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In spite of the lack of accurate information about the treatability of western wood species with waterborne wood preservatives, consumption of these products continues to increase. Western wood species, notably Douglas-fir, are notoriously difficult to treat with waterborne systems, yet there is relatively little data on the effects of wood characteristics on treatment. In this study, Douglas-fir grown under various silvicultural regimes and collected through a stand management cooperative, was treated with ammoniacal copper zinc arsenate (ACZA) or chromated copper arsenate (CCA) to determine the effects of wood and stand characteristics on treatability.

Nine geographic locations within the Pacific Coastal region and 3 different silviculture regimes (none, thinned, thinned and fertilized) were studied. Geographic location and prior silvicultural practices were associated with significant effects on treatment of wood from some sites. ACZA or CCA treatability did not significantly differ with position in the tree, but there were significant differences

in CCA or ACZA treatability with juvenile wood percentage. These patterns were not consistent in CCA treatments. These results suggest that some silvicultural practices such as thinning or fertilizing may impact wood characteristics which in turn affect treatability.

THE EFFECTS OF TREE POSITION AND SILVICULTURAL PRACTICES ON TREATABILITY OF DOUGLAS-FIR LUMBER

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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The Effects of Tree Position and Silvicultural Practices on Treatability of Douglas-fir Lumber

1.0. LITERATURE REVIEW

1.1. Introduction

Wood must be protected physically, chemically, or biologically against agents of decay to extend its service life when exposed to adverse conditions. Ideally, the best approach to protection is to keep wood products dry. Secondary protection can be accomplished by use of naturally durable woods, but the limited supply of these species requires the use of less durable species protected with supplemental preservative treatments [Haygreen and Bowyer, 1982]. Many less durable species are moderately or very difficult to treat and have wide variation in treatability. One exception is southern pine, an easily treated wood which is the major species in the southeastern United States.

Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), the predominant species in the western United States, is mainly used for plywood, lumber, poles, and piling [Micklewright, 1990]. Douglas-fir heartwood is difficult to penetrate with fluids, however, and accounts for only about 5 percent of the volume of all treated wood products [Micklewright, 1990].

1.2. Background and Problem

Treatability, as measured by the penetration, retention, and distribution of preservatives in wood, is influenced by wood properties, treating processes, and preservative characteristics [Nicholas, 1973; Hunt and Garratt, 1967]. Among the above factors, wood properties and chemical characteristics represent the most important causes of treatment problems in the wood preserving industry.

Previous studies of the treatability of western species with oilborne preservatives have shown that treatability varies between species and even within a species [Graham, 1954, 1956; Miller and Graham, 1963]. Other studies of the treatability of Douglas-fir with oilborne chemicals noted that heartwood is more difficult to treat than sapwood and that Pacific Coast-type wood grown in low elevation sites is easier to treat than Inter Mountain-type wood from dry interior or high elevation sites [Miller, 1961; Miller and Graham, 1963; Bramhall, 1966].

Studies with waterborne preservatives have produced similar results [Cooper, 1973; Cooper and Ross, 1977; Gjovik, 1983; Kumar and Morrell, 1988, 1989; Mitchoff, 1990]. These results have shown that wood species, geographic source and elevation all affect treatability.

All of the previous treatability studies have examined the relationship between geographic regions or species with only limited concerns about variability of wood within a tree or with the effects of silvicultural practices at the site where the tree was grown.

1.3. Treatability with Waterborne Preservatives

Although treatment studies with waterborne preservatives are similar to those with oilborne preservatives, there are some differences between these systems. Oilborne preservatives do not penetrate cell-wall capillaries, and flow only through tracheids and bordered pit pairs in softwoods. Waterborne preservatives can flow through the cell-wall capillaries as well as tracheids and pit pairs and can fix to the cell wall [Walters and Côté, 1960; Nicholas, 1973].

Waterborne preservatives are characterized by insolubilization mechanisms which occur by reactions between the preservative and the wood. Chromated copper arsenate (CCA) is an acidic formulation containing chromium trioxide (CrO_3), cupric oxide (CuO), and arsenic pentoxide (As_2O_5). Once applied, the copper in these systems binds to the hydroxyl groups (-OH) in the cell wall [Belford et al, 1957]. The chromium helps in the fixation of preservative in the wood and serves as a corrosion inhibitor in the treatment plant. Hexavalent chromium is reduced to trivalent chromium which forms insoluble complexes (for example: $CrAsO_4$, $Cu(OH)AsO_4$ and $Cr_2O_3 \cdot xH_2O$) between copper, arsenic and wood components [Nicholas, 1973].

Ammoniacal copper zinc arsenate (ACZA) is a basic formulation containing cupric oxide (CuO), zinc oxide (ZnO), and arsenic pentoxide (As_2O_5). These chemicals are solubilized using ammonia (NH_3) in water. Once the ammonia evaporates, the copper and zinc form insoluble precipitates with arsenic within the wood [Lebow, 1992]. The nature of these precipitation reactions is poorly understood.

Waterborne preservatives, which include chromated copper arsenate (CCA), ammoniacal copper zinc arsenate (ACZA), acid copper chromated (ACC), and chromated zinc chloride (CZC), now represent about 75 percent of treated wood production in the United States [Micklewright, 1990]. Despite the increasing importance of waterborne chemicals, there is little information about the treatability of western species with waterborne wood preservatives, especially Douglas-fir.

1.4. Wood Characteristics

In general, sapwood is relatively easy to treat with preservatives, whereas heartwood is much more difficult to penetrate. Graham and Miller (1963), however, noted dramatic differences in sapwood permeability with geographic source.

The pits in both sapwood and heartwood aspirate as the wood dries below the fiber saturation point, but pits in sapwood can de-aspirate when the wood is soaked in water as hydrogen bonds between the pit membrane and the border are broken [Thomas and Nicholas, 1966; Thomas and Kringstad, 1971].

During heartwood formation, extractives including resin, gums, and tannins are deposited in heartwood. Extractives may provide natural durability against termites or fungi, but also clog the bordered pits, tracheid lumens, and resin ducts. These blocked pits make it difficult for liquids to penetrate into heartwood.

Cell diameter, cell length, cell-wall thickness, extractive content and wood density all vary with position in the tree. Lengths and diameters of softwood tracheids generally increase from the lower trunk to the base of the crown and then decrease toward the top of the tree. Cell-wall thickness varies with height in the trunk for some softwoods [Panshin and de Zeeuw, 1980]. The levels of most heartwood extractives tend to increase from the pith to the outer heartwood boundary while resin content in softwoods is highest near the pith at the butt of the tree, decreasing outward and upward in the stem. Although density patterns with height in a tree vary with growth factors in some species of softwoods, density in the genus Pseudotsuga generally decreases from the base to the top of the tree [Panshin and de Zeeuw, 1980].

Wood density is designated as the mass per unit volume with both values at the same moisture content [Siau, 1971]. Density, therefore, usually indicates how much liquid the wood can hold in its cell cavities. Retention is normally expressed as weight of preservative per unit volume of wood. Thus, the lower the wood density, the greater the potential preservative retention [Hunt and Garratt, 1967]. Wood density alone, however, is poorly correlated with treatability [Belford and Firth, 1966].

The juvenile wood of conifers (first 5 to 20 rings) has lower specific gravity, shorter tracheids, thinner cell walls and larger lumen diameters than mature wood. Cell lengths and cell-wall thickness in juvenile wood tend to increase from the pith toward the bark [Bendtsen, 1978]. Tracheid length and diameters, specific gravity, portion of latewood and chemical composition all vary with tree age [Erickson and Harrison; Erickson and Arima, 1974]. In spite of the variability of wood characteristics within a tree, wood must be uniformly treated to provide optimum performance.

1.5. Stand Characteristics

Geographical location has obvious influences on environmental conditions under which trees grow, but it may also affect wood characteristics within a species. For example, tori of the bordered pits in the green material of mountain-grown Douglas-fir were not in the center of the pit chambers or were already aspirated [Griffin, 1919]. Several studies have reported that wood or plywood of the same species from different geographic regions differs in wood treatability [Miller, 1961; Miller and Graham, 1963; Cooper and Ross, 1973; Mitchoff, 1990]. A study of environmental effects on specific gravity of the Coast-type Douglas-fir noted the highest specific gravity and the greatest tracheid wall thickness in trees growing on low elevation dry sites [Lassen and Okkonen, 1969]. The lowest specific gravity was noted in trees grown on middle elevation sites. The relationship between specific gravity and elevation might be associated with summer precipitation, moisture capacity on the sites, or more subtle genetic differences.

Geographic locations may have different silviculture treatments and stand densities. Some of silvicultural practices are to accelerate growth and improve wood quality. Silvicultural treatments affect wood density, proportion of heartwood, chemical composition, percent of juvenile wood, latewood percentage and cell lengths and thickness. The paper industry has increased pulp yield and its properties through silvicultural treatments [Parker et al, 1976]. The solid wood industry has also used silvicultural procedures such as fertilization, thinning and spacing to produce higher quality structural lumber products [Bendtsen, 1978; Haygreen and Bowyer, 1982]. Unfortunately, there is little data on the effects of silvicultural practices on treatability. However, faster growth might translate into increasing percentages of more easily treated sapwood, thereby improving treatment. Alternatively, increasing growth rates may lead to thinner cell walls containing more easily aspirated pits, making treatment more difficult.

2.0. JUSTIFICATION

The lack of accurate information about treatability with waterborne preservatives of western species makes it difficult to identify methods for improving treatability.

In this study, the effects of wood and stand characteristics on treatability of Douglas-fir with ammoniacal copper zinc arsenate or chromated copper arsenate was studied using material collected through a stand management cooperative.

3.0. OBJECTIVES

The objective of this study was to learn the effects of stand and wood characteristics on Douglas-fir treatability.

4.0. MATERIALS AND METHODS

4.1. Specimens

One hundred forty two Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) boards (50 x 150 mm) collected through a stand management cooperative (SMC) program from 9 different sites in western Oregon or Washington were examined. Each stand had unequal numbers of sample boards from an unequal number of trees as a result of selection factors for other parts of the study (Table 1).

These stands were established at three different initial densities (100 to 300 stems, 400 to 600 stems and over 1,000 stems per acre). The initial stand density of one site (Pack Forest) was not reported. Stands were thinned, fertilized or left untreated at different ages and various times. After the first silvicultural manipulations, the stand densities were adjusted to 110, 210, 250, or 300 stems per acre in the Larson Plantation, Capitol I, Bellfountain and Capitol II sites, respectively. The stand densities after the first thinning at the remaining sites were not reported (Table 1).

Each stand had different average percentages of juvenile wood (20.7 to 98 %) and average stand ages (25 to 85 years). The juvenile wood percentages were represented as the means of portion of log volume from 0 to 20 rings of a subsample of logs from the stand and may not directly relate to the sample boards examined in the current study. Mean stand ages were

Table 1. Characteristics of 9 different stands in Oregon or Washington from which samples were obtained for treatability trials.

Silvicultural Characteristic	Longview Fib.210	Willamette Industry	Bohemia	Bell-fountain	Larson Plant.	Cap.I	Cap.II	Exp.P1	Pack Forest
Number of Sample Trees	9	10	2	5	6	2	5	4	8
Number of Sample Boards	34	30	6	15	11	5	14	10	17
Average Stand Age (Yrs)	46	39	36	45	25	61	56	85	65
Average % Juvenile Wood	45.2	63.4	63.4	45.7	97.6	30.0	30.0	20.7	26.5
Initial Stand Density (Stems/Acre)	250	500	150	600	1200	1000	100	400	-
Final Stand Density (Stems/Acre)	-	-	-	210	300	250	110	-	-
Thinning Times (Yrs)	32,38	25,36	28	17,22,28 31,38	6	45	-	45, period.[a]	since[b] 20
Fertilization Times (Yrs)	30,40	25,33	-	-	freq.	-	-	-	-
Location(OR/WA)	OR	OR	OR	OR	OR	WA	WA	WA	WA

a. Thinned at age 45 then periodically thereafter
b. Thinned a various times since age 20

measured by counting the growth rings at stump height and again represent a stand average which may vary from the subsample selected for treatment (Table 1). Wood samples came from only 2 different vertical positions in the tree (0 to 4.8, 4.8 to 9.6 m from the butt) and the amount of lumber recovered from each stand was unequal. The sample boards were air-seasoned to about 10 percent moisture content prior to evaluation.

Eight defect-free specimens were cut (50 x 37.5 x 150 mm long) from each sample board and were serially numbered. Four samples were allocated to treatment with chromated copper arsenate, while the remainder were treated with ammoniacal copper zinc arsenate. The specimens were end-coated two times, 24 hours apart with an epoxy resin (Gluvit Epoxy Waterproof Sealer and Gluvit Catalyst, Chelsea, Massachusetts) to minimize end-grain preservative penetration. The coated specimens were cured overnight, then the specimens were re-numbered on the ends to simplify sample identification after treatment.

The coated specimens were equilibrated to constant moisture content in a standard room (65 % RH, 22 °C). Twenty specimens were randomly chosen, and weighed every 3 days until the moisture content stabilized to approximately 10 to 12 percent MC after 14 weeks.

The conditioned specimens were weighed (nearest 0.1 g) in the standard room to obtain pre-treatment wood weight for determining gross preservative retention. Specimens were placed in burlap bags, which were then wrapped in plastic to maintain the moisture content.

4.2. Preservative Treatments

The specimens were treated with 2.22 percent ACZA or 1.8 percent CCA solution (oxide basis) in commercial treating cylinders at JH Baxter and Co. (Eugene, OR) or Cascade Pacific Industries, Inc. (Jasper, OR) using full cell treatment cycles appropriate for Douglas-fir lumber. The specimens were treated to a target retention of 6.4 Kg/m^3 (oxide basis).

In the ACZA treatment, specimens were pre-steamed for 7.42 hours at 116 ^{o}C. A preliminary vacuum (660 mm Hg) was then applied for 1.58 hours to remove air from the wood cells and then the cylinder was filled with ACZA solution at 49 ^{o}C under vacuum. Pressure was raised to 792 kilopascals (Kpa) and held for 6.42 hours. The solution was removed and the specimens were subjected to a 3.58 hour long final vacuum (660 mm Hg).

For the CCA treatment, an initial vacuum (762 mm Hg) was drawn for 15 minutes, then solution was added to the vessel. Pressure was raised to 965 Kpa and held for 5.5 hours. Solution was withdrawn and the specimens were subjected to a 15 minute final vacuum (762 mm Hg).

All specimens for each chemical were treated in a single charge to minimize treatment variations. Each treated specimen was blotted and reweighed to determine gross retention. The specimens were then close-piled for 1 week to allow preservative fixation. Specimens were then air-dried prior to preservative analysis.

4.3. Analysis of Preservative Retention and Penetration

Gross preservative retentions were calculated for each specimen using the following equation [AWPA Standard M11-87]:

$$\text{Retention } (Kg/m^3) = \frac{(T_2-T_1) \text{ X C X } 10}{V}$$

T_1 = Initial weight of specimen before treatment (g)

T_2 = Final weight after treatment (g)

C = Solution concentration (%)

V = Wet volume of block in cubic centimeters

Three 5 mm diameter by 20 mm long cores were removed from the wide face of each specimen. Mean values of 12 cores from the 4 replicates per chemical per board were used for measuring tangential preservative penetration and preservative retention using an ASOMA 8620 X-ray Fluorescence Analyzer (XRF; ASOMA Instruments, Austin, TX).

Copper penetration was assessed by spraying Chrome Azurol S, which turns deep blue in the presence of copper, over split borings [AWPA Standard A3-89]. Average depth (nearest 0.1 mm) of penetration was measured for each specimen on 3 cores from several points randomly chosen on the tangential surface.

After measuring penetration, the sample cores were cut into zones corresponding to 0 to 5 mm, 5 to 10 mm and 10 to 15 mm from the wood surface. The wood from these zones was ground to pass a 30 mesh screen using a Wiley mill and analyzed for chemical content by XRF. Douglas-fir wood densities at 10 percent moisture content for XRF analysis were 440 and 550 Kg/m^3 as determined from two different groups of samples in the stand management cooperative data [Briggs, 1988].

The specimens were then cut perpendicular to the grain to segregate heartwood and sapwood on the basis of a color test [AWPA Standard M2-91, 1992]. A 0.1 percent solution of methyl orange made the freshly cut heartwood surface reddish and the sapwood yellowish. Only the data from heartwood samples were used for a statistical analysis.

4.4. Data Analysis

The personal computer version of SAS software was used for statistical analysis of the data for gross retention, ASOMA retention, and penetration for each sample [Schlotzhauer and Littell, 1991; SAS institute, 1991].

For comparisons of stand characteristics, the data for each board were means of 4 replications and were grouped by

3 stand densities, 3 silviculture treatments or 9 geographic locations to test normality and perform an analysis of variance (ANOVA). The means of each treatment with more than 5 replications were then evaluated using Fisher's Protected Least Significant Difference multiple comparison t-test (FPLSD test) at the 5 percent significance level. Data for comparisons of stand density, silviculture treatment and geographic locations were transformed using logarithmic transformation since the data was usually not normally distributed [Stafford and Sabin, 1993]. For comparisons of log position effects, the data were means of 4 replications and the data of each treatment with various replications were grouped by 6 stand ages, 6 juvenile wood percentages or 2 vertical positions in the tree in intra- or interstands to test normality and perform an analysis of variance (ANOVA). The means from stand ages or juvenile wood percentages were then evaluated using Fisher's Protected Least Significant Difference multiple comparison t-test (FPLSD test) at the 5 percent significance level. The means from vertical tree position were evaluated using the Wilcoxon Rank Sum Test for comparing two independent groups at the 5 percent significance level. Data for comparison of vertical position, stand age and juvenile wood percentage were again transformed using a logarithmic transformation since the data were usually not normally distributed [Stafford and Sabin, 1993].

5.0. RESULTS and DISCUSSION

5.1. Effects of Site on Douglas-fir Treatability

For the purpose of comparing regional differences in ACZA or CCA retention and penetration, the data were combined into those from Oregon and from Washington (Table 2). Samples from stands in Oregon had significantly better ACZA gross retentions and penetrations than those from sites in Washington (retention: $p=0.0001 < \alpha$, penetration: $p=0.0152 < \alpha$). Mean ACZA XRF, CCA gross and XRF retention and CCA penetration for samples from stands in Oregon did not differ significantly from those of stands in Washington (Figure 1).

Wood samples from the Longview, Willamette, Bohemia, Bellfountain and Larson site in Oregon or from the Capitol I,

Table 2. Mean ACZA and CCA retention and penetration of Douglas-fir samples from 5 stands in Oregon or 4 stands in Washington[a].

	Oregon	Washington	p[b]
ACZA			
Gross Retention (Kg/m^3)	7.14(1.78)	5.83(2.02)	0.0001
XRF Retention (Kg/m^3)	4.69(1.80)	4.07(1.35)	0.137
Penetration (mm)	3.36(2.54)	2.24(1.84)	0.0152
CCA			
Gross Retention (Kg/m^3)	2.07(1.27)	1.71(1.09)	0.1782
XRF Retention (Kg/m^3)	5.29(2.58)	4.95(2.36)	0.6353
Penetration (mm)	3.83(2.29)	3.82(2.33)	0.9585

a. Values represent means of 83 sample boards from Oregon and 33 sample boards from Washington. Values in parentheses represent one standard deviation.
b. p-values tested by Wilcoxon Rank Sum test at $\alpha = 0.05$, mean values with $p>0.05$ are not significantly different.

Table 3. Mean ACZA or CCA retention and penetration of Douglas-fir samples from 5 stands in Oregon receiving different silvicultural treatments[a].

Silvicultural Site	Retention (Kg/m^3) Gross	XRF	Penetration (mm)
		ACZA	
Longview	7.16(1.58)ab	4.91(1.90)ab	2.78(2.07)a[b]
Willamette	6.98(1.77)ab	4.67(1.88)ab	4.27(3.16)a
Bohemia	8.11(1.56)a	5.92(1.46)a	4.62(4.24)a
Bellfountain	6.59(1.29)b	3.90(1.64)b	2.60(1.50)a
Larson	7.74(2.67)ab	4.63(1.50)ab	3.05(1.43)a
		CCA	
Longview	2.10(1.48)a	5.81(3.04)ab	3.98(2.80)ab
Willamette	2.00(1.27)a	5.20(2.11)ab	3.76(1.78)ab
Bohemia	2.00(0.50)a	6.87(3.24)a	5.24(2.66)a
Bellfountain	1.91(0.93)a	3.87(1.40)b	2.81(1.31)b
Larson	2.42(1.48)a	5.32(2.79)ab	4.25(2.63)ab

a. Values represent means of all sample boards from a given silvicultural site. Values in parentheses represent one standard deviation.
b. T-group letters tested by Fisher's Least Significant Difference test at $\alpha = 0.05$, mean values with the same letter are not significantly different.

Capitol II, Experimental Plot 1 and Pack Forest site in Washington were compared independently in gross and XRF retentions and penetration (Table 3, 4). In comparisons between samples from Oregon sites (Table 3), mean ACZA gross and XRF retentions of samples from the Bohemia site were significantly higher than those for the Bellfountain site. Mean ACZA gross and XRF retentions for these two sites were not significantly different from those for the other sites. Mean ACZA penetration for the sites in Oregon did not significantly differ. The Bohemia site had the highest retentions and penetration, while the Bellfountain site had the lowest gross or XRF retention and penetration (Figure 2).

Mean CCA gross retentions for the sites in Oregon did not differ significantly. CCA retentions as analyzed by XRF were generally higher than gross retentions. Lower gross retentions might reflect experimental error due to drying prior to weighing after treatment. CCA treated samples were stored under cover for 48 hours after treatment as part of a routine plant practice and some drying might have occurred over this period. Mean CCA XRF retention and penetration for the Bohemia site were significantly higher than those for the Bellfountain site. Wood samples from these sites did not differ significantly from those for the other sites. As with ACZA, the highest XRF retention and penetration values were found at the Bohemia site while the lowest values were from the Bellfountain site (Figure 3).

In wood samples from Washington (Table 4), mean ACZA gross retention of samples from the Capitol II site was significantly better than those for the other sites. Wood samples for the Capitol II site had better mean ACZA XRF retention than those for the Capitol I and Pack Forest sites. Samples from the Capitol II did not differ significantly from the Experimental Plot 1 in mean ACZA XRF retention. There were no significant differences in mean ACZA penetration among samples from the sites in Washington. The Capitol II site had the highest values for mean ACZA gross and XRF retentions and penetration, while those from the Capitol I site were the lowest (Figure 4). Among mean CCA gross retentions for the sites in Washington, the Capitol II

Table 4. Mean ACZA or CCA retention and penetration of Douglas-fir samples from 4 stands in Washington receiving different silvicultural treatments[a].

Silvicultural Site	Retention (Kg/m^3) Gross	XRF	Penetration (mm)
	ACZA		
Capitol II	7.58(2.27)a	5.07(1.16)a	2.93(2.00)a[b]
Capitol I	4.41(0.68)b	2.83(0.13)b	1.06(0.76)a
Experimental	5.17(1.50)b	3.83(1.24)ab	2.57(1.68)a
Pack Forest	4.92(0.94)b	3.55(1.24)b	1.55(1.80)a
	CCA		
Capitol II	2.62(1.11)a	6.20(2.65)a	5.05(2.53)a
Capitol I	0.66(0.66)c	4.64(2.65)ab	4.27(1.74)ab
Experimental	1.46(0.79)b	5.06(2.11)ab	4.12(2.04)ab
Pack Forest	1.26(0.72)bc	3.58(1.56)b	2.04(1.48)b

a. Values represent means of all sample boards from a given silvicultural site. Values in parentheses represent one standard deviation.
b. T-group letters tested by Fisher's Least Significant Difference test at $\alpha = 0.05$, mean values with the same letter are not significantly different.

was significantly better than the other sites. Samples from the Experimental Plot 1 site were significantly better treated than those from the Capitol I site, but did not differ significantly from the Pack Forest site. Mean CCA XRF retention and penetration of samples from the Capitol II site were significantly better than those for the Pack Forest site, but these results did not differ significantly from those for the other sites (Figure 5).

Mean ACZA gross retentions of wood samples from the Longview, Willamette, Bohemia, Bellfountain, Larson and Capitol II sites were all at levels above the target retention (6.4 Kg/m^3) while those from the other three silvicultural sites were far below this level (Table 5). The

Table 5. Mean ACZA or CCA retention and penetration of Douglas-fir samples from 9 stands receiving different silvicultural treatments[a].

Silvicultural Site	Wood Density (Kg/m^3)	Retention (Kg/m^3) Gross	XRF	Penetration (mm)
		ACZA		
Longview	500.20(43.95)	7.16(1.58)a	4.91(1.90)abc	2.78(2.07)ab[b]
Willamette	484.23(44.12)	6.98(1.77)a	4.67(1.88)abc	4.27(3.16)a
Bohemia	508.64(30.45)	8.11(1.56)a	5.92(1.46)a	4.62(4.24)a
Bellfountain	454.75(16.32)	6.59(1.29)a	3.90(1.64)bcd	2.60(1.50)ab
Larson	479.73(27.55)	7.74(2.67)a	4.63(1.50)abc	3.05(1.43)a
Capitol II	534.38(53.25)	7.58(2.27)a	5.07(1.16)ab	2.93(2.00)a
Capitol I	493.72(50.22)	4.41(0.68)b	2.83(0.13)d	1.06(0.76)c
Experimental	529.75(65.21)	5.17(1.50)b	3.83(1.24)bcd	2.57(1.68)ab
Pack Forest	533.57(43.65)	4.92(0.94)b	3.55(1.24)cd	1.55(1.80)bc
		CCA		
Longview	499.57(37.83)	2.10(1.48)ab	5.81(3.04)abc	3.98(2.80)a[b]
Willamette	482.78(44.31)	2.00(1.27)ab	5.20(2.11)abc	3.76(1.78)a
Bohemia	511.56(27.50)	2.00(0.50)ab	6.87(3.24)a	5.24(2.66)a
Bellfountain	460.71(26.22)	1.91(0.93)ab	3.87(1.40)bc	2.81(1.31)ab
Larson	482.39(32.40)	2.42(1.48)ab	5.32(2.79)abc	4.25(2.63)a
Capitol II	532.64(51.58)	2.62(1.11)a	6.20(2.65)ab	5.05(2.53)a
Capitol I	502.82(47.26)	0.66(0.66)c	4.64(2.65)abc	4.27(1.74)a
Experimental	519.30(62.71)	1.46(0.79)abc	5.06(2.11)abc	4.12(2.04)a
Pack Forest	536.01(56.05)	1.26(0.72)bc	3.58(1.56)c	2.04(1.48)b

a. Values represent means of all sample boards from a given silvicultural site. Values in parentheses represent one standard deviation.
b. T-group letters tested by Fisher's Least Significant Difference test at $\alpha = 0.05$, mean values with the same letter are not significantly different.

Bohemia site had the highest retention, while the Capitol I had the lowest. Samples from the Bohemia site had significantly better average ACZA XRF retention than those from the Capitol I site. Mean ACZA XRF retention for the Bohemia site did not significantly differ from those from the Longview, Willamette, Larson or Capitol II sites. Mean ACZA XRF retention for the Capitol I site did not differ significantly from the Bellfountain, Experimental Plot 1 or Pack Forest sites. Mean ACZA penetration was highest in samples from the Bohemia site, but these levels were only significant in comparison with those from the Capitol I and Pack Forest sites. The Capitol I site had the lowest ACZA penetration but this level did not differ significantly from that of the Pack Forest site. ACZA treated samples tended to be differentiated into two or three groups based upon gross or XRF retention and penetration, but these groupings were not consistent among the 3 variables.

Gross retentions from sample blocks treated with ACZA were higher than XRF retentions, but both measures showed similar trends (Figure 6). Gross retention values often exceed those measured chemically. This difference may reflect sampling variation or screening of biocide near the wood surface [Kumar and Morrell, 1990]. ACZA treated samples from the Bohemia site had the highest gross and XRF retentions, while those from the Capitol I site had the lowest values. Preservative penetration in samples treated with ACZA followed trends which were similar to those noted with retention. Mean ACZA gross and XRF retentions and penetration values indicated that samples from the Bohemia site were among the most easily treated specimens with ACZA and samples from the Capitol I were among the most difficult to treat. Any strong linear relationship between wood density and treatability was absent in sample boards treated with ACZA ($-0.06 \leq r \leq 0.16$). Mean CCA gross retention was highest in samples from the Capitol II site and lowest in those from the Capitol I site (Table 5). Samples from the Capitol II site were not significantly different from those for the other sites except for the Capitol I and Pack Forest sites. Gross retentions from the Capitol I site did not differ significantly from the Experimental Plot 1 or Pack Forest sites. Samples from the Bohemia site had significantly better average XRF retention than those from the Pack Forest and Bellfountain sites, but these values did not significantly differ from those from the other sites. Mean CCA penetration had similar trends with those found with XRF retention (Figure 7). Like ACZA treatment, mean CCA XRF retention and penetration measurements indicated that samples from the Bohemia site were among the most easily treated specimens, while those in samples from the Pack Forest were the most difficult to treat with CCA. The correlation coefficients ($0.08 \leq r \leq 0.23$) suggested the absence of any strong linear relationship between wood density and CCA treatability.

Previous studies of treatability of western species with oil-borne preservatives [Graham, 1954, 1956; Miller, 1961; Miller and Graham, 1963; Bramhall, 1966] or water-borne preservatives [Cooper, 1973; Cooper and Ross, 1977; Kumar and Morrell, 1988, 1989; Mitchoff, 1990] noted that geographic source affects treatability. Wood from the west side of the Cascades is generally easier to treat than Intermountain-type wood, but these studies did not examine the effects of stand management conditions on treatability.

The present study indicates that ACZA or CCA treatability also varies widely within the Pacific Coastal region. The stands from which samples were obtained had different stand ages, juvenile wood percentages, initial stand densities, thinning times and fertilization times (Table 1). Although it is unclear which variables affected treatability, there is considerable potential for these factors to influence wood properties which may subsequently affect treatability. These results suggest that previous studies showing geographic influences on treatability may be confounded by the effect of forest management conditions in the stands where the test trees were grown.

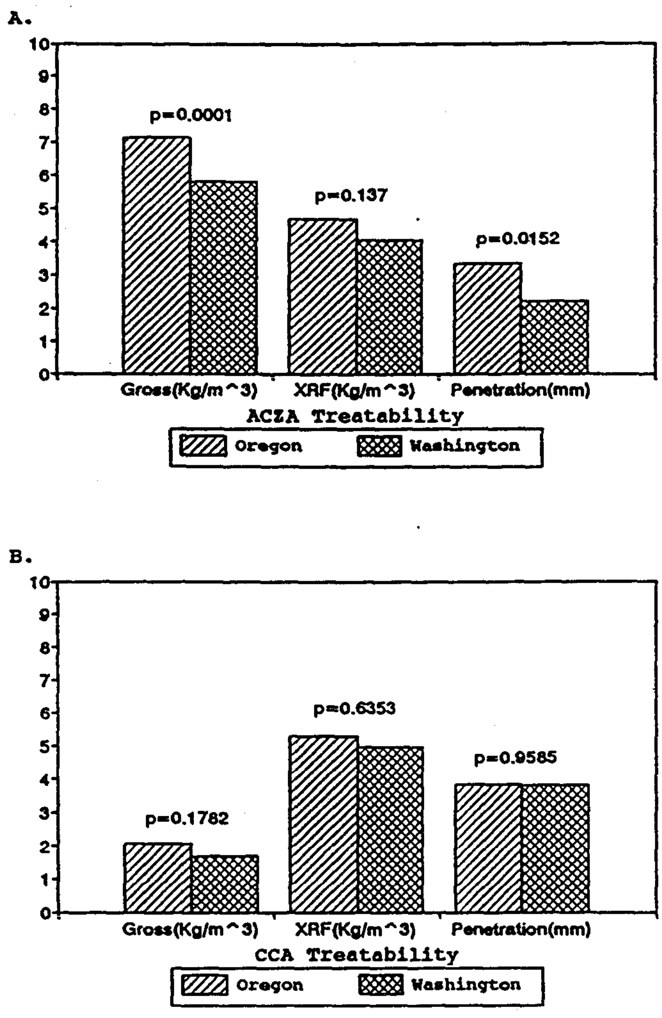


Figure 1. ACZA (A) or CCA (B) treatability of Douglas-fir lumber from 5 stand sites in Oregon or 4 stand sites in Washington. Bars with $p>0.05$ are not significantly different by Wilcoxon Ranked Sum Test at $\alpha = 0.05$.

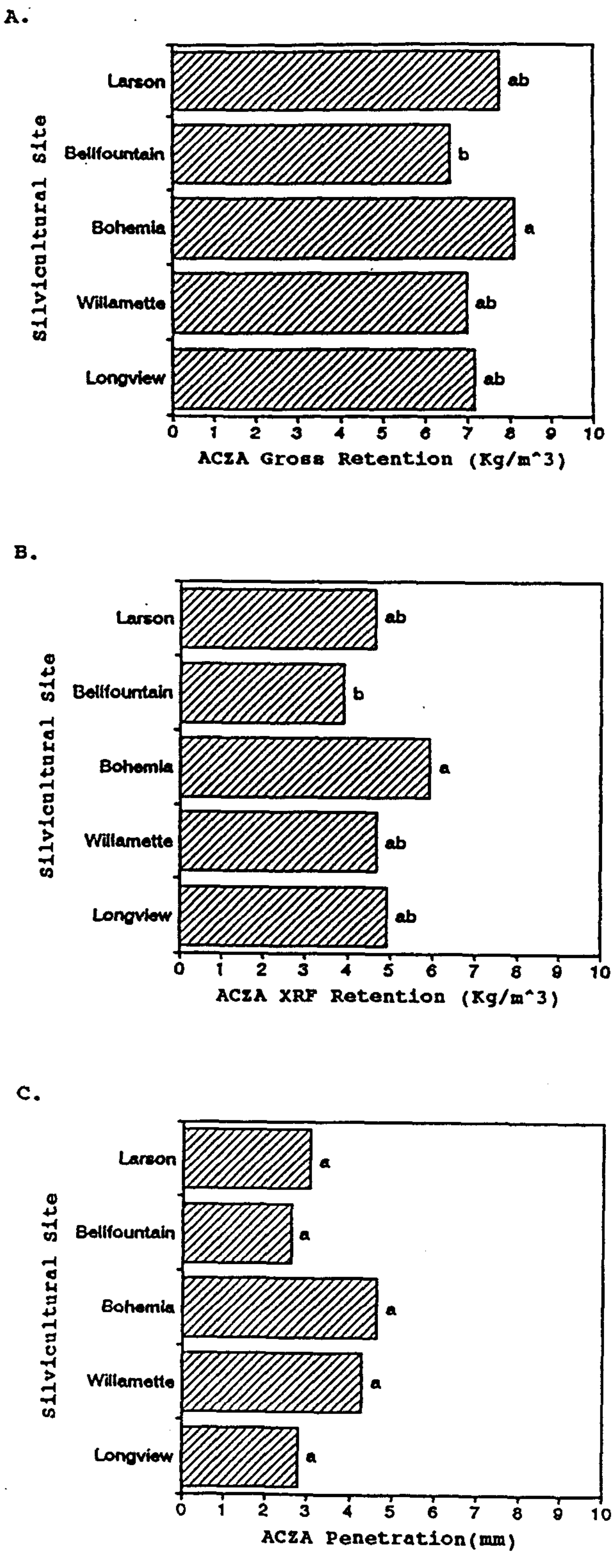


Figure 2. ACZA treatability of Douglas-fir samples from 5 stands in Oregon with different silvicultural manipulations as measured by A) gross retention, B) chemical assay retention or C) preservative penetration. Bars with the same letter(s) are not significantly different by Fisher's Least Significant Difference Test at $\alpha = 0.05$.

A.

B.

C.

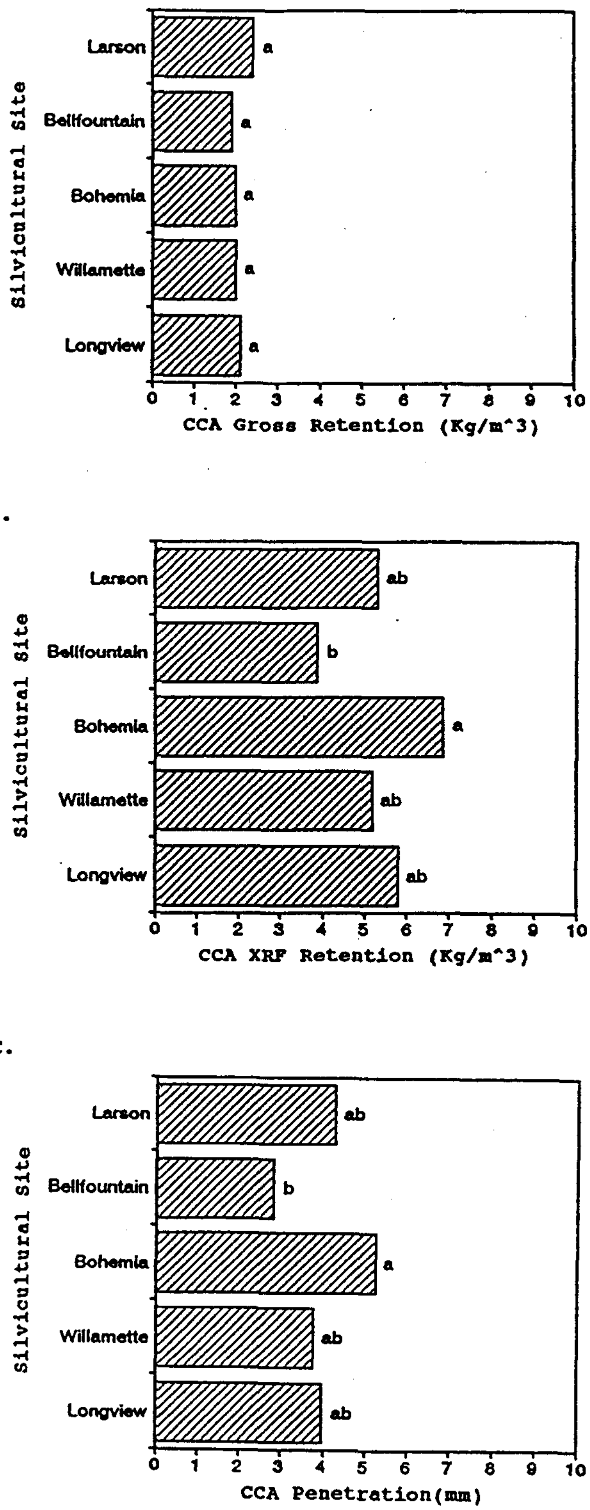
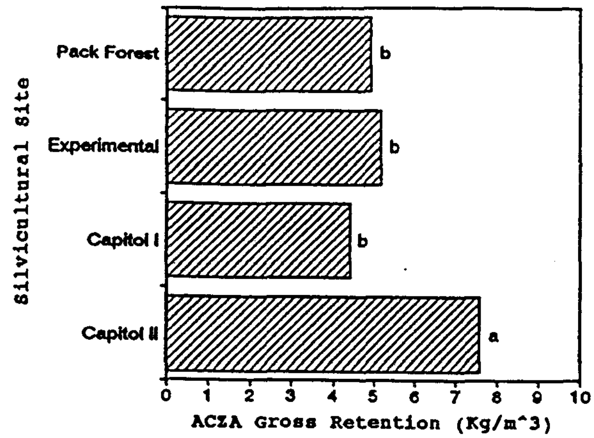
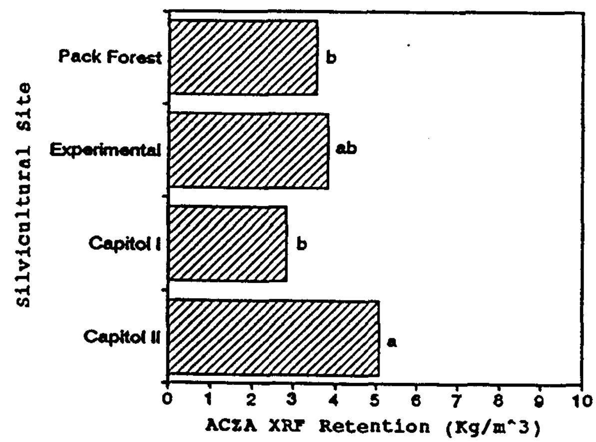


Figure 3. CCA treatability of Douglas-fir samples from 5 stands in Oregon with different silvicultural manipulations as measured by A) gross retention, B) chemical assay retention or C) preservative penetration. Bars with the same letter(s) are not significantly different by Fisher's Least Significant Difference Test at $\alpha = 0.05$.

A.



B.



C.

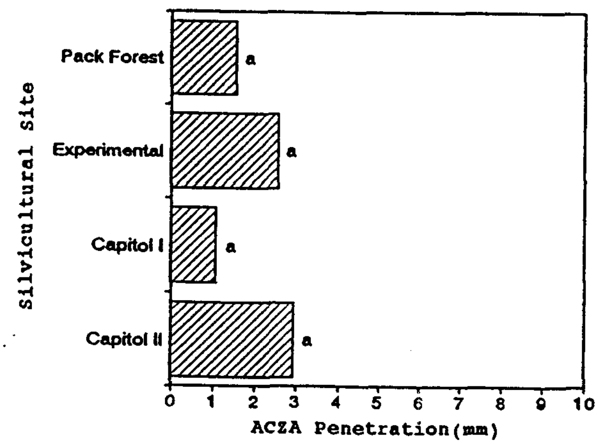


Figure 4. ACZA treatability of Douglas-fir samples from 4 stands in Washington with different silvicultural manipulations as measured by A) gross retention, B) chemical assay retention or C) preservative penetration. Bars with the same letter(s) are not significantly different by Fisher's Least Significant Difference Test at $\alpha = 0.05$.

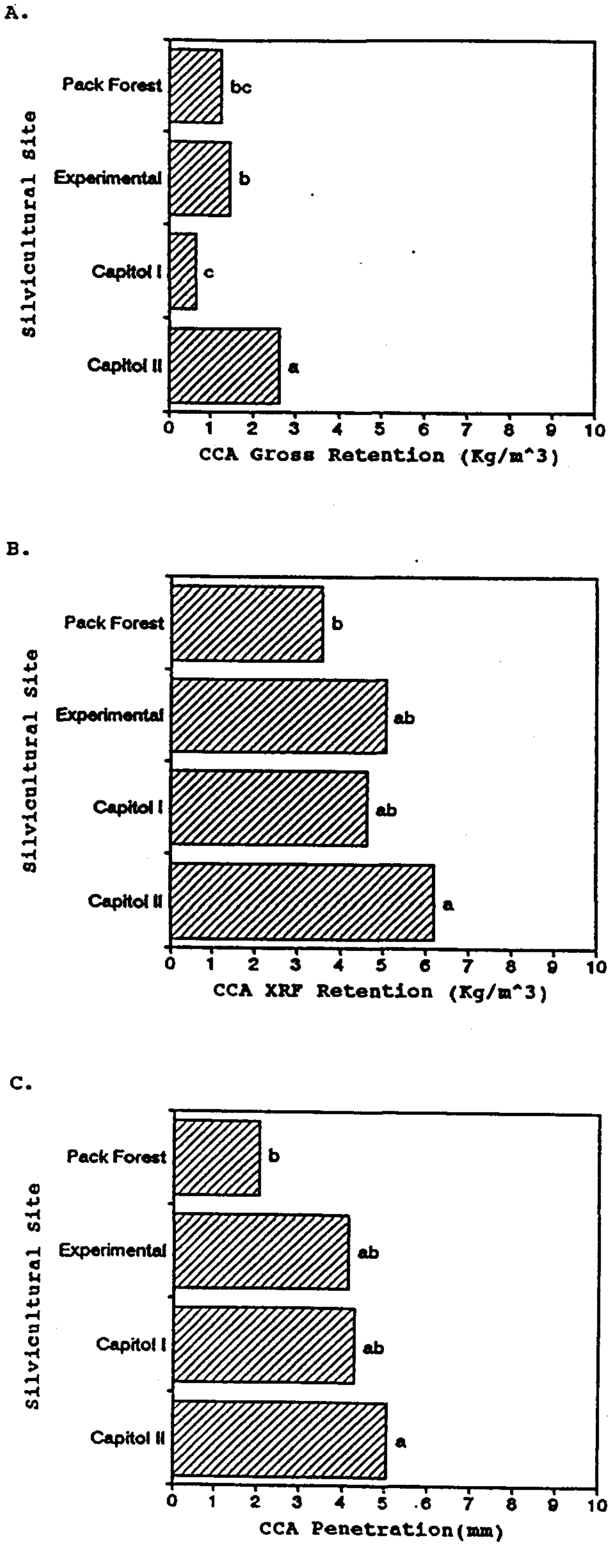


Figure 5. CCA treatability of Douglas-fir samples from 4 stands in Washington with different silvicultural manipulations as measured by A) gross retention, B) chemical assay retention or C) preservative penetration. Bars with the same letter(s) are not significantly different by Fisher's Least Significant Difference Test at $\alpha = 0.05$.

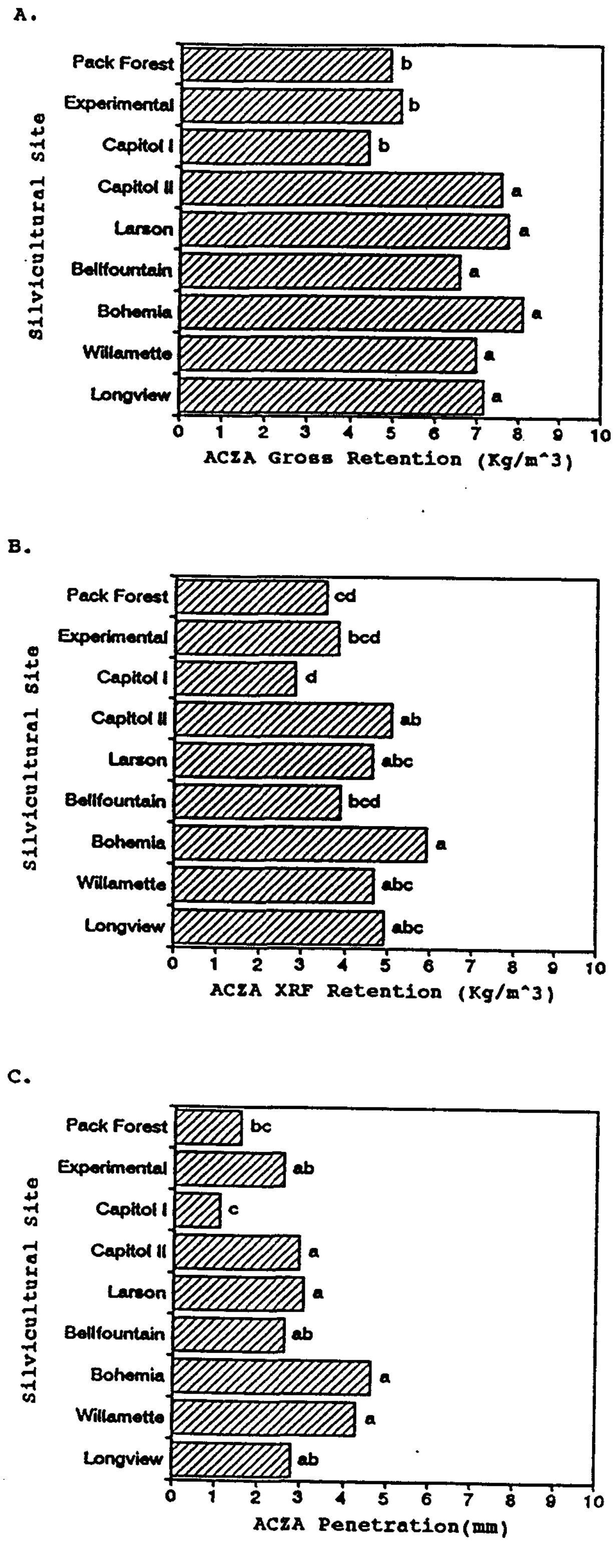


Figure 6. ACZA treatability of Douglas-fir samples from 9 stands with different silvicultural manipulations as measured by A) gross retention, B) chemical assay retention or C) preservative penetration. Bars with the same letter(s) are not significantly different by Fisher's Least Significant Difference Test at $\alpha = 0.05$.

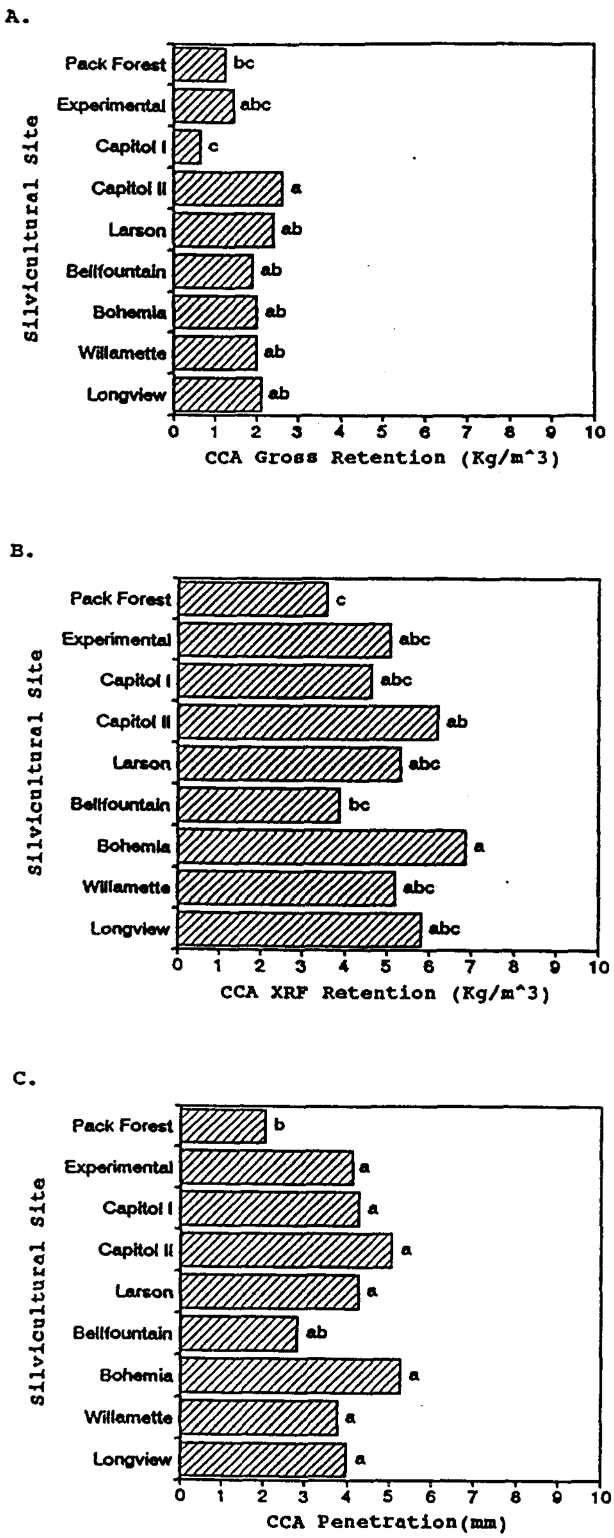


Figure 7. CCA treatability of Douglas-fir samples from 9 stands with different silvicultural manipulations as measured by A) gross retention, B) chemical assay retention or C) preservative penetration. Bars with the same letter(s) are not significantly different by Fisher's Least Significant Difference Test at $\alpha = 0.05$.

5.2. Effects of Silviculture Practices on Treatability

For comparative purposes, ACZA or CCA retentions and penetrations were combined into 3 different categories of stand management; natural, thinned only and thinned-and-fertilized (Table 6). Only the capitol II site was not manipulated. The Bohemia, Bellfountain, Capitol I, Experimental Plot 1 and Pack Forest site were thinned at various ages and times. The Longview, Willamette and Larson site were thinned and fertilized at different times and ages. The types and rates of fertilizer employed at each site were not reported.

The differing stand locations and configurations make it difficult to make definitive statements concerning the effects of various silvicultural practices on treatment; however, they can provide useful clues for future studies of this nature. Among 5 stands in Oregon, ACZA or CCA gross and XRF retentions and penetration from 3 thinned-and-fertilized stands were not significantly different from those from 2 thinned stands (Table 6; Figure 8). However, among 4 stands in Washington, 3 thinned stands had significantly lower ACZA gross and XRF retentions and CCA gross retention than those for samples from the natural stand (Table 6; Figure 9).

Gross ACZA retentions of samples from the natural and thinned-and-fertilized stands did not differ significantly from one another but had significantly better values than those from the thinned stands. XRF retentions also

Table 6. Mean ACZA and CCA retention and penetration of Douglas-fir samples from 5 stands in Oregon or 4 stands in Washington receiving 3 different silvicultural manipulations[a].

		Silvicultural Treatment		p^b
Oregon		Thinned/Fertilized	Thinned	
ACZA	Gross Retention (Kg/m^3)	7.18(1.86)	6.99(1.49)	0.9438
	XRF Retention (Kg/m^3)	4.76(1.81)	4.43(1.80)	0.6066
	Penetration (mm)	3.43(2.56)	3.13(2.54)	0.4446
CCA	Gross Retention (Kg/m^3)	2.12(1.38)	1.94(0.83)	0.9008
	XRF Retention (Kg/m^3)	5.48(2.63)	4.66(2.36)	0.1686
	Penetration (mm)	3.94(2.37)	3.45(2.01)	0.3947
Washington		None	Thinned	
ACZA	Gross Retention (Kg/m^3)	7.58(2.27)	4.95(1.16)	0.0005
	XRF Retention (Kg/m^3)	5.07(1.16)	3.57(1.17)	0.0039
	Penetration (mm)	2.93(2.00)	1.90(1.69)	0.0964
CCA	Gross Retention (Kg/m^3)	2.62(1.11)	1.26(0.75)	0.0012
	XRF Retention (Kg/m^3)	6.20(2.65)	4.33(1.98)	0.0640
	Penetration (mm)	5.05(2.53)	3.20(2.00)	0.0513

a. Values represent means of all sample boards from 5 stands in Oregon or 4 stands in Washington receiving a given silvicultural treatment. Values in parentheses represent one standard deviation.
b. p-values tested by Wilcoxon Rank Sum Test at $\alpha = 0.05$, mean values with $p>0.05$ are not significantly different.

Table 7. Mean ACZA or CCA retention and penetration of Douglas-fir samples from stands receiving 3 different silvicultural manipulations.[a]

Silviculture Treatment	Retention (Kg/m^3) Gross	XRF	Penetration (mm)
		ACZA	
None	7.58(2.27)a	5.07(1.16)a	2.93(2.00)a[b]
Thinned	5.90(1.66)b	3.96(1.54)b	2.47(2.19)a
Thinned/Fertilized	7.17(1.86)a	4.76(1.81)ab	3.43(2.56)a
		CCA	
None	2.62(1.11)a	6.20(2.65)a	5.05(2.53)a
Thinned	1.57(0.85)b	4.48(2.15)b	3.31(1.98)b
Thinned/Fertilized	2.11(1.36)ab	5.48(2.63)ab	3.94(2.37)ab

a. Values represent means of all sample boards receiving a given silvicultural treatment. Values in parentheses represent one standard deviation.
b. Mean values with the same letter are not significantly different using Fisher's LSD test at $\alpha = 0.05$.

significantly differed between thinned and natural stands, but samples from these two stands did not differ from those from the thinned-and-fertilized stands. ACZA penetration did not significantly differ among the 3 stand management regimes (Table 7, Figure 10).

Samples from the natural stand had significantly better gross CCA retention, XRF retention and penetration than those from the thinned stands, but did not significantly differ from the thinned-and-fertilized stands. Wood from the natural stand appeared to be the most treatable followed by the thinned-and-fertilized stands and finally the thinned stands (Table 7, Figure 11).

In general, ACZA or CCA treatment results followed similar trends among the three silvicultural treatments, although CCA treated samples had higher XRF retentions and penetration depths than those of ACZA treated samples. These results are interesting since ACZA is generally associated with better treatment of Douglas-fir heartwood.

Previous studies about Douglas-fir wood quality have shown that some silvicultural manipulations, such as fertilization or thinning, influence on lower wood density, lower latewood percentages and decrease tracheid length and tangential tracheid diameter. These changes are greatest in the fertilized-and-thinned stand followed by the fertilized, thinned and non-manipulated control stands. Latewood percentage decreased significantly from 40 percent to 29 percent after thinning and fertilization. This manipulation also caused a decrease of 16 percent (from 0.523 to 0.438) in specific gravity [Erickson and Lambert, 1958]. Thinning and fertilization produced lower density wood with lower latewood percentage, slightly decreased tangential tracheid diameter and length after 9 year growth periods [Erickson and Harrison, 1974]. The lower the wood density, the greater the potential preservative retention. Wood density, however, is poorly correlated with treatability because it is impossible to completely fill all available void volume owing to variations of tracheid pits and resin canals in softwoods. Relatively dense latewood is generally easier to treat owing to the decreased susceptibility of pits in this zone [Hunt and Garratt, 1967; Nicholas, 1973]. Thus, silviculture practices which increase latewood percentages should result in treatability improvements.

The results of these comparisons should be viewed with caution since they are hampered by the lack of comparability of the various sites.

5.3. Effects of Initial Stand Density on Treatability

ACZA or CCA gross retention, XRF retention and

Table 8. Mean ACZA or CCA retentions and penetrations of Douglas-fir samples from 5 sites in Oregon or 3 sites in Washington with 3 different initial stand densities[a].

Initial Stand Density[b]	Retention(Kg/m^3) Gross	XRF	Penetration (mm)
Oregon	ACZA		
High	7.74(2.67)a	4.63(1.50)a	3.05(1.43)a[c]
Moderate	6.84(1.61)a	4.40(1.82)a	3.69(2.79)a
Low	7.31(1.59)a	5.07(1.85)a	3.07(2.53)a
	CCA		
High	2.42(1.48)a	5.32(2.79)a	4.25(2.63)a
Moderate	1.97(1.15)a	4.73(1.98)a	3.43(1.68)a
Low	2.09(1.36)a	5.98(3.04)a	4.18(2.78)a
Washington	ACZA		
High	4.41(0.68)b	2.83(0.13)b	1.07(0.76)a
Moderate	5.17(1.50)b	3.83(1.24)ab	2.57(1.68)a
Low	7.58(2.27)a	5.07(1.16)a	2.93(2.00)a
	CCA		
High	0.66(0.66)b	4.64(1.16)b	4.27(2.00)a
Moderate	1.46(0.79)ab	5.06(2.11)ab	4.12(2.04)a
Low	2.62(1.11)a	6.20(2.65)a	5.05(2.53)a

a. Values represent means of all sample boards from 5 sites in Oregon or 3 sites in Washington with a given initial stand density. Values in parentheses represent one standard deviation.
b. Where the low density stand has 100-300 stems per acre, the moderate density stand has 400-600 stems per acre, and the high density stand has over 1,000 stems per acre.
c. Mean values with the same letter are not significantly different using Fisher's LSD test at $\alpha = 0.05$.

penetration of samples from 5 stands in Oregon or 3 stands in Washington were combined into 3 initial stand densities; 100 to 300, 400 to 600 and over 1,000 stems per acre (Table 8). The initial stand density of the Pack Forest site was not reported and the data from the site was excluded in the statistical analysis (Table 1). In Oregon, stands with the high, moderate and low initial stand densities did not differ significantly in ACZA retention or penetration(Table 8; Figure 12). In Washington, however, ACZA and CCA gross retention and XRF retention of samples from the low initial stand density site were significantly better than those from the high initial stand density. ACZA or CCA retentions for samples from the moderate initial stand densities did not

Table 9. Mean ACZA or CCA retentions and penetrations of Douglas-fir samples from sites with 3 different initial stand densities[a].

Initial Stand Density[b]	Retention(Kg/m^3) Gross	Retention(Kg/m^3) XRF	Penetration (mm)
	ACZA		
High	7.03(2.75)a	4.25(1.52)a	2.63(1.54)a[c]
Moderate	6.54(1.71)a	4.29(1.73)a	3.48(2.65)a
Low	7.38(1.77)a	5.07(1.69)a	3.03(2.38)a
	CCA		
High	2.04(1.52)a	5.18(2.68)a	4.26(2.40)a
Moderate	1.87(1.10)a	4.79(1.99)a	3.55(1.75)a
Low	2.22(1.31)a	6.03(2.92)a	4.40(2.72)a

a. Values represent means of all sample boards from sites with a given initial stand density. Values in parentheses represent one standard deviation.
b. Where the low density stand has 100-300 stems per acre, the moderate density stand has 400-600 stems per acre, and the high density stand has over 1,000 stems per acre.
c. Mean values with the same letter are not significantly different using Fisher's LSD test at $\alpha = 0.05$.

differ significantly from those for the low or high initial stand densities. Penetrations of ACZA or CCA treated samples did not differ significantly among stands with the three initial densities (Table 8; Figure 13).

Comparisons of 8 sites with different initial stand densities in Oregon and Washington showed no significant differences in ACZA or CCA retentions and penetration between the 3 initial stand density levels (Table 9; Figure 14, 15).

Although there were minimal effects of stand density on Douglas-fir treatability in the current study, a previous study suggests that initial planting density affected the diameter of juvenile wood showing that the site with the initial low stand density produced larger juvenile wood core than the initial high stand density during the same period [Clark and Saucier, 1989]. Juvenile wood usually has lower specific gravity, lower latewood percentages, thinner cell walls, larger lumen diameters, and lower cellulose and higher lignin contents than mature softwoods. Some of these characteristics can affect treatability improvements [Hunt and Garratt, 1967; Bendtsen, 1978].

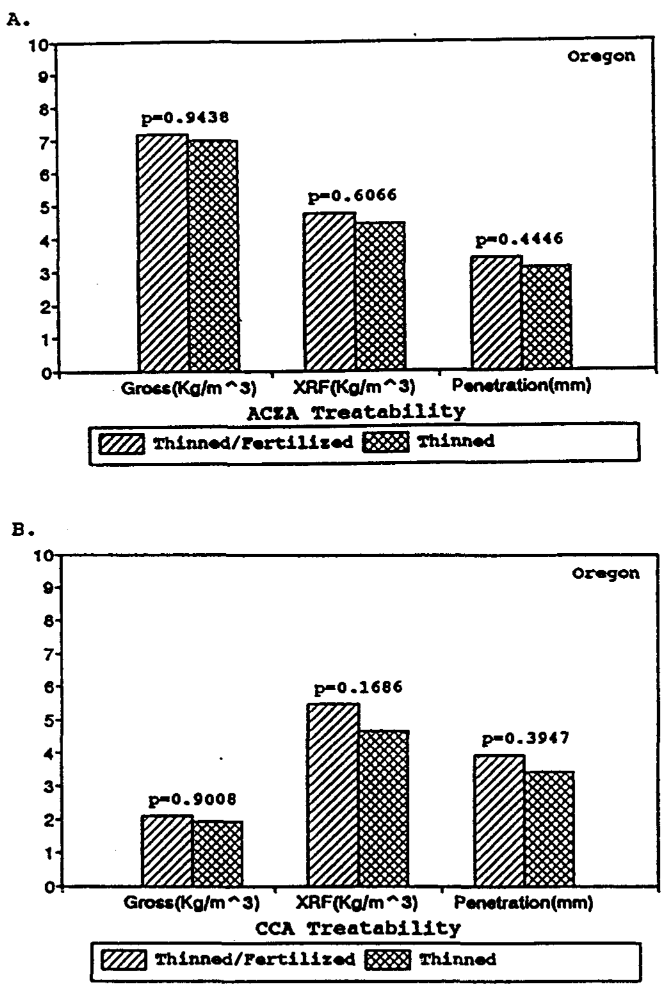


Figure 8. ACZA (A) or CCA (B) treatability of Douglas-fir lumber from 5 sites in Oregon receiving 2 different silvicultural manipulations. Bars with $p>0.05$ are not significantly different by Wilcoxon Ranked Sum Test at $\alpha = 0.05$.

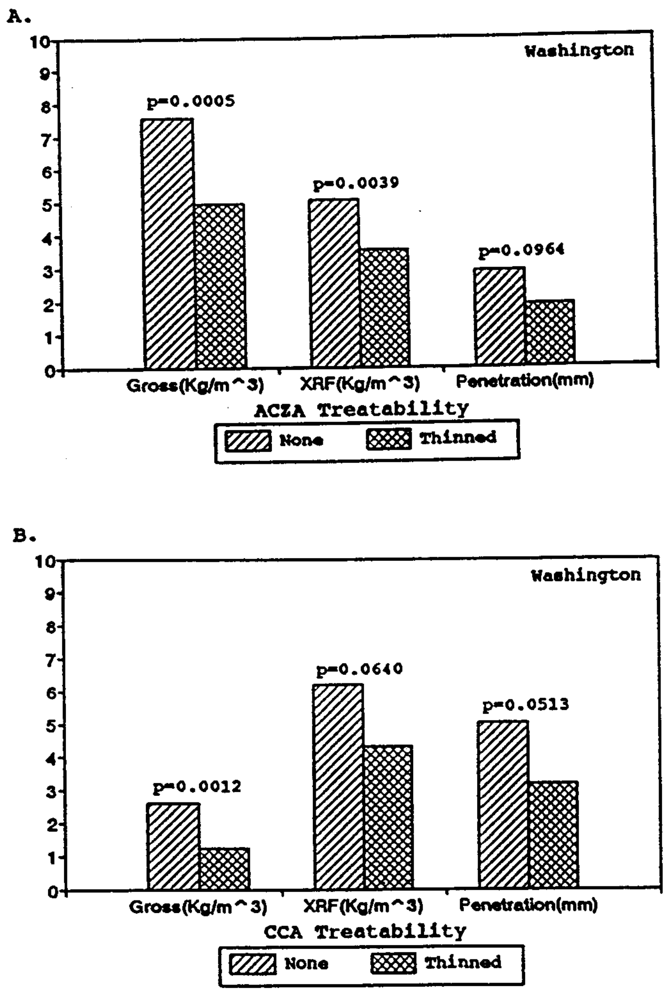


Figure 9. ACZA (A) or CCA (B) treatability of Douglas-fir lumber from 4 sites in Washington receiving 2 different silvicultural manipulations. Bars with $p>0.05$ are not significantly different by Wilcoxon Ranked Sum Test at $\alpha = 0.05$.

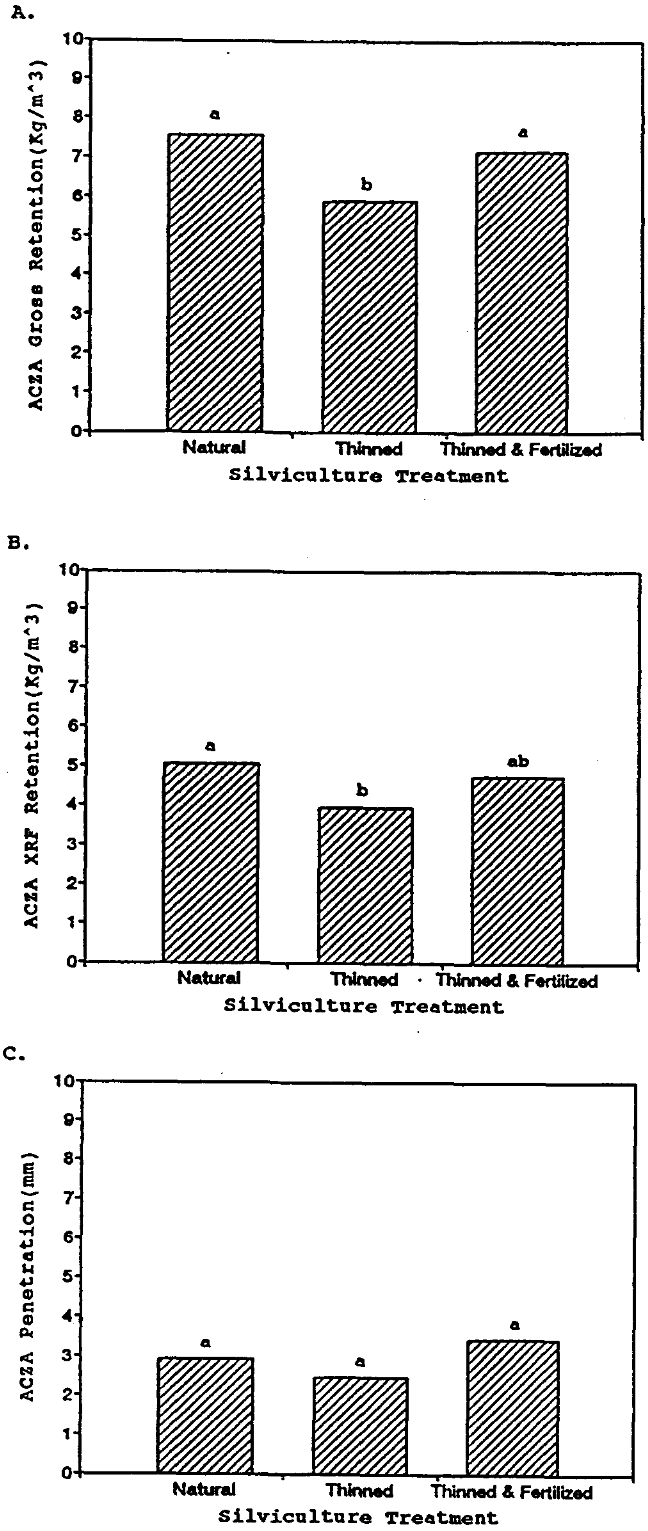


Figure 10. ACZA treatability of Douglas-fir samples from stands receiving 3 different silvicultural manipulations as measured by A) gross retention B) chemical assay retention or C) preservative penetration. Bars with the same letter(s) are not significant different by Fisher's Least Significant Difference Test at $\alpha = 0.05$.

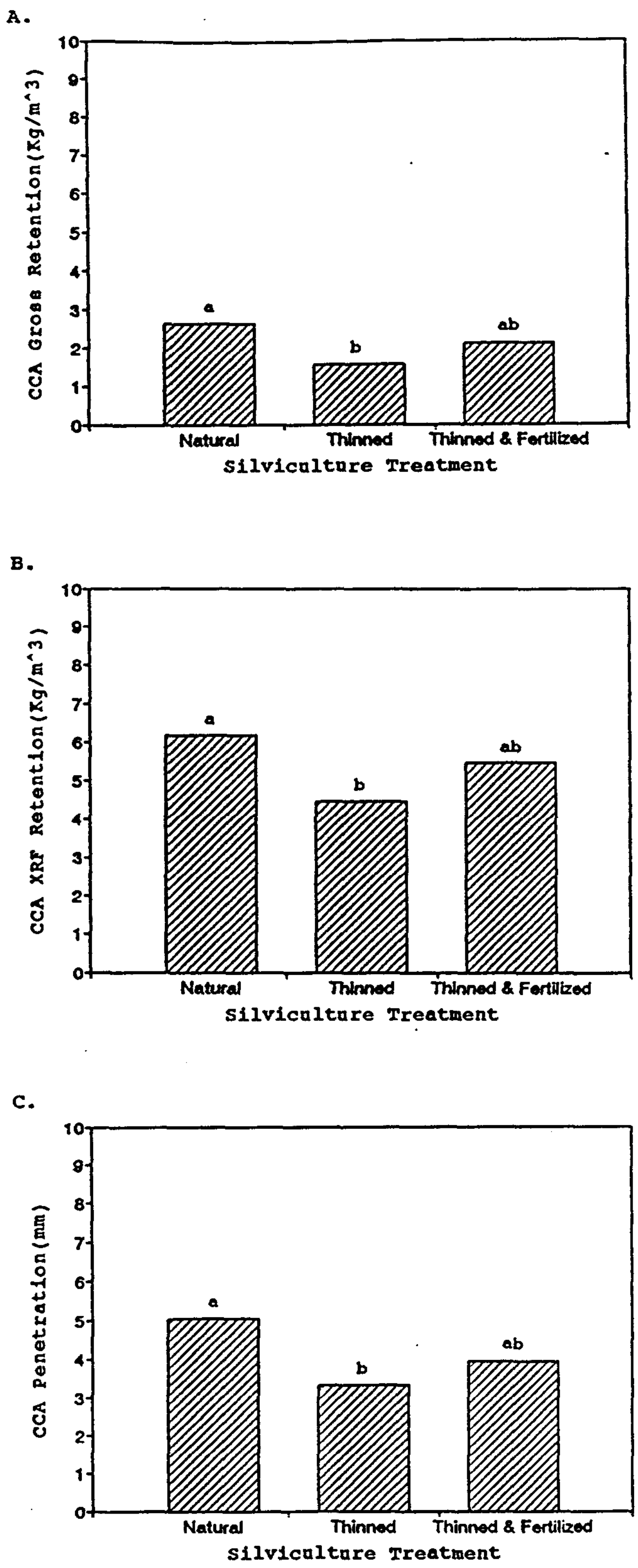
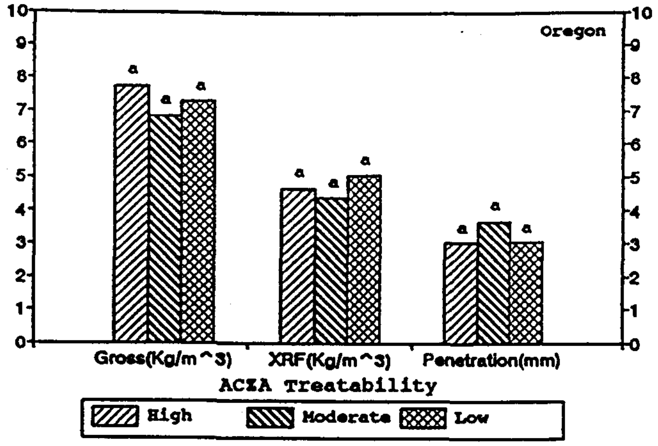


Figure 11. CCA treatability of Douglas-fir samples from stands receiving 3 different silvicultural manipulations as measured by A) gross retention B) chemical assay retention or C) preservative penetration. Bars with the same letter(s) are not significant different by Fisher's Least Significant Difference Test at $\alpha = 0.05$.

A.



B.

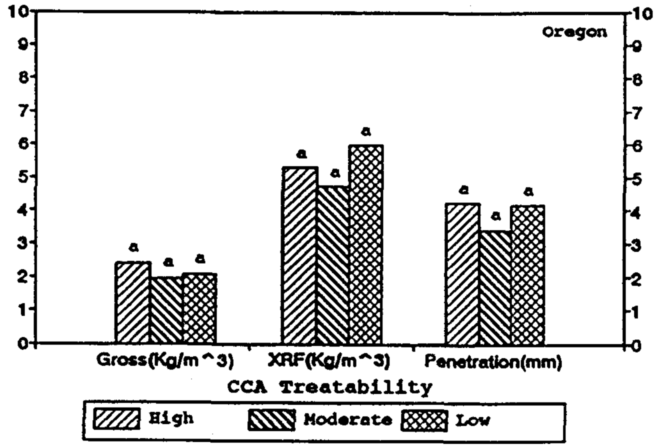


Figure 12. ACZA (A) or CCA (B) treatability of Douglas-fir lumber samples from 5 sites in Oregon with 3 different initial stand densities. Bars with the same letter are not significantly different using Fisher's LSD test at $\alpha = 0.05$.

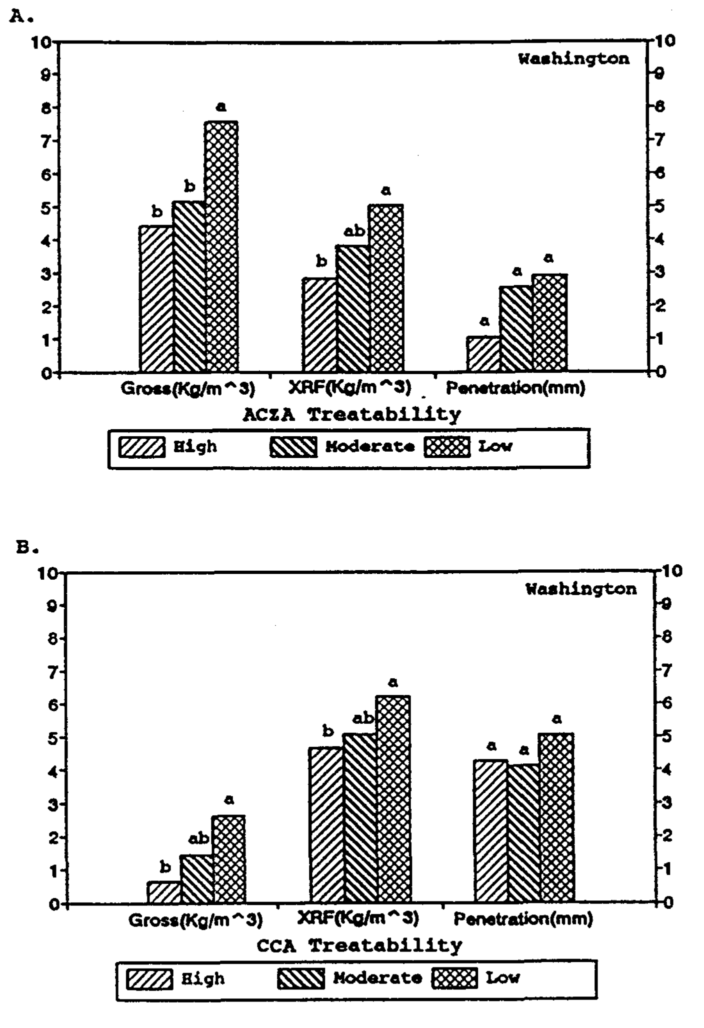


Figure 13. ACZA (A) or CCA (B) treatability of Douglas-fir lumber samples from 3 sites in Washington with 3 different initial stand densities. Bars with the same letter are not significantly different using Fisher's LSD test at $\alpha = 0.05$.

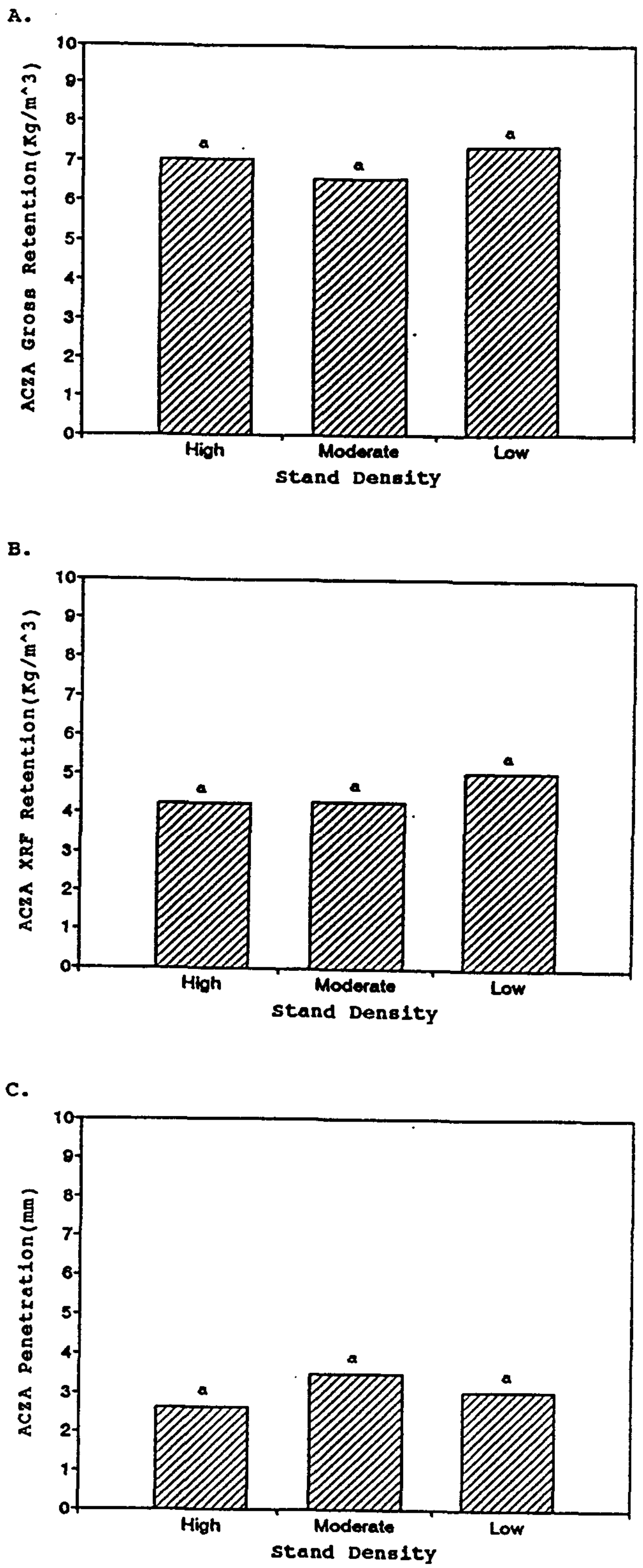


Figure 14. Effect of high, moderate or low stand density on treatability of Douglas-fir lumber with ACZA as measured by A) gross retention, B) chemical assay retention or C) preservative penetration. Bars with the same letter(s) are not significantly different by Fisher's Least Significant Difference Test at $\alpha = 0.05$.

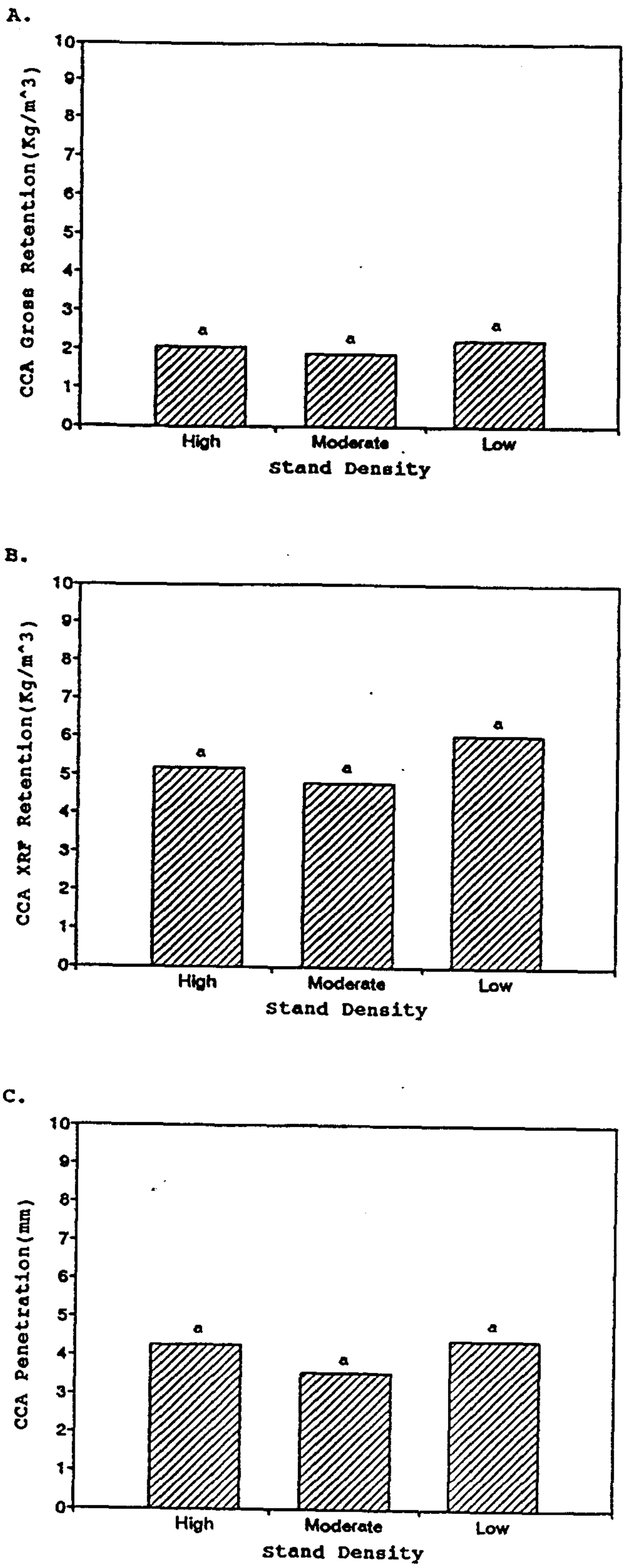


Figure 15. Effect of high, moderate or low stand density on treatability of Douglas-fir lumber with CCA as measured by A) gross retention, B) chemical assay retention or C) preservative penetration. Bars with the same letter(s) are not significantly different by Fisher's Least Significant Difference Test at $\alpha = 0.05$.

5.4. Effects of Vertical Tree Position on Treatability

Mean ACZA or CCA gross retention, XRF retention and penetration were generally greater at the height-1 than the height-2, but these values did not differ significantly between the 2 vertical positions (Table 10; Figure 16). In intrastand comparisons, mean ACZA or CCA gross retention, XRF retention and penetration also did not differ significantly between the tree positions. There were insufficient data from the Bohemia, Larson and Capitol I sites to employ the Wilcoxon test because sample boards came from only the height-1 in the Bohemia, the height-2 in the Capital II site and only one sample board came from the height-2 in the Larson site (Table 11, 12). Mean ACZA gross retention of

Table 10. Mean ACZA and CCA retention and penetration of Douglas-fir samples in lumber cut from 2 different heights in the tree[a].

Treatment Chemical	Tree Height[b]	Retention (Kg/m^3) Gross	XRF	Penetration (mm)
ACZA	Ht.1	6.95(2.12)	4.68(1.76)	3.09(2.42)
ACZA	Ht.2	6.50(1.61)	4.26(1.61)	2.97(2.42)
		p=0.4278	p=0.2501	p=0.4819[c]
CCA	Ht.1	2.11(1.36)	5.41(2.64)	4.06(2.41)
CCA	Ht.2	1.76(0.99)	4.87(2.30)	3.47(2.09)
		p=0.2802	p=0.2904	p=0.1405

a. Values represent means of all sample boards from a given tree position. Values in parentheses represent one standard deviation.
b. Height.1 means wood samples cut from 0 to 4.8 m from the butt, height.2 means wood samples from 4.8 to 9.6 m above the butt.
c. Mean values with $p>\alpha$ are not significantly different using Wilcoxon Rank Sum test at $\alpha = 0.05$.

Table 11. Mean ACZA retention and penetration of Douglas-fir samples from 2 different heights in trees removed from 9 stands in Oregon or Washington[a]

Silvicultural Site	Tree Height[b]	ACZA retention(Kg/m^3) Gross	XRF	Penetration (mm)
Longview	Ht.1	7.11(1.69)	4.85(1.95)	3.08(2.30)
	Ht.2	6.89(0.97)	4.49(1.11)	2.09(1.52)
		p=0.7300	p=0.8525	p=0.1841[c]
Willamette	Ht.1	7.07(1.98)	4.89(1.97)	4.35(3.27)
	Ht.2	6.73(1.06)	4.06(1.60)	4.04(3.09)
		p=0.9539	p=0.2476	p=0.5435
Bohemia	Ht.1	-	-	-
	Ht.2	8.37(1.67)	6.08(1.63)	4.73(4.89)
Bellfountain	Ht.1	7.42(0.86)	3.61(0.66)	2.00(0.28)
	Ht.2	6.45(1.33)	3.95(1.76)	2.70(1.61)
		p=0.3153	p=0.9273	p=0.7842
Larson	Ht.1	7.66(2.56)	4.57(1.45)	3.05(1.36)
	Ht.2	7.07(0.00)	5.27(0.00)	4.20(0.00)
Capitol II	Ht.1	7.23(2.78)	4.81(1.05)	2.05(1.04)
	Ht.2	8.29(1.81)	5.77(1.16)	4.23(2.78)
		p=0.2984	p=0.1082	p=0.2558
Capitol I	Ht.1	5.87(2.96)	4.44(3.23)	1.55(1.15)
	Ht.2	-	-	-
Experimental	Ht.1	5.63(1.86)	4.37(1.12)	2.55(2.11)
	Ht.2	4.24(0.11)	2.75(0.67)	2.60(0.36)
		p=0.1556	p=0.0528	p=0.8973
Pack Forest	Ht.1	4.87(1.63)	3.80(1.46)	0.50(0.71)
	Ht.2	4.94(0.87)	3.48(1.29)	1.81(1.92)
		p=0.8961	p=0.6953	p=0.2948

a. Values represent means all sample boards from a given tree position in each stand. Values in parentheses represent one standard deviation.
b. Height.1 samples cut from 0 to 4.8 m from the butt, height.2 samples from 4.8 to 9.6 m from the butt.
c. Mean values with $p>\alpha$ are not significantly different using Wilcoxon Rank Sum test at $\alpha = 0.05$.

Table 12. Mean CCA retention and penetration of Douglas-fir samples from 2 different heights in trees removed from 9 stands in Oregon or Washington[a].

Silvicultural Site	Tree Height[b]	CCA retention(Kg/m^3) Gross	XRF	Penetration (mm)
Longview	Ht.1	2.26(1.66)	5.43(3.34)	4.06(3.21)
	Ht.2	1.66(0.10)	6.16(2.07)	3.65(1.95)
		p=0.3809	p=0.4257	p=0.9576[c]
Willamette	Ht.1	1.85(1.28)	5.68(2.10)	4.16(1.71)
	Ht.2	2.40(1.24)	3.88(1.62)	2.66(1.58)
		p=0.3257	p=0.0564	p=0.0879
Bohemia	Ht.1	-	-	-
	Ht.2	1.97(0.58)	5.93(2.85)	4.83(2.88)
Bellfountain	Ht.1	2.18(0.49)	2.77(0.21)	2.05(0.07)
	Ht.2	1.87(0.99)	4.06(1.43)	2.93(1.38)
		p=0.9273	p=0.1704	p=0.1998
Larson	Ht.1	2.32(1.45)	5.11(2.76)	4.09(2.57)
	Ht.2	2.13(0.00)	10.64(0.00)	6.90(0.00)
Capitol II	Ht.1	3.16(1.04)	6.44(1.98)	4.70(2.13)
	Ht.2	2.16(0.90)	6.68(3.54)	6.28(3.01)
		p=0.2986	p=0.9247	p=0.2986
Capitol I	Ht.1	1.20(1.20)	5.96(3.41)	4.50(1.49)
	Ht.2	-	-	-
Experimental	Ht.1	1.92(0.47)	5.60(2.17)	4.70(2.06)
	Ht.2	0.53(0.12)	3.99(1.89)	2.97(1.76)
		p=0.0275	p=0.3662	p=0.3662
Pack Forest	Ht.1	1.17(0.62)	2.39(1.14)	0.30(0.28)
	Ht.2	1.28(0.78)	3.87(1.56)	2.48(1.32)
		p=0.0896	p=0.2400	p=0.0651

a. Values represent means all sample boards from a given tree position in each stand. Values in parentheses represent one standard deviation.
b. Height.1 samples cut from 0 to 4.8 m from the butt, height.2 samples from 4.8 to 9.6 m from the butt.
c. Mean values with $p>\alpha$ are not significantly different using Wilcoxon Rank Sum test at $\alpha = 0.05$.

wood samples from the Capitol II and Pack Forest site, XRF retentions of wood samples from the Capitol II and Bellfountain site and penetrations of the Bellfountain, Capitol II, Experimental Plot I and Pack Forest sites were greater in the height-2 samples than in those in the height-1 (Figure 17). Samples from the Bellfountain, Capitol II and Pack Forest sites had larger XRF retentions and penetrations in the height-2 than those in the height-1. Wood samples from the Longview site showed improvement in CCA XRF retention in the height-2 samples. Only CCA treated sample blocks from the Bellfountain and Capitol II sites had the same results as those in sample blocks treated with ACZA (Figure 18).

In general, softwood tracheid length and diameter increase from the base of the tree to below the crown [Panshin and de Zeeuw, 1980]. Cell wall thickness does not follow a consistent pattern with height in a tree. Thickness increases slightly as one moves inward from the lower trunk, but decreases inward in the upper stem in some softwoods [Panshin and de Zeeuw, 1980]. Softwoods with long, thin tracheids are more easily treated [Nicholas, 1973]. As a result, treatability should be better in samples from the height-2. The results from this study, however, showed that there were no consistent differences in treatability between the two positions.

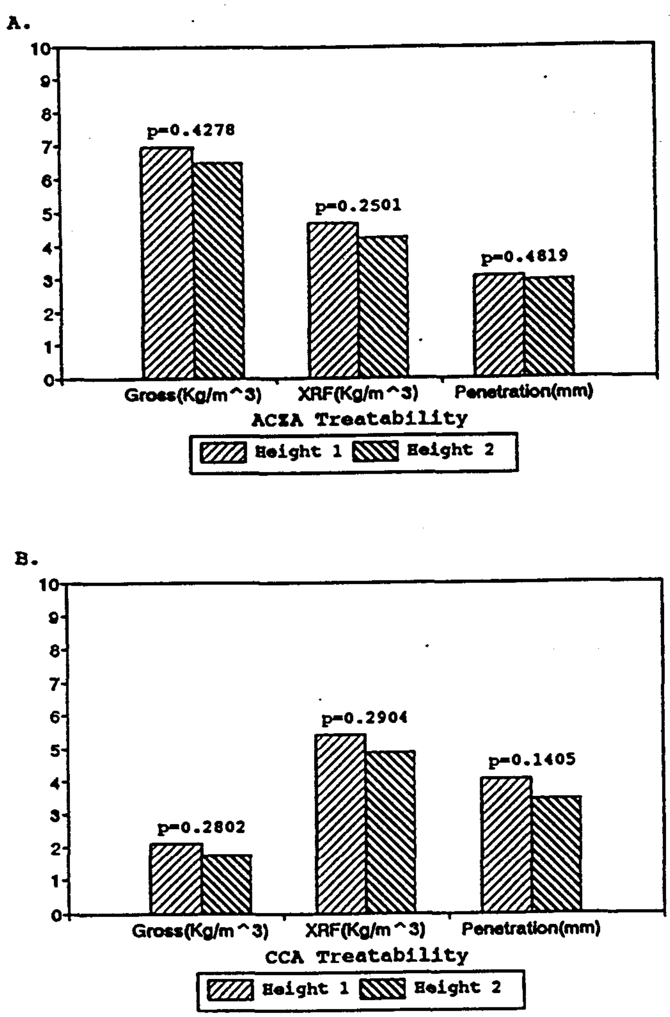


Figure 16. ACZA (A) or CCA (B) treatability of Douglas-fir lumber removed from 0 to 4.8 m or 4.8 to 9.6 m above the butt. Bars with $p>\alpha$ are not significantly different by Wilcoxon Ranked Sum Test at $\alpha = 0.05$.

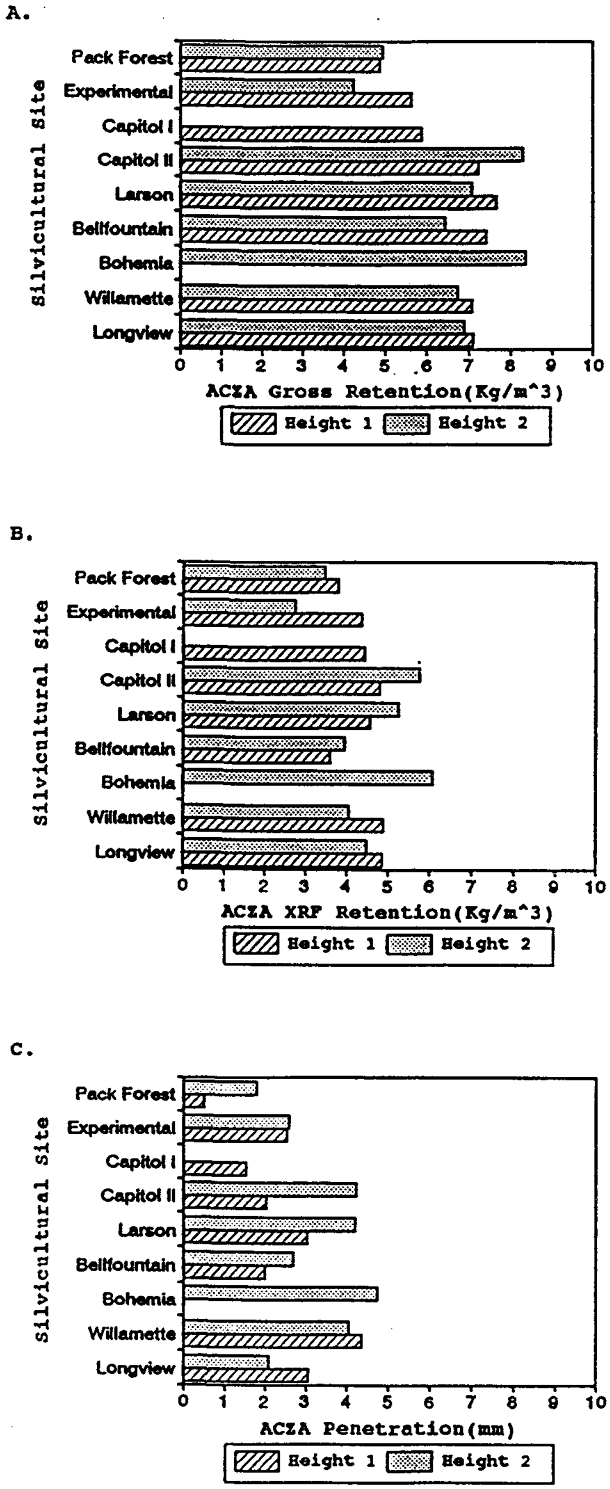


Figure 17. Effect of geographic source and vertical position in Douglas-fir trees on treatability with ACZA as measured by A) gross retention, B) chemical assay retention or C) penetration.

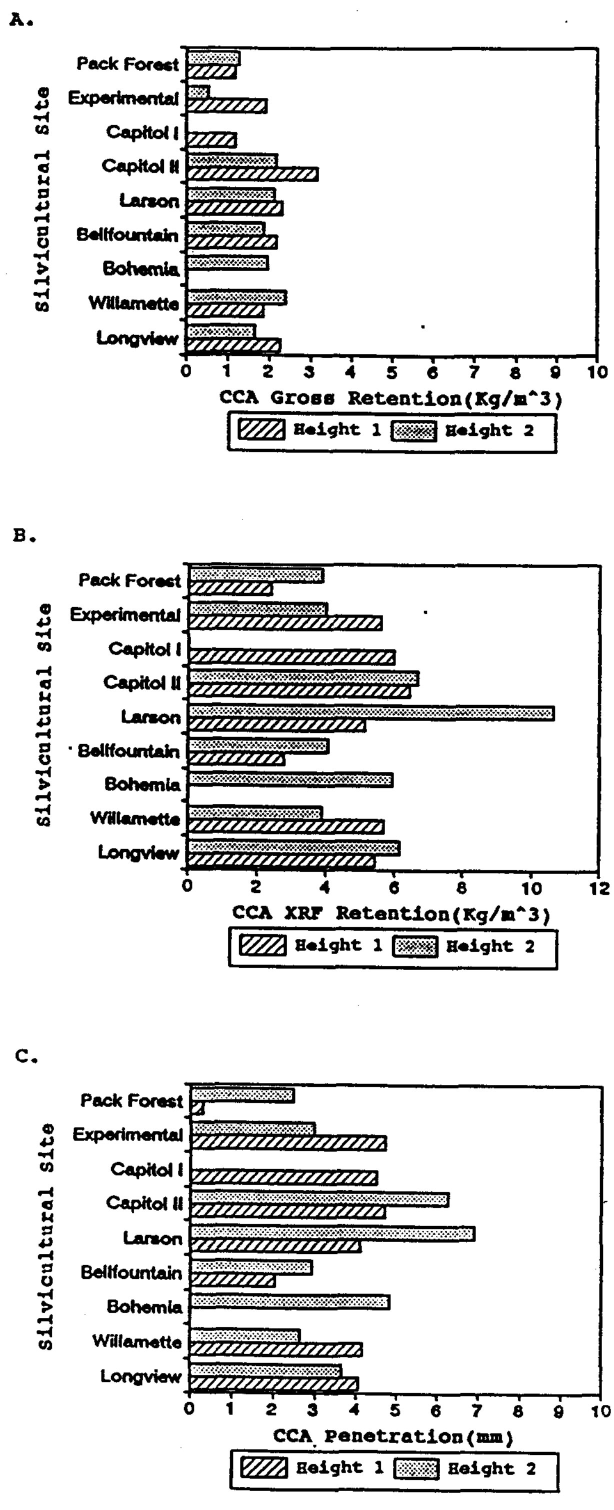


Figure 18. Effect of vertical position on CCA treatability of Douglas-fir lumber cut from trees grown on 9 silvicultural sites as measured by A) gross retention, B) chemical assay retention or C) penetration.

5.5. Effects of Juvenile Wood Percentage on Treatability

Most sample boards in this study came from logs with different juvenile wood percentages representing the portion of log volume occupied by the first 20 growth rings (20.7, 26.5, 30.0, 45.2, 63.4 and 97.6 percent). Thus, these values may not represent the real juvenile wood percentage of smaller sample boards used in this study. The data came from a management history report of the stands from which sample trees were selected [Fahey, unpublished] (Table 1).

Table 13. Effect of juvenile wood percentage in the logs on mean ACZA or CCA retention and penetration of Douglas-fir samples[a].

Juvenile Wood (%)[b]	Retention (Kg/m^3) Gross	XRF	Penetration (mm)
	ACZA		
20.7	5.17(1.50)b	3.83(1.24)ab	2.57(1.68)ab[c]
26.5	4.92(0.94)b	3.55(1.24)b	1.55(1.80)c
30.0	6.90(2.42)a	4.60(1.40)ab	2.53(1.95)b
45.2	6.96(1.50)a	4.56(1.86)ab	2.72(1.88)ab
63.4	7.16(1.76)a	4.87(1.86)a	4.33(3.28)a
97.6	7.74(2.67)a	4.63(1.50)ab	3.05(1.43)ab
	CCA		
20.7	1.46(0.79)ab	5.06(2.11)ab	4.12(2.04)a
26.5	1.36(0.72)b	3.58(1.56)b	2.64(1.48)b
30.0	2.26(1.31)ab	5.87(2.65)a	4.89(2.35)a
45.2	2.04(1.31)ab	5.15(2.74)ab	3.58(2.45)a
63.4	2.00(1.17)ab	5.47(2.35)a	4.00(1.97)a
97.6	2.42(1.48)a	5.32(2.79)ab	4.25(2.63)a

a. Values represent means of all sample boards from logs with a given juvenile wood percentage. Values in parentheses represent one standard deviation.
b. Juvenile wood percentage is the portion of log volume in the first 20 years of growth.
c. Mean values with the same letter are not significantly different by Fisher's LSD test at $\alpha = 0.05$.

Mean retention and penetration of wood samples treated with ACZA differed significantly among the 6 juvenile wood percentage categories (Table 13). Wood samples from logs with 20.7 and 26.5 percent juvenile wood had significant lower gross ACZA retentions than sample boards from the logs with 30.0, 45.2, 63.4 or 97.6 percent juvenile wood. XRF ACZA retentions were significantly higher in wood samples from the logs with 63.4 percent juvenile wood than those from the 26.5 percent juvenile wood, but these groups did not differ significantly from the other juvenile wood categories. Wood samples from logs with 26.5 percent juvenile wood had the lowest XRF retentions. Penetration in samples from the logs with 26.5, 30.0 and 63.4 percent juvenile wood differed significantly from each, while those with 26.5 percent juvenile wood were significantly lower than those from the other categories (Figure 19). Interestingly, ACZA treatability of wood from the logs with over 45.2 percent juvenile wood was significantly better while wood from the logs with under 30 percent juvenile wood was relatively poor. The reasons for these effects are unclear. While juvenile wood contains shorter fibers and cell walls with lower fibril angles, these differences might be expected to decrease rather than improve treatability.

Gross CCA retentions, XRF retentions and penetrations differed significantly with juvenile wood percentage (Table 13). Gross retentions were highest in wood from the logs with 97.6 percent juvenile wood while wood from the logs with

26.5 percent juvenile wood had the lowest retentions. Gross retentions in wood samples from the logs with 20.7, 30.0, 45.2 or 63.4 percent juvenile wood did not differ statistically. XRF retentions for the wood from the logs with 20.7, 45.2, or 97.6 percent juvenile wood also did not differ significantly. XRF retentions of wood samples from the logs with 26.5 and 30.0 or 63.4 percent juvenile wood differed significantly from each other, but not from the

Table 14. Effect of juvenile wood percentage in the logs in Oregon or Washington on mean ACZA or CCA retention and penetration of Douglas-fir samples[a].

Juvenile Wood (%)[b]	Retention (Kg/m_3) Gross	XRF	Penetration (mm)
Oregon	ACZA		
45.2	6.96(1.50)a	4.56(1.86)a	2.72(1.88)b[c]
63.4	7.16(1.76)a	4.87(1.86)a	4.33(3.28)a
97.6	7.74(2.67)a	4.63(1.50)a	3.05(1.43)ab
	CCA		
45.2	2.04(1.31)a	5.15(2.74)a	3.58(2.45)b
63.4	2.00(1.17)a	5.47(2.35)a	4.00(1.97)a
97.6	2.42(1.48)a	5.32(2.79)a	4.25(2.63)a
Washington	ACZA		
20.7	5.17(1.50)b	3.83(1.24)a	2.57(1.68)a
26.5	4.92(0.94)b	3.55(1.24)a	1.55(1.80)a
30.0	6.90(2.42)a	4.59(1.40)a	2.53(1.95)a
	CCA		
20.7	1.46(0.79)a	5.06(2.11)ab	4.12(2.04)a
26.5	1.26(0.72)a	3.58(1.56)b	2.04(1.48)b
30.0	2.20(1.31)a	5.87(2.63)a	4.89(2.35)a

a. Values represent means of all sample boards from the log with a given juvenile wood percentage. Values in parentheses represent one standard deviation.
b. Juvenile wood percentage is the portion of log volume in the first 20 years of growth.
c. Mean values with the same letter are not significantly different by Fisher's LSD test at $\alpha = 0.05$.

remaining groups. The lowest penetration values occurred in wood from the logs with 26.5 percent juvenile wood (Figure 20), while CCA penetration did not differ significantly in wood from the logs with 20.7, 30.0, 45.2, 63.4 or 97.6 percent juvenile wood.

Samples from Oregon stands were from the logs with 45.2, 63.4 or 97.6 percent juvenile wood. ACZA or CCA gross and XRF retention and CCA penetration did not significantly differ among samples from logs with these juvenile wood percentages (Table 14). Only ACZA penetration differed significantly between samples from the logs with 63.4 percent juvenile wood and the 45.2 percent juvenile wood. Samples from the logs with 63.4 percent juvenile wood had the deepest penetration and samples from logs with 45.2 percent juvenile wood had the shallowest value (Figure 21).

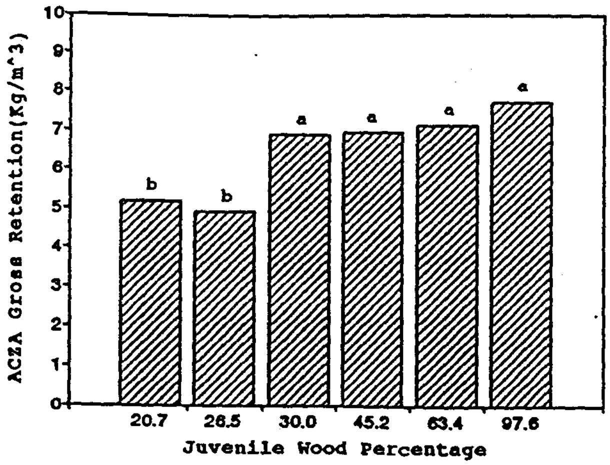
In Washington, ACZA gross retention or CCA XRF retention and penetration for the samples from logs with different percentages of juvenile wood were significantly different (Table 14). Samples from the logs with 30.0 percent juvenile wood showed the highest treatment values while the lowest values were those from the logs with the 26.5 percent juvenile wood (Figure 22). Correlation tests between the juvenile wood percentage in the logs and treatability suggested the absence of any strong linear relationship ($-0.013 \leq r \leq 0.350$).

Silvicultural treatments early in stand establishment can increase the volume of juvenile wood [Haygreen and

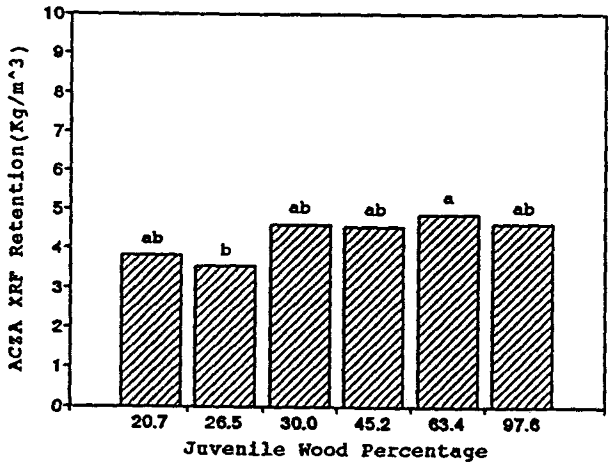
Bowyer, 1982]. Lower density, thinner cell walls and larger lumen diameters in juvenile wood could help preservatives flow into the wood, however, increased juvenile wood percentages did not affect CCA treatment in the present study. The higher lignin contents in juvenile wood may also react more readily with copper and zinc thereby producing better preservative fixation [Lebow, 1992].

The results show that trees from stands with higher juvenile wood percentages tend to have better ACZA treatability, while CCA treatability varied more widely. These results imply that increasing the percentage of juvenile wood can enhance some treatments, however, this material will have other negative properties particularly with regard to structural applications. The negative effects of juvenile wood may, therefore, outweigh any improvements in treatment. It is also important to note that most samples in this study were cut from sites near the pith, and should contain a high percentage of juvenile wood. As a result, separations based upon stand average juvenile wood percentages may be measuring the effects of other factors on treatability.

A.



B.



C.

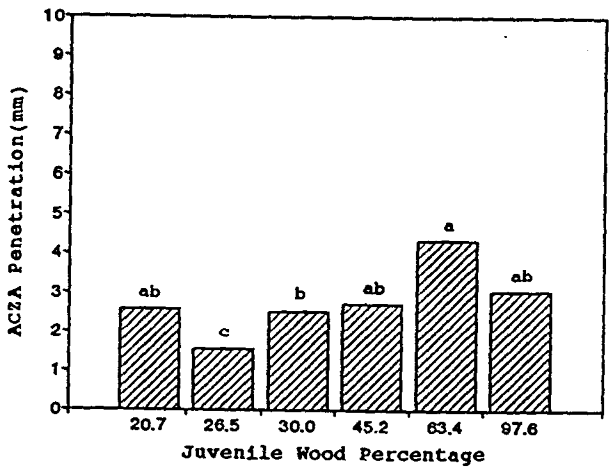


Figure 19. Effect of juvenile wood percentage on ACZA treatability of Douglas-fir samples as measured by A) gross retention, B) chemical assay retention or C) penetration. Bars with the same letter(s) do not differ significantly by Fisher's Least Significant Difference Test at $\alpha = 0.05$

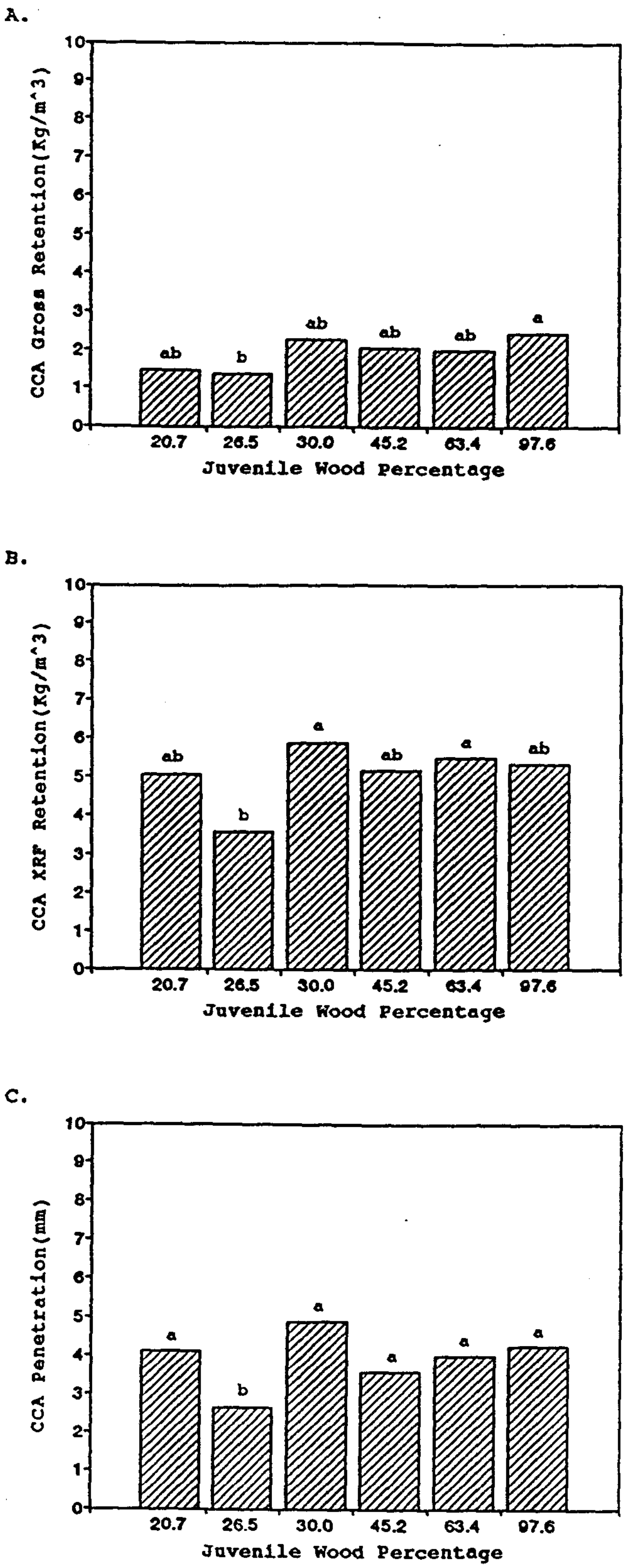
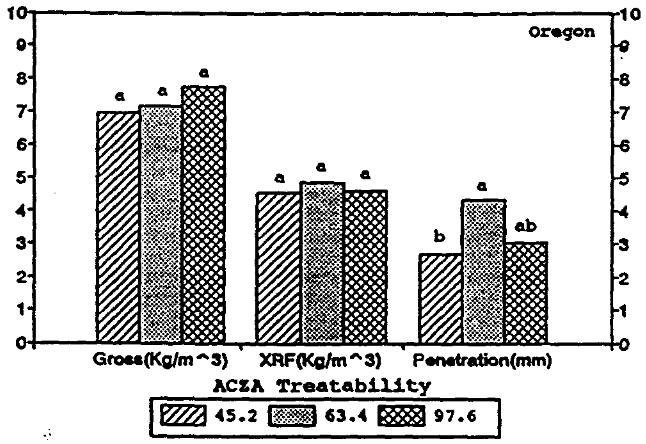


Figure 20. Effect of juvenile wood percentage on CCA treatability of Douglas-fir samples as measured by A) gross retention, B) chemical assay retention or C) penetration. Bars with the same letter(s) do not differ significantly by Fisher's Least Significant Difference Test at $\alpha = 0.05$

A.



B.

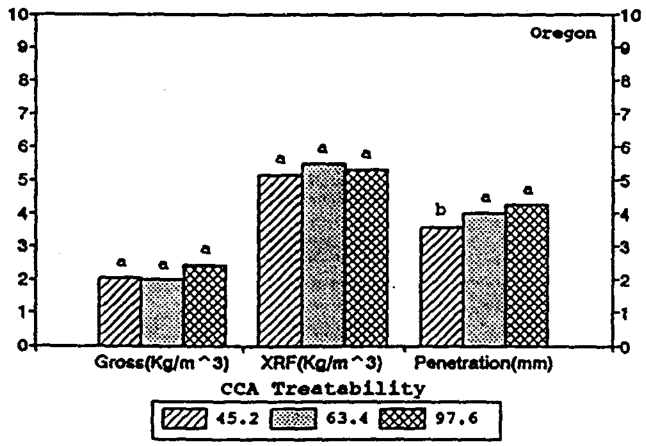


Figure 21. ACZA or CCA treatability of Douglas-fir lumber from the logs with various juvenile wood percentage in Oregon. Bars with the same letter(s) are not significantly different by Fisher's LSD test at α = 0.05.

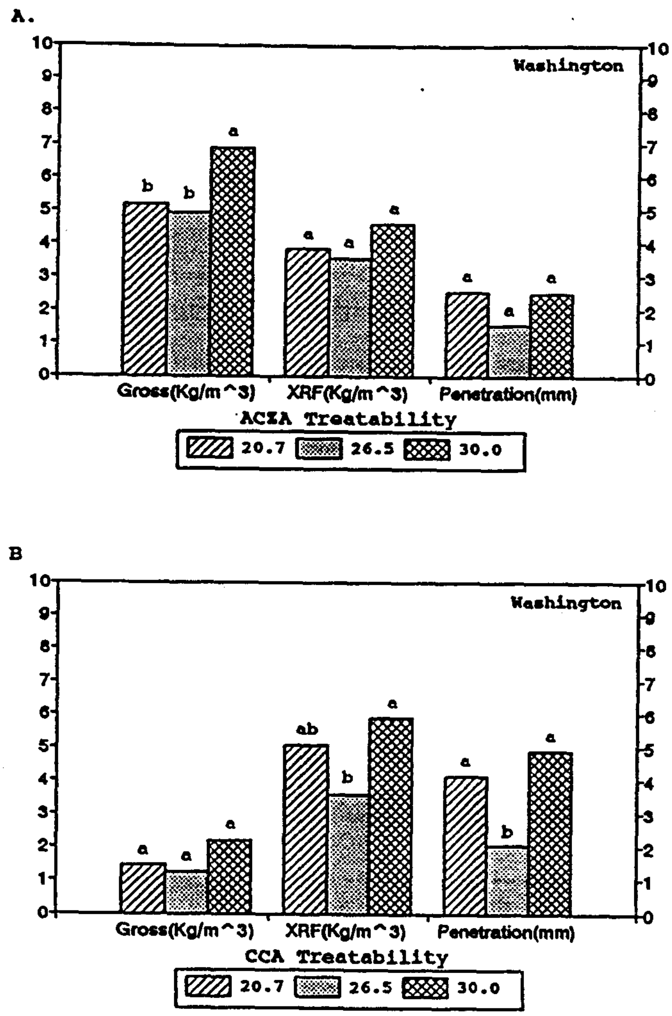


Figure 22. ACZA or CCA treatability of Douglas-fir lumber from the logs with various juvenile wood percentage in Washington. Bars with the same letter(s) are not significantly different by Fisher's LSD test at α = 0.05.

6.0. CONCLUSIONS

ACZA or CCA treatability differed widely among 9 geographic locations within the Pacific Coastal region and 3 different silviculture regimes. In Oregon, wood samples from the Bohemia site were the most treatable while those from the Bellfountain site were among the most difficult to treat with ACZA or CCA. In Washington, samples from the Capital II site were the most easily treated with ACZA or CCA, while samples from the Capitol I site were the most difficult to treat with ACZA and those from the Pack Forest were the most difficult to treat with CCA.

Wood from a control stand receiving no silvicultural manipulations was the most treatable followed by the thinned-and-fertilized stands then thinned stands. Samples from the sites with the low initial stand density in Washington had significantly better CCA and ACZA retentions than those of wood from the high initial density.

Vertical position in a tree did not statistically affect ACZA or CCA treatability of Douglas-fir, although treatability of wood samples from the height-1 was slightly better than that of wood samples from the height-2.

Juvenile wood percentage appeared to be positively correlated with ACZA indicating that increased juvenile wood enhanced treatability, but this relationship must be viewed with caution since the percentage represents an average of all samples in the stand. This level may vary widely from that of the smaller sample evaluated for treatability. There were significant differences in CCA treatability among the various juvenile wood percentages, but these patterns were not consistent.

The results suggest that silvicultural treatments which increase the volume of juvenile wood should be considered for improving treatability, but the effect on solid wood quality also must be considered and may negate the potential treatment benefits.

While this study suggests that silvicultural practices can affect treatability, the original study design limited the conclusions which can be drawn. The original study sought to select a range of materials from stands which had a variety of silvicultural prescriptions, but did not attempt to control the variations between the individual sites. As a result, no direct comparisons among the treatments were possible.

An alternative approach to the design of such a study would involve the selection of several large sites across the Pacific Northwest which had similar elevations, soil types and precipitation levels. The variables such as stand density, thinning regions, fertilization schedule and pruning would be replicated within a portion of each site, permitting direct comparison of variables. This approach would require a longer time period to achieve results, but would result in more definitive separations. As stands become increasingly managed, the effects of various silvicultural manipulations must be more thoroughly examined so that foresters and wood scientists can select those practices which produce the most useful fiber.

7.0. LITERATURE CITED

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APPENDIX

Appendix 1. ACZA or CCA XRF retention of Douglas-fir sample boards from 9 stands receiving different silvicultural treatments, as measured by assay zone[a].

ACZA XRF Retention (Kg/m3)

Silvicultural Site	0-5 mm				5-10 mm				10-15 mm			
	Cu	Zn	As	Total	Cu	Zn	As	Total	Cu	Zn	As	Total
Longview	5.56	1.92	2.04	9.52	1.85	0.87	0.83	3.55	0.76	0.35	0.55	1.66
Willamette	5.36	1.83	1.98	9.17	1.79	0.81	0.79	3.39	0.72	0.26	0.47	1.45
Bohemia	6.27	2.33	2.59	11.19	1.91	0.85	0.89	3.65	0.81	0.33	0.55	1.69
Bellfountain	4.73	1.63	1.75	8.11	1.37	0.62	0.62	2.61	0.44	0.17	0.37	0.98
Larson	5.49	1.85	1.90	9.24	1.83	0.85	0.81	3.49	0.52	0.18	0.48	1.18
Capitol II	6.03	2.11	2.27	10.41	2.03	0.92	0.88	3.83	0.75	0.33	0.51	1.59
Capitol I	3.98	1.63	1.46	7.07	0.45	0.13	0.35	0.93	0.12	0.07	0.28	0.47
Experimental	4.82	1.73	1.83	8.38	1.18	0.57	0.62	2.37	0.30	0.11	0.36	0.77
Pack Forest	4.63	1.61	1.64	7.88	1.03	0.47	0.54	2.04	0.28	0.09	0.35	0.72

CCA XRF Retention (Kg/m3)

Silvicultural Site	0-5 mm				5-10 mm				10-15 mm			
	Cr	Cu	As	Total	Cr	Cu	As	Total	Cr	Cu	As	Total
Longview	7.34	2.27	3.49	13.10	1.71	0.64	0.76	3.11	0.65	0.25	0.43	1.33
Willamette	7.09	2.27	3.32	12.68	1.32	0.49	0.53	2.34	0.28	0.11	0.18	0.57
Bohemia	8.14	2.55	3.97	14.66	1.93	0.74	0.83	3.50	0.16	0.09	0.17	0.42
Bellfountain	5.49	1.55	2.32	9.36	0.94	0.33	0.41	1.68	0.30	0.11	0.18	0.59
Larson	7.06	2.14	3.21	12.41	1.51	0.57	0.72	2.80	0.35	0.14	0.26	0.75
Capitol II	7.56	2.43	3.66	13.65	2.48	0.94	1.01	4.43	0.67	0.24	0.27	1.18
Capitol I	6.58	2.09	3.18	11.85	0.99	0.40	0.41	1.80	0.13	0.05	0.11	0.29
Experimental	6.43	1.96	3.02	11.41	1.83	0.69	0.86	3.38	0.24	0.09	0.22	0.55
Pack Forest	5.26	1.53	2.38	9.17	0.66	0.24	0.33	1.23	0.13	0.05	0.14	0.32

a. Values represent means of samples removed 0 to 5 mm, 5 to 10 mm, and 10 to 15 mm from all sample boards from a given silvicultural site. 12 cores were removed per each zone per each board.