In: Cooper, S.L., compiler. Where we've been, where we are, and where we're going. Proceedings 25th Forest Vegetation Management Conference; 2004 January 20-22; Redding, CA. Redding, CA: University of California, Shasta County Cooperative Extension; 61-72.

Balderston Plantation Revisited: A Tale of Two Sites 25 Years After Early Treatments

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Abstract

The West's first study of how brush competition and soil fertility effect tree growth began 28 years ago at Balderston Plantation on the Eldorado National Forest. Balderston plantation is unusual because it occupies two strongly contrasting soil types: a productive Cohasset soil series derived from a Pleistocene volcanic mudflow, and a less-productive Mariposa series formed on much older marine metasediments. Cohasset and Mariposa soils differ in depth, stone content, water holding capacity, and nitrogen availability. Collectively, these features translate to 2-fold differences in site index. Established in 1967 following brushfield conversion by bulldozer, Balderston was planted to ponderosa pine. Tree survival was good but—despite two release treatments—manzanita quickly returned to the site and trees were barely emerging from the brush at the start of the experiment. Trees were examined in 1975 and judged to be under severe water and nutrient stress. A factorial series of brush control and N fertilization treatments were applied the following year, and trees were remeasured at intervals to the present. The primary importance of early vegetation control and secondary importance of nutrition were clear in the first 5 years after treatment. Although the fertilization effect was short-lived, vegetation control effects persist to the present. By age 37, untreated plots on the poorer soil consisted of dense brush with a few spindly pine trees and we doubt that a forest will ever emerge without further intervention. The better soil is another story. A forest emerged without treatment on the Cohasset soil series, but not without cost. There, an understory of dead brush has created a fuel ladder extending from the ground to the tree canopy. Effects of early silvicultural treatment were striking on both soils. Standing volumes were as much as 10-times greater than for the untreated controls on the Mariposa soil, and double those of controls on the better Cohasset. With appropriate treatment, growth on both soil types exceeded those projected by yield tables. The Balderston study offers managers clear choices in shaping the course of their future forests. However, long-term studies are difficult to maintain, and the key to maintaining them is vigilance.

Introduction

Ponderosa pine (*Pinus ponderosa*) is the tree of choice for planting drier and less productive sites of California and southern Oregon. Woody shrubs such as *Arctostaphylos* sp. and *Ceanothus* sp. are common companions, often forming dense thickets following disturbance during site preparation. Such shrubs are notorious for their competitive effects, and growth reductions can be severe when shrub canopies cover as little as 20 percent of the ground (Oliver 1984, Shainsky and Radosevich 1986, White and Newton 1989). Fiske (1982) concluded that many pine plantations faced with average competition from shrubs ultimately would fail. But as Tappeiner et al. (1992) have stated, a weakness of shrub competition

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studies is that they are short-term and the net effect of shrubs on long-term plantation development is uncertain.

The oldest shrub control studies in California pine plantations lead to differing conclusions. McDonald and Powers (2003), reporting findings from a low productivity site in the Cascades, showed that trees growing with dense shrub cover produced less than 1 percent of the volume of trees growing free of shrub competition for 30 years. Oliver (1990), reporting 20-year findings from a much more productive Sierra Nevada site, found that stands with dense shrub achieved more than half the volume of brush-free stands and that the practical effect of brush competition was a lengthened rotation. Such long-term studies raise questions about the universality of shrub control prescriptions and how site quality influences long-term silvicultural response. This paper addresses these issues.

Balderston Plantation

Background

Our site is an 80-acre ponderosa pine plantation growing on the western slope of California's Sierra Nevada at 3,200 feet elevation on the Georgetown Ranger District of the Eldorado National Forest. The climate is typically Mediterranean, meaning that summers are warm and droughty while winters are cool and wet. Precipitation begins in late fall and averages 53 inches annually. Of this, about half falls as winter snow. The forest type is lower elevation mixed-conifer. Wildfire in 1947 led to a brushfield dominated by whiteleaf manzanita (*Arctostaphylos viscida*). In 1966 the area was cleared by bulldozing brush and some topsoil into windrows spaced about 1 chain apart. Clearings were planted the following spring with ponderosa pine at an 8-foot spacing. A release spray of 2,4,5-T was applied in 1968 to reduce brush reinvasion.

The herbicide treatment was ineffective and by 1975 manzanita again dominated the site. Planted tree survival was satisfactory, but growth was poor and many trees were chlorotic on the western half of the plantation. Closer inspection revealed that the area was underlain by two distinct and contrasting soil series. The western half contained the Mariposa series (fine-loamy, mixed, mexic, ruptic-lithic-xerochreptic Haploxerults) formed from Paleozoic marine sediments. Soil on the eastern half was classified as the Cohasset series (fine-loamy, mixed, mesic, ultic Haploxeralfs) formed from a Pleistocene andesitic mudflow. The Mariposa series was a poorer soil. It averaged about half the effective profile depth of the Cohasset, had a higher gravel content, lower available water holding capacity, and tested much lower in an anaerobic index of soil N availability (Table 1). Foliar N concentrations verified the soil tests, indicating severe N deficiency on the Mariposa series and borderline deficiency on the Cohasset series where trees were darker green. Clearly, the Mariposa and Cohasset series presented strong contrasts in soil fertility. Trees of the same age growing on a geologic contact between contrasting soils and governed by the same local climate made the site extremely attractive for addressing the following questions:

1. How severely are young trees affected by brush competition?
2. Will N fertilization affect growth rates?
3. Is there an interaction between brush competition and N fertilization?

4. Do effects vary by site quality?

As we will see, we now can address a fifth question:

5. How long do treatment effects last?

Table 1. Characteristics of the Balderston Plantation study site at the start of the study.

Characteristic	Soil series	
	Mariposa	Cohasset
Parent material	Marine metasediments (Paleozoic Era)	Andesitic mudflow (Pleistocene Epoch)
Soil classification	Haploxerults, ruptic-lithic	Ultic Haploxeralfs, loamy
Gravel content (%)	25+	5-10
Soil depth (feet)	2-3	4-6
Available water-holding capacity (inches)	4.3	5.7
Mineralizable soil N (ppm)	3	10
Mean tree height (feet)	4	6
Foliar N concentration (%)		
Current foliage	0.83	1.12
Year-old foliage	0.76	0.92
Brush biomass (tons/acre)	8.7	12.5
Estimated site index (feet at 50 years)	35	76

Treatments

One-tenth acre treatment plots were established on each soil series in 1975 at the end of the 9th growth year. Brush was removed manually on half of the plots. Based on sample weights taken in the field we estimated brush dry mass to average 9 tons per acre on the Mariposa soil series and about one-third more on the Cohasset (Table 1). Brush removal or retention treatments were crossed with three rates of N fertilization (0, 200, and 400 lbs N per acre) applied by hand as urea. Each treatment was replicated three times in a blocked design, producing 18 plots on each soil series. To our knowledge, this was the first plantation experiment of this type in the West.

The experiment was meant to run 5 years and we had no plans for measurements beyond that. But because of their historical significance and demonstration value, the Georgetown Ranger District agreed at our urging to protect the plots from other uses. In fall 1986, when stands were 20 years old and about a decade after the original treatments, some replicates of the original plots were retreated. On the Mariposa soil series, a third of the replicates on which brush had previously been removed received no further treatment. Another third received a second brush removal treatment. The final third received brush removal and an additional 200 lbs of N per acre. Plots on the Cohasset soil series were treated similarly with one exception. On the Cohasset series, stands were approaching canopy closure on all treatment plots and the Ranger District precommercially thinned each plot from below, leaving about half of the original number of trees. No records were kept of thinning volumes, and slash was left to decompose on the plots.

Data collection

Measurements taken regularly for the first 5 years included breast height diameter, height, and nutrient concentrations in current and 1-year-old foliage of trees, as well as N concentrations in the soil solution. A grant from the Sierra-Cascade Intensive Forest Management Research Cooperative allowed us to remeasure trees in fall 2000. Because ponderosa pine produces one whorl of branches each year, we were able to reconstruct cumulative height growth patterns for each individual tree. Several of the plots were remeasured in fall 2003 to provide updated data for this conference. Thus, the most recent measurements were at stand age 37 years, 28 years after the original treatments.

Results

After 5 Years

We soon noted that trees on one of the treatment blocks on the soils classified as Cohasset were growing at a slower rate than the others. Closer inspection proved the soil to actually be the Jocal series which formed in a contact zone between the volcanics and the metasedimentaries. Although the Jocal and Cohasset series are both deep and well drained, Jocal is sufficiently different that this block of treatments was dropped from further measurement and these plots were not included in retreatment.

Responses in the first year following treatment were striking enough to justify publication (Powers and Jackson 1978). Needle fascicle weight was increased substantially by brush removal and increased even more when brush removal was combined with fertilization (fertilization alone had no effect on first-year growth). Five-year volume responses were examined through analysis of variance. Despite a severe and obvious N deficiency, trees on the Mariposa soil did not respond to fertilization unless it was combined with brush removal (Figure 1). First-year gains in fascicle weight triggered by brush removal and by combined treatments forecasted sizable gains in stem volume. Five-year volume increment was tripled by brush removal and increased 9-fold when brush removal was combined with fertilization. On the Cohasset series, both N fertilization and brush removal individually increased 5-year volume growth, but the loss of one replicate precluded significance at $\alpha = 0.05$ (differences were significant at $\alpha = 0.10$). Fertilizing at rates greater than 200 lbs N per acre did not increase growth. Given that trees on even the most productive treatment were well-short of commercial size, the question remained as to how long the treatment responses last.

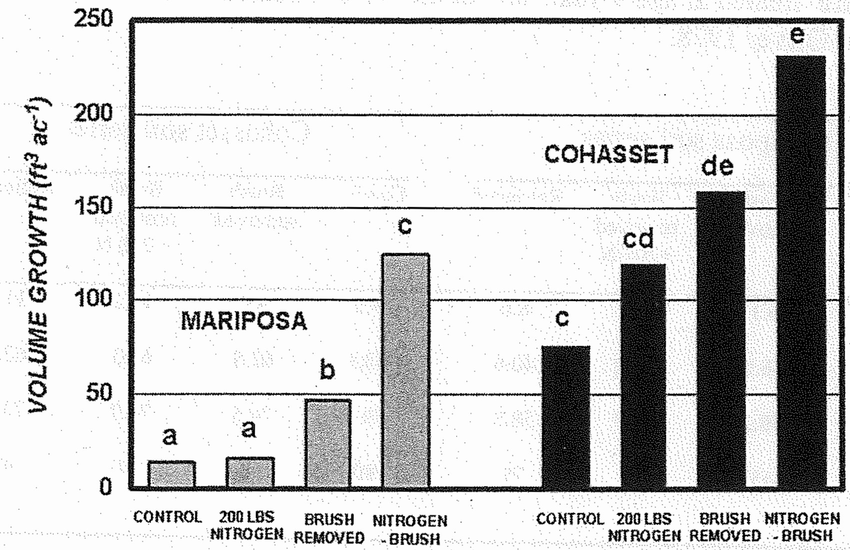

Figure 1. Five-year volume growth at Balderston Plantation between years 9 and 14. Means not sharing common letters differ at $\alpha = 0.05$ by Fisher's protected LSD. From Miles and Powers 1988.

After 28 Years

Treatment had no obvious effect on survival. Even on control plots, most trees present in 1976 were still alive in 2003 unless removed by thinning. Unfortunately, some treatment plots on the Mariposa soil series were lost inadvertently in recent years to operational brush clearing. While loss of replication precluded meaningful tests of statistical significance, plots that did survive offered a rare glimpse into the long-term consequences of early stand treatment.

By age 37, nearly three decades after the initial treatments, effects of N fertilization no longer were evident on either soil unless brush also had been removed. Trees on the Mariposa soil series released from brush competition at age 9 had mean stand diameters and heights twice as great as those on untreated controls (Table 2). Those receiving the combination of brush removal and fertilization had greater mean stand diameters than those receiving brush removal only. On the poorer Mariposa soil, trees receiving brush removal and fertilization at age 9 and then retreated at age 20 were substantially larger than in any other treatment. On the more productive Cohasset soil, retreatment held no advantage over a single early combination of brush removal and fertilization (Table 2). When the three tallest trees per plot were averaged (equivalent to the 60 tallest trees per acre), all treatments (particularly brush removal) produced an apparent increase in site index.

Table 2. Mean stand diameters and heights at 37 years on two soil series at Balderston Plantation. Plots were treated at age 9 years and some were retreated at age 20. Site index based on Powers and Oliver 1978.

Stand mean	Mariposa soil series				Cohasset soil series			
	Control	Brush removed	Brush removed +200 N	Retreated	Control	Brush removed	Brush removed + 200 N	Retreated
Diameter breast ht (in.)	3.0	6.1	7.0	8.6	7.9	9.9	12.2	11.7
Total height (ft)	15.4	36.9	31.2	40.6	48.9	62.8	63.3	62.0
Dominant height (ft)	20.6	49.2	41.7	58.8	59.6	74.5	70.7	73.4
Apparent site index (ft/50 yr)	26	65	57	79	80	99	94	97

An apparent rise in site index could reflect two possibilities: a rise in height growth rate that continued, or a jump that was short-lived and eventually paralleled that on untreated plots. Cumulative height growth patterns of dominant trees were compared on control and brush removal treatments (Figure 2). On the Mariposa soil, growth rates increased following initial brush removal and continued to separate from those remaining under brush competition (Figure 2A). On the Cohasset soil (Figure 2B), differences were less striking and plateaued about a decade after release from brush. Following that, height growth patterns for treated and untreated plots were essentially parallel.

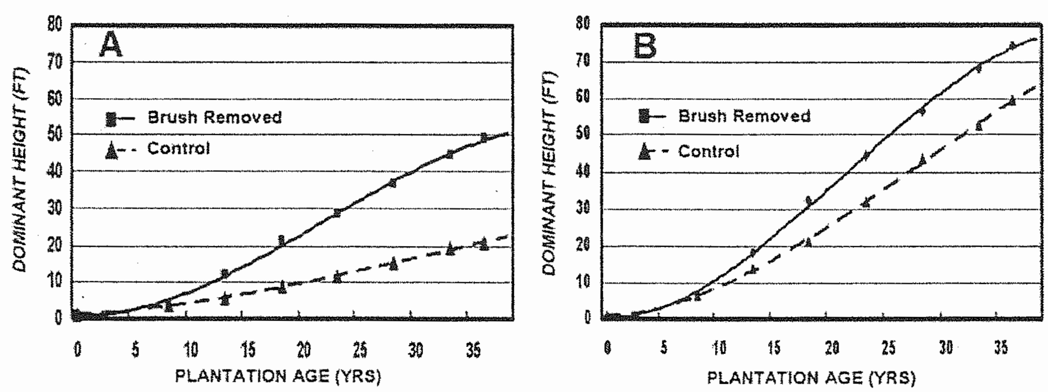

Figure 2. Effect of brush removal at 9 years on cumulative height growth of dominant trees for two soil series at Balderston Plantation. (A) Mariposa series. (B) Cohasset series.

As suggested in Table 2, combining brush removal with N fertilization had no substantive long-term influence on stand volume growth over brush removal, alone. However, early benefits of brush removal on stand volume growth continued to be obvious at stand age 37

(Figure 3). On the Mariposa soil, stand volumes were increased nearly 9 fold by a one-time removal of brush, amounting to a net gain in increment of 1,440 $ft^3\ ac^{-1}$. The same treatment on the Cohasset soil led to gains that were proportionally less (78 percent greater than the control), but nearly twice as great in absolute increment (2,340 $ft^3\ ac^{-1}$). Thus, for the same cost of silvicultural investment, wood production returns on the more productive Cohasset soil were 52 percent and 32 percent greater from brush control and retreatment, respectively than on the less-productive Mariposa.

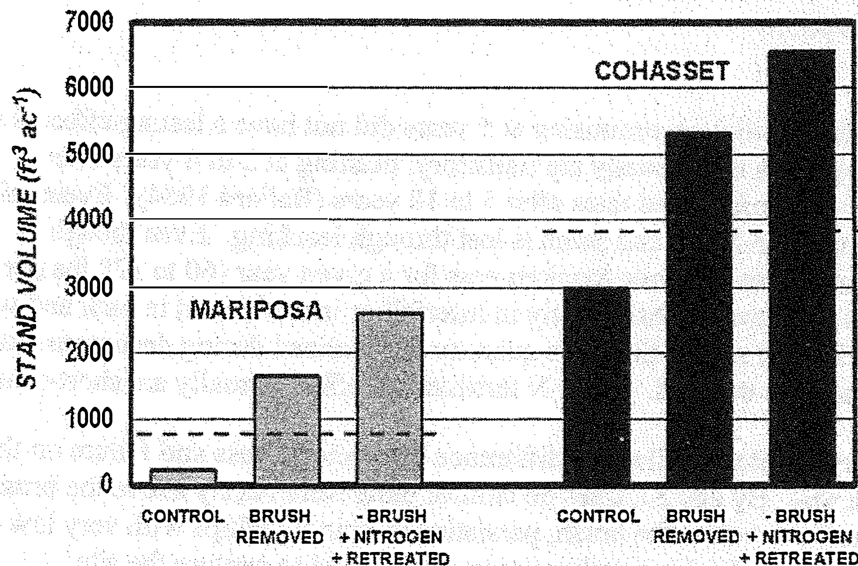

Figure 3. Standing volume at 37 years for two soil series at Balderston plantation following brush removal at age 9 and brush removal plus N fertilization at age 9 plus retreatment at age 2[illegible]. Dashed lines indicate yield projections for each site index and spacing (Oliver and Powers 1978).

Discussion and Conclusions

Results After 5 Years

Despite extreme soil infertility, trees on the Mariposa soil series did not respond to N fertilization unless fertilization was combined with brush removal. This classical case of the "Principle of Limiting Factors" illustrates the overriding importance of plant competition for moisture and nutrients on droughty sites. In their comparison of plantations growing along an environmental gradient, Reynolds and Powers (2000) showed that moisture stress develops quickly on droughty sites. Although stomatal conductance, transpiration, and net assimilation rates were similar on all sites in the spring when soil moisture was high, rates on droughty sites fell well-below those on better sites by mid-summer. McDonald and Fiddler (1990), Petersen et al. (1988) and Shainsky and Radosevich (1986) have shown the ability of woody shrubs to reduce soil water availability to young trees. Powers and Ferrell (1996) found that [illegible]-year-old pines growing in brush on a droughty site were not affected by fertilization, but that manzanita leaf mass and area were doubled by fertilization, transpiring water, creating water stress in trees, and blocking N uptake.

The unusual situation presented by the Balderston study is that soils of contrasting fertility and moisture storage occur side-by-side. Because climate and plantation age are identical for the two soils, differences due entirely to soil type can be examined without confounding. On the more productive Cohasset soil, trees responded positively to fertilization as well as to brush removal. Although the Cohasset soil was more fertile than the Mariposa, trees responded well to fertilization because soil moisture was less of a limiting factor. Similar positive responses to fertilization and to brush removal have been found on other Cohasset soils but not on poorer soils (Powers and Ferrell 1996, Powers and Reynolds 1999). For the short term at least, fertilization and brush control treatments seem to be additive on better sites and synergistic on poorer.

Results After 28 Years

The fact that initial N fertilization so promising at 5 years did not have a lasting effect is not surprising. Growth responses to N usually are transitory, peaking at 2 to 4 years after treatment, and declining to unfertilized rates after 5 to 10 years (Ballard 1984). Eventually, N is immobilized into organic forms and some is lost through leaching. Even though fertilization rates commonly exceed tree requirements for a given year (60 to 120 lbs per acre per year), much of this is returned subsequently in litterfall or immobilized in bark and wood. Of the amount returned to the soil in litter, the quantity mineralized during decomposition is only a fraction of annual tree demand. Thus, N fertilization effects usually are short-term.

On the other hand, brush control spelled the difference between success and failure on the poor quality Mariposa soil. By age 37, trees on control plots were barely above the brush canopy and many trees were below the brush, persisting as spindly whips with very low needle retention (Figure 4A). Lacking early release, trees failed to capture the site. Untreated stands on Mariposa soil remain nearly impenetrable manzanita brushfields with little hiding cover or forage that might justify wildlife value. Untreated, such plots persist as tinder poised for the next visit by wildfire. By contrast, trees on the more productive Cohasset soil overtopped the brush within 2 decades (Figure 2B). Crowns closed and the understory of manzanita and *Ceanothus integerrimus* soon succumbed to shading. Despite this, woody brush skeletons persist, creating a continuous ladder of dry fuels between the ground and the tree canopy (Figure 4B).

The fact that Mariposa trees competing with brush remained stunted explains the apparent differences noted in site index between treated and untreated trees (Table 2). Rather than truly improving site quality, brush control (with or without fertilization) simply allowed released trees to express inherent site potential. The same was true on the Cohasset soil. A jump in height growth lasting less than 2 decades simply allowed released trees to approach site potential. Oliver (1990), studying a plantation on a more productive site at Challenge Experimental Forest, concluded that brush control simply delays stand development and that the time needed to reach a particular target tree size may take 7 to 13 years longer, depending on spacing. We agree that this probably is universally true for very productive sites. For poor sites, it is not true. We conclude that without brush control, a target tree size on poor sites may never be achieved. Our conclusions are supported by even longer-term studies of shrub control on a poor site near Mt. Shasta (McDonald and Powers 2003). On poor sites, trees will not overcome the tremendous competitive influence of aggressive woody shrubs.

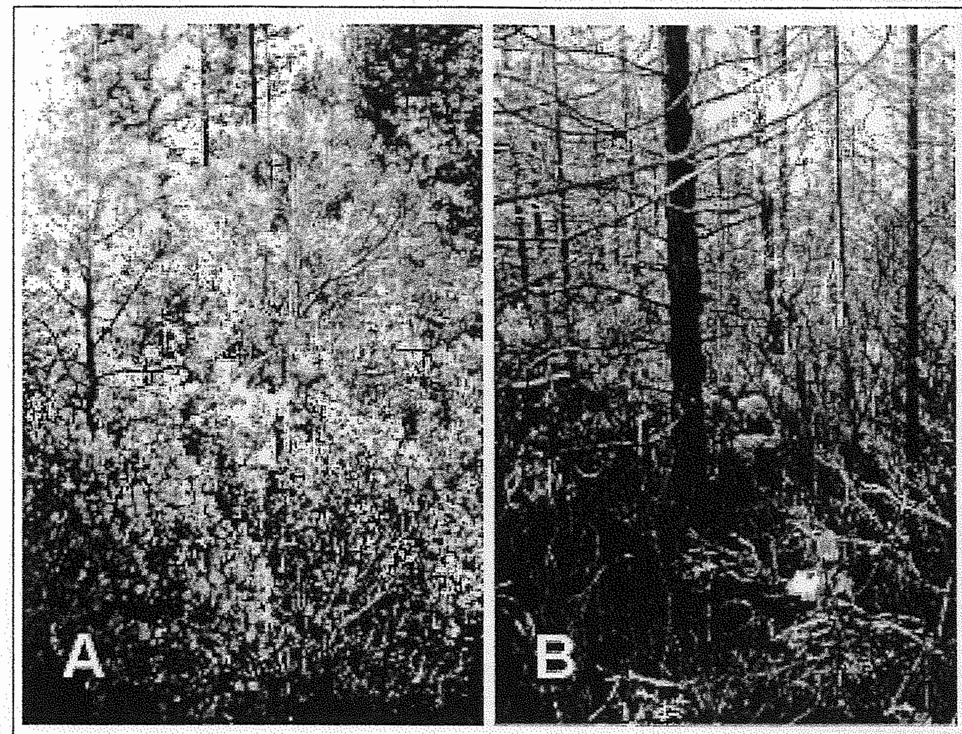

Figure 4. Control (untreated) stands at 37 years at Balderston Plantation. (A) Mariposa soil series. Only a few trees have overtopped the brush. (B) Cohasset soil series. Although understory shrubs have been shaded out by canopy closure, a fuel ladder persists.

The potential that could be realized through active management is illustrated in Figure 5. Stands released from early brush competition quickly close canopies, creating forest-like conditions. Herbs and grasses appear seasonally because of the sheltering influence of the high canopy. Volume increases are substantial, with mean annual increments averaging between 45 and 70 ft^3 ac^{-1} on the Mariposa soil series, depending on treatment. On the Cohasset series, net volume increments are even greater, varying between 144 and 178 ft^3 ac^{-1}, not counting the increment removed in thinnings.

Put simply, early brush control spelled the difference between success and failure on the droughty and infertile Mariposa site. On the better Cohasset site, tree canopies did close without brush control and trees did dominate the site. Despite crown closure, stands on Cohasset remain at high risk to ground fire because a persistent fuel ladder connects the ground with the forest canopy. Ladder fuels are absent in plots receiving early shrub treatment. Our long-term findings also may be useful to managers in ranking plantations for silvicultural investment. For example, poorer sites might receive high priority for vegetation control following reforestation after wildfire because treatment delays increase the likelihood of plantation failure. If the objective is growth and yield, better sites will provide much higher returns on intensive silvicultural investments.

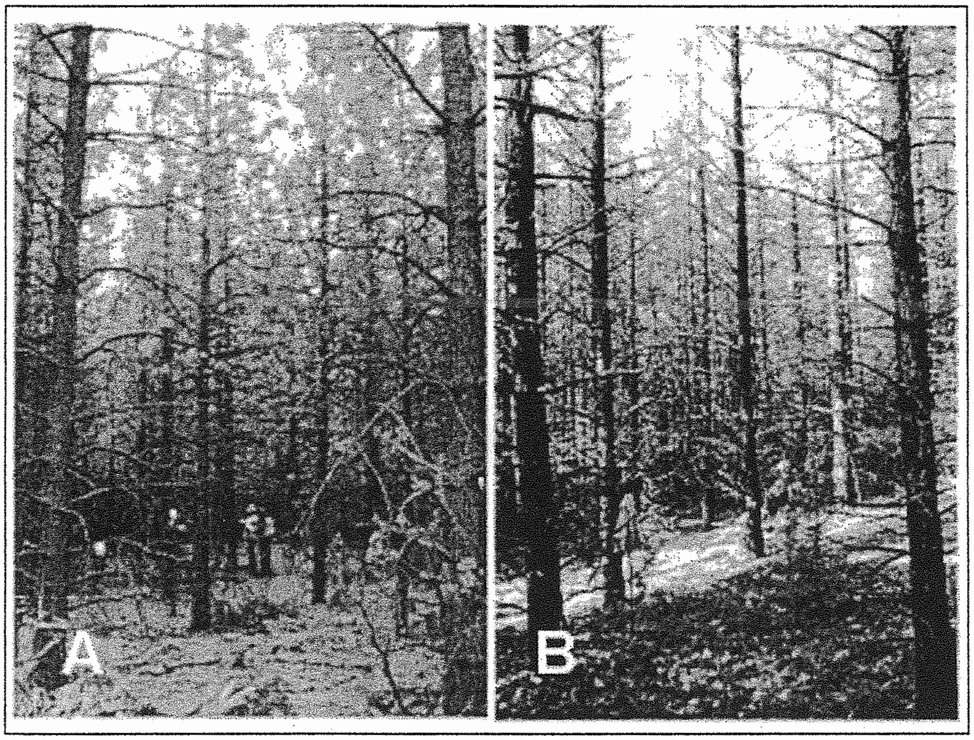

Figure 5. Thirty seven year old stands fertilized and released from brush competition at 9 years, and thinned and retreated at age 20. (A) Mariposa soil series. (B) Cohasset soil series.

Acknowledgments

We express our appreciation to Gary Cabodi, Culturist on the Georgetown Ranger District, Eldorado National Forest (retired) for his diligence in seeing that the Balderston Plantation plots were protected. We also are indebted to Jerry Anderson (retired) who served as Eldorado National Forest Soil Scientist and Regional Soil Scientist during the early stages, for supporting the experiment in many ways. Bud Veirs (Eldorado Forest Silviculturist) and Duane Nebeker (retired) were timber management specialists on the Eldorado and , along with Grant Jackson (currently, Montana State University), were instrumental in establishing the original treatment plots, and their efforts are most appreciated. Remeasurements were made possible by funding through the Sierra-Cascade Intensive Forest Management Research Cooperative and through the National Fire Plan.

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