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# Comparative Effects of Precommercial Thinning, Urea Fertilizer, and Red Alder in a Site II, Coast Douglas-Fir Plantation

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## Abstract

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We varied the number of red alder retained with 300 Douglas-fir per acre on a high-quality site in coastal Oregon. Alder densities of 0, 20, 40, and 80 per acre were tested. Our 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 1,400 to 5,700 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 nonfertilized 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.

Keywords: Mixed stands, competition (plant), Douglas-fir, *Pseudotsuga menziesii*, red alder, *Alnus rubra*, thinning, nitrogen fertilization, volume growth.

## Summary

In a site II, Douglas-fir plantation near the central Oregon coast, we compared 17-year survival and growth of Douglas-fir and other species in three replicates of six silvicultural regimes imposed 9 years after planting. Our purpose was to quantify effects of these regimes on growth and yield of Douglas-fir, red alder, and the two species combined. In five of the six regimes, conifer density was reduced to 300 trees per acre (TPA); nearly all were planted Douglas-fir. Regimes 1 to 4 tested the effects of admixing 0, 20, 40, or 80 red alder per acre, respectively. Regime 5 retained 300 Douglas-fir, but no alder, and substituted 200 lb nitrogen (N) per acre as urea fertilizer for N biologically fixed by admixed alder. Regime 6 remained nonfertilized and nonthinned and totaled to about 4,000 TPA of several species. We installed three replicates of each regime. Thinning decreased TPA by about 13-fold but reduced stand volume by only about 32 percent. Subsequent 17-year change in mean tree volume was more than doubled by thinning, but volume growth per acre was 12 percent less on thinned than on nonthinned plots. Fertilization with urea did not stimulate tree or stand growth. Absence of a measurable increase in growth after fertilization with 200 lb N/acre was consistent with an absence of enhanced growth from N presumably fixed by admixed red alder. Through 17 years of observation, retaining 20, 40, or 80 red alder per acre had no measurable, positive effect on associated Douglas-fir. Retaining 80 per acre with 300 Douglas-fir trees after thinning, however, clearly increased mortality of Douglas-fir and decreased yield of the Douglas-fir component. Combined yield of both species was similar for alder admixtures of 0 through 80 red alder per acre. Similar comparisons are needed at other sites especially those with known N-deficiency. At such sites, the N-fixing capacity of associated red alder is more likely to enhance yields of Douglas-fir.

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## Introduction

Current regimes for intensively managing Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) plantations include early control of competing vegetation, precommercial thinning to reduce conifer stocking to desired levels, and one or more fertilizations with about 200 lb nitrogen (N) per acre to enhance growth. Volunteers of red alder (*Alnus rubra* Bong.), however, can present a silvicultural dilemma. Because of prevalent volunteer seedlings after disturbance and rapid juvenile growth, red alder frequently threatens full and uniform distribution of associated, higher valued Douglas-fir (Howard and Newton 1984, Knapp and others 1984, Newton and Cole 1994, Ruth 1956). This risk is generally greater on high-quality, mesic sites where early height growth of red alder is more rapid than that of Douglas-fir compared to slower relative growth rates on lower quality, drier sites (Newton and others 1968). Although young red alder is relatively easy to control with some herbicides (Peterson and others 1996), continuing public concern for possible, long-term effects of chemicals either jeopardizes use of herbicides or increases the cost of using them.

On the positive side, however, red alder is an extensively distributed hardwood with increasing commercial value. Moreover, red alder can fix large quantities of atmospheric N to replace N lost in harvest and site preparation. Published estimates of N fixed annually by red alder in pure and mixed stands range from 20 to 300 lb N/acre (Binkley 1992, Hibbs and others 1994). Some of this variation in the rate of N-fixation relates to alder density in the stands that were investigated. Cumulative amounts of N fixed per acre likely will increase linearly with increasing stocking (of alder in upper crown positions) to an equilibrium value (Bormann and Gordon 1984), then remain relatively constant until major changes occur in the environment or stand. Additions of N have particular significance to coast Douglas-fir stands of the Pacific Northwest because growth on lower quality sites frequently is limited by insufficient quantities of available N. Availability of soil phosphorus also can be increased by presence of red alder in Douglas-fir plantations (Giardina and others 1995).

Resolving this silvicultural dilemma requires investigation of the net consequences of admixed red alder to growth of associated Douglas-fir. Where should future regimes for managing Douglas-fir include red alder to replace or supplement conventional applications of N-fertilizer? Further development of mixed-species options for supplying N requires (1) quantification of negative and positive effects of admixed red alder on stand yield and value at a wide range of site qualities, and (2) comparison of the cost-effectiveness of retaining or planting alder vs. applying fertilizer. In summary, optimum density of alder admixture needs definition and comparison with optimum fertilizer dosage for Douglas-fir. Currently, this optimum fertilizer dosage seems to lie between 150 and 300 lb N per acre applied several times per rotation. For N-deficient sites, an economically optimum alder density in mixed stands could be about 40 trees per acre (TPA) maintained in a dominant/codominant position until about one-half of the red alder and associated Douglas-fir are removed at the first commercial thinning (Miller and Murray 1979). Quantification should be made on both poor and good quality sites, because the balance between negative competitive effects of red alder and beneficial effects of its N-fixing capacity are likely to differ by site quality. For example, computer simulations of mixed-stand yields over several rotations indicate that density of alder should vary by site quality (Comeau and Sachs 1992).

Our study was designed to test two working hypotheses about the consequences on a high-quality site of increasing the number of red alder retained with Douglas-fir:

1. With increasing alder stocking, negative competitive effects of red alder on associated Douglas-fir will gradually offset potentially positive effects of increased nitrogen and improved organic matter status. Thus, we speculated that yield of Douglas-fir on our N-rich site will increase at lower densities of admixed alder but progressively decline as increasing numbers of red alder overtop or damage more Douglas-fir.
2. Benefits of soil improvement by red alder to Douglas-fir yield will be similar in magnitude to the benefits of N-fertilization. At this site II location, we anticipated a maximum increase in volume growth of only 10 percent in response to fertilization with 200 lb N/acre.

**Materials and Methods**

To test these predictions, we compared volume growth of Douglas-fir, red alder, and both species on plots representing varying densities of red alder with a constant Douglas-fir density of 300 TPA after precommercial thinning. As shown in the following tabulation, the 0-alder level (treatment [TMT] 1) corresponds to a conventional regime that removes all red alder by herbicide or cutting. Admixtures of 20, 40, and 80 alder per acre were assumed to straddle the financially optimum number of alder to retain in mixed stands (Miller and Murray 1979). Treatment 6 (“do nothing”) corresponds to a management regime in which control of competing red alder and precommercial thinning are precluded by environmental concerns or management costs. A code number for each treatment follows:

	<u>Red alder retained (no./acre)</u>				
<u>Urea</u>	<u>0</u>	<u>20</u>	<u>40</u>	<u>80</u>	<u>All</u>
<i>Lb N/acre</i>	----- Treatment number -----				
0	1	2	3	4	6
200	5	-	-	-	-

Treatments 1 to 4 define a red alder response surface; treatment 5 simulates a conventional regime that eliminates red alder and periodically uses urea fertilizer to increase stand growth.

**Experimental Design**

Our experimental design was a randomized assignment of six treatments in each of three blocks. Blocks were based on an earlier conifer-release spray as documented by the Ranger District’s spray-treatment map of the plantation and incidence of deformed or unusual bole or branch form (in the 1974-76 bole segment) of the Douglas-fir (Miller and Obermeyer 1996). Thus, the six plots in block 1 probably were not sprayed, those in block 2 probably were sprayed to some extent, and plots in block 3 probably were fully sprayed. It was necessary, however, to switch treatment on two plots because one (plot 13) had insufficient red alder for the randomly assigned treatment.

**Location**

Our study was installed in a 9-year-old Douglas-fir plantation within the Waldport Ranger District, Siuslaw National Forest, in western Oregon. Study plots sampled typical Coast Range topography; aspects were northerly and westerly, elevation averaged about 800 ft, and slopes ranged between 10 and 70 percent.

## Soils

Most study plots were located on Slickrock gravelly clay loam developing from sandstone colluvium of an ancient land flow (fig. 1).<sup>1</sup> Portions of some plots were on Bohannon gravelly loam (a residual soil also developing on sandstone), on an intergrade between the two series, or on eroded Slickrock (associated with deeply incised draws). Slickrock soils differ from Bohannon by being deeper than 4 ft and having finer textures. Both are Andic Haplumbrepts of the heavy, loamy, mixed-acid family. Among the 18 study plots, total N-content in the soil to 39-in depth averaged 11,440 lb/acre, ranging from 8,000 to 20,700 lb N/acre (Cromack and others 1999). An additional 100 lb N/acre was contained in the forest floor developing under the 9-year-old stand.

## Stand History

After intense slash burning, this 50-acre clearcut was auger-planted in January 1971 with 2-1 Douglas-fir seedlings of a local seed source. Nominal spacing was 10 ft by 10 ft. The preceding stand, logged in 1969, was 130-year-old Douglas-fir and hemlock (*Tsuga heterophylla* (Raf.) Sarg.). Site preparation before planting consisted of the following activities:<sup>2</sup>

- August 1969—Preburn spray (2 lb/acre of A.E. Amitrol-T in water; 10 gal of combined solution per acre).
- May 1970—Preburn spray (1 lb/acre of A.E. 2,4-D + 1 lb/acre of 2,4,5-T in water; 10 gal combined solution per acre).
- August 1970—Broadcast burned; over nearly all the unit, fire consumed all forest floor, twigs, and branches.

When the plantation was 4 years old, about 30 acres were aerially sprayed with Esteron Brush Killer (1 lb/acre of A.E. 2, 4-D and 1 lb/acre of A.E. 2, 4, 5-T) in water. The entire unit was not sprayed at that time because bud burst of conifers had progressed so that spray damage was likely on some portions.

## Plot Installation and Thinning

Eighteen 0.75-acre, square treatment areas were installed in the 9-year-old plantation. Centered within each treatment area was a 0.2-acre measurement plot (fig. 1). Within 15 of these treatment areas, conifer density was reduced after the 1979 growing season to about 300 evenly spaced conifers per acre; nearly all were planted Douglas-fir. Surplus conifers were cut, but surplus red alder were controlled by the “hack-and-squirt” method to reduce incidence of sprouting. Subsequent resprouting and new regeneration were rare. Three of the eighteen plots were not thinned (TMT 6).

## Tree Measurement and Volume Computation

Within 0.2-acre measurement plots, trees retained after thinning were identified by numbered aluminum tags and their diameter at breast height (d.b.h.) was measured to the nearest 0.1 in. All trees marked for cutting were tallied by 1-in d.b.h. classes. In the next 17 years, d.b.h. and height of residual trees were measured at 3- or 4-year intervals.

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<sup>1</sup>Bush, George. March 4, 1980. Soils report—Risley Creek area, Siuslaw National Forest. On file with: Pacific Northwest Research Station, Forestry Sciences Laboratory, 3625 93d Ave SW, Olympia, WA 98512-9193.

<sup>2</sup>The use trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

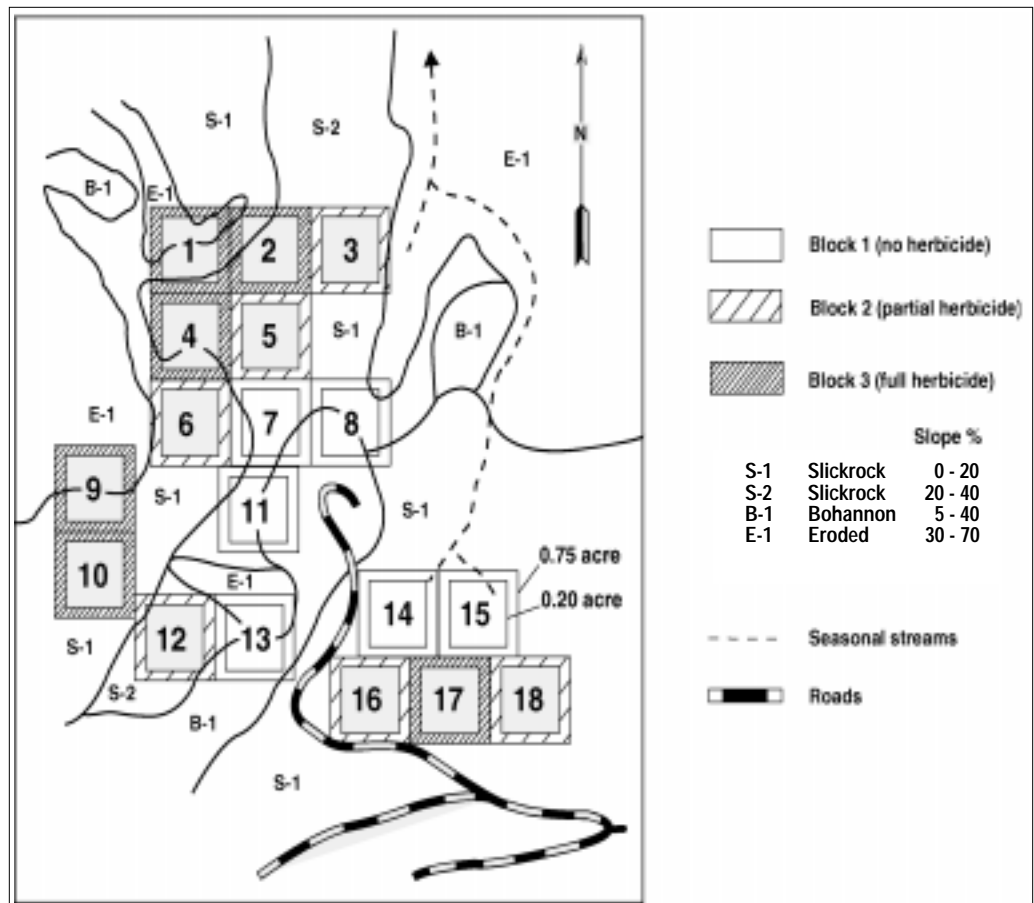


Figure 1—Plot locations, size, and blocking based on earlier herbicide application in the experimental area.

Heights of 30 Douglas-fir per plot were measured to the nearest 1.0 ft to obtain a reliable estimate of height and stand volume. Height sampling consisted of measuring every other Douglas-fir as encountered on the tree list, unless that tree was obviously deformed. Additionally, the tree of largest d.b.h. on each plot was included in the height sample. Heights of 8 to 16 alder per plot also were measured; these included all residual red alder on measurement plots (4-16) plus some alder in similarly treated buffer areas.

Total stem volume, including tip and stump, was calculated for each tree from height-d.b.h. equations and regional volume equations for the appropriate species. Regional volume equations used included those for Douglas-fir (Bruce and DeMars 1974), western hemlock (Wiley and others 1978), and red alder and other species (Browne 1962). Heights of nonmeasured trees were calculated from fitted height-diameter relations in metric units by using the equation form:

$$\text{Est. ht.} = A * \text{EXP}(B * \text{DBH} ** C) + 1.37 \text{ m},$$

where C was fixed at -1.0.

Height-diameter relations for Douglas-fir were fitted for individual plots, but those for red alder were fitted to pooled data from plots having the same treatment.



## Fertilization

Three treatment areas were fertilized on March 6, 1983 (three growing seasons after plot establishment and thinning); 200 lb N/acre as urea (46-0-0) was uniformly spread within string-bounded lanes to control distribution of the amount allocated to each lane. Volatilization losses were unlikely for several reasons: the surface soil was moisture-saturated at fertilization, precipitation totaled 4.6 in, and maximum temperature at the soil surface was 65 °F (18 °C) during the next 4 days.

## Data Summarization and Statistical Analysis

Individual tree data were summarized for each 3- to 4-year growth period after thinning: 1980-82, 1983-85, 1986-88, 1989-92, 1993-96, and for the total 17-year period. Gross and net growth in basal area and cubic volume per acre of Douglas-fir, as well as change in average height of Douglas-fir, were compared by covariance analysis, using initial (9 yr) basal area, volume or mean height, respectively, as covariates (SAS Institute Inc. 1988). Volume growth of red alder and of all species were compared by ANOVA because covariance adjustment based on differing starting volumes of the red alder treatments was inappropriate. We did not include the nonthinned treatment (TMT 6) in these statistical analyses because it was *a priori* so much different from the other five treatments. Instead, we compared data from TMT 6 and TMT 1 (thinned, without alder or fertilizer) without statistical tests.

Because the number of red alder retained in the thinned stands is a continuous variable, we used the method of polynomials to fit an approximate response function to alder TPA in treatments 1-4. In both ANOVA and covariates, we used non-orthogonal contrasts to separate the following treatments:

Contrast	Treatment numbers	Indicates the effects of:
1	1 vs. 5	N-fertilization
2	1 through 4	Increasing alder density, linear relation
3	1 through 4	Increasing alder density, lack-of-fit

By reusing TMT 1 in these contrasts, we affected to some unknown extent the probability levels at which we can ascribe statistical significance; therefore, we drew conclusions conservatively. Unadjusted means from ANOVA analysis of volume growth for red alder and all species were separated by Bonferroni multiple-comparison procedures (SAS Institute Inc. 1988). All tests of statistical significance were made at  $P \leq 0.10$ .

## Results

### Trees Per Acre and Average D.b.h.

**Initial stand**—Before thinning at plantation age 9, density of Douglas-fir among the 18 plots ranged from 970 to 2,610 TPA (table 1). Density of red alder ranged from 0 to 410 TPA, with the lower densities a likely consequence of herbicide applied aerially 5 years earlier to portions of the plantation. Numerous trees of other species regenerated naturally so that combined density of all species ranged from 1,250 to 5,710 TPA. In general, stand density was greatest in plots in block 3 (full coverage of herbicide).

**After thinning**—Average TPA of Douglas-fir (0.1 in d.b.h. and larger) after thinning ranged from 293 to 307 among treatment means, compared to 1,875 in the nonthinned control (table 2). Quadratic mean d.b.h. (Dq) of residual Douglas-fir in thinned plots averaged nearly 4.0 in compared to 1.2 in for nonthinned plots. The largest 300 TPA of Douglas-fir in nonthinned plots, however, were similar in Dq and mean height as those in thinned plots (table 2). Control plots averaged 10-fold more trees of combined species, but only 16 percent more volume, than the thinned plots with the most alder (80 alder per acre). By chance, admixed alder in this 80 TPA treatment averaged greater d.b.h. and height than those in the 20 and 40 TPA admixture (table 2).

**Table 1—Number of trees, 0.1 in and larger, by species, before and after thinning at plantation age 9, per acre basis<sup>a,b</sup>**

Douglas-fir stand	Treatment no.	Plot no.	Before thinning			After thinning		
			DF	RA	All	DF	RA	All
Pure:								
0N	1	13	1370	285	1870	300	0	300
		3	1000	95	2130	300	0	300
		4	1390	0	2460	305	0	310
200N	5	11	1165	100	1410	310	0	310
		5	1240	0	1950	305	0	305
		1	1435	0	3370	305	0	310
Mixed:								
20	2	7	1020	110	1250	295	20	320
		16	1745	295	3280	300	20	320
		10	2465	380	3475	295	25	320
40	3	8	970	230	1765	290	40	330
		6	1160	75	1505	285	35	320
		9	1200	270	1730	305	40	345
80	4	14	1125	185	1915	305	70	375
		12	2140	410	2745	290	80	370
		17	2385	320	4980	310	80	390
NT	6	15	1440	185	3290	1440	185	3290
		18	2610	100	5710	2610	100	5710
		2	1575	0	3070	1575	0	3070

<sup>a</sup>Plots within each treatment are ordered by blocks 1, 2, and 3 based on coverage of an herbicide spray at age 4: block 1 = none, block 2 = partial, and block 3 = full coverage.

<sup>b</sup>DF = Douglas-fir, RA = red alder, all = includes DF, RA, mostly western hemlock, and Sitka spruce; NT = nonthinned.

**Table 2—Average stand statistics after thinning at plantation age 9, trees 0.1 in d.b.h. and larger, by treatment and species, per-acre basis<sup>a</sup>**

Douglas-fir stand	Treatment no.	Stems			Dq			Height		CVTS <sup>b</sup>		
		DF	RA	All	DF	RA	All	DF	RA	DF	RA	All
		----- Number -----			----- Inches -----			-- Feet --		-- Cubic feet --		
Pure:												
0N	1	302	0	303	3.8	0	3.8	21.6	—	244	0	244
200N	5	307	0	307	3.7	0	3.7	19.7	—	233	0	233
Mixed:												
20	2	297	22	320	3.8	3.3	3.8	22.1	24.7	256	17	273
40	3	293	38	332	3.9	2.7	3.7	22.0	22.2	252	22	274
80	4	302	77	379	3.6	3.6	3.6	21.6	26.9	231	77	309
NT (All)	6	1875	95	4023 <sup>c</sup>	1.2	1.8	.9	9.4	14.4	285	55	359
(300)		300	—	—	3.8	—	—	21.2	—	228	—	—

<sup>a</sup> DF = Douglas-fir, RA = red alder, all = all species, NT = nonthinned.

<sup>b</sup> CVTS = Cubic volume total stem, including tip and stump.

<sup>c</sup> Statistics for “all” include other species beside DF and RA.

**Trends with time**—Thinning prescribed for five of the six treatments reduced stand density to about 300 TPA of Douglas-fir and from 0 to 80 TPA of red alder. Subsequent 17-year losses of Douglas-fir on thinned plots ranged from 5 to 90 TPA (fig. 2). Retention of 20, 40, or 80 alder per acre (7, 13, and 27 percent, respectively) subsequently reduced numbers of associated Douglas-fir by about 10, 17, and 23 percent, respectively. Smaller average size of alder in the 40-TPA admixture (table 2) could explain below-average losses of Douglas-fir in this treatment (fig. 2). Losses of Douglas-fir were related positively to number of associated alder (adjusted  $r^2 = 0.599$ ;  $P < 0.002$ ). Our linear equation for predicting losses of Douglas-fir for the 17 years was:

$$\text{Tree losses} = 19.0 + \text{ATPA} (0.719) ,$$

where ATPA = number of alder per acre after thinning.

Nine years after about 430 Douglas-fir per acre were planted, the three nonthinned plots averaged 4,023 TPA of combined species (table 2). Nearly all were Douglas-fir (47 percent) and western hemlock (51 percent). Initial density of red alder averaged 95 TPA among the three nonthinned plots; however, plot 2 (full herbicide coverage) contained no red alder. We tagged all trees 0.1-in d.b.h. and larger on these nonthinned plots to investigate their eventual fate. Within 17 years, stand density had declined by 78 percent to 878 TPA. Percentage losses by species averaged as follows:

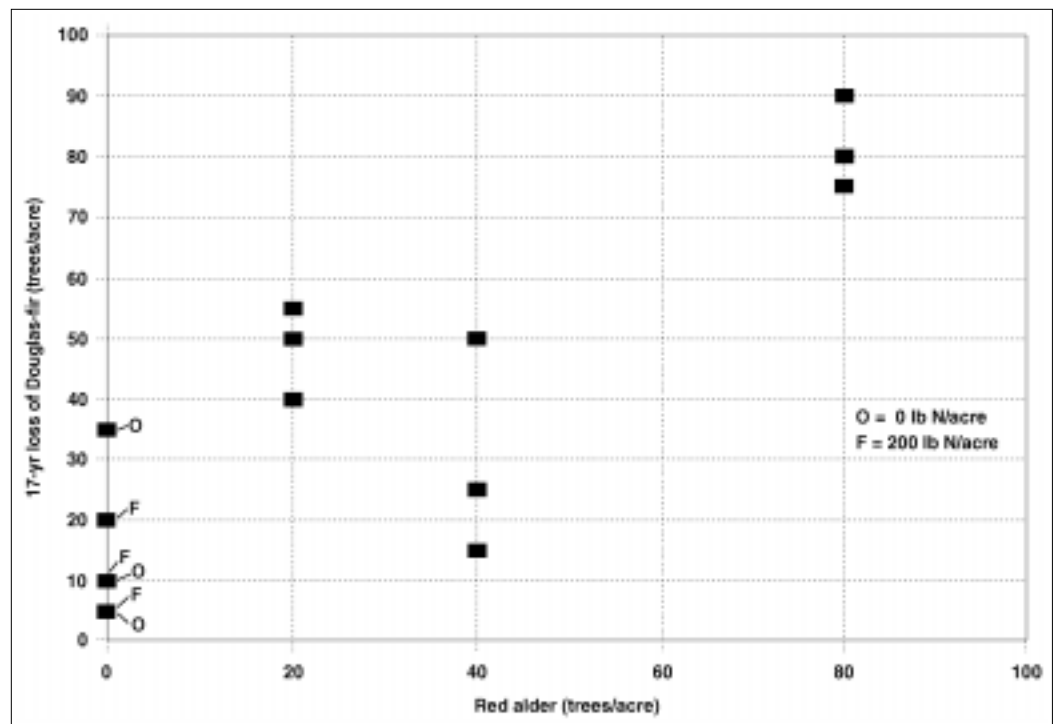


Figure 2—Mean numbers of Douglas-fir that died from the original 300 per acre retained after thinning 17 years earlier.

Species	Stems/acre				
	1979	1996	Total lost	No.	Percent
Douglas-fir	1875	353	1522	81	
Red alder	95	77	18	19	
Western hemlock	2053	448	1605	78	
All	4023	878	3145	78	

Losses were similar for Douglas-fir and for the more shade-tolerant hemlock.

### Mean Height

**After thinning**—At age 9, mean height of the residual 300 TPA of Douglas-fir among mixed-species plots was similar (21.2 to 22.1 ft; table 2) but averaged much taller than Douglas-fir in nonthinned plots (9.4 ft) because the latter included many small trees. Treatment means of alder in thinned plots ranged from 22.2 to 26.9 ft (table 2). By chance, alder in the 80-TPA alder treatment averaged taller (table 2) than those in the 20- and 40-TPA admixtures. Average height of Douglas-fir was less than that of associated red alder. At plantation age 9, Douglas-fir/red alder height ratios ranged from 0.80 to 0.99 among thinned plots and 0.44 among nonthinned plots (table 3). Note that plots with 40 TPA alder admixture averaged the most favorable Douglas-fir/red alder height ratio (0.99) and also below-average losses of Douglas-fir on the next 17 years (fig. 2).

**Table 3—Mean heights of live Douglas-fir and red alder in the mixed-species stands, by treatment and plantation age<sup>a</sup>**

Alder retained	Treatment no.	Age (years) and species											
		9		12		15		18		22		26	
		DF	RA	DF	RA	DF	RA	DF	RA	DF	RA	DF	RA
<b>Mean height (ft)</b>													
0	1	21.6	—	29.6	—	36.7	—	44.4	—	52.8	—	60.9	—
20	2	22.1	24.8	30.5	32.7	37.7	38.2	44.8	43.5	54.6	51.8	62.3	55.9
40	3	22.0	22.2	30.9	28.6	37.9	35.5	45.1	41.9	55.0	49.9	61.8	54.1
80	4	21.6	26.9	30.5	35.3	38.1	41.9	45.4	49.0	55.4	57.9	63.5	63.8
All	6	9.4	21.6	15.4	30.4	26.1	40.2	36.3	47.4	47.9	55.8	55.4	61.7
<b>Coefficient of variation (SD/mean * 100)</b>													
0	1	8	—	6	—	5	—	3	—	4	—	3	—
20	2	13	22	12	17	12	16	11	15	8	13	7	13
40	3	2	17	4	14	4	14	2	10	1	8	3	9
80	4	6	14	5	10	5	8	4	6	5	5	6	5
All	6	18	17	17	13	9	5	8	10	5	10	4	11
<b>Height ratio (DF/RA)</b>													
20	2	0.89		0.93		0.99		1.03		1.05		1.11	
40	3	.99		1.08		1.07		1.08		1.10		1.14	
80	4	.80		.86		.91		.92		.96		.99	
All	6	.44		.51		.65		.76		.86		.90	

<sup>a</sup> DF = Douglas-fir, RA = red alder, all = nonthinned, SD = standard deviation.

**Trends with time**—Mean height of Douglas-fir and alder increased progressively in subsequent years (table 3 and fig. 3). Change in mean height, however, resulted from both growth and, in some plots, death or severe damage of sample trees. Some trees were replaced with comparable substitutes when available. Effects of a changing sample were especially evident in nonthinned plots (fig. 3). As indicated by the Douglas-fir/red alder height ratio, Douglas-fir initially averaged shorter than associated red alder (table 3). With 20 alder per acre, the Douglas-fir/red alder height ratio exceeded 1.0 by plantation age 18. This implied shift of Douglas-fir to dominance occurred by year 12 in the 40-TPA alder treatment, probably because the ratio was already 0.99 at year 9. With 80-TPA alder and in nonthinned stands, however, Douglas-fir continued to average shorter than alder through year 26 after planting (table 3).

Coefficients of variation (CV) associated with these mean heights were < 23 percent; CV of Douglas-fir were usually less than those for alder heights (table 3). The CV usually declined with tree age, perhaps because shorter trees died from competition. This potential effect of a changing sample was of concern for only one plot (plot 5) where the periodic annual increment (PAI) of surviving trees of the original sample was 2.34 ft and that of survivors plus replacements was 2.15 ft. The lower PAI for this fertilized plot lowered the treatment mean below that of the nonfertilized mean.

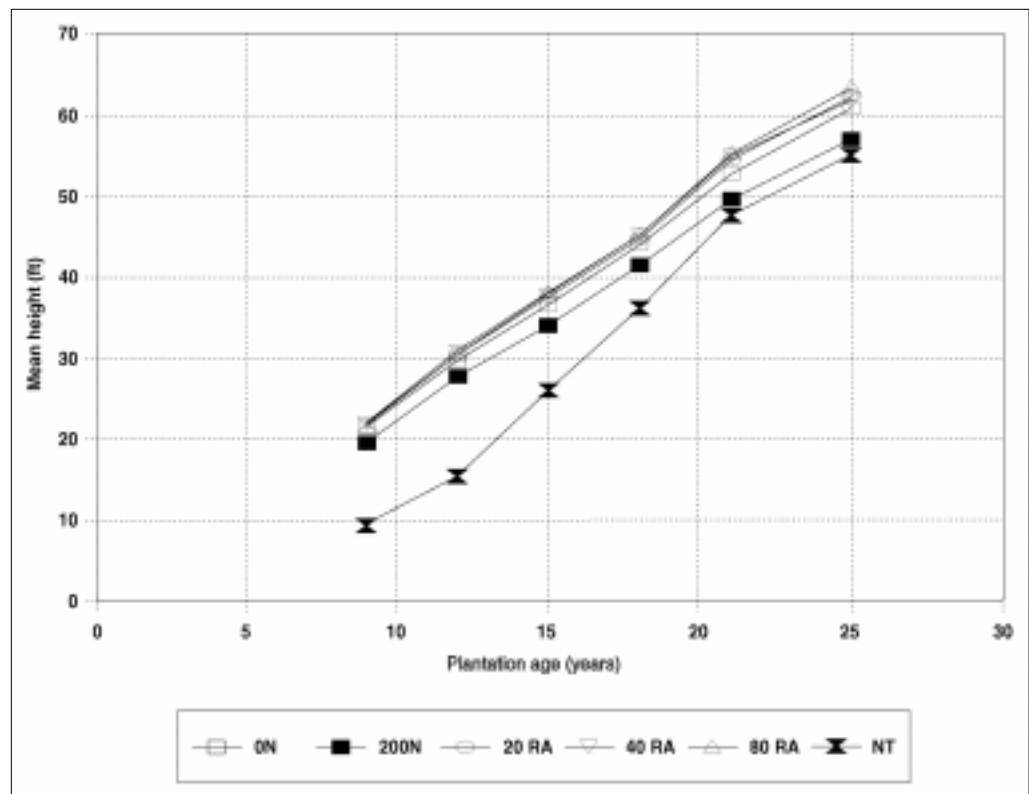


Figure 3—Trends of average height of Douglas-fir surviving each growth period, by treatment.

**17-year change in mean height**—The effect of retaining different numbers of red alder on mean height of associated Douglas-fir was examined with covariance analysis, in which treatment means of observed height were adjusted for initial differences in starting height among treatments. As noted earlier, change in mean height represents net height growth of sample trees and change in sample trees because some trees die and are replaced with other trees. Observed mean height growth on 12 thinned plots (TMT 1-4 in blocks 1, 2, and 3) ranged from 2.24 to 2.59 ft/year in the 17-year period after thinning (fig. 4). Adjusted means for each treatment also are displayed (fig. 4). A linear fit of these adjusted means for the four treatments (0, 20, 40, and 80 alder/acre) was significant ( $P \leq 0.041$ ) and unlikely to be improved by a curvilinear fit (table 4). Thus, mean height of Douglas-fir improved slightly with increasing numbers of admixed alder (fig. 4); adjusted height growth on the 80 TPA plots averaged 2.53 ft or 9 percent greater than growth on plots without alder (TMT 1). Change in sample trees caused by mortality had little influence on these means but did affect contrast 1. Contrast 1 (fertilized vs. nonfertilized) also was significant ( $P \leq 0.062$ ; table 4). Although both observed and adjusted means for fertilized tree were about 7 percent less than nonfertilized trees (table 5), about half of this apparent 7 percent reduction in height growth after fertilization is an artifact of a changing height sample on plot 5. Thus, a recomputed mean based on PAI of surviving trees on this plot (2.34 vs. 2.15 ft) would increase the treatment mean from 2.16 to 2.23, netting about a 4-percent reduction in mean height growth after fertilization.

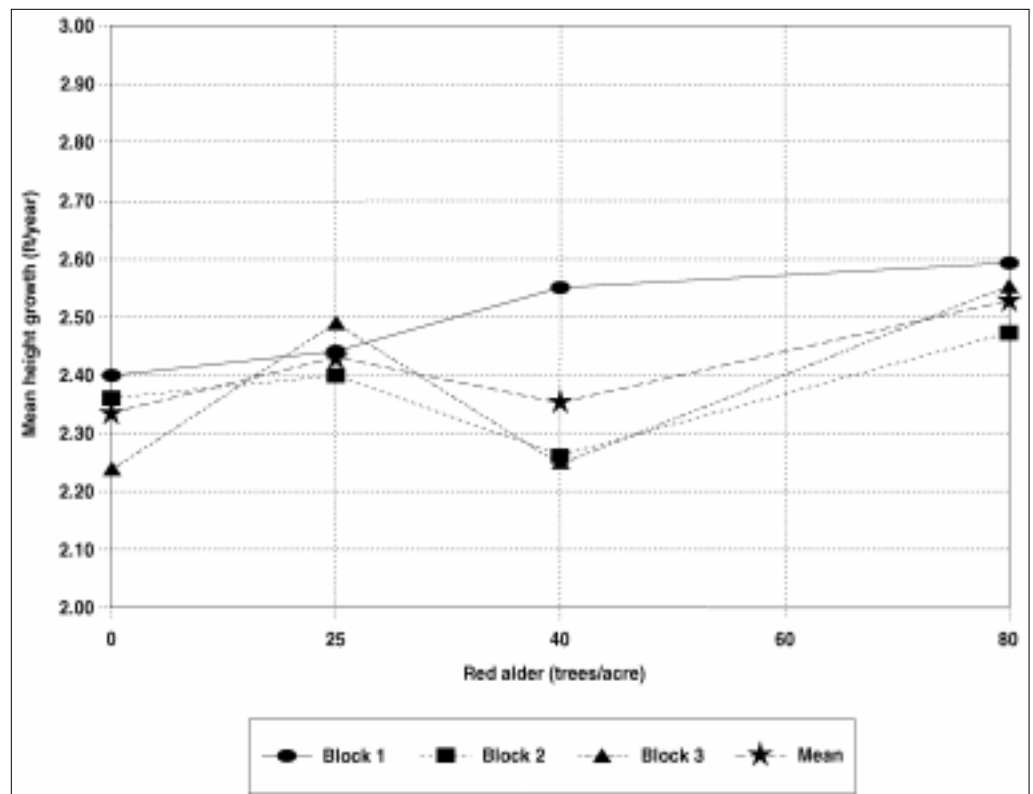


Figure 4—Mean annual height growth of Douglas-fir (age 9-26) related to numbers of alder retained after thinning, by plot, block, and treatment means.

**Table 4—Degrees of freedom, mean squares, and P-values from analyses of covariance of the mean annual changes in 17-year height, basal area, and volume of Douglas-fir in thinned stands**

Source of variation	D.f.	Annual change							
		Mean height		Basal area		Volume			
		MSE	P-value	MSE	P-value	Gross		Net	
						MSE	P-value	MSE	P-value
Block	2	0.0156	0.184	0.6593	0.414	470	0.208	488	0.236
Covariate <sup>a</sup>	1	.0009	.727	.0204	.865	677	.135	277	.348
Contrasts: <sup>b</sup>	4								
1=Fertilizer	(1)	.0353	.062	.2351	.569	34	.715	18	.805
2=Linear	(1)	.0450	.041	16.283	.002	8518	.001	11,642	.001
3= L. of f.	(2)	.0121	.252	.6863	.401	208	.457	398	.296
Error	7	.0072	—	65.75	—	237	—	274	—
Total	14								

<sup>a</sup> Covariate = postthinning height, basal area, or volume, respectively.

<sup>b</sup> Contrast 1 = fertilized vs. nonfertilized; contrast 2 = linear fit to adjusted means of treatments 1-4; contrast 3 = lack of fit (to linear) of treatments 1-4.

**Table 5—Average annual change (age 9-26) in mean height, basal area, and volume on fertilized vs. nonfertilized plots, by species<sup>a</sup>**

Fertilizer	Treatment	Douglas-fir						All species Observed <sup>c</sup>
		Height		Gross, basal area		Gross volume		
		Obs'd	Adj'd <sup>b</sup>	Obs'd	Adj'd <sup>b</sup>	Obs'd	Adj'd <sup>b</sup>	
<i>Lb/acre</i>		--- Ft ---		-- Ft <sup>2</sup> /acre --		----- Ft <sup>3</sup> /acre -----		
0	1	2.33	2.33a	8.50	8.49a	233	233a	233a
200	5	2.16	2.17b	8.90	9.00a	226	228a	226a
		<b>Relative to treatment 1 (nonfertilized=100)</b>						
200	5	93	93	105	106	97	98	97

<sup>a</sup> This table supplements table 4. Within columns, means followed by the same letter are not significantly different ( $P > 0.10$ ).

<sup>b</sup> Adjusted means from covariance analysis, where covariate = postthinning mean height, basal area, or volume per acre, respectively.

<sup>c</sup> Covariance adjustment is inappropriate.

### Basal Area Per Acre

Our estimates of stand basal area were based on measurement of each tree and not on a sampling of trees for height and derived volume. Because our estimates of basal area and basal area growth are free of sampling error, this variable is a better measure of stand response to treatment.

Gross basal area growth of residual Douglas-fir in the 17-year-period after thinning (14 years after fertilization) was similar for fertilized and nonfertilized plots (table 5). The apparent 5- to 6-percent greater basal area growth on fertilized plots, however, was statistically nonsignificant ( $P = 0.569$ ; table 4).

Basal area growth of Douglas-fir after thinning declined with increasing numbers of admixed alder (fig. 5). After slight adjustment for initial differences in postthinning basal area among plots, this growth-alder density relation was linear with negative slope ( $P = 0.002$ ; table 4).

### Cubic Volume Per Acre

To avoid misinterpretations, we define our terms as follows: (1) Gross PAI is the estimated volume added to tree boles between measurements. This total volume growth, expressed on an annual basis, was accumulated on trees that either survived or died in specified 3- or 4-year periods between measurements. (2) Periodic annual mortality (PAM) is the volume in trees that died in specific periods, also expressed on an annual basis. This mortality volume includes the cumulative volume at the start of the period and any growth added before death. (3) The difference between gross PAI and PAM is the net annual change in live-stand volume in specified periods.

**After thinning**—Mean volume of Douglas-fir among the thinned treatments ranged from 231 to 256 ft<sup>3</sup>/acre and averaged 17 percent less than volume of all Douglas-fir in nonthinned control (285 ft<sup>3</sup>), but more than the 300 largest Douglas-fir in nonthinned plots (228 ft<sup>3</sup>).



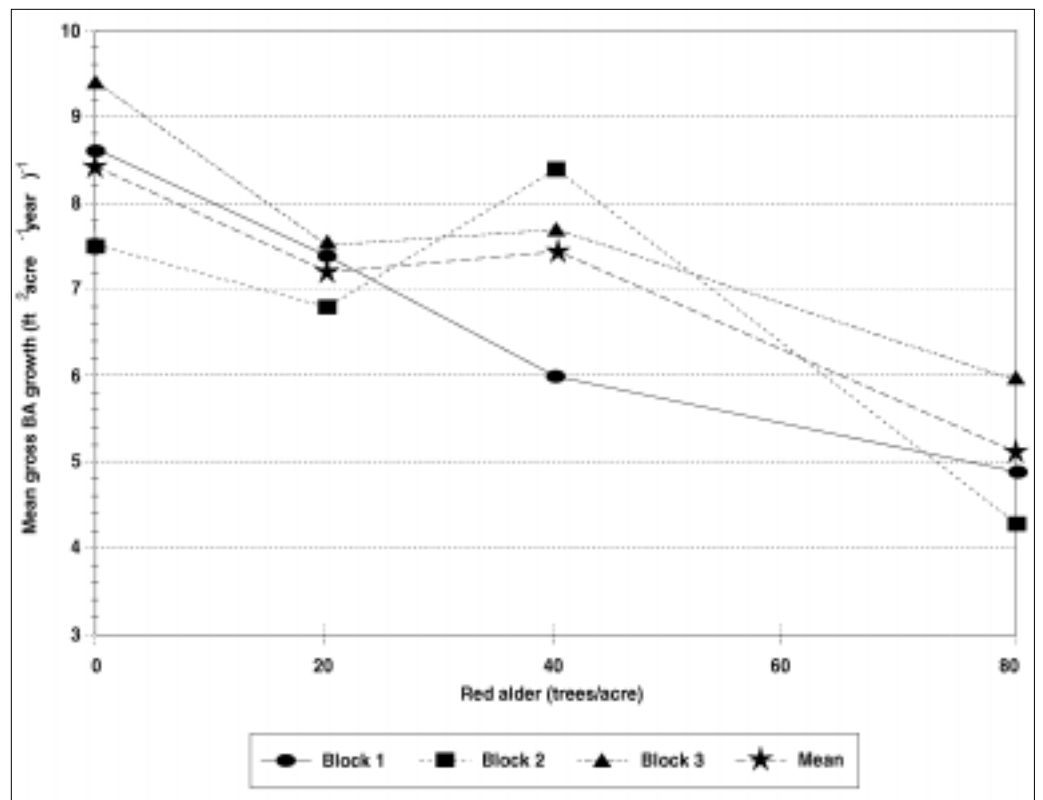


Figure 5—Mean gross basal area growth of Douglas-fir (age 9-26) related to number of red alder retained after thinning, by plot, block, and adjusted treatment means.

**Trends of gross PAI**—In both pure and mixed stands, observed mean gross PAI of Douglas-fir volume peaked in years 16 to 18 after planting (table 6). Gross growth of Douglas-fir in pure stands exceeded that of Douglas-fir in mixed stands in all periods. Mean PAI of fertilized plots in the pure stands was consistently less than that of non-fertilized plots, thereby indicating that volume growth was not increased after fertilization at age 12. Within mixed stands, gross PAI of red alder was proportional to alder stocking; PAI of associated Douglas-fir was irregular over time, in contrast to the smoothly declining trend in pure stands (table 6).

**Gross and net PAI in the 17-year period**—Average growth (PAI) among various treatments depends in part on initial stand volume. For Douglas-fir, we provide both observed treatment means and those adjusted by covariance to a common or average postthinning stand volume (table 7). In the 17-year period after thinning, adjusted gross PAI of Douglas-fir was not significantly related to respective initial volumes ( $P \leq 0.135$ ). Hence, adjusted means were within 2 percent of observed means (table 7). Among the 15 thinned plots, gross and net volume growth of the Douglas-fir component was least where admixed with 80 TPA of red alder (table 7). Gross 17-year PAI of the Douglas-fir component was reduced in mixed stands (fig. 6). A linear fit of adjusted means was significant ( $P \leq 0.001$ ) and curvilinear fit was not needed (table 4). Net PAI in this mixed-stand treatment averaged about 40 percent less than that in the pure Douglas-fir treatment. Both gross and net PAI on fertilized plots averaged within 2 percent of growth on nonfertilized plots.

**Table 6—Observed mean annual increment (gross PAI) and mortality (PAM) in stand bole volume, by treatment, age, and species**

Stand and treatment	Treatment no.	PAI (PAM)	Plantation age (inclusive years)					
			10-12	13-15	16-18	19-22	23-26	10-26
----- Cubic feet per acre -----								
<b>Douglas-fir</b>								
Pure:								
0N	1	PAI	134	203	288	265	247	232
		(PAM)	0	0	0	7	10	4
200N	5	PAI	132	196	277	262	243	226
		(PAM)	0	0	4	3	1	3
Mixed:								
20	2	PAI	101	151	221	207	221	205
		(PAM)	0	0	12	1	7	9
40	3	PAI	147	195	256	241	177	206
		(PAM)	0	0	6	7	15	6
80	4	PAI	123	162	190	166	110	155
		(PAM)	0	0	4	22	45	16
NT <sup>a</sup>	6	PAI	147	178	194	169	954	167
		(PAM)	0	5	21	35	3	23
<b>Red alder</b>								
Mixed:								
20	2	PAI	6	11	17	13	24	18
		(PAM)	0	0	0	0	0	0
40	3	PAI	14	26	28	34	27	26
		(PAM)	0	0	0	0	0	0
80	4	PAI	44	75	94	107	79	82
		(PAM)	1	0	1	0	2	1
NT <sup>a</sup>	6	PAI(PAM)	62	106	121	134	101	107
		(PAM)	0	0	0	2	2	1

<sup>a</sup> NT = nonthinned control.

**Table 7—Average annual change in cubic volume of thinned stands during a 17-year period (1979-96), by treatment and species, per acre basis<sup>a</sup>**

Douglas-fir stand and treatment	Treatment no.	Gross PAI			Mortality (PAM), obs'd	Net PAI		
		Obs'd	Adj'd	0N=100 <sup>b</sup>		Obs'd	Adj'd	0N=100 <sup>b</sup>
		--- Ft <sup>3</sup> ---	Percent			----- Ft <sup>3</sup> -----	Percent	
<b>Douglas-fir</b>								
Pure:								
0N	1	233	233a	100	4	229	229a	100
200N	5	226	228a	98	3	224	225a	98
Mixed:								
20	2	210	207b	89	9	201	199b	87
40	3	206	205b	107	6	200	199b	87
80	4	155	157c	67	16	138	139c	61
<b>Red alder</b>								
Mixed:								
20	2	18b	—	—	0	18b	—	—
40	3	26b	—	—	0	26b	—	—
80	4	82a	—	—	1	81a	—	—
<b>All species</b>								
Pure:								
0N	1	233a	—	100	4	229a	—	100
200N	5	226a	—	97	3	224a	—	98
Mixed:								
20	2	224a	—	96	9	215a	—	94
40	3	233a	—	100	6	227a	—	99
80	4	240a	—	103	17	219a	—	96

<sup>a</sup> Within columns and species, means with same letter are not significantly different (P > 0.10).

<sup>b</sup> Based on adjusted means where provided.

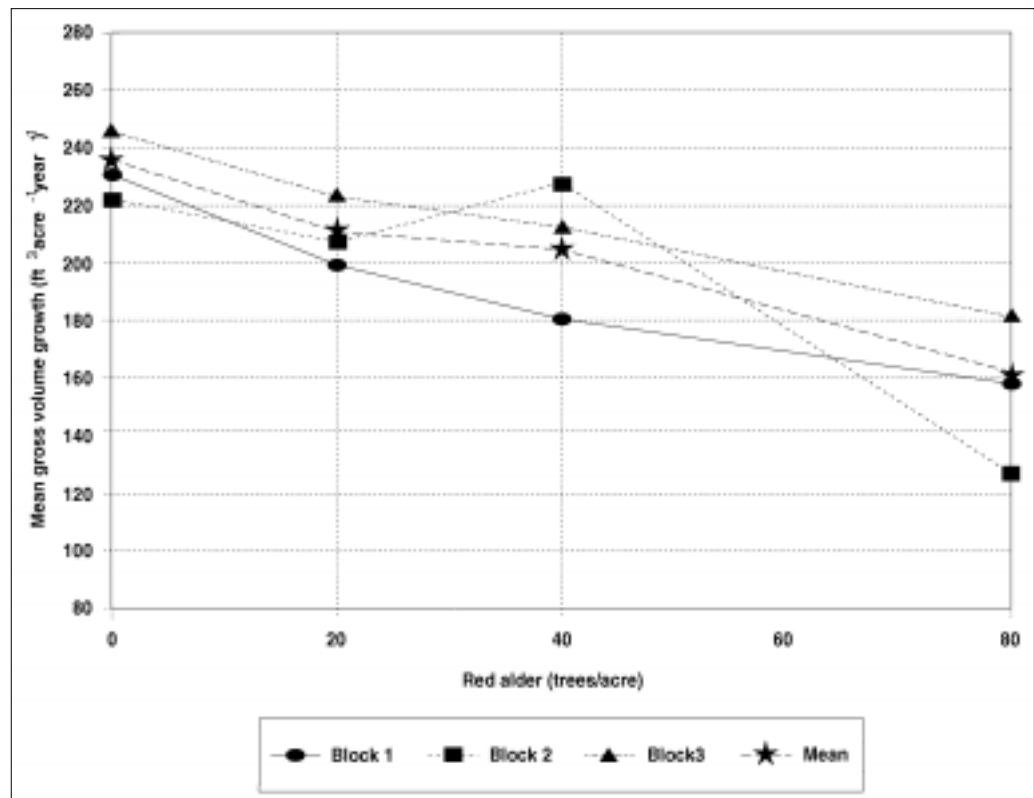


Figure 6—Mean gross annual volume growth of Douglas-fir (age 9-26) related to numbers of red alder retained after thinning, by plot, block, and adjusted treatment means.

Gross volume PAI of red alder ranged from 18 to 82  $\text{ft}^3 \cdot \text{acre}^{-1} \cdot \text{year}^{-1}$  for 17 years (table 7). Growth per acre with 80 alder/acre was greater than that with 40 or 20 alder ( $P \leq 0.10$ ; table 7). The PAI/tree also was greatest with 80 alder/acre ( $1.02 \text{ ft}^3 \cdot \text{acre}^{-1} \cdot \text{year}^{-1}$ ) and least with 40 alder/acre ( $0.65 \text{ ft}^3 \cdot \text{acre}^{-1} \cdot \text{year}^{-1}$ ). Recall that by chance, average initial size of admixed alder also was greatest with the 80-alder treatment and least with the 40-alder admixture.

Neither gross nor net PAI of combined species (total stand) differed among the five treatments ( $P \leq 0.10$ ; table 7). Volume PAI in fertilized plots averaged 2 percent less than that in nonfertilized plots (table 7).

**Periodic annual mortality (PAM)**—Mortality of Douglas-fir averaged greater in mixed stands, especially with 80 TPA or more of red alder (table 7). Mortality of red alder also was limited to this highest density of the controlled alder admixtures. For the 17-year period of observation, volume of dead Douglas-fir in pure stands was less than 2 percent of gross PAI, compared to 4 to 14 percent of gross PAI in the mixed stands (table 7).

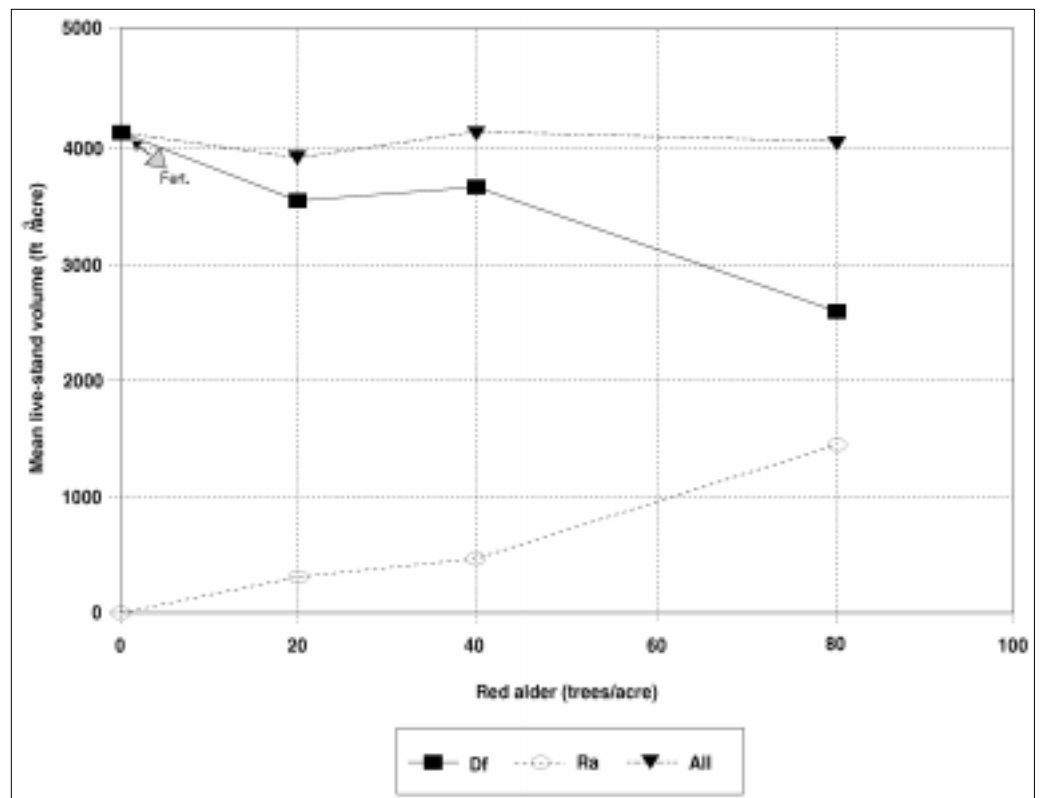


Figure 7—Mean live-stand volume at plantation age 26, by species and treatment.

### Yield at Plantation Age 26

Cumulative net yield of Douglas-fir at age 26 after planting declined with increasing density of admixed alder (fig. 7). The reduction was linearly related to increasing numbers of retained alder. Decrease in Douglas-fir yield was offset by corresponding increases in alder volume, so that yield of combined species was similar across all densities of red alder admixture. Among the three mixed-stand treatments, yield of red alder was generally proportional to alder density (fig. 7). In pure stands, average yields of fertilized and nonfertilized plots were similar.

### Discussion

Differences in 17-year growth among the 18 plots at this location were influenced by factors other than treatment. These included (1) differences in soil quality and (2) residual effects of herbicide applied to some plots 4 years after planting. Additionally, in nonthinned plots, increases in mean height were clearly influenced by (3) changes in height samples when smaller trees that died were replaced with larger trees. To assign treatment effects correctly, one must consider the influence of these nontreatment factors when interpreting treatment means and statistical significance.

Evidence for possible differences in site quality is provided by soil sampling before thinning (Cromack and others 1999). Among the 18 plots, total N averaged about 11,400 lb/acre in the 0- to 40-in depth (table 8); plots that were subsequently fertilized averaged the least content of total N (10,400 lb/acre) and those that remained nonthinned averaged the most (14,000 lb N/acre). Results from ANOVA, however, indicated that initial differences in total N among treatments were statistically nonsignificant ( $P \leq 0.683$ ).

**Table 8—Average soil characteristics among the 6 treatments and 3 experimental blocks, by soil depth<sup>a</sup>**

Douglas-fir stand and treatment	Content of $\geq 6$ -mm fraction in:		Total N in 0-40 in	Net mineralizable N in:	
	0-6 in	18-40 in		0-6 in	18-40 in
	----- Percent -----		Lb N/acre	--- Ppm ---	
Pure:					
0N	17	28	11,000	72	46
200N	8	27	10,400	99	52
Mixed:					
20	7	30	10,500	86	34
40	12	27	11,500	78	55
80	12	19	11,300	91	48
All	16	25	14,000	96	65
Block (herbicide):					
1 None	14	28	9,800	92	44
2 Partial	11	23	12,300	90	57
3 Full	12	28	12,200	78	48
All	12	26	11,400 <sup>b</sup>	87	50

<sup>a</sup>Data adapted from Cromack and others (1999).

<sup>b</sup>ANOVA indicated that differences were nonsignificant among treatments ( $P \leq 0.683$ ) and blocks ( $P \leq 0.267$ ), mean square error = 8,282,886; SE = 1662 lb/acre or 15 percent of grand mean.

Residual effects of early conifer-release spray also enhanced Douglas-fir growth on some plots. Recall that our six treatments were randomly assigned within each of three blocks that had received no, partial, or full application of herbicide spray at plantation age 4 years. Five years later and before thinning, average number and size of red alder were less on herbicide-treated plots, but number of conifers had increased by about 50 percent (Miller and Obermeyer 1996). Between age 9 and 15 years, 6-year volume growth in thinned stands that had received full herbicide coverage averaged more than in stands that had not been released (202 vs. 156  $\text{ft}^3 \cdot \text{acre}^{-1} \cdot \text{year}^{-1}$ ). Although Miller and Obermeyer (1996) acknowledge uncertainty about herbicide being the sole cause of growth differences, they provide reasons for believing that differences among the blocks at this location resulted largely from herbicide treatment.

In our statistical analyses of 17-year basal area and volume growth of Douglas-fir, block means were nonsignificant (table 4) yet still retained a logical progression of more growth on herbicide-treated plots. This implies an extended carryover effect of herbicide applied to the 4-year-old plantation. We suspect, however, that growth benefits of the earlier herbicide applications may be exaggerated. Plots not treated with

herbicides averaged the least content of total N to 40-in depth (9,800 lb/acre; table 8), even though the component of N-fixing red alder—hence the amount of N added to the soil—should have been greater on these plots. This suggests that the six plots in this block averaged less soil N and poorer site quality before herbicide application. In summary, we infer from our extended measurements through 22 years after herbicide application that stands in the three blocks continue to perform differently but acknowledge continued uncertainty as to the explanation. We urge others to examine existing study areas for possible extended effects of early vegetation control. By doing this, longer term consequences of early vegetation management to stand growth can be quantified.

### **Stand Development in Nonthinned Plots**

Of the original 4,023 TPA of all species in the nonthinned plots at age 9, 78 percent died in the next 17 years (table 9). This averaged about 4.6 percent per year, probably because our tally included trees as small as 0.1 in d.b.h. Percentage losses of red alder (19 percent) were much less than Douglas-fir (81 percent) and western hemlock (78 percent). This attests to the ability of alder to maintain crown position on this mesic site. As a consequence of drastic losses of small Douglas-fir and western hemlock trees, Dq increased rapidly, and the forest floor was littered with aluminum tags!

The large number of trees in nonthinned plots increased mortality and reduced growth of Douglas-fir crop trees. Of the original 300 largest (by d.b.h.) Douglas-fir in the nonthinned plots at age 9, 48 (16 percent) died by age 26 (table 9). Volume growth of these surviving crop trees averaged 8.68 ft<sup>3</sup>/tree compared to 13.60 ft<sup>3</sup> for 287 of the 300 original Douglas-fir in the thinned plots.

### **Effect of Thinning**

We reduced conifer density to about 300 TPA by expending 4 to 17 person-hours per acre (Miller and Obermeyer 1996). Additional time was required to “hack-and-squirt” surplus alder. This 87-percent reduction in stand density was sudden, compared to the 17 years required to attain a 78-percent reduction largely by natural suppression in nonthinned stands.

The consequences of thinning as an independent treatment in this study area are best isolated by comparing stand development and yield of pure Douglas-fir plots (TMT 1) and nonthinned plots (TMT 6). Because no statistical tests were planned originally to infer differences between these treatments, none are provided (table 9).

At age 9 years, thinned plots of TMT 1 started with fewer trees and less volume per acre than nonthinned plots; however, average volume per tree was 9-fold greater. During the next 17 years, thinned plots lost 15 TPA compared to 3,145 TPA in nonthinned plots. Despite huge losses of trees, nonthinned plots continued to accumulate more total volume than thinned plots (table 9). The large increase in mean volume of surviving trees in nonthinned plots to 5.37 ft<sup>3</sup> at age 26 is explained by the death of numerous small trees and from growth of surviving trees. In the 26-year-old plantation, thinned plots averaged about 66 percent fewer trees than nonthinned plots, but these trees individually averaged 2.5-fold larger in volume (13.6 vs. 5.4 ft<sup>3</sup>). Moreover, Douglas-fir crop trees in thinned stands averaged 1.6-fold more volume per tree than those in the nonthinned stands. Thus, thinning concentrated somewhat less volume growth per acre on fewer trees.

**Table 9—Average stand statistics for thinned (TMT 1) and nonthinned (TMT 6) plots, trees 0.1 in d.b.h. and larger, per acre basis<sup>a</sup>**

Item	Treatment			Difference (T-NT), all
	Thinned DF	Nonthinned DF	All	
Start (yr 9):				
TPA (no.)	302	300	4023	-3721
Volume (per acre)	244	228	359	-115
(per tree)	.81	.76	.09	.72
End (yr. 26):				
TPA (no.)	287	352	878	-591
Volume (per acre)	4135	2380	4797	-662
(per tree)	14.41	9.44	5.45	8.95
Change:				
TPA (no.)	-15	-48	-3145	-3130
Volume (per acre)	3891	2152	4438	-547
(per tree)	13.60	8.68	5.37	8.23

<sup>a</sup> DF = Douglas-fir, all = all species, T = thinned, NT = nonthinned.

## Effect of Fertilizing

Growth in the pure Douglas-fir plots was not detectably increased by 200 lb N/acre applied 3 years after thinning. Key statistics (from tables 4 and 5) for nonfertilized (TMT 1) and fertilized (TMT 5) Douglas-fir follow:

Item	Treatment		Difference	P=
	Fertilized	Nonfertilized		
Ann. change (17 years): <sup>3</sup>				
Mean height (ft)	2.17	2.33	-0.16	0.062
Gross basal area (ft <sup>2</sup> per acre)	8.89	8.50	.39	.569
Gross volume (ft <sup>3</sup> per acre)	228	233	-5	.715

Mean annual changes in mean height, gross basal area, and volume of Douglas-fir on fertilized plots were similar to those on nonfertilized plots. As related previously, about one-half the apparent 7-percent reduction in height growth after fertilization is explained by change in sample trees on one plot after death of some of the original sample trees. Differing amounts of top damage was not an explanation because the number of height trees with top damage was similar in fertilized and nonfertilized plots. Estimates of ending stand volume and volume growth also would be reduced by substituting shorter trees in our height sample in one fertilized plot. Therefore, we believe that N-fertilizer had no measurable effect on growth at this location.

<sup>3</sup> Adjusted by covariance for differences in starting values among treatments. The relation was linear ( $P \leq 0.10$ ) for height, basal area, and volume.



### **Effect of Increasing Numbers of Red Alder**

These results justify our original concerns during design of this field trial. Because of the site II quality of this location and the large amounts of total N reported for similar coastal Oregon soils, we anticipated less than a 10-percent increase in volume growth in the subsequent decade (Miller and others 1988). Moreover, we doubted that such small differences in growth would be detectable, despite our installing relatively large plots and measuring heights on half the residual Douglas-fir trees (30 of 60 per plot). In retrospect, our treatment effects were small and background variation was increased by site variation (slope percent, aspect, soil) and herbicide application several years before our treatments were applied.

In pure Douglas-fir plots, 17-year mortality after thinning annually averaged 1.2 TPA or 0.37 percent of the original trees. Increasing stand density by adding 20, 40, or 80 dominant or codominant red alder accelerated mortality and increased incidence of Douglas-fir with top damage. We suspect that Douglas-fir nearest vigorous red alder were most likely to be killed or top-damaged. We have observed that the steep branch angle of red alder (fig. 8) prolongs survival of its branches in the lower crown. Unfortunately, this ensures continued physical barriers and less light to neighboring Douglas-fir, especially those downslope from red alder.

Our equation for predicting Douglas-fir losses in the 17-year period of observation was  $Y = 19 + ATPA (0.719)$ , where ATPA is red alder TPA. This implies that each alder in the mixed stand displaced about one of the 300 Douglas-fir. These tree-loss estimates are consistent with stand yields at age 26 (fig. 7). Average yield of Douglas-fir was greatest in pure stands and gradually declined as alder density increased. These results supported our initial hypothesis: by increasing alder density, negative effects of red alder on associated Douglas-fir will gradually offset the potentially positive effects of increased N and improved organic matter status. We erroneously anticipated, however, that yields of Douglas-fir would be slightly increased by N-fertilizer and at lower densities of admixed alder. In reality, we measured no fertilizer effect and declines in Douglas-fir yield as red alder were added.

Results from this coastal Oregon site contrasted strongly with those of an earlier investigation at a location having poorer site quality in the Cascade Range in southwest Washington. Data from that location were the basis for original speculations about a suitable number of red alder to admix in Douglas-fir plantations (Miller and Murray 1978). At that poor, site V location, a 1929 Douglas-fir plantation grew taller and produced more bole volume in response to both N-fertilizer (Miller and Tarrant 1983) and a nearly 2:1 alder-fir planting mix (Miller and Murray 1978). This large complement of planted alder explained the 30 or more percent N-increase (ca. 1,000 lb N/acre) in the duff and soil in the mixed stand compared to adjacent pure stands about 30 years after planting (Tarrant and Miller 1963). Not only were benefits of improved N-status likely to be greater at that Cascade site than our coastal Oregon site, but competitive effects of alder in the mixed stand at the Cascades site were minimized because alder was interplanted 4 years after the Douglas-fir were planted. Moreover, the newly planted alder were severely frost damaged in the first year. Consequently, at plantation age 58, yield of Douglas-fir in the mixed plantation exceeded that in the pure Douglas-fir plantation, and combined yield of both species was nearly twice that of the pure stand (Miller and Murray 1978).

We suspect that trials at lower quality, N-deficient sites would have results differing from those at our coastal site. We anticipate that growth of Douglas-fir on poorer quality soil would increase from both N-fertilizer and N fixed by red alder, providing this species would grow vigorously. Moreover, where moisture or temperature relations are less



Figure 8—Steep branch angles of red alder prolong survival of lower branches that shade or damage neighboring conifers.

favorable to red alder than at our coastal site, we assume that red alder height and crown growth would be less vigorous, hence, less likely to overtop or damage nearby Douglas-fir. Binkley (1992) also observed that only on N-limited sites is growth of associated non-N-fixing trees generally greater in mixed stands than in pure stands. In fact, these predictions will be tested by results from a parallel trial in the Cascade Range of Washington (Murray and Miller 1986).

Note that the experimental design of both trials does not permit separating effects of increasing total stand density from increasing proportion of red alder. This “additive” design limits understanding of competitive relations in mixed stands (Harper 1977, Hibbs and DeBell 1994). Our admixing 20, 40, and 80 TPA of red alder to a constant 300 TPA of Douglas-fir changes both total stand density and proportion of red alder (6, 11, and 12 percent, respectively). More discriminating “substitutive” or “replacement” designs for red alder/Douglas-fir mixtures have been installed to quantify competing relations (Shainsky and others 1994). Unfortunately, however, these plots are small and less adequate for comparing stand yields at longer growth periods.

### **Red Alder vs. N-Fertilization**

At this coastal Oregon plantation, 200 lb N/acre applied as urea failed to stimulate volume growth of Douglas-fir. This suggests that the amount of N available to this plantation before fertilization was not limiting growth; in fact, amounts of total and mineralizable N were large. At age 9, our three fertilized plots averaged 10,400 lb total N/acre to 40 in depth and 99 parts per million anaerobically mineralizable N in the 0- to 6-in depth (Cromack and others 1999). From our observed lack of response to N-fertilizer, we infer that N fixed by bacteria associated with alder roots also would be unlikely to stimulate growth of associated Douglas-fir. Because admixed alders in this plantation survived in dominant or codominant positions, we speculate that photosynthesis should have provided energy for both alder growth and associated N-fixing actinomycetes. We

estimated by two methods, but did not attempt to measure, the amount of N-fixation in the 17-year period of observation. Firstly, by regressing N-gains estimated in various published studies and years of alder presence, we estimated average annual fixation at about 60 lb N/acre for well-stocked alder stands (data on file at the Forestry Sciences Laboratory, Olympia, WA). Based on this annual mean fixation rate, amounts fixed by the 20, 40, or 80 alder per acre retained in our mixed-species stands for 17 years could exceed our 200 lb N/acre fertilization. Secondly, based on others' assumptions about N-fixation and proportions of red alder (Hibbs and DeBell 1994), we estimated that 17-year N-fixation in our plots ranged from 150 to 230 lb N/acre (20 TPA alder) to 540 to 800 lb N/acre (80 TPA alder).

## Conclusions

- Volunteer regeneration provided a 10-fold increase in tree numbers over planting density. About 80 percent of these volunteers died by plantation age 26 years.
- Thinning to 300 TPA Douglas-fir at age 9 slightly reduced live stand volume at plantation age 26 years but more than doubled the size of crop trees.
- Retaining red alder reduced numbers, growth, and yield of associated 300 TPA of Douglas-fir.
- Absence of a measurable increase in growth after fertilization with 200 lb N/acre at this site was consistent with a corresponding absence of enhanced growth from N fixed by admixed red alder.
- Similar comparisons of red alder and fertilizer for enhancing growth of Douglas-fir are needed at other locations, especially those with known N-deficiency.

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## Metric Equivalents

1 inch (in) = 2.54 centimeters

1 foot (ft) = 0.3048 meter

1 square foot (ft<sup>2</sup>) = 0.0929 square meter

1 cubic foot (ft<sup>3</sup>) = 0.028 cubic meter

1 acre = 0.4047 hectare

1 square foot per acre = 0.2296 square meter per hectare

1 cubic foot per acre = 0.06993 cubic meter per hectare

1 pound (lb) = 453.592 grams

1 gallon (gal) = 3.785 liters

## Literature Cited

- Binkley, D. 1992.** Mixtures of nitrogen<sub>2</sub>-fixing and non-nitrogen<sub>2</sub>-fixing tree species. In: Cannell, M.G.R.; Malcolm, D.C.; Robertson, P.A., eds. The ecology of mixed-species stands of trees. British Ecological Society Spec. Publ. 11. Oxford: Blackwell Scientific Publications: 99-123.
- Bormann, B.T.; Gordon, J.C. 1984.** Stand density effects in young red alder plantations: productivity, photo synthate partitioning, and nitrogen fixation. *Ecology*. 65: 394-402.
- Browne, J.E. 1962.** Standard cubic-foot volume tables for commercial tree species in British Columbia. Victoria, BC: B.C. Forest Service, Forest Surveys and Inventory Division. 107 p.
- Bruce, D.; DeMars, D.J. 1974.** Volume equations for second-growth Douglas-fir. Res. Note PNW-239. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 5 p.
- Comeau, P.; Sachs, D. 1992.** Simulation of the consequences of red alder management on the growth of Douglas-fir using FORCYTE-11. FRDA Rep. 187. Victoria, BC: B.C. Ministry of Forests, Research Branch; Forestry Canada, Pacific Forestry Centre. 45 p.
- Cromack, K., Jr.; Miller, R.E.; Helgerson, O.T.; Smith, R.B.; Anderson, H.W. 1999.** Soil carbon and nutrients in a coastal Oregon Douglas-fir plantation with red alder. *Soil Science Society of America Journal*. 63: 232-239.
- Giardina, C.P.; Huffman, S.; Binkley, D.; Caldwell, B.A. 1995.** Alders increase soil phosphorus availability in a Douglas-fir plantation. *Canadian Journal of Forest Research*. 25: 1652-1657.
- Harper, J.L. 1977.** Population biology of plants. London; New York: Academic Press. 892 p.
- Hibbs, David E.; DeBell, Dean S. 1994.** Management of young red alder. In: Hibbs, David E.; DeBell, Dean S.; Tarrant, Robert F., eds. The biology and management of red alder. Corvallis, OR: Oregon State University Press: 202-215.
- Hibbs, David E.; DeBell, Dean S.; Tarrant, Robert F. 1994.** The biology and management of red alder. Corvallis, OR: Oregon State University Press. 256 p.
- Howard, Kerry; Newton, Michael. 1984.** Overtopping by successional Coast-Range vegetation slows Douglas-fir seedlings. *Journal of Forestry*. 82: 178-180.
- Knapp, W.H.; Turpin, T.C.; Beuter, J.H. 1984.** Vegetation control for Douglas-fir regeneration on the Siuslaw National Forest: a decision analysis. *Journal of Forestry*. 82: 168-172.
- Miller, R.E.; McNabb, D.H.; Hazard, J.W. 1988.** Predicting Douglas-fir growth and response to nitrogen fertilization in western Oregon. *Soil Science Society of America Journal*. 53(5): 1552-1560.
- Miller, R.E.; Murray, M.D. 1978.** The effects of red alder on growth of Douglas-fir. In: Briggs, D.G.; DeBell, D.S.; Atkinson, W.A., eds. Utilization and management of alder. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station: 283-306.

- Miller, R.E.; Murray, M.D. 1979.** Fertilizer versus red alder for adding nitrogen to Douglas-fir forests of the Pacific Northwest. In: Gordon, J.C.; Wheeler, C.T.; Perry, D.A., eds. Symbiotic nitrogen fixation in the management of temperate forests. Corvallis, OR: Oregon State University: 356-373.
- Miller, R.E.; Obermeyer, E.L. 1996.** Initial and continued effects of a release spray in a coastal Oregon Douglas-fir plantation. Res. Pap. PNW-RP-487. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 11 p.
- Miller, R.E.; Tarrant, R.F. 1983.** Long-term growth response of Douglas-fir to ammonium nitrate fertilizer. *Forest Science*. 29: 127-137.
- Murray, M.D.; Miller, R.E. 1986.** Early survival and growth of planted Douglas-fir with red alder in four mixed regimes. Res. Pap. PNW-RP-366. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 13 p.
- Newton, M.; El-Hassan, B.A.; Zavitkovski, J. 1968.** Role of red alder in western Oregon forest succession. In: Trappe, J.M.; Franklin, J.F.; Tarrant, R.F.; Hansen, G.M., eds. *Biology of alder*. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station: 73-84.
- Newton, Michael; Cole, Elizabeth. 1994.** Stand development and successional implications: pure and mixed stands. In: Hibbs, David E.; DeBell, Dean S.; Tarrant, Robert F., eds. *The biology and management of red alder*. Corvallis, OR: Oregon State University Press: 106-115.
- Peterson, E.B.; Ahrens, G.R.; Peterson, N.M. 1996.** Red alder manager's handbook for British Columbia. FRDA Rep. 240. Victoria BC: B.C. Ministry of Forests. 124 p.
- Ruth, Robert. 1956.** Plantation survival and growth in two brush-treatment areas in coastal Oregon. Res. Pap. 17. Portland, OR: U.S. Department of Agriculture, Forest Service. Pacific Northwest Forest and Range Experiment Station. 14 p.
- SAS Institute, Inc. 1988.** SAS/STAT user's guide. 6.03 ed. Cary, NC.
- Shainsky, L.J.; Yoder, B.J.; Harrington, T.B.; Chan, S.S.N. 1994.** Physiological characteristics of red alder: water relations and photosynthesis. In: Hibbs, David E.; DeBell, Dean S.; Tarrant, Robert F., eds. *The biology and management of red alder*. Corvallis, OR: Oregon State University Press: 73-91.
- Tarrant, R.F.; Miller, R.E. 1963.** Accumulation of organic matter and soil nitrogen beneath a plantation of red alder and Douglas-fir. *Soil Science Society of America Proceedings*. 27: 231-234.
- Wiley, K.N.; Bower, D.R.; Shaw, D.L.; Kovich, D.G. 1978.** Standard cubic-foot volume tables for total and merchantable-stem volumes and tariff access for western hemlock in Oregon and Washington. For. Pap. 18. Centralia, WA: Weyerhaeuser, Western Forest Research Center. 157 p.

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