Soil Changes and Tree Seedling Response Associated with Site Preparation in Northern Idaho

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ABSTRACT. *Conifer regeneration in western North America is often hampered by low soil moisture, poor soil nutrient status, and competing vegetation. Three site preparation techniques were evaluated at two different elevations in northern Idaho as potential remedies for these problems: (1) soil mounds without control of competing vegetation, (2) soil mounds with herbicidal control of competing vegetation, and (3) scalping (removal of soil surface organic horizons and mineral topsoil). Treatments were evaluated for effects on soil nutrient levels, soil physical properties, and the growth of Douglas-fir* (Pseudotsuga menziesii *var.* glauca) *and western white pine* (Pinus monticola) *seedlings. Both species generally grew best when planted in the mounded treatment with competing vegetation removed and worst after scalping. Mounding with herbicide application resulted in the lowest bulk density, best seedling growth, and increased water availability. Mounding may be a viable site preparation method in the Inland Northwest on less productive sites that have severe competition. Scalping, especially when competition was not a problem, generally did not produce favorable seedling growth responses. Scalping may also reduce longer term seedling growth by removing surface organic matter. West. J. Appl. For. 12(3):81–88.*

As demand for timber-derived products continues to increase, more emphasis is being placed on site preparation to achieve adequate regeneration, a primary objective on most managed forests (Fiedler 1982, Sutton 1993). Site preparation techniques can reduce competition, prepare the site for mechanical planting, and condition the soil to enhance seedling survival (Fox 1977, Morris and Lowery 1988).

In western North America, managers prepare sites primarily by mechanical methods, burning, or a combination of both (Stewart 1974, Ferdinand 1982, Sutton et al. 1991). Mechanical treatment usually entails some variation of soil scarification, including dozer-blade patching and scalping. Soil scarification is effective for removing competing vegetation and for preparing the site for planting (Sloan and Ryker 1986, Sutton 1993, Wood et al. 1993). Slash removal or the concentration of slash into windrows by bulldozers, however, may reduce soil nutrient levels between the piles (Ross and Walstad 1986). Piling harvest residue off-site also may compact the soil and remove surface organic matter, which can result in decreased seedling growth (Minore and Weatherly 1990). Although many of these site preparation methods improve site plantability and initial seedling survival, long-term growth can be impaired (Powers et al. 1990).

In contrast, forest management practices in the southeastern United States commonly include other site preparation techniques, such as chopping, disking, and soil mounding for successful establishment and rapid growth of southern pine seedlings (Morris and Lowery 1988, Reisinger et al. 1988, Sutton 1993). Soil mounding, the creation of elevated planting beds which concentrate surface organic matter and mineral topsoil, has become popular because of high water tables in many southern soils. In addition to increasing nutrient availability and reducing competition (Shultz and Wilhite 1974), mounding increases seedling growth by decreasing soil resistance for root penetration (Shoulders and Terry 1978, Tuttle et al. 1984).

Mounding also has been successfully used on upland sites. Francis (1979) found soil mounding on shallow, fragipan soils increased yellow-poplar *(Liriodendron tulipifera)* growth by keeping roots above the hardpan layer. Increases in organic matter and nutrient content of the root zone by mounding were beneficial to *Pinus radiata* in Australia (Attiwill et al. 1985), *Eucalyptus nitens* in New Zealand (Frederick et al. 1983), and yellow-poplar in Illinois (Gilmore et al. 1968). On such upland sites, tree growth increased because of increases in available moisture and nutrients, rather than because of improved drainage or aeration. In cold, wet environments mounds have been used to create warmer temperature regimes by exposing a large surface area for heat absorption (Kubin and Kemppainen 1994, Stathers and Spittlehouse 1990). Mounding increased pine seedling height growth for 5 yr after planting in Canada (Sutton et al. 1991) and up to 13 yr on upland sites in Sweden (Fries 1993).

Scalping often is used in the Inland Northwest to provide control of competition from grasses and sedges (Sloan and Ryker 1986). Scalping removes the surface organic horizons and 2 to 15 cm of mineral topsoil and can increase first year survival and growth of many tree species (Sloan and Ryker 1986, Messier et al. 1995). Scalping also has been shown to reduce the frequency of drought damage to seedlings because it eliminates competition (Barnard et al. 1995, Nilsson and Orlander 1995). When competition is relatively light, however, scalping can reduce seedling growth because of less moisture and nutrient storage (Miller and Brewer 1984). Herbicides also can control competition. Using herbicides to create a "scalp" eliminates the competing vegetation and creates a mulch on the soil surface that conserves moisture and moderates temperature (Boyd 1985, Allen and Wentworth 1993, Fleming et al. 1994).

In northern Idaho and other parts of the Inland Northwest, the success of forest plantings is markedly limited by low soil moisture, high evaporative demand, and often severe competition from grasses, sedges, shrubs, and forbs during the growing season. Reforestation success after planting Douglas-fir (*Pseudotsuga menziesii* var. *glauca*) and western white pine *(Pinus monticola)* on clearcuts with low nutrient and moisture levels (Duryea and Lavender 1982) and/or competing vegetation has been poor (Boyd 1985, Graham et al. 1991). Intensive site preparation techniques that maintain or increase organic matter in the upper soil horizons or reduce competition could improve soil moisture and nutrient conditions on these sites. Consequently, this study provides the basis to evaluate the impact of soil mounding and scalping on soil water and nutrient levels and their effect on the growth of planted Douglas-fir and western white pine seedlings. Two sites, at differing elevations, were examined to provide a range of environmental conditions representative of common sites in the Inland Northwest.

Study Area

The two study sites are located on the Priest River Experimental Forest on the westward slope of a spur of the Selkirk Mountains in northwestern Idaho (lat. 48°21'N, long. 116°50'W). The low-elevation site is at an elevation of 715 m on a flat bench adjoining the Priest River. Of the two sites, it is warmer and drier, but subject to occasional summer frosts. Before this study, the site was occupied by grasses, forbs, and a few lodgepole pine *(Pinus contorta)*. The soil is a silt loam, medial, frigid Ochreptic Fragixeralf. The habitat type is *Abies grandis/Clintonia uniflora* (Cooper et al. 1991).

The high-elevation site is at an elevation of 1,456 m with north to northeast facing aspects and slopes ranging from 10 to 35%. The soil is a coarse, loamy, Andeptic Cryorthent. Soil temperature and moisture regimes are frigid and typic xeric. The habitat type is *Tsuga heterophylla/Clintonia uniflora* (Cooper et al. 1991). This study area previously consisted of a mixed stand of western hemlock *(Tsuga heterophylla),* grand fir *(Abies grandis),* and western white pine, and is considered a highly productive site for this region. This forest was clearcut, tractor skidded, and the slash piled and burned in the fall of 1981.

Temperature and precipitation characteristics for Priest River Experimental Forest are typical of the region between the Cascade and northern Rocky Mountain crests of the Inland Northwest. Mean annual precipitation ranges from 60 to 130 cm, about 50% falling as snow. Rain on snow events occasionally occur during the winter months. Drought increases in late June, reaching a maximum during July and August. Significant rainfall begins again in September, increasing in October. Extensive snowfall begins in late October and November. Mean annual air temperature is 6.6°C (Finklin 1983). Continuous temperature and precipitation measurements were available near the experimental sites (less than 3 km from either site at an elevation of 825 m).

A randomized complete block experiment was established at each site in the summer of 1982. The low-elevation site had three treatments and a control for each planted species, with four replications in one large block. The high-elevation site consisted of three treatments and a control for each planted species, with the three replications in three separate 1 ha cutting areas having approximately the same slope, aspect, soil, and habitat type.

The treatments on these sites consisted of: (1) soil mounds without competing vegetation control, (2) soil mounds plus herbicide (Roundup®)[1], (3) a scalped area with 10 cm of organic horizons and mineral topsoil along with the competing vegetation physically removed, and (4) a control with no postharvest site preparation. Mounded treatments were created using a small crawler tractor to mound the upper 10 cm of mineral soil and forest floor. Each treatment was approximately 30 m long, 4 m wide, and, for the mounded treatments, approximately 46 cm high. In May 1983 the treatments were planted with locally adapted, 1 yr old container-grown Douglas-fir or western white pine on a 0.5 × 0.5 m spacing. A single genetic source was used for western white pine; two different sources (at elevations corresponding to the two sites) were used for Douglas-fir (Rehfeldt 1979, Rehfeldt et al. 1981). Roundup® was applied to one soil mounding treatment at a rate of 1.5 l active ingredient/ha. Herbicide was applied twice during the growing season for 3 yr, and seedlings were protected from direct exposure. Competing vegetation in the remaining mound, scalp, and control treatment was not removed during the study.

Methods

Seedling Sampling and Measurements

Fifteen seedlings of each species in 1983, ten seedlings of each species in 1984, and five seedlings of each species in 1985, were randomly selected and carefully excavated from each treatment replication four times during each growing season

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[1] The use of trade or firm names in this paper is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

(June to September). Seedlings were measured for height and rooting depth, dried at 60°C for 24 hr, and weighed. Individual seedling stems plus foliage were ground together to pass a 20 mesh sieve. Total seedling nitrogen (N) and phosphorus (P) were analyzed by Kjeldahl digestion methods using the salicylic acid-sodium thiosulfate modification (Bremner and Mulvaney 1982) and analyzed on an Alpkem Rapid Flow Analyzer. After dry ashing of foliage and stems at 450°C and leaching with 2N $\mathrm{HNO3}$, seedling calcium (Ca) and magnesium (Mg) were analyzed by atomic absorption spectroscopy and potassium (K) by flame emission.

Soil Sampling and Analysis

Soil samples were collected from the side of the hole left when the seedlings were removed. Fifteen samples were collected in 1983, ten in 1984, and five in 1985 from each treatment replication for each sample date. All soil samples were passed through a 2 mm sieve and dried at 105°C before analysis. Organic matter was determined by weight loss after combustion at 375°C for 16 hr (Ball 1964). Total soil N and P were analyzed by the Kjeldahl digestion method using the salicylic acid-sodium thiosulfate modification (Bremner and Mulvaney 1982) and analyzed on an Alpkem Auto Analyzer. Soil exchangeable Ca, Mg, and K were extracted using 1N $\mathrm{NH4OAc}$ (Thomas 1982). Ca and Mg were analyzed by atomic absorption spectroscopy, and K was analyzed by flame emission. Nitrate ($\mathrm{NO3-}$) was determined in a 1N KCl extract using an Alpkem Rapid Flow Analyzer (Keeney and Nelson 1982). Potentially mineralizable N was estimated using the anaerobic incubation technique on undried samples (Powers 1980). Soil acidity was determined electrometrically on a 2:1 water:soil mixture. Field capacity and permanent wilting point of disturbed samples were determined at 0.033 MPa and 1.5 MPa using pressure plates (Cassel and Nielsen 1986). Available water in the root zone was calculated using the average seedling rooting depth and the difference between field capacity and permanent wilting point in each treatment and year. Bulk density was determined using a core sampler (Blake and Hartge 1986).

Differences in growth variables and soil properties among site preparation treatments were evaluated using one-way analysis of variance (ANOVA) for a randomized complete block design followed by Scheffe's multiple range test (Scheffe 1953). All statistical analyses were performed using SAS programs and a significance level of $P < 0.05$.

Results and Discussion

Site Preparation Effects on Soil Properties

After the first growing season, no significant differences were detected in total P, total N, CEC, and pH of soils at both sites (see Page-Dumroese et al. 1989). Similar results from mounding studies in the southeastern United States were reported by Schultz and Wilhite (1974). However, after three growing seasons, the Idaho sites generally had higher soil organic matter content, total N and P, CEC, and cations in both mound treatments, especially at the low-elevation site (Table 1). Organic matter incorporated into mounds contributed to increased soil total N, total P, and base cations, and was similar to other reported results (Schultz and Wilhite 1974, Morris et al. 1983, Tuttle et al. 1984, Attiwill et al. 1985). In contrast, the scalped treatment soil had less organic matter and total N and lower CEC values at both elevations. Base cation levels were lowest in the

Table 1. Soil physical and chemical properties and competing plant biomass[1] 3 yr (1985) after site preparation.

	Low elevation				High elevation			
	Mound	Mound-herbicide	Scalp	Control	Mound	Mound-herbicide	Scalp	Control
Chemical properties								
Organic matter (%)	16.9(1.7)a	17.2(2.1)a	8.4(2.7)b	12.3(1.7)ab	24.2(1.6)x	18.3(2.0)x	10.8(2.6)y	27.4(3.0)x
CEC (cmol+/kg)	14.4(1.5)ab	16.1(1.5)a	10.5(1.1)b	13.3(1.2)ab	19.9(2.8)x	18.7(2.8)x	11.4(3.4)y	20.5(2.5)x
Total N (g/kg)	2.9(0.1)a	3.0(0.2)a	1.3(0.2)a	2.6(0.1)a	2.8(0.2)x	2.8(0.2)x	1.5(0.5)y	2.2(0.2)x
Total P (g/kg)	3.1(0.1)a	3.2(0.1)a	1.6(0.2)a	2.5(0.1)a	1.5(0.1)x	2.1(0.1)x	1.4(0.1)x	1.5(0.1)x
Ca (mg/kg)	10.9(1.3)a	10.3(1.5)a	4.1(1.6)a	7.6(1.3)a	4.6(1.7)x	8.9(1.8)x	9.9(2.0)x	3.9(2.3)x
Mg (mg/kg)	3.1(0.3)a	3.2(0.4)a	1.1(0.4)a	1.7(0.3)a	1.5(0.8)x	2.7(0.8)x	2.5(0.9)x	1.3(1.0)x
K (mg/kg)	4.4(0.2)a	4.5(0.2)a	2.3(0.2)a	3.2(0.2)a	2.9(0.1)xy	4.1(0.1)xy	6.4(0.2)x	2.0(0.2)y
pH	6.0(0.1)a	5.6(0.1)b	6.1(0.1)a	6.0(0.1)a	5.4(0.1)x	5.5(0.1)x	5.8(0.1)x	5.3(0.1)x
Physical properties								
Bulk density (mg/m^3)	0.70(0.08)a	0.68(0.07)a	0.92(0.09)b	0.76(0.08)a	0.58(0.05)x	0.58(0.06)x	0.85(0.06)y	0.65(0.07)x
Field capacity (%)	101.3(7.5)a	102.6(7.9)a	42.1(6.3)c	62.8(7.0)b	97.3(5.6)x	97.5(5.4)x	37.5(4.2)y	77.5(4.8)xy
Permanent wilting point (%)	51.6(5.4)a	50.1(4.6)a	11.1(4.3)c	30.2(4.5)b	49.2(4.1)x	48.5(4.1)x	6.5(3.5)y	32.7(3.9)x
Aboveground competition[2] (kg/ha)	4,759a	70d	207c	1,122b	820a	< 25b	< 25b	< 25 b
Belowground competition (kg/ha)	4,433a[3]	210d	477c	2,638b	891a	< 25b	< 25b	< 25 b

Note: Values in parentheses are standard error of the mean. Within each elevation, means in the same row followed by the same letter are not significantly different ($P < 0.05$).

[1] Competition data are presented for the third growing season because no appreciable changes were measured during the first two growing seasons.

[2] Competition values taken from Graham et al. 1989.

[3] Belowground competition biomass (roots) was measured to a soil depth of 15 cm.

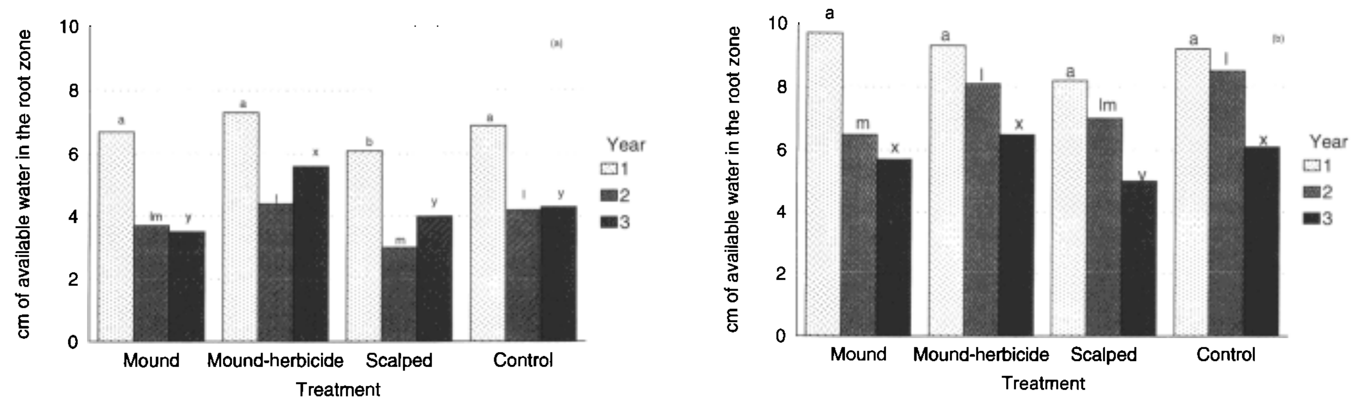

Figure 1. Average yearly (1983–1985) available soil water volume in the root zone as affected by site preparation treatment. Within each sample date, different letters indicate significant differences ($P < 0.05$). (a) low-elevation site; (b) high-elevation site.

scalp treatment at the low-elevation site as compared to the other treatments, but generally higher in the same treatment at the high-elevation site.

The untreated (control) bulk densities of the soil on each of these sites are very low (Table 1), as is common in ash-cap soils of northern Idaho (Page-Dumroese 1993). Mounding did not appreciably change soil bulk density, but scalping resulted in greater bulk densities at both elevations. Removal of the surface organic matter and low bulk density surface mineral soil along with soil compaction by the crawler tractor during scalping left residual soils with bulk densities 15% greater than the control. Clayton (1990) and Lopushinsky et al. (1992) both found similar results after tractor yarding. Soil mounding reduces mechanical impedance (Gent and Morris 1986), which increases both the volume of soil exploited by seedling roots and rooting density (Schultz 1973, Morris and Lowery 1988).

Available soil water-holding capacity also was affected by the different site treatments (Table 1). The mound treatments increased soil field capacity and permanent wilting point in the root zone at both elevations, although differences at the high-elevation site were less pronounced than the low-elevation site. Mean annual available water in the root zone differed little among the treatments (Figure 1), although the mounds and control had slightly higher amounts than the scalp treatment. Lack of large differences in available water in the root zone may be caused by the fine texture of the ash-cap soil. Other studies have noted that mounding in coarse-textured soils can increase available water storage in the soil profile by increasing infiltration and interception (Swank et al. 1972, Nilsson and Orlander 1995). During the first year of this study, soil moisture differences did not cause any statistical differences in predawn plant moisture stress (D. Page-Dumroese, unpublished data). This was not surprising since this was a very wet year, with 47 mm of rainfall above the growing season average (see Finklin 1983 for comparison).

Potentially mineralizable N was greatest in the mounded soils at both sites immediately after harvest (year 1), then declined in the second and third year (Table 2). Scalping reduced potentially mineralizable N at both sites. Nutrient uptake or below ground organic matter turnover dynamics may explain declining potentially mineralizable N patterns (Gower and Son 1992). All treatments at the high-elevation site had much higher potentially mineralizable N than at the low-elevation site. This likely reflects inherent differences in total soil N between the sites (Powers 1980).

At both elevations, potentially mineralizable N followed the same pattern as soil organic matter content. After timber harvesting, a reserve of N is left in the less than 2 mm diameter surface organic matter. Mounding the soil mixes this organic matter into the surface mineral soil, which is conducive to N mineralization (Salonius 1983). N mineralization in soil mounds also can be increased by changes in soil temperature (Stathers and

Table 2. Soil mineralizable N and nitrate concentration as affected by site preparation.

	Mineralizable N (mg/kg)			Nitrate (mg/kg)		
Treatment	Year 1	Year 2	Year 3	Year 1	Year 2	Year 3
Low elevation						
Mound	82.7(13.3)a	34.5(17.8)f	62.9(14.5)j	19.8(1.6)a	13.1(1.0)fg	2.0(0.9)k
Mound-herbicide	89.2(13.7)a	23.1(19.5)f	57.8(15.0)jk	23.8(1.5)a	18.3(1.1)f	4.7(0.9)j
Scalped	8.9(15.4)b	12.7(18.6)f	17.7(15.0)k	18.1(1.7)a	5.1(1.0)g	0.9(1.0)k
Control	28.7(15.7)ab	11.3(17.7)f	32.3(14.8)jk	16.1(1.5)a	1.4(0.9)g	1.4(0.9)k
High elevation						
Mound	130.9(12.6)m	45.2(8.8)s	36.9(6.3)x	17.3(1.0)m	16.3(3.1)s	2.4(0.4)x
Mound-herbicide	112.2(13.3)m	47.6(11.1)s	51.7(6.7)x	18.8(1.1)m	17.7(3.3)s	3.6(0.5)x
Scalped	75.8(13.1)n	40.8(11.0)s	18.6(7.3)x	12.4(1.0)m	17.2(2.6)s	1.5(0.5)x
Control	92.7(13.0)m	65.7(11.2)s	65.7(8.4)x	12.8(1.0)m	15.1(3.5)s	4.7(0.5)x

NOTE: Values in parentheses are standard error of the mean. Within each elevation and year, means in the same column followed by the same letter are not significantly different ($P < 0.05$).

Table 3. Height and rooting depth of 3 yr old western white pine and Douglas-fir seedlings as affected by site preparation.

	Low elevation		High elevation	
Treatment	Height	Rooting depth	Height	Rooting depth
Western white pine	(cm)		(cm)	
Mound	27(1.2)b	28 (1.1)ab	31(0.9)xy	31(1.5)x
Mound-herbicide	39(1.3)a	34(0.8)a	33(1.0)x	29(1.3)x
Scalped	32(0.8)ab	22(0.9)b	22(1.1)z	21(1.2)y
Control	34(1.4)ab	24(0.9)ab	25(0.9)yz	28(1.4)x
Douglas-fir				
Mound	33(0.9)b	21(0.7)b	36(0.8)x	26(1.0)x
Mound-herbicide	43(1.1)a	29(0.9)a	38(0.9)x	29(0.8)x
Scalped	29(1.1)b	20(0.9)b	29(1.0)y	18(0.7)y
Control	34(1.0)b	21(0.7)b	39(0.9)x	23(0.9)xy

NOTE: Values in parentheses are standard error of the mean. Within each elevation and species, means in the same column followed by the same letter are not significantly different ($P < 0.05$).

Spittlehouse 1990) and moisture (Pritchett and Wells 1978). Similar work elsewhere indicates that improved potentially mineralizable N will lead to increased N availability later in the rotation (Burger and Pritchett 1984, Fox et al. 1986).

Soil NO3- concentration was usually highest during year 1 at both locations regardless of site preparation treatment and decreased to low levels by the third year (Table 2). Mounding generally maintained higher NO3- levels compared to the scalped treatments and control, which reflects higher total N levels in these soils. Soil NO3- levels were much less affected by site treatment at the high-elevation site. Scalped treatments, which also had lower soil moisture contents and organic matter, had the lowest NO3- levels. Soil NO3- increases have been shown to occur quickly following disturbance on many forest sites in the Inland Northwest, but decline steadily (Jurgensen et al. 1981, Clayton and Kennedy 1985).

Seedling Growth and Nutrition

Mounding, in combination with control of competing vegetation, promoted height growth and biomass production of both Douglas-fir and western white pine seedlings at both sites (Table 3 and Figure 2). This same combination treat-

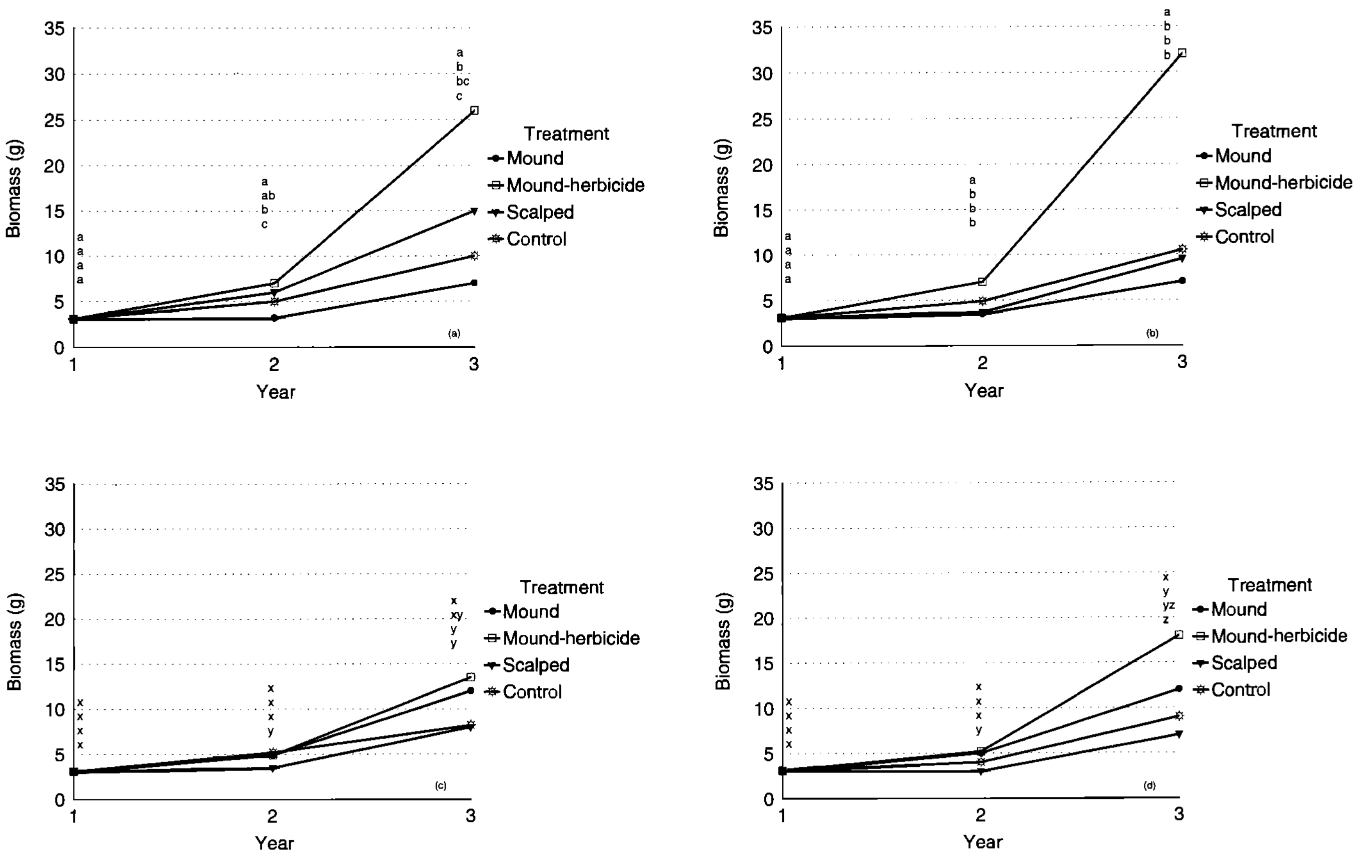

Figure 2. Average yearly (1983–1985) cumulative biomass of seedlings as affected by site preparation treatment. Within each year, different letters indicate significant differences ($P < 0.05$). (a) low-elevation site, western white pine seedlings; (b) low-elevation site, Douglas-fir seedlings; (c) high-elevation site, western white pine seedlings; (d) high-elevation site, Douglas-fir seedlings.

ment increased *Pinus radiata* volume production at age 8.5 yr by more than twofold in Australia (Sands and Zed 1979, Turvey and Cameron 1986) and resulted in a fivefold increase in height growth of Scots pine *(Pinus sylvestris)* and lodgepole pine 13 yr after planting and site preparation in Sweden (Fries 1993). In contrast, seedling growth on the scalped treatment was generally less than on the control. Other studies have documented reduced growth of conifers after scalping (Glass 1976, Ballard 1978). Some studies have reported seedling growth increases after scalping because of decreased competition (Boyd 1985, Sloan and Ryker 1986, Fleming et al. 1994). At our northern Idaho site, however, scarification to remove competition also removed approximately 4 to 6 cm of the volcanic ash-cap. Ash-cap removal has been shown to reduce growth of both Douglas-fir and western white pine (Miller 1991).

Mounding usually permitted the greatest rooting depth of 3 yr old seedlings of both species (Table 3), which is most likely a response to lower soil bulk densities, better porosity, and soil aeration created during the mounding process. Although seedlings growing in the scalp treatment had the smallest height and root depth, they had the greatest numbers of ectomycorrhizal short roots (Harvey et al. 1996). This suggests either the slow growth rate of roots reduced the capability of stressed seedlings to defend themselves against infection or the lower nutrient status of the soil reduced their defensive capability.

Competition was a very important factor at these sites, especially at the low-elevation site where biomass of competing vegetation on the mounded treatments without herbicide was 13 times greater than on the control and 2 times greater than on the scalp treatments (Table 1). Herbicide application was very effective in reducing competition on the mounded treatments. At the high-elevation site, competition was not as prolific, and both scalping and herbicide application were equally effective in reducing it. Seedlings that are overtopped by competing vegetation most likely have reduced light for photosynthesis and less available soil moisture (Stathers and Spittlehouse 1990).

Three years after treatment, seedlings of both species growing in the mounds with herbicide application generally had the highest tree nutrient concentrations (Table 4). Mounding without competition control at the high-elevation site usually did not affect seedling nutrient concentrations, but competition control appeared to be critical for seedling nutrient uptake at the low-elevation site. Seedlings growing on the scalped and control treatments generally had similar nutrient concentrations. Usually higher seedling nutrient concentrations were associated with higher soil organic matter contents. Other studies have shown that soil mounding with competition control increased seedling growth and nutrient levels, but without competition control, it reduced growth and uptake (Turvey and Cameron 1986).

Nutrient uptake increases after competition control and mounding can be attributed primarily to increased soil porosity (as measured by soil bulk density) and decreased understory competition which may have facilitated greater nutrient uptake from expanded root system development.

Management Implications

Overall seedling growth differences among site preparation treatments were most likely the results of differing levels of competing vegetation and changes in soil physical proper-

Table 4. Nutrient concentrations of 3 yr old western white pine and Douglas-fir seedlings as affected by site preparation.

Treatment	Total N	Total P	Ca	Mg	K
Western white pine	(g/kg)		(mg/kg)		
Low elevation					
Mound	7.9 (0.1)a	2.1(0.1)a	579(24)c	220(32)b	1,202(22)b
Mound-herbicide	10.7 (0.1)a	2.1(0.1)a	4,039(26)a	1,529(34)a	7,855(24)a
Scalped	10.0 (0.1)a	2.2(0.1)a	1,862(26)b	655(35)b	3,237(23)b
Control	9.5 (0.1)a	2.3(0.1)a	1,527(26)bc	552(35)b	2,676(24)b
High elevation					
Mound	10.8(0.1)x	2.3(0.1)x	1,641(41)xy	635(25)xy	3,160(30)xy
Mound-herbicide	11.7(0.1)x	2.3(0.1)x	2,987(49)x	1,109(25)x	5,631(37)x
Scalped	9.7(0.1)x	2.3(0.1)x	8,85(47)y	338(29)y	1,761(35)y
Control	9.5(0.1)x	2.3(0.1)x	9,20(48)y	321(25)y	1,443(31)y
Douglas-fir					
Low elevation					
Mound	7.5(0.1)b	2.3(0.1)a	767(27)b	357(53)b	1,308(21)b
Mound-herbicide	10.3(0.1)a	2.2(0.1)a	5,344(31)a	3,286(58)a	3,286(23)a
Scalped	8.7(0.1)b	2.3(0.1)a	1,408(29)b	644(57)b	2,074(22)b
Control	8.1(0.1)b	1.9(0.1)a	1,341(29)bc	556(58)b	2,104(23)b
High elevation					
Mound	9.3(0.1)y	2.3(0.1)y	1,539(34)xy	644(48)xy	2,661(28)x
Mound-herbicide	10.4(0.1)x	2.5(0.1)x	2,247(38)x	1,180(55)x	4,711(32)x
Scalped	10.0(0.1)x	2.2(0.1)y	1,104(39)y	449(56)y	2,555(32)x
Control	8.2(0.1)y	2.1(0.1)y	1,309(38)xy	483(55)y	2,396(32)x

NOTE: Values in parentheses are standard error of the mean. Within each elevation and species, means in the same column followed by the same letter are not significantly different ($P < 0.05$).

ties. Mounding seems a viable option to improve early seedling growth on less productive forest sites in the Inland Northwest if competition is controlled after planting. It may be especially appropriate on sites where regeneration success is limited, such as on drier, coarse-textured sites where moisture conservation is essential for reforestation. The mounded treatment with herbicide application had the lowest soil bulk densities, best seedling growth, and greatest rooting depth. Soil nutrient amounts, especially total N and organic matter, increased in both mounded treatments, but this did not seem to have much effect on seedling growth. This would change, however, as the trees become older and have a higher nutrient demand (Sutton et al. 1991). On sites where competition is not severe, leaving the surface organic horizons undisturbed after harvesting may be just as successful as mounding.

Scalping is common in the Inland Northwest and may benefit seedling establishment and growth because it eliminates competing vegetation from the planting site. Where competition was not severe (the high-elevation site), scalping soil did not improve seedling growth. Scalping to remove competition at the low-elevation site did not improve Douglas-fir seedling growth during the first 3 yr, but did increase biomass production of western white pine as compared to the control. Use of crawler tractors to produce a "scalped" condition adversely affects soil bulk density. Long-term seedling growth will most likely be depressed after scalping because growth-limiting moisture and/or nutrient conditions, due to the loss of surface organic matter, are likely to exist for decades (Powers 1991).

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