British Columbia, and the Wind River Experimental Forest near Carson, Washington. Douglas fir on these sites were reported to still be responding to N fertilization after 12 and 18 years. Less than 2% of the added ¹⁵N was recovered as mineral N after a 14-day laboratory incubation of soil samples from the fertilized and nonfertilized plots. This indicates that gross mineralization could be >50x greater than net mineralization in these infertile soils if the remaining 98% of the added ¹⁵N were all biologically immobilized. Net mineralization was significantly greater ($p < 0.10$) in soils from the fertilized plots than in those from the nonfertilized plots at the Wind River site. Although the current differences

in N availability did not appear to be related to differences in microbial immobilization, such large rates of immobilization require further investigation as a factor in long-term response to fertilization.

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[Non-OSU Link](#)

73. Sturrock, R.N., E.J. Phillips and R.G. Fraser. 1994. A trial of push-falling to reduce *Phellinus weirii* infection of coastal Douglas-fir. B.C. Ministry of Forests FRDA-Report 217. vi + 22 p.

Keywords: tree/stand protection
economics
tree/stand health
soil properties

Abstract: In push-falling, whole trees are pushed over by a bucket- and thumb-equipped excavator then grapple skidded to a landing where root masses are cut off and stems are bucked into logs. Harvesting of trees and removal of diseased roots is thus achieved with one stand entry. The productivity and economics of push felling were evaluated in a second-growth Douglas fir (*Pseudotsuga menziesii*) stand in coastal British Columbia. Results indicated that costs are comparable to those for conventional harvesting alone and that push felling can effectively remove infected roots. Before harvest <80% of the site was undisturbed but disturbed soils occupied 50.6% of the site after harvest. Changes in total bulk densities were relatively minor.

[OSU Link](#)

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74. Thies, W.G., E.E. Nelson and D. Zabowski. 1994. Removal of stumps from a *Phellinus weirii* infested site and fertilization affect mortality and growth of planted Douglas-fir. *Canadian-Journal-of-Forest-Research* 24(2): 234-239.

Keywords: site preparation
mechanical preparation
fertilization
tree/stand protection
tree/stand health
growth
soil properties

Abstract: A field study was established in a 4.9 ha clearcut on the west slope of the Cascade Range (44 degrees 21'N, 122 degrees 39'W), Oregon, to evaluate the effects of stump removal (of both infested and non-infested stumps) and fertilizing with ammonium nitrate on the incidence of laminated root rot (caused by *Phellinus weirii*) in Douglas fir (*Pseudotsuga menziesii*) seedlings. A 2x4 set of factorial treatments of stump removal in combination with nitrogen fertilizing was applied in August 1980 to 0.04-ha circular plots within the clearcut. Treatments included stump removal (either all stumps removed or the plot left undisturbed) and broadcast application of ammonium nitrate (0, 336, 672, or 1345 kg N/ha). Diameter at breast height and height of Douglas fir, planted as 2+1 bare root seedlings 4

months after treatment (in January 1981), were recorded 5 and 9 seasons after outplanting. Soil bulk density in the upper 20 cm was measured with a single-probe neutron densimeter. Stump removal reduced the number of seedlings killed by laminated root rot but had no significant effect on seedling growth. Stump removal increased soil bulk density only 7% as measured 9.7 years after treatment. Fertilizer increased the growth in diameter at breast height, and height growth of the seedlings but had no effect on mortality. There were no significant interactions between fertilizing and stumping treatments. Increased total soil N could still be detected on fertilized, nonstumped plots 9.7 years after treatment.

[OSU Link](#)

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75. Trofymow, J.A., H.J. Barclay and K.M. McCullough. 1991. Annual rates and elemental concentrations of litter fall in thinned and fertilized Douglas-fir. *Canadian-Journal-of-Forest-Research* 21(11): 1601-1615.

Keywords: fertilization
thinning
soil properties

Abstract: Overstorey litterfall (primarily needles) was collected for 15 years (1972-86) within control and treated plots in a Douglas fir (*Pseudotsuga menziesii*) stand near Shawnigan Lake, British Columbia. Treated plots were thinned or fertilized, or both. Thinned plots had two-thirds of their basal area removed; fertilized plots were treated with 448 kg N/ha of either urea or ammonium nitrate, and the fertilized plots were refertilized at the same rate 9 years later. The annual rate of litterfall in control plots averaged 1890 kg/ha. In control plots, significant yearly variations were observed in litterfall mass and concentrations of K, Mg, and Ca but not N or P. Thinning decreased rates of litterfall by 80%, but rates returned to control-plot levels after 13-15 years in unfertilized plots and after 8-10 years in fertilized plots. Fertilizer treatment without thinning depressed litterfall in the year of treatment but increased the rate by 20-80% in subsequent years. Litterfall N concentrations increased by 40-80% the year of fertilizer treatment and then began decreasing 3-6 years later. Nitrogen fertilization reduced litterfall P, K and Mg concentrations for 8, 4 and 1 year(s), respectively, following fertilizer treatment. The effects were greater in ammonium nitrate plots than in urea plots. Rates of litterfall correlated poorly with stand density but well with basal area and stemwood increment. Correlations with the latter two variables varied with time and treatment.

[OSU Link](#)

[Non-OSU Link](#)

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

Keywords: fertilization
soil properties
growth
tree physiology

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

[OSU Link](#)

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77. Turner, J., D.W. Johnson and M.J. Lambert. 1980. Sulphur cycling in a Douglas-fir forest and its modification by nitrogen application. *Acta Oecologica Oecologia Plantarum* 1(1): 27-35.

Keywords: fertilization
soil properties

Abstract: [See FA 39, 1857] In a study of a 42-yr-old nitrogen-deficient stand in Washington State, subject to acid rain and elevated inputs of S, excess S was found to be stored and cycled as SO₄. A nitrogen (urea) fertilizer experiment reported previously resulted in the incorporation of foliar SO₄ into organic S and a reduction in concn. of litterfall SO₄. Nitrogen stress induced in the same experiment by addition of carbohydrate (sucrose and sawdust) to the forest floor resulted in greater return of SO₄ via litterfall.

[OSU Link](#)

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78. Velazquez-Martinez, A. and D.A. Perry. 1997. Factors influencing the availability of nitrogen in thinned and unthinned Douglas-fir stands in the central Oregon Cascades. *Forest-Ecology-and-Management* 93(3): 195-203.

Keywords: fertilization
thinning
soil properties

Abstract: Soil N mineralized during 7-day anaerobic incubation at 40 degrees C (available N) was compared at 2 soil depths and correlated with soil and site factors in Douglas fir [*Pseudotsuga menziesii*] stands with different combinations of thinning and multinutrientfertilizing. Available N expressed either on an area basis (kg ha⁻¹) or on a concentration basis (mg kg⁻¹) at the 2 depths did not vary significantly by stocking density, treatment, or density-treatment interaction. There was a significant difference between the soil depths, averaging 39 mg kg⁻¹ at 0-20 cm depth, and 20 mg kg⁻¹ at 20-40 cm depth. Available N was positively correlated with total soil N, exchangeable Ca, and adjusted aspect (the former 2 factors accounting for 46% of the total variation), and negatively with rock content and slope steepness. Stand density had no effect.

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

79. 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.

[OSU Link](#)
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80. Wang, Z., M. Newton and J.C. Tappeiner, II. 1995. Competitive relations between Douglas-fir and Pacific madrone on shallow soils in a Mediterranean climate. *Forest-Science* 41(4): 744-757.

Keywords: release treatments
manual release
soil properties
growth

Abstract: A large area of Pacific Coast forests is characterized by shallow soil, with negligible rainfall in the growing season. The availability of bedrock water and its effects on growth and ecophysiology of 11-yr-old planted Douglas fir (*Pseudotsuga menziesii*) and sprouting Pacific madrone (*Arbutus menziesii*) was studied. The study was carried out at 3 regulated densities (0, 330 or 1322 clumps/ha) of madrone sprouts on shallow (<50 cm) residual soils in the Klamath Mts of SW Oregon. Total bedrock water depleted from March to September, as observed in drill holes by neutron probe, and did not suffer significantly among the 3 densities of madrone sprouts. However, cover in plots with the highest density of madrone depleted 50 mm of water from the 1.5 m layer by June, whereas vegetation on lower density treatments withdrew 15-28 mm by June, with later withdrawal distributed more uniformly through the growing season. Madrone density significantly affected basal diameter and height growth of Douglas fir. Madrone was consistently taller than Douglas fir in all plots. The height of 11-yr-old madrone sprout clumps (424-465 cm) did not differ significantly among densities. Madrone leaf area index and biomass were higher at the high density of madrone than at medium density. Physiological

advantages and rooting habits of madrone give it a competitive advantage over Douglas fir at this site, that it might not have if bedrock did not provide the principal water reservoir for summer growth.

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81. Wass, E.F. and R.B. Smith. 1997. Impacts of stump uprooting on a gravelly sandy loam soil and planted Douglas-fir seedlings in south-coastal British Columbia. Pacific-Forestry-Centre,-Canadian-Forest-Service Information-Report BC-X-368. vi + 15 p.

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Abstract: Studies to determine levels and impacts of soil disturbance caused during root-disease control by stump removal were initiated on a cutover on southern Vancouver Island immediately prior to the control operation and the establishment of a plantation of Douglas-fir (*Pseudotsuga menziesii*). Soil surface condition was assessed on the stumped area. Soil disturbance was measured at 699 planting spots. Vegetation development was assessed at 10% of the spots. Of all planting spots, 180 were undisturbed soil, 277 deposits and 242 gouges. The soil, a gravelly sandy loam, increased naturally in soil density with depth from 1.05 t/m³ at the surface to over 1.60 t/m³ at depths more than 40 cm. Disturbance did not significantly increase soil density. Unlike previous studies of this nature, ease of soil penetrability was increased by the stump uprooting disturbance and vegetation development was not greatly dissimilar between disturbed and undisturbed soil. The relatively low soil impacts were attributed to the ability of the excavator to pile stumps without pushing topsoil, and the low site sensitivity to compaction. These low impacts on soil and reduced vegetative competition on disturbed soil resulted in tree growth rates which were significantly greater after 10 years on deposits (12% in height and 18% in diameter) and gouges (6% in height and 8% in diameter) than on undisturbed soil.

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