Factors influencing initial sprouting of red alder

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Received October 24, 1983[2]
Accepted February 20, 1984

HARRINGTON, C. A. 1984. Factors influencing initial sprouting of red alder. Can. J. For. Res. **14**: 357–361.

Two studies were established to investigate factors influencing sprouting of red alder (*Alnus rubra* Bong.). In the first study, 4-year-old planted trees were cut at five stump heights (0, 10, 30, 50, and 70 cm) during 4 months of the year (January, May, July, and September). The percent of stumps surviving was greatest with cuts in January at 30 cm or higher; survival was least with 0- and 10-cm cuts during July and September. In the second study, 29 natural stands varying in age from 1 to 32 years were cut in February. Sprouting was most vigorous and consistent in very young stands. Few stumps sprouted in the oldest stands; in addition, the older stands had fewer sprouts per stump and the sprouts were shorter. Stumps with a level surface had the greatest mortality and were least likely to sprout; stumps with the cut surface facing south or west had the least mortality and were most likely to sprout. Based on the results from both studies, specific cutting practices are recommended to achieve different management objectives.

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L'auteur a conduit deux études pour analyser les facteurs qui influencent la formation de rejets de l'aulne roux (*Alnus rubra* Bong.). Dans la première étude, des arbres d'une plantation âgée de 4 ans furent coupés à cinq hauteurs de souche (0, 10, 30, 50 et 70 cm), à 4 mois de l'année (janvier, mai, juillet et septembre). Les souches coupées à 30 cm ou plus en janvier eurent le plus haut taux de survie, alors que peu des souches coupées à 0 et 10 cm en juillet et septembre ont survécu. Dans la deuxième étude on a coupé, en février, 29 peuplements naturels dont l'âge variait de 1 à 32 ans. C'est dans les très jeunes peuplements que la formation de rejets fut la plus vigoureuse et consistante. Peu de souches ont produit des rejets dans les peuplements plus âgés; de plus, les peuplements âgés avaient moins de rejets par souche et les rejets étaient plus courts. Les souches à surface horizontale eurent la plus forte mortalité et leur pouvoir de rejet fut négligeable; les souches dont la section de coupe était exposée au sud ou à l'ouest eurent le moins de mortalité et leur pouvoir de rejets fut plus élevé. Les résultats de ces deux études permettent de recommander des pratiques de coupe compatibles avec divers objectifs d'aménagement.

[Traduit par le journal]

Introduction

Red alder (*Alnus rubra* Bong.) is the most widely distributed hardwood species in western Oregon, Washington, and British Columbia. The species has rapid juvenile growth and the ability to fix atmospheric nitrogen, grows well under a wide variety of site conditions, and can be reproduced both from seed and vegetatively. The species has many of the silvical traits desirable for short-rotation culture. The same characteristics that make red alder a candidate for short rotations, however, also make it a strong competitor with many of the coniferous species in the region, most of which have slower juvenile growth. One characteristic of concern to forest managers interested in either short-rotation hardwood management or management of pure conifer stands is the ability of the species to sprout or coppice following cutting. Most of the information that has been available on this topic consists of unpublished office reports and general field observations (cf. Worthington et al. 1962). This report summarizes information from two studies that evaluated the effects of height and aspect of cut, tree age, and season of year on sprouting of red alder. Specific cutting practices are recommended for either maximizing or minimizing stump sprouting.

Materials and methods

Study areas and experimental design

Three different locations were used for the studies on coppicing of red alder: McCleary, WA, Centralia, WA, and Otis, OR. McCleary and Centralia are in the Puget Sound Lowlands of western Washington where the mean annual temperature is 10–11°C, the average number of frost-free days ranges from 160 to 175, and the mean annual precipitation is 1100–1600 mm. The study area at McCleary is approximately 30 km west of Olympia, WA, at an average elevation of 90 m. The plots at Centralia are located about 30 km south of Olympia at elevations of 75–140 m. The Otis plots are on the northern Oregon coast near Lincoln City, OR, at elevations of 40–200 m. In the Otis area, the mean annual temperature is 10°C, the average number of frost-free days is 210, and the annual precipitation is 2400 mm.

Effects of season of cut and stump height

The first study, designed to look at the effects of season of year and stump height on coppicing, was established on an alluvial flat south of Wildcat Creek on the McCleary Experimental Forest. The previous forest cover, primarily red alder, was clear-cut in 1977 and broadcast burned in the fall of 1978. Four blocks, each containing nine plots were planted in March 1979 using 2-year-old red alder seedlings grown from local seed. Each plot had five rows of five seedlings spaced 2.0 m apart and had a 3.5-m unplanted buffer strip on all sides. The buffer strips were intended to prevent shading from, or root grafting with, adjacent plots. Dead seedlings were replaced 2 months after planting. During the first growing season, vigorously sprouting shrubs or trees, or new natural seedlings, were clipped off at ground level. At the end of the 1980 growing season, the trees averaged 2.4 m tall and 1.3 cm diameter at breast height (dbh, 1.3 m).

One plot in each block was randomly selected to be cut in September 1980, January 1981, May 1981, or July 1981. The remaining plots were reserved for future experiments. The treatment dates were selected to represent the end of the growing season when leaves are still on the trees, the dormant season, the beginning of the growing season when the trees have just leafed out, and the middle of the growing season, respectively. Five stump heights were selected: 0, 10, 30, 50, and 70 cm above ground. Five randomly selected trees were cut at each stump height in each plot. All trees were cut straight across using a hand bow saw.

The stumps were examined at the end of the 1981 and 1982 growing

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[2]Revised manuscript received February 9, 1984.

seasons. Stumps were tallied as alive or dead (based on the presence of living sprouts), and the percent of cut stumps that sprouted was determined. Diameter was measured on all stumps, and the total number of stems originating from each stump was counted. Some of these young spaced trees had live lower branches; therefore, the measured stems could be sprouts originating at the root collar or along the stem, sprouts originating from cut branches, or uncut low branches. The three tallest stems per stump were measured for total height above ground, height above ground where they originated, diameter (measured 10 cm above the point of origin), compass direction (i.e., aspect) of the point of origin on the stem, and stem type (i.e., stump sprout, branch sprout, or branch).

Survival and growth data were analyzed using a split-plot analysis of variance, season of year was the whole-plot treatment, and stump height was the split-plot treatment. Information on the three stem types was combined for the analyses of stem height and diameter. Although there are physiological differences between the different stem types, from a management standpoint it seemed reasonable to combine them for these analyses. High mortality resulted in empty cells for some treatments; this required specifying weighted orthogonal contrasts in the analyses (Hull and Nie 1981). When treatment effects were statistically significant ($p \leq 0.05$), treatment means were separated using Tukey's test (Mendenhall 1968). Differences between dead and living stumps in stump diameter or in pretreatment (i.e., 1980) height or dbh were compared using a paired t-test; the t-tests were done separately for each season and stump height. The hypothesis that sprout origin was independent of compass direction (i.e., aspect) was tested using the chi-square test of independence.

Effects of tree age and aspect of cut surface

A second study was designed to look at the effects of tree age on sprouting ability. Twenty-nine plots were established in natural stands; the plots were split geographically between Centralia (18 plots) and Otis (11 plots). Average tree age ranged from 1 to 16 years at Otis and from 2 to 32 years at Centralia. All stands were primarily red alder (95% or more by basal area). Previous forest history was variable; however, the stands were apparently all naturally seeded following wildfire, logging, road construction, strip mining, or abandonment of agricultural land. A treatment plot was laid out in each stand to include a 100-tree interior measurement plot plus buffer strips equal in width to average tree height. Interior measurement plots ranged from 6.1 × 6.7 m in a 1-year-old stand to 22.9 × 39.6 m in a 32-year-old stand. During February 1982 the interior measurement plots and the buffer strips were cut using chain saws. Stump height was kept between 15 and 20 cm; the angle of the cut was not controlled, however, and stumps were created with level or angled surfaces.

The plots were revisited after one growing season. Stumps were tallied as alive or dead and the percentage of cut stumps that sprouted was determined. For both dead and living stumps, diameter, height, and aspect of the cut surface were measured. On each plot, 25 living stumps were chosen at random; for these stumps, the total number of sprouts per stump was determined and the three tallest sprouts were identified. The same measurements were made on the three tallest sprouts per stump as were made at McCleary.

Survival and growth data from the Centralia and Otis plots were plotted against stand age, and the simple correlation coefficients between age and the measured stump characteristics were determined. Linear regression lines were initially fitted separately for the two areas; the data were combined when the slopes of the lines were not significantly different. Differences in diameter between living and dead stumps were tested using a paired t-test. The hypotheses that sprout origin was independent of compass direction and that mortality was independent of the aspect of the stump surface were tested using the chi-square test of independence. In all analyses $p \leq 0.05$ was used to judge statistical significance.

Results and discussion

Effects of season and stump height

Both season of year and stump height had significant effects on stump mortality (Table 1); in addition, the season by stump height interaction was also significant. Low stump heights resulted in high mortality, especially when trees were cut in July or September. Best survival resulted from the January cut, although, even then, survival was poor at the 0- and 10-cm stump heights. Most mortality occurred during the 1st year; 2nd-year mortality occurred almost entirely in the plots cut in July.

In the analyses of 1st-year data, both season of cut and stump height had statistically significant effects on length of the tallest stem per plant, length of the three tallest stems per plant, diameter of the tallest stem per plant, the diameter of the three tallest stems per plant. The total number of stems per plant was significantly different by stump height but not by season. The season by stump height interaction was not significant in the analyses of 1st-year stem length, diameter, or number of stems.

In the analyses of 2nd-year data, the effects of stump height were significant for all variables; the effects of season, however, were no longer significant. Season of cut probably affected 1st-year stem diameter and height through its influence on length of the growing season; e.g., stumps cut in July had a shorter growing season the 1st year than the stumps cut in January. All treatments would have had the same length of growing season the 2nd year when the effect of season was not significant. In general, only the 0-cm treatment was significantly different from the other stump height treatments (Table 2).

As expected, stem type differed with the height of the cut. All the stems on the 0-cm cut stumps were stump sprouts coming from the vicinity of the root collar; however, no true root sprouts or suckers were observed in any plot. Even on the

TABLE 1. The effects of month of cut and stump height on the percent of red alder stumps at McCleary that were dead after two growing seasons

Stump height (cm)	Month of cut			
	September	January	May	July
0	85	85	85	100
10	90	50	60	95
30	60	20	50	65
50	30	10	35	20
70	10	5	20	15

TABLE 2. Effects of stump height on selected characteristics of red alder stumps, two growing seasons after cutting

Stump height (cm)	Stems per plant	Length* (m)		Diameter† (cm)	
		Tallest	Three tallest	Tallest	Three tallest
0	5.3	1.59*a*‡	1.29*a*	1.69*a*	1.36*a*
10	5.0	2.12*b*	1.86*b*	2.03*ab*	1.73*ab*
30	7.2	2.31*b*	2.03*b*	2.18*ab*	1.80*ab*
50	6.8	2.32*b*	1.99*b*	2.16*ab*	1.79*ab*
70	9.0	2.55*b*	2.18*b*	2.43*b*	2.02*b*

*Length was calculated as total height above ground minus the height of origin on the stem.

†Stem diameter measured 10 cm above the point of origin.

‡Within a column, means followed by the same letter were not significantly different (Tukey's test, $p \leq 0.05$). The number of stems per plant was not tested because of the significant season of cut × stump height interaction.

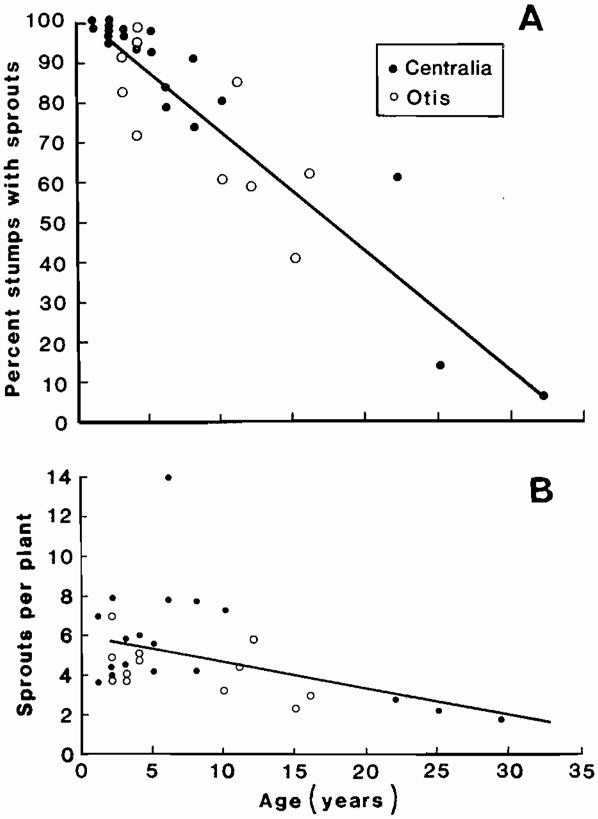

FIG. 1. Relationship between average tree age per plot and (A) the percentage of stumps with sprouts at the end of the first growing season or (B) the number of sprouts per plant.

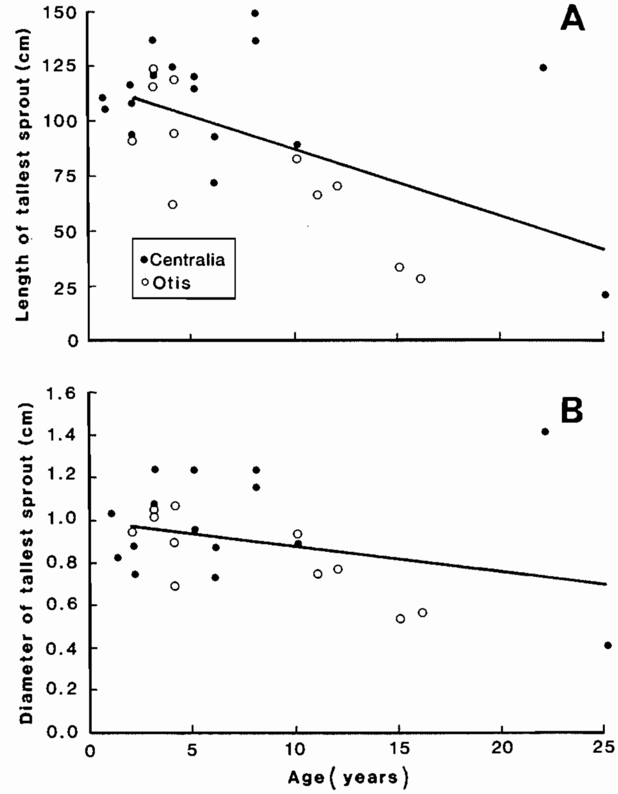

FIG. 2. Relationship between average tree age per plot and (A) length of the tallest sprout per plant or (B) diameter of the tallest sprout per plant. Sprout length was defined as height of the terminal above ground minus height on the stem where the sprout originated.

stumps cut higher, stem sprouts generally originated from suppressed buds at the root collar or along the lower stem (within 15 cm of the ground). An occasional sprout of adventitious origin was observed coming from callus tissue that formed around the edges of the cut surface. The percentage of stems classified as branch sprouts or branches increased with cut height; 83% of the stems on the 10-cm cut stumps were stump sprouts, 14% were branch sprouts, and 3% were branches. At the 70-cm cut 13% of the stems were stump sprouts, 71% were branch sprouts, and 16% were branches.

There were no significant differences in stump diameter or in pretreatment height or dbh between stumps that sprouted and those that did not. That is, whether or not a stump sprouted was not associated with its relative size at the time of cutting.

The distribution of stem sprouts around the stem was related to stem aspect. More sprouts than expected were found on the west, southwest, and south sides of stumps; fewer than expected were found on the north and northeast sides. The relationship between sprout occurrence and stem aspect was strongest in the plots cut in January and weakest in the plots cut in July.

Effects of tree age and aspect of cut surface

Most stems observed at Centralia and Otis were stem sprouts originating from suppressed buds along the lower stem or around the root collar. A few sprouts of adventitious origin were observed coming from callus tissue growing around the edges of the cut surface of the stump. No root sprouts were observed. Owing to self-pruning in dense natural stands, no lower branches were alive at the time of cutting; thus, no branches or branch sprouts were found on any of the stumps.

The correlation between tree age at the time of cutting and the percentage of stumps that sprouted after one growing season was negative and significant ($r = -0.92$, Fig. 1A). Sprouting was very consistent from 1- and 2-year-old plots; from 3 years of age and on, however, the percentage of stumps that sprouted was more variable among plots. The number of sprouts per stump (Fig. 1B) was negatively related to tree age, ($r = -0.28$), but the correlation was not significant. On plots with tree ages from 1 to 12 years, the number of sprouts per stump was quite variable, ranging from 3 to 13.8. All plots older than 12 years, however, averaged three or fewer sprouts per plant.

Length of the tallest sprout per plant (Fig. 2A) and average length of the three tallest sprouts per plant were both significantly correlated with tree age ($r = -0.56$ and $r = -0.53$). In contrast with most of the other variables, however, diameter of the tallest sprout per plant (Fig. 2B) and average diameter of the three tallest sprouts per plant were only very weakly related with tree age ($r = -0.33$ and $r = -0.24$, not significant).

The aspect of the cut surface of the stump was found to be related to stump mortality. Both young trees (age 1–5 years) and older trees (age 6–16 years)[3] had different patterns of mortality by stump aspect than would be expected by chance (Table 3). Stumps cut level (aspect = 0) had the greatest mortality; stump surfaces facing south, southwest, or west (aspect = 3) resulted in the least stump mortality. Aspect of the

[3]The oldest plots (i.e., those greater than age 16 years) were not included in this analysis due to low and unequal numbers of stumps in each aspect class.

TABLE 3. Percent mortality of red alder stumps at Centralia and Otis by age-class and aspect of the stump surface

Age-class (years)	Aspect class*			
	0	1	2	3
1−5	25	21	15	12
6−16	59	33	44	27

*0, level; 1, north or northeast; 2, east, northwest, or southeast; 3, south, southwest, or west.

stump surface, however, did not influence the number of sprouts per stump or the height or diameter of the tallest sprout per stump. Stump diameter was significantly greater on live stumps than on stumps that failed to sprout, and in general, the differences in mean diameter between live and dead stumps widened as plot age increased.

Stem sprouts were most common on south or west stem aspects; however, the occurrence of stem sprouts was not significantly different by aspect class. The lack of statistical significance in this study is in contrast with the highly significant relationship found at McCleary. The McCleary plots were located on a fairly broad, flat stream bottom, while the Centralia and Otis plots varied widely in their aspects and slopes. Thus, it is possible that if a general relationship does exist between sprout occurrence and stem aspect, in the Centralia and Otis plots it was confounded by the variation in plot aspect and slope.

Summary

Red alder can sprout when cut and is capable of successfully regenerating via coppice. The species would not, however, be considered a vigorous or prolific sprouter. Stem sprouts originate from suppressed buds near the root collar or along the lower stem. The species does not sprout from the roots. If live branches exist below the level of the cut, either these lower branches or sprouts originating from them may become new main stems.

In the study at McCleary, cutting in January resulted in the best survival; cuts in July or September had the least survival. The superiority of dormant-season cuts in minimizing mortality and increasing the number and vigor of the resulting sprouts has been previously reported for other species (Belanger 1979; DeBell and Alford 1972; Strong and Zavitkovski 1982). Cutting during the growing season, from April or May through August, was considered the poorest time to cut by these authors. Several studies, however, considered a September cut to be more similar to a dormant season cut than to a cut during the growing season (Strong and Zavitkovski 1982; DeBell and Alford 1972; Wenger 1953). The high mortality following the September cut at McCleary may indicate that red alder has a different physiological status at this time of the year than other species that have been studied. Based on the information from this study, January cuts minimize mortality; based on similar studies with other species, red alder trees cut during the period of November through February would probably react similarly to those cut in January. Trees cut from April through October would probably have much greater mortality and possibly would also have reduced vigor. More detailed studies would be needed to refine these recommendations.

The effects of stump height on subsequent sprouting, particularly the poor sprouting when stumps are cut low, have been reported for other species (DeBell 1971; Belanger 1979; El Houri Ahmed 1977). Stump height can affect future sprouting, at least in part, because of its influence on the number of suppressed or trace buds present. For species that sprout only from suppressed buds along the stem, low cuts may not leave any buds or a sufficient number of buds on the stump (cf. Hook and DeBell 1970). For red alder, however, stem sprouts are more likely to come from the lower 10−15 cm of the stem or from around the root collar than from higher up on the stem. Thus, the high mortality of the 0- and 10-cm cut stumps at McCleary is probably due to factors other than lack of suppressed buds; e.g., El Houri Ahmed (1977) suggested rapid decay of low-cut stumps as a reason for low sprouting of *Eucalyptus microtheca*. In addition to its direct effects on sprouting, stump height can also affect the probability that a lower branch will contribute to regeneration.

Red alder wood is not considered resistant to decay. It has been speculated that cutting treatments that affect moisture and temperature of the cut surface may influence build up and activity of decay organisms, which in turn may influence sprouting success. In the plots at Centralia and Otis, it was found that a level cut, which would have maximized water retention on the stump, resulted in the greatest stump mortality. Angled cuts had lower mortality; cuts facing south, southwest, or west usually had the least mortality. Mortality on the plots at McCleary was somewhat higher than would be expected for their age. The fact that the cuts were level may have increased mortality. Crowther and Patch (1980) in their discussion of coppicing chestnut, hazel, and willow, recommended a sloped or angled cut to shed water.

The percent of stumps that sprouted was strongly correlated with tree age. Almost all very young trees (age 1−2 years) sprouted prolifically. On the average, a lower percentage of trees 3−10 years old sprouted; additionally, sprouting became more variable within an age-class. Red alder stands 10 years old or less may be reproducible by coppice; stands less than 6 years old appear to be the best candidates for coppice regeneration. To maximize biomass production in red alder stands, rotations of 10−15 years have been recommended (DeBell et al. 1978; Zavitkovski et al. 1979); however, a noncoppice method of regeneration should be chosen for stands more than 10 years old. In such stands, 1st-year sprouting is 70% or less, the number of sprouts per stump is low, and the spacing between stumps is greater than at younger ages. Thus, the percentage of area adequately regenerated via sprouts would be low. In addition, sprout vigor, as evidenced by length of sprouts, is less for older stumps. Smith (1962) commented that "the period of satisfactory sprouting is usually coincident with that of most rapid growth and ordinarily ends before the trees become effective seed bearers." This generalization applies well to red alder; the species generally has most rapid growth prior to age 10 and begins seed production on a stand basis at about 10 years of age (Fowells 1965).

At all three study locations, relative tree size in young stands was not a good predictor of which stumps sprouted. In these stands, differences in tree size may have been more related to variations in microsite conditions, stand density, or tree age than to intertree competition. In stands 10 years or older, however, it was quite consistent that the smaller stumps did not sprout. Relative tree size may have been better correlated with tree vigor in these somewhat older stands. Low-vigor trees may not have had sufficient carbohydrate reserves or the hormonal balance required to trigger sprout initiation.

Red alder stumps are more likely to have sprouts on the south, west, and southwest aspects of the stem than on other aspects. This is especially true when trees are cut during the dormant season. These sides of the stem would be the warmest and thus, buds on these aspects may initiate growth first. Red alder is a thin-barked species and this may make it especially responsive to differences in temperature on the stem. In another study near Otis, a young red alder plantation was thinned by removing every other tree in each row; epicormic branches, when present, were mostly confined to south and west aspects (unpublished data, Forestry Sciences Laboratory, Olympia, WA).

Management recommendations

To maximize sprouting of red alder following cutting the following procedures are recommended: (*i*) cut during the dormant season; (*ii*) make stumps taller than 10 cm; (*iii*) do not make a level cut; angle or slope the stump surface (toward the southwest); (*iv*) cut trees when young (less than 6 years old).

To minimize sprouting of red alder following cutting the following procedures are recommended: (*i*) cut during the growing season; (*ii*) cut stumps 10 cm or lower; (*iii*) make a level cut; (*iv*) if feasible, delay cutting until trees are 10 years or older.

Acknowledgments

This work was supported in part by a grant from the U.S. Department of Energy under Interagency Agreement No. DE-AI05-810R20914. Plots used in these studies were on land belonging to, or managed by the Simpson Timber Co., the Washington Irrigation and Development Co., or the U.S. Department of Agriculture Forest Service Hebo Ranger District and Cascade Head Experimental Forest. I would like to thank Jack Booth, Cascade Head Experimental Forest, Otis, OR, and John Wisch, Washington Irrigation and Development Co., Centralia, WA, for their help in plot establishment. I would also like to thank James Wilcox and Mary Culliton, Forestry Sciences Laboratory, Olympia, WA, for their assistance in data analysis.

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