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VEGETATIVE COMPETITION, SITE-PREPARATION, AND PINE PERFORMANCE: A LITERATURE REVIEW WITH REFERENCE TO SOUTHCENTRAL OREGON

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INTRODUCTION

An increasing demand for forest products and a declining forest land base are often cited as the reasons for intensifying management of commercial timberlands in the United States (Ellefson 1973). Recently, the national goal of increased exports, coupled with renewed use of wood for energy, has stimulated more intensive timber management (Haines 1981). The first step to improving productivity is prompt establishment of a fully stocked stand of trees after harvest or the natural demise of the previous stand. Failure to regenerate stands immediately can result in substantial losses in time, value, and volume yield (Brodie and Tedder 1982). Legal as well as economic reasons encourage prompt reforestation; many states, including Oregon, now require successful reforestation within a specified period of time following harvest operations.

Planting nursery stock is the most dependable method of regenerating lodgepole (Pinus contorta Dougl. ex Loud.) and ponderosa (Pinus ponderosa Dougl. ex Laws.) pines in southcentral Oregon (Adams 1970, Barrett 1979, Lotan and Perry 1983, Roy 1983). Natural regeneration can be slow and unpredictable (Cochran 1973a, Harrington and Kelsey 1979).

Most areas that need reforestation in southcentral Oregon require some type of site preparation, unless the area has been burned recently (Zavitkovski and Woodard 1970, Barrett 1979). Spot treatments to control vegetation around planted seedlings have generally been ineffective in this region; more comprehensive site preparation is usually required to ensure the survival and adequate growth of pine seedlings (Dahms 1950, Roy 1953, Baron 1962, Loewenstein et al. 1968, Larson and Schubert 1969, Bentley et al. 1971, Stewart and Beebe 1974, Thompson 1974, Clark and McLean 1975, Barrett 1979, Crouch 1979, Tappeiner and Radosevich 1982, McDonald 1983, Ross et al. 1986).

Site preparation is any measure used to prepare a site for either natural or artificial regeneration of a forest stand (Dingle 1976, Stewart 1978). It encompasses a diverse group of activities that may be used singly or in various combinations to remove flammable logging residues or other debris, suppress competing vegetation, alter animal habitat, prepare a mineral soil seedbed or open planting spots, improve soil conditions, create a favorable seedling microsite, or control disease and insects. Site-preparation requirements depend primarily on the crop tree species, the post-harvest conditions, the method of regeneration, and both the biotic and the abiotic environment of the specific site. In southcentral Oregon, the primary objective of site preparation usually is to reduce competition for limited soil moisture, light, and nutrients, so that planted conifers have a better chance of development. Secondary objectives include increasing access, facilitating planting, reducing flammable material, altering the habitat of pest animals to reduce seedling damage, and improving physical conditions of the soil (Crouch 1979, Lindstrand 1983).

The general types of site preparation available to forest managers include mechanical and chemical methods and prescribed burning. Biological methods involving livestock grazing constitute a possible fourth category. Cattle and sheep effectively suppress undesirable vegetation in young plantations (Krueger 1983, Sharrow and Leninger 1983, Monfore 1985), although more studies are needed to document the response of crop trees to livestock grazing. Also, since grazing is usually applied after the crop trees are established, it is more appropriately categorized as a release treatment.

Foresters in southcentral Oregon rely primarily on mechanical and, to a lesser extent, chemical methods of site preparation for vegetation control. Scarification by bulldozers equipped with brushrakes is the most common method of preparing pine sites for planting (Adams 1970, Schubert and Adams 1971, Stewart 1978). Logging debris and vegetation are pushed into piles or windrows, and the organic debris is either left to decompose or burned. However, concern has increased that intensive mechanical site-preparation treatments could reduce long-term site productivity by altering physical and chemical soil properties (Haines et al. 1975, Will and Youngberg 1978).

Because of the potential for fires to escape in arid climates, foresters in this region have approached prescribed burning cautiously. However, recent research indicates that opportunities for safely using prescribed fire in this region to control competing vegetation during regeneration of ponderosa pine may be greater than were previously recognized (Martin 1982, Kauffman and Martin 1985a,b).

Reforestation costs are of major concern to foresters. These costs must be carried for a long time, and the rate of return on investments can be relatively low (Newton and Webb 1970). As a result, foresters must critically assess the cost/benefit ratio associated with reforestation treatments. The increases in wood production anticipated from site preparation must be great enough to justify its cost economically. Even federal agency foresters, who are not profit-oriented, need to insure that they are getting the best survival and growth possible with their budgets. Therefore, conifer performance should be evaluated over a long period of time to determine whether early increases in survival and growth resulting from site preparation will be maintained throughout the rotation.

DESCRIPTION OF THE KLAMATH REGION

Geology

Southcentral Oregon encompasses Klamath and Lake Counties, located in the western third of the Basin and Range Province. This physiographic province is characterized by northwest-trending, fault-block mountains with steep scarp slopes surrounding internally drained valleys. Elevations range from about 3,930 ft[1] to over 8,200 ft. The region has a long and complex geologic history, but the present geomorphology is primarily the result of volcanism and faulting during the last 2 million years (Duncan and Steinbrenner 1975).

Duncan and Steinbrenner (1975) divided this province into the high lava plains and the rimrock valleys. Most of the commercial timberland is found in the high lava plains. Slopes on the plains are generally less than 20 percent and rarely exceed 40 percent (Duncan and Steinbrenner 1975, Wenzel 1979).

Soils developing on the lava plains are derived from fine volcanic ash over deeply weathered basalt, andesite, tuffs, and buried soils. These soils are generally medium-textured, stony, and reddish brown (Wenzel 1979). Within the basalt plains are pockets of rhyolitic rocks associated with dome-shaped eruptive centers. Soils originating from this parent material are shallow to moderately deep, coarse-textured, gravelly, and weakly developed. Meadows interspersed throughout the region are found on clay-textured soils that developed where shallow lakes once existed (Duncan and Steinbrenner 1975). Soils in this region have been described and mapped on the Klamath Indian Reservation (U. S. Bureau of Indian Affairs 1958), the Weyerhaeuser Company's Klamath Tree Farm (Duncan and Steinbrenner 1975), and the Fremont National Forest (Wenzel 1979).

Climate

The climate of southcentral Oregon is influenced by both maritime and continental air masses, buffered by the Cascade Range to the west, the Rocky Mountains to the east, and other lesser mountain ranges (Franklin and Dyrness 1973). Moving from the Cascades eastward, there is a general trend of decreasing precipitation, increasing summer temperatures, and decreasing winter temperatures. Variations in precipitation and temperature occur along this west-east gradient in response to local topographic features. The rain shadow created by the Cascade Range limits annual precipitation to 10 to 20 inches. Precipitation is somewhat seasonal, with 55 to 75 percent occurring between October 1 and March 31, most of it as snow. Summer months are dry (1 to 3 inches of rainfall), with the only precipitation occurring as thunderstorms. Frost can occur any night of the year.

Characteristic Vegetation

In much of the Pacific Northwest, typical plant communities have been characterized to facilitate land management decisions. Dyrness and Youngberg (1966) described six plant communities within the ponderosa pine and white fir (Abies concolor [Gord. & Glend.] Hildebr.) zones of southcentral Oregon in relation to soil properties. Dealy (1971) identified plant communities around Silver Lake (Lake County, OR) with respect to the management of mule deer habitat. Franklin and Dyrness (1973) reviewed the ecological literature covering the plant communities and successional patterns in eastern Oregon. Comprehensive descriptions of plant communities in southcentral Oregon can be found in the Area Guides for this region published by the U.S.D.A. Forest Service (Volland 1976, Hopkins 1979a,b).

Changes in moisture availability and, to a lesser extent, temperature regimes along altitudinal gradients are important determinants of vegetation patterns in southcentral Oregon. The vegetation at any particular location depends upon the interaction of climatic and edaphic factors. Forests are usually restricted to the higher elevations, where soil moisture is sufficient for reproduction and survival. The most commercially important tree species in this

[1] See Appendix 1 for English-to-metric conversion factors and abbreviations.

region are ponderosa pine, lodgepole pine, Douglas-fir (Pseudotsuga menziesii [Mirb.] Franco), and white fir. At lower elevations, the forests are replaced by shrub-steppe communities composed of sclerophyllous shrubs and herbaceous species characteristic of xeric habitats. At the interface between the forests and shrub-steppes, an open savanna region dominated by western juniper (Juniperus occidentalis Hook.) is sometimes present. Common woody shrubs that are found alone or in association with trees include greenleaf manzanita (Arctostaphylos patula Greene), snowbrush (Ceanothus velutinus Dougl. ex Hook.), antelope bitterbrush (Purshia tridentata [Pursh] DC.), rabbitbrush (Chrysothamnus spp.), curlleaf mountain-mahogany (Cercocarpus ledifolius Nutt.), currant (Ribes spp.), big sagebrush (Artemisia tridentata Nutt.), squawcarpet (Ceanothus prostratus Benth.), snowberry (Symphoricarpos spp.), serviceberry (Amelanchier spp.), and cherry (Prunus spp.). Two important forbs are mullein (Verbascum spp.) and thistle (Cirsium spp.). Grasses from the genera Agropyron, Bromus, Festuca, Poa, Sitanion, and Stipa, as well as sedges (Carex spp.), are found throughout the region.

History of Land Use

The available evidence indicates that none of the Indian tribes which inhabited the region for some 5000 years (Good 1941) had a significant impact on the vegetation of the region. Prior to the arrival of settlers, fire was the major determinant of vegetation in this area (Johnson and Smathers 1976). Most fires were started by lightning, but Indians probably caused some fires, either intentionally or by accident (Weaver 1943). Frequent, low-intensity ground fires resulted in grassy ponderosa pine forests with an open, park-like stand structure.

Grazing in the Klamath Region began in the mid-1850's. Large herds of cattle grazed the open range in the southern portion of Klamath County beginning around 1870. Overgrazing of the rangeland over the next 60 years (Volland 1963) enabled woody species such as western juniper to invade the bunchgrass-sagebrush communities (Johnson and Smathers 1976). Also during this period, many exotic species were introduced that rapidly invaded the disturbed natural ecosystems. One of the most successful introduced species was downy brome (Bromus tectorum L.), a dominant component of some plant communities in this region today (Morrow and Stahlman 1984). In 1930, the Indian Service began regulating grazing on the Klamath Indian Reservation. In 1961, the U.S.D.A. Forest Service purchased much of the land that was previously the Klamath Indian Reservation, and this agency now regulates grazing on these lands.

Logging began in the Klamath Region in 1863, when the U.S. government built a small mill at Fort Klamath (Good 1941). Several other small mills began operating in the next decade, but logging did not begin in earnest until the railroad reached Klamath Falls in 1909. Between 1910 and 1923, logging in the Klamath Region increased dramatically, with the construction of 39 mills and 8 box factories employing a total of about 4,200 people. The opening of the Weyerhaeuser Company plant in Klamath Falls in 1931 represented a significant addition to the regional lumber industry.

Logging on private lands in the early 1900's has been described as economic clearcutting (Barrett 1979). The high fixed costs of railroad logging prompted heavy cutting to make the operation profitable. After World War II, log trucks and crawler tractors replaced railroad logging, and a trend toward lighter cuttings evolved (Barrett 1979). Lighter cuttings provided an opportunity to rapidly develop the road system needed to increase access to the timber resource and to improve wildfire suppression in the valuable uncut forests. Extensive bark beetle (Dendroctonus spp.) infestations led to sanitation-salvage and presalvage cuttings as a means to utilize beetle-killed trees, as well as to prevent future losses to bark beetles. These cutting practices, based on the tree-vigor classification system of Keen (1943), were common until the early 1960's. Harvesting since that time has been largely based on a minimum diameter limit, with the limit set by market conditions.

Forest fire prevention activities developed concurrently with the logging industry. Although successful at reducing the incidence of severe wildfires, fire control has created dense conifer understories and shrub communities, buildup of dead fuels, and increased long-term risk of more destructive fires (Weaver 1961, Johnson and Smathers 1976).

Present Status of Timber Resources

An estimated 10.1 million acres of unreserved commercial timberland lie east of the crest of the Cascade Range in Oregon (Farrenkopf 1982). Over 3.0 million acres (29 percent) of this commercial forest land are located in Klamath and Lake Counties. Of the 10.1 million acres of commercial timberland, approximately 7.6 million acres (75 percent) are public land and the remainder are privately owned. In Klamath and Lake Counties, however, about 40 percent of the commercial timberland is privately owned. Most of this area is industrial forest land; over half of the industrial forest land in eastern Oregon is located in Klamath and Lake Counties.

The two most common forest types in eastern Oregon are ponderosa and lodgepole pine. Ponderosa pine occupies 4.3 million acres of commercial timberland and lodgepole pine is found on another 2.5 million acres. These forest types account for over 60 percent of the commercial timberland in eastern Oregon (Farrenkopf 1982). However, selective harvesting and fire control are reducing the area dominated by ponderosa pine (Barrett 1979). Such practices have allowed more shade-tolerant true firs and Douglas-fir to become established in the understory of ponderosa pine forests. After overstory removal, the areas become occupied by mixed conifers.

Timberland in eastern Oregon is generally less productive than timberland in more favorable environments. About 21 percent of the commercial forest land is capable of producing at least 85 ft^3 of wood/acre/yr, and another 49 percent is capable of producing 50 to 84 ft^3/acre/yr. The remaining 30 percent of the land produces less than 50 ft^3/acre/yr (Farrenkopf 1982).

The estimated total volume of growing stock on commercial timberland in eastern Oregon is 21 billion ft^3 (Farrenkopf 1982). Ponderosa and lodgepole pines constitute over 50 percent of the total growing stock volume. About 25 percent of the total growing stock volume is located in Klamath and Lake Counties.

The annual timber harvest in eastern Oregon has fluctuated around 2 billion board feet (Scribner scale) since the late 1960's (Farrenkopf 1982). In recent years, annual harvest has exceeded net annual growth by nearly 50 percent in this part of the state. This current imbalance between growth and harvest is because much of the harvest comes from old growth stands (Barrett 1979). Eventually, net annual growth should equal or exceed annual harvest as vigorous young stands replace overmature stands.

EFFECTS OF ASSOCIATED VEGETATION ON PINE PERFORMANCE

Herbaceous and woody vegetation can have deleterious effects on the survival and growth of pine seedlings in two ways. More importantly, competition can limit the availability of resources required for proper physiological functioning of the seedlings. Without an adequate supply of moisture, nutrients, light, and space, seedlings may grow at a rate well below their optimum, or even die. Secondly, certain vegetation types may create a suitable habitat for insect and animal pests with the potential to damage or kill young seedlings. Local populations of these pests can seriously threaten reforestation efforts (Black 1970, Brodie et al. 1979). Research throughout the range of ponderosa pine has shown that effective vegetation control increases site resources available to pines and reduces damage caused by destructive animals.

An early attempt to quantify the competitive effects of vegetation involved the impact of manzanita and snowbrush on the establishment and growth of ponderosa pine in central Oregon (Dahms 1950). This study indicated that brush had no effect on natural regeneration of pines but greatly reduced the growth of established seedlings. Furthermore, manzanita reduced height growth of pines more severely than did snowbrush.

Two early studies in northern California observed the effects of competing vegetation on the survival of planted ponderosa pines. Roy (1953) found that 2-year survival of planted pines decreased consistently as the ground cover of shrubs and grasses increased. Baron (1962) found the survival of pine seedlings planted in a mixture of 1-year-old grasses was 20 percent, compared to 70 percent where grasses were absent.

More recent research has attempted to identify the site resources limiting the survival and growth of ponderosa pine and to quantify more precisely the effects of competition on pine performance. In dry areas, the most important factor influencing survival and growth of pine seedlings is the availability of soil moisture. Many studies have shown that competing vegetation can significantly reduce soil moisture throughout the growing season.

Impact of Herbaceous Competition

Depletion of soil moisture by grasses has been studied throughout the arid regions of the western United States. Several studies in Oregon and Washington have shown that control of grasses can increase survival and growth of planted pines. In central Washington, chemical control of grasses significantly increased survival of planted ponderosa pines (Stewart and Beebe 1974). Reduced mortality was attributable in part to less damage by pocket gophers (Thomomys sp.) and meadow voles (Microtus sp.) on the chemically treated plots. Root and stem girdling by these species was reduced by 39 percent on the sprayed plots, compared to the untreated controls.

Crouch (1979) found that atrazine treatments increased the survival and growth of ponderosa pine seedlings planted in southcentral Oregon by reducing herbaceous competition and losses to pocket gophers (T. mazama Merriam). This study, installed where the previous plantation had failed because of pocket gopher damage, achieved 55 percent survival on plots receiving a fall application of atrazine following planting, versus 25 percent on controls. The number of pocket gopher mounds was reduced approximately eight-fold on the sprayed plots. After 10 years, total height averaged 7.3 ft on treated plots and only 4.9 ft on the controls.

Inconsistent results were reported for a series of studies evaluating the effects of herbaceous vegetation control on the survival and growth of planted ponderosa pine seedlings in eastern Oregon and central Washington (Dimock and Collard 1981). The herbicide treatments resulted in a wide range of herbaceous vegetation control in each study. However, performance of conifer seedlings was improved in only two of the six trials; a mixture of dalapon and atrazine significantly improved survival in one study and greatly increased height growth in another. The authors attributed the lack of significant differences in the other four trials to the unusually cool and wet weather during the 1975 and 1976 growing seasons. Apparently, droughty conditions never occurred on these latter four sites during the study.

Heidmann (1969) compared soil moisture in undisturbed, hand-scalped, and chemically treated plots in a dense perennial grass community in an Arizona forest. The chemically treated plots had the highest soil moisture throughout the dry months for 2 years following application. Scalping increased the soil moisture content, compared to the undisturbed plots, but not as much as did the chemical treatment. The author attributed the difference to the presence of the dead grass mulch on the sprayed plots. However, the scalped plots had to be retreated three times during the 2-year study, and water use by the sprouting grass also may have contributed to the difference.

Another study in Arizona compared the competitive influence of two grasses, Arizona fescue (Festuca arizonica Vasey) and mountain muhly (Muhlenbergia montana [Nutt.] Hitchc.), on ponderosa pine seedlings (Larson and Schubert 1969). Seedlings were grown alone and in competition with each of the grasses. Root and shoot growth of pines was significantly greater in the absence of grass competition. Arizona fescue, a cool-season grower, competed more severely for soil moisture and had a greater impact on the growth of pine seedlings than did mountain muhly, a warm-season grower. Roots of both species grew 50 percent faster than pine roots and, at the end of 2 years, the dry weight biomass of grass roots was 11 to 16 times that of tree roots. As a result of more rapid root growth, the grasses depleted soil moisture faster and to lower levels than did the pines. The only pines that survived were those that had roots extending at least 16 inches below the surface, where moisture remained high for all cover types.

Eckert (1979) also showed depletion of soil moisture by perennial grasses in a forested area of Nevada. Control with atrazine resulted in increased soil moisture during the growing season for 2 years following treatment. During the first year, soil moisture tensions at the 6-inch depth were below 1.0 bar on treated and untreated plots until early June. Moisture tensions at the highest atrazine levels remained below 2.0 bars at one site and below 10.0 bars at the other site throughout the year. On control plots, however, moisture tensions exceeded 15.0 bars (permanent wilting point) by the middle of July. At the 12-inch depth, moisture tensions remained below 1.0 bar throughout the year on treated plots, but reached 15.0 bars by September 1 on the controls. Increased survival and growth of planted Jeffrey (Pinus jeffreyi Grev. & Balf.) and ponderosa pines were attributed to the more favorable moisture conditions resulting from grass control.

Published literature considering the effects of herbaceous competition on lodgepole pine is sparse. A greenhouse study in British Columbia compared the survival and growth of lodgepole pine growing in different densities of native and domestic grasses for 6 months (Clark and McLean

1975). Survival, height growth, and total biomass of lodgepole pine decreased with increasing density of grass and less frequent watering.

Impact of Brush Competition

Tarrant (1957) compared soil moisture to a depth of 24 inches under live and dead manzanita in a central Oregon brushfield. The soil moisture content was significantly lower at all depths under the live manzanita throughout the summer, becoming two to three times lower by September.

Several studies in northern California have assessed the impact of brush competition on the performance of planted ponderosa pines. Bentley et al. (1971) found that competition from manzanita and snowbrush reduced height growth of pines in a 5-year-old plantation by as much as 50 percent. Mortality from the fifth to the seventh year after plantation establishment ranged from 25 percent where brush density was high to no mortality where brush density was low.

Oliver (1979) evaluated the effects of spacing and brush control on ponderosa pine performance in a 12-year-old plantation. Total height, d.b.h., crown width, crown ratio, and branch diameter were all significantly greater where trees were free of brush competition. Losses in diameter growth were equivalent to nearly 3 years of growing time where brush density was highest. The author speculated that brush competition could delay the first commercial thinning by as much as 6 years, if the diameter growth was suppressed by the same proportion over the ensuing 15 years.

In the Sierra Nevada of California, control of bearmat (Chamaebatia foliolosa Benth.) significantly improved the survival and growth of planted ponderosa pines (Tappeiner and Radosevich 1982). After 19 years, survival was 9 percent in the undisturbed bearmat, compared to 90 percent where bearmat was completely controlled. Average height of the trees in the treated plot was 18.7 ft, compared to only 5.2 ft in the control. The authors forecast a 75 percent reduction in net wood production over a 50-year rotation as a result of bearmat competition.

Lanini and Radosevich (1986) considered the effects of shrub suppression on microenvironmental factors and on physiological responses of several conifer species in northern California. Predawn and midday water potential, total height, stem diameter, and canopy volume of conifers were greatest where shrub control was most complete. Ponderosa pine was found to be most responsive to increased light, although soil moisture was also important.

Impact of Competing Vegetation on Established Stands

Competition from woody and herbaceous vegetation also affects the growth of dominant trees. Barrett and Youngberg (1965), working in central Oregon, found that understory vegetation consumed significant amounts of water in a stand of ponderosa pine saplings thinned to different densities. Water use on plots where the understory vegetation was undisturbed was 45 percent greater than on plots where all of the understory vegetation was removed. Competition from understory vegetation had a highly significant effect on d.b.h., height, and volume growth of the pines throughout a 20-year period (Barrett 1970, Barrett 1973, Barrett 1982). Volume growth reductions caused by competition ranged from about 40 to 50 percent at the three widest spacings (250, 125, and 62 trees/acre) until 16 years after thinning.

Oliver (1984) assessed the effects of tree spacing and brush competition on growth of a ponderosa pine plantation in northern California. The 11-year-old plantation was thinned to four different densities in 1970. Five years after thinning, tree growth had declined because of competition from understory vegetation, so a brush-density treatment was superimposed on the original tree-spacing study. All, none, or half of the understory brush was removed from one-third of each spacing main plot. After 5 years, diameter, height, and volume growth of the pines were significantly greater only on the plots where all of the understory brush had been removed. Depending on spacing, complete brush removal increased diameter growth from 45 to 140 percent and height growth from 62 to 175 percent compared to tree growth on the plots where the understory vegetation was allowed to develop normally.

Powers and Jackson (1978) evaluated the response of ponderosa pine in northern California to fertilization and brush removal in a 9-year-old plantation located on two different soil types. One year after treatment, significant increases in height and diameter growth (at 30 cm) were observed only for the combination of fertilization and brush removal on the less fertile soil. On the more fertile soil, brush removal increased foliar biomass by 40 percent, although no significant differences in diameter (at 30 cm) and height growth were observed within the 1-year time frame of the study.

These studies indicate that, where woody vegetation, forbs, or grasses are present, effective vegetation control increases survival and growth of pines (Fig. 1). The choice between removing and leaving associated vegetation depends upon management objectives, environmental constraints, the species and amounts of vegetation present, the costs of alternative treatments, and the expected returns from vegetation control. However, mortality and growth losses occurring as a result of delayed or inadequate vegetation control can be considerable. The greatest benefits from vegetation management can be achieved by identifying and treating weed problems before mortality or growth losses occur. Such a program requires a thorough understanding of the ecology of all of the species in the system and a knowledge of how they will respond to disturbances.

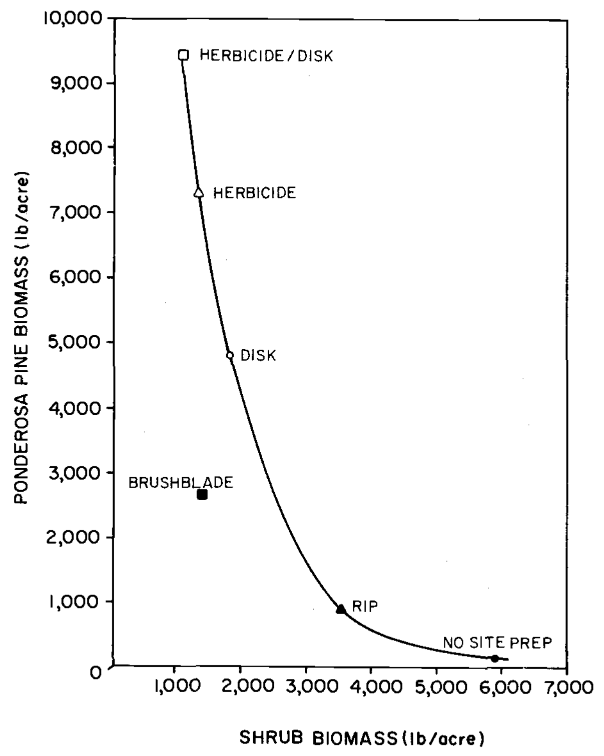

FIGURE 1.

RELATIONSHIP BETWEEN PONDEROSA PINE AND ABOVEGROUND SHRUB BIOMASS (OVEN-DRY) 8 YEARS AFTER SITE PREPARATION AND PLANTING IN SOUTHCENTRAL OREGON (SEE ROSS ET AL. 1986).

Potential Benefits of Competing Vegetation

Zavitkovski and Woodard (1970) have suggested that associated vegetation may increase the survival and growth of pine seedlings by altering the microenvironment. This conjecture is based to a large extent on ecological observations of natural plant communities, rather than of managed plantations (Conard et al. 1985).

The addition of nitrogen (N) to forest soils by species which fix atmospheric N has received considerable attention. Ceanothus spp. and Purshia spp. are N fixers in southcentral Oregon, but their importance to forest productivity is not well understood. In a workshop on Ceanothus spp., it was concluded that there was no proof that long-term nutritional benefits would balance reduced conifer growth attributable to competition from Ceanothus spp. (Conard et al. 1985). As the studies discussed previously have shown, any beneficial influence that grass and shrubs may have is likely to be more than offset by their competitive effects reducing pine survival and growth.

Vegetation control to enhance pine performance does not require complete removal of all noncrop vegetation. It is necessary only to suppress vegetation to a level that does not significantly impair pine performance. Consequently, some of the benefits conceivably associated with the presence of noncrop vegetation (e.g., nutrient production, cycling, and retention; food and cover for livestock and wildlife; aesthetic values) can be retained.

SITE PREPARATION

Methods

Site-preparation methods are broadly classified as mechanical, chemical, prescribed burning, or combinations of the three (Stewart 1978). Each category includes a large number of specific treatments. For example, mechanical treatments are available to disk, furrow, terrace, trench, strip, rip, slit, drag, chop, till, churn, pile, or crush litter, logging slash, residual vegetation, and soil (Stewart 1978). Each site is unique and requires a specific prescription (Dingle 1976). Fortunately, past research and experience have identified particular treatments that work best for certain conditions.

History

Schubert and Adams (1971) described the history of site preparation in California, a pattern similar to that in southcentral Oregon. Prior to 1930, no effort was made to prepare sites for artificial seeding or planting. By 1930, the necessity of vegetation control for regeneration of conifers on nonstocked lands was apparent. Mechanical methods of site preparation were developed first. Between 1930 and 1945, attempts to reforest brushfields involved planting in mechanically cleared strips 6 to 8 ft wide and spaced about 20 ft apart. Survival and growth of pines in these plantations was poor because of competition from encroaching vegetation and damage from insects and animals. The failure of these early plantations indicated a need for more thorough site preparation. Since the 1950's, more comprehensive site preparation has been commonly used and has produced the most successful plantations.

Research throughout the range of ponderosa pine has consistently found partial vegetation control to be less effective than more complete treatments. In central Washington, scalping to remove all vegetation within 12 inches of seedlings did not significantly improve survival of planted pines (Stewart and Beebe 1974). After studying root growth of pines and grasses, Larson and Schubert (1969) concluded that partial site preparation would not be adequate in the Southwest. They recommended a broadcast herbicide treatment or bulldozing to prepare planting sites. In Idaho, Loewenstein et al. (1968) found that plants located more than 2 ft from pine seedlings were competing with the trees for soil moisture and nutrients. Thompson (1974) concluded from a series of planting trials with ponderosa pine in interior British Columbia that "...the more intensive the reduction [of vegetative competition] the better."

Mechanical Treatments

In the pine region of northern California and southcentral Oregon, a common method of complete site preparation has been to push the vegetation into windrows spaced at least 50 ft apart (Adams 1970, Schubert and Adams 1971, Stewart 1978). Windrowing is usually done by a bulldozer equipped with a toothed land-clearing blade, although other types of blades are sometimes used. Variable amounts of litter and topsoil are also displaced into the windrows. The organic debris in the windrows is left to decompose or is burned. In the past few years, it has become more common to push the vegetation and logging debris into circular piles instead of windrows. Survival on brushraked sites has been good, but the growth of seedlings has not been examined critically.

The Weyerhaeuser Company has identified several other mechanical treatments that are useful in southcentral Oregon (Gutzwiler 1976). On areas occupied by low brush and herbaceous vegetation, a D-9 Caterpillar® tractor equipped with an 11-ton Rome® disk and V-blade has provided good vegetation control and favorable conditions for planting. Contour ripping has been used to increase the plantability of rocky or high density soils. Ripped rows are created by a D-7 Caterpillar® or larger tractor equipped with a V-blade and pulling one or two tines extending from 18 to 24 inches into the soil. The V-blade moves organic debris and some vegetation to the side, creating cleared lanes 10 to 13 ft wide separated by rows of debris 3 to 6 ft wide. Since ripping does little to control competing vegetation or remove organic debris, it is sometimes preceded by another site-preparation activity. Other mechanical site-preparation techniques used in the Pacific Northwest are summarized by Gutzwiler (1976) and Stewart (1978).

Chemical Treatments

Chemical site preparation is applicable to most forest lands in eastern Oregon. Herbicides were first tested on brush in central Oregon in the early 1950's. Dahms (1955) reported that an aerial application of 1 lb a.e. (acid equivalent) per acre of low-volatile-ester 2,4-D caused 100 percent mortality of manzanita. This treatment killed the aerial portion of only 18 percent of snowbrush plants, but at a rate of 2 lb a.e./acre the kill increased to 48 percent. Dahms (1961) found 2,4-D and 2,4,5-T to be equally effective on manzanita when applied between early May and July. Snowbrush was more susceptible to 2,4,5-T, but 2,4-D produced equivalent control at slightly higher rates. Snowbrush sprouted after all of the treatments, indicating the need for subsequent release treatment in some cases.

Herbicides have also been used to control herbaceous vegetation. Atrazine and dalapon are used most widely for grass control on forest lands throughout the western United States (Schubert and Adams 1971, Barrett 1979). In southcentral Oregon, Crouch (1979) found that a spring application of atrazine at the rate of 4 lb a.i. (active ingredient) per acre was ineffective, but a fall application significantly reduced the cover of grasses and forbs. A second atrazine treatment in the fall of the following year further decreased herbaceous vegetation. The reduction in herbaceous vegetation following one or two fall applications of atrazine was still apparent after 10 years.

As a result of research in this region and elsewhere, herbicides are currently available that will kill or severely injure most of the important weed species in southcentral Oregon. Several publications have summarized the information concerning the efficacy and selectivity of herbicides appropriate for this region (Stewart 1976,1978, Conard and Emmingham 1983, Miller and Kidd 1983, Conard and Emmingham 1984a,b, Boyd et al. 1985).

Prescribed Burning

The use of prescribed burns for site preparation in the inland Northwest has been limited in the past by a lack of information on how and when to burn to achieve safe and effective treatment (Kauffman and Martin 1985a). Historically, foresters east of the crest of the Cascade Range have been reluctant to set fires because of unpredictable weather and fire behaviour (Schubert and Adams 1971). When conditions are safe for burning, fires may not consume enough fuel to adequately remove logging slash and control competing vegetation. Also, many of the grass and brush species that present an obstacle to reforestation are resistant to fire (Martin and Dell 1978). Although plant tops may be killed by fire, many of the shrubs and grasses will sprout. Furthermore, fire stimulates germination of dormant manzanita and snowbrush seeds. Despite these limitations, prescribed fire has been used in the inland Northwest for site preparation and may increase in importance as research progresses (Barrett 1979). The current use of prescribed fire for site preparation is described by Martin (1976) and Stewart (1978). Guidelines for planning a prescribed burn are presented by Martin and Dell (1978).

The time of year when prescribed burns are conducted will influence the level of shrub control. In ponderosa pine and mixed conifer stands of the Sierra Nevada of California, shrub mortality was greatest following late spring or early autumn burns (Kauffman and Martin 1985a,b).

Several studies have explored the use of preharvest burns to increase the safety and efficacy of burning for vegetation control (Martin 1982, Kauffman and Martin 1985a,b). Shrubs should be less vigorous and easier to control when they are subordinate in a stand. The technique involves a minimum of two or three preharvest burns. The first burn reduces the fuel loads and disrupts the vertical continuity of fuels. It also kills some plants, destroys many seeds in the duff and soil, and stimulates other seeds to germinate. Subsequent fires are designed to kill sprouting plants and young seedlings, as well as to destroy more seeds. In central Oregon, for example, almost all established shrubs (snowbrush, greenleaf manzanita, and antelope bitterbrush) were killed by two underburns conducted at a 3-year interval in two ponderosa pine stands (Martin 1982). The second burn also killed shrub seedlings that had become established following the first burn. These preliminary results from preharvest burns are encouraging, but definitive results will not be available until the 1990's.

Impact of Site Preparation on Soils, Site Productivity, and Pine Performance

The basic purpose of site preparation is to insure the rapid and successful establishment of a well-stocked stand of crop trees that can fully utilize the growth potential of a site. However, other objectives, such as disposing of slash to reduce the fire hazard and clearing debris to facilitate planting, frequently take precedence. Consequently, some methods used may inadvertently alter the productive capacity of a site by affecting the chemical, physical, hydrological, and biological properties of the soil. The net effect of a given site-preparation treatment depends on the degree to which the treatment impairs these conditions. Selecting the most appropriate treatment for a given site involves weighing the expected costs or impacts, the potential benefits, and the overall silvicultural system and management objectives. Therefore, it is necessary to understand both the detrimental and beneficial effects of alternative site-preparation treatments. The potential impact of site preparation on soil properties depends on the method used, how carefully it is implemented, and the original soil conditions.

Impact of Mechanical Treatments

The impact of mechanical site preparation on soil properties and site productivity is of particular importance in southcentral Oregon because of the widespread use of machinery to prepare planting sites. Mechanical treatments fall into two general categories: 1) treatments that disturb and rearrange the vegetation, litter, and soil, but leave the treated materials distributed uniformly over the area; and 2) treatments that concentrate the vegetation, litter, and occasionally surface soil on a small portion of the total land area (Gutzwiler 1976).

Effects of Uniform Redistribution of Surface Layer Material

Mechanical treatments of the first type generally will have little effect on long-term site productivity (Gutzwiler 1976). When such treatments are used properly, subsequent erosion and compaction are not serious. On a gently sloping site in the Piedmont of North Carolina, chopping, which did not disturb the forest floor, resulted in negligible erosion during the period from 9 to 21 months after site preparation (Pye and Vitousek 1985). Disking, however, which buried the forest floor, resulted in the erosional loss during the same period of 3,570 lb/acre of soil containing 4 lb/acre of N and 1 lb/acre of phosphorus (P). Application of herbicides following disking doubled the erosional losses. Nevertheless, nutrient losses following these treatments were well below the expected inputs during a 20-25 year rotation. Without data for a longer period of time, it is not possible to know what the total erosional losses will be; but as the crop trees and associated vegetation become established, erosion should decrease.

On well-aerated soils, treatments that incorporate organic matter into the soil, such as disking and bedding, will temporarily increase the availability of nutrients because of the increased rates of mineralization (Haines and Pritchett 1965, Haines et al. 1975, Wollum and Davey 1975). This increase occurs after the readily available carbon (C) is utilized by the microbial population and the nutrients are released. Indirect effects on soil moisture and microenvironmental conditions associated with removing the vegetative cover, already mentioned for chemical site preparation, also may occur following mechanical treatments.

Effects of Nonuniform Redistribution of Surface Layer Material

The more intensive mechanical treatments that concentrate organic matter and topsoil into piles or windrows, on the other hand, have a great potential to reduce site productivity. These treatments may be detrimental in two ways: 1) concentrating slash, vegetation, litter, and surface soils into piles or windrows reduces the nutrient capital of the intervening areas; 2) compaction by heavy machinery may adversely affect soil structure, particularly on saturated soils. The extent of these effects also depends on the skill of the operator and care taken during implementation of mechanical treatments.

The response of ponderosa pine in central and southcentral Oregon to fertilization with N, P, and sulfur (S) indicates that nutrient availability limits pine growth throughout this region (Youngberg and Dyrness 1965, Cochran 1973b, 1977, 1978, 1979a, Youngberg 1975, Will and Youngberg 1978). Significant increases in the growth of pole-size lodgepole pine have also been observed during the first 8 years following fertilization in southcentral Oregon (Cochran 1975, 1979b). In California, Zinke (1960) found a high correlation between the total soil N and site index at 300 years for ponderosa pine. He concluded that any silvicultural practice which lowered the total N of the soil would reduce productivity. Analogous results have been reported by Helms (1983) for 15-year-old ponderosa pine plantations in northern California. Consequently, any forest management practices that remove large amounts of N, P, or S (and perhaps micronutrients as well) from the rooting zone of crop trees may reduce the future productivity of soils.

The amount of nutrients removed from an area during mechanical site preparation depends on how much soil and organic matter are displaced. The depth of soil removed in scarification operations ranges from 0.6 to 2 inches (Glass 1976, Ballard 1978, Pye and Vitousek 1985, Sarigumba 1985). Obsolete recommendations for sites occupied by sprouting vegetation in California called for removal of at least 6 inches of soil from the area to be planted (Schubert and Adams 1971). The depth of soil displacement is important because nutrients tend to be concentrated in the upper soil profile. Will and Youngberg (1978) found that most of the S in central Oregon soils was located in the A_1 horizon (2 to 6 inches in depth). Gutzwiler (1976) reported that 50 percent or more of the organic matter, N, and P are located in the A horizon of southcentral Oregon soils (Fig. 2). Zinke (1983), studying six soil types common in northeastern California, reported that 50 to 80 percent or more of the total C and 41 to 80 percent or more of the N was contained in the surface foot of soil.

Removing 1 to 2 inches of topsoil into piles or windrows can reduce soil nutrients in the intervening areas. Ross et al. (1986) determined the concentrations of soil C and nutrients (N, P, and S) in the surface soil in an 8-year-old site-preparation study near Klamath Falls, Oregon. Total C, N, and extractable P concentrations in the top 10 cm of soil of brushbladed plots were about half those in the control plots, a difference attributable to the displacement of surface soil into windrows outside of the treated areas. Studies in the southeastern U.S.A. found that organic matter and nutrient concentrations of surface soils were lower several years after windrowing than they were in control or less intensively treated plots (Stransky et al. 1983, 1985, Tuttle et al. 1983, Pehl 1984). The long-term impact of removing above-ground organic debris on site productivity is not known, but the importance of organic debris in a number of processes indicates that the complete removal of organic debris from most of a site should be avoided, if possible (Harvey 1982).

The nutrients displaced into windrows can be a considerable proportion of the nutrient reserves on a site (Webber 1978, Morris et al. 1983, Pye and Vitousek 1985). In the North Carolina Piedmont, burned windrows contained as much N as would be deposited from all sources during a 20- to 25-year rotation (Pye and Vitousek 1985). If the piles and windrows are not burned, they eventually decompose to supply soil nutrients (Harvey 1982). However, this process takes many decades, and the nutrients released are confined to a relatively small area of the plantation.

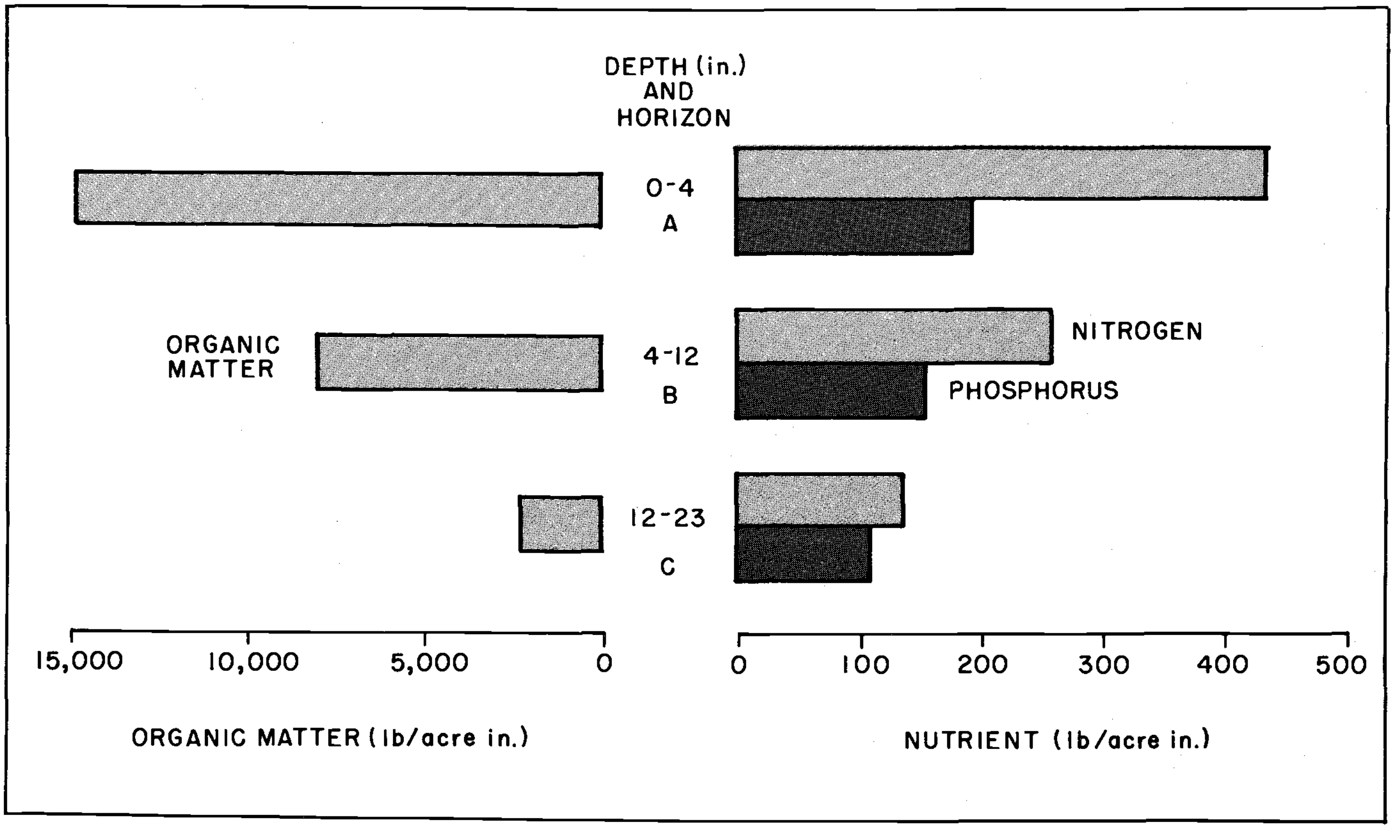

FIGURE 2.

SOIL ORGANIC MATTER AND NUTRIENT PROFILE IN AN ASH CLAY LOAM (POKEGAMA SERIES) TYPICAL OF MANY SOILS THROUGHOUT SOUTHCENTRAL OREGON (FROM GUTZWILER 1976).

Effects of Soil Changes after Intensive Treatment

Soil compaction occurs when soil particles are forced closer together, thereby reducing macropore spaces and increasing soil density. Infiltration rates, water percolation through the soil, soil gas exchange, and growth of roots are also reduced (Gutzwiler 1976). Compaction creates a less favorable environment for the survival and growth of conifer seedlings. The resistance of a soil to compaction depends on soil texture, organic matter content, horizon sequence, initial bulk density, and moisture content (Gutzwiler 1976). Any operation that removes the cushion provided by the forest floor increases the chances of soil compaction occurring (Gutzwiler 1976). Since bulk density normally increases with soil depth, treatments that remove surface soil automatically will result in higher bulk density conditions for seedlings.

Most studies of the effects of compaction on tree growth have dealt with conifers growing in skid trails created during logging. Compaction from site preparation will usually be less than from logging, since most of an area is passed over only once during site preparation (Gutzwiler 1976). However, a relatively small increase in bulk density can lead to substantial conifer growth reductions. In the southern Washington Cascades, Robbins (1984) found that a 15 percent increase in soil density resulted in a 20 percent decrease in volume of 9- to 18-year-old ponderosa pine. Cochran and Brock (1985) detected a significant decline in height growth of ponderosa pine seedlings associated with compacted soils resulting from logging and site-preparation activities in the central Oregon Cascades.

A study in east Texas considered the effects of site preparation on soil bulk density (Stransky 1981). Treatments included a logged-only control, burning, chopping, and KG-blading. Three years after treatment, chopped and KG-bladed plots had significantly higher bulk densities than either control or burned plots. Unfortunately, the effects of soil compaction on the growth of planted loblolly pine (Pinus taeda L.) seedlings could not be separated from the effects of competition with associated vegetation in this experiment. Survival and growth of planted pines was greatest on the mechanically treated plots, where bulk densities were significantly higher but competition from hardwoods was significantly less, than on the control and burned plots. Other studies in the southeastern U.S.A. have found significant increases in bulk density of surface soil following site preparation by brushraking (DeWit and Terry 1983, Tuttle et al. 1983).

Tree Performance after Intensive Mechanical Treatments

The impact of scarification and other site-preparation treatments on the growth of planted conifers has been evaluated in several studies. In southcentral Oregon, brushblading increased ponderosa pine growth compared to an untreated control through the first 8 years (Ross et al. 1986). However, pines growing on herbicide-only, disk-only, and herbicide/disk plots were significantly larger in all respects than trees on the brushbladed plots. Since the growth of pines on the brushbladed plots did not fit the general relationship between pine biomass and brush biomass (Fig. 1), the poorer performance probably resulted from less favorable soil conditions.

Glass (1976) compared loblolly pine growing on a rootraked area and an adjacent broadcast-burned area in North Carolina. The rootraking operation pushed the vegetation, forest floor, and 2 inches of topsoil into the windrows. After 20 years, the broadcast-burned area had 11 cords/acre more wood than the rootraked area. Site index (base age 50 years) predictions were 79 ft for the broadcast-burned area and only 65 ft for the rootraked area.

Sarigumba (1985) reported results of a site-preparation study in southeast Georgia that compared scalping, bedding, harrowing, and no treatment. Scalping, bedding, and harrowing were preceded by burning. Scalping moved 1 to 2 inches of topsoil out of the immediate seedling environment. Bedding and harrowing, on the other hand, incorporated organic matter into the surface layer of mineral soil within the seedling environment. After 25 years, slash pine (Pinus elliottii var. elliotti Engelm.) volume was 34, 32, 28, and 25 cords/acre on the harrow, bed, control, and scalp treatments, respectively. The reduced growth of the pines on the scalped plots was attributed to the displacement of topsoil.

In New Zealand, Ballard (1978) evaluated the effects of windrowing in a 7-year-old radiata pine (Pinus radiata D.Don) plantation. An estimated 1 inch of topsoil was moved into the windrows, along with the vegetation and litter. The author did not state whether the windrows were burned, but comments in the paper suggest that they were not. Volume production increased 19 percent on the windrows and decreased 40 percent between the windrows, compared to an adjacent, unscalped site. The author predicted the volume loss over a

26-year rotation on the windrowed site would amount to 2 years growing time, or 714 ft^3/acre of wood production. Volume losses would have been considerably greater if windrows had not been planted, since they covered approximately one-third of the area. The reduced growth of trees in the inter-windrow area was attributed to a restricted supply of nutrients, poorer soil physical conditions, and a higher incidence of red band needle blight (Dothistroma pini Hulbary) infection. Also, artificial frost pockets may have been created between the windrows.

Although none of these studies identify the specific reason for slower conifer growth on mechanically prepared sites, they do indicate that removing organic debris and soil over large areas can be detrimental to future productivity. Reduced conifer growth probably results from changes in a number of environmental factors. Conversely, treatments that do not displace large amounts of organic debris and soil leave a site in a more productive condition.

Impact of Chemical Treatments

Of the three general types of site preparation, chemical methods tend to have the least direct effects on soil properties. Since chemical application does not disturb the site, the only changes in soil properties that will occur (at least with nonpersistent herbicides) are indirect effects resulting from plant mortality. One of the most important changes is the increase in soil moisture content following chemical site preparation (Tarrant 1957, Heidmann 1969, Eckert 1979). Higher daytime soil temperatures, lower soil surface temperatures at night, increased microbial activity, and greater nutrient losses from leaching may also result from the removal of the vegetative cover by herbicides (Gregory 1981). These impacts are usually minor and of short duration following a conventional chemical treatment.

Impact of Prescribed Burning

Frequency and intensity of burning are important in determining the long-term impact of fire on site productivity (Wells et al. 1979). Despite the seemingly drastic changes caused by prescribed burning, most of the effects on soil are relatively minor (Haines et al. 1975, Wells et al. 1979), although they are highly variable (Wells et al. 1979). The variability can be attributed primarily to differences in the amount of fuel consumed and the temperature to which soils are heated.

Prescribed burning to prepare a site for planting normally requires a high-fuel-consumption fire to remove organic debris and kill the competing vegetation (Gregory 1981, Kauffman and Martin 1985b). High-fuel-consumption fires remove the insulating vegetation and forest floor covers; volatilize large amounts of N and lesser amounts of S, P, and chlorine (Cl); transform other elements to soluble forms that are more easily absorbed by plants or lost by leaching; disrupt soil structure; and possibly induce water repellency (Wells et al. 1979). Exposed mineral soil may exhibit decreased infiltration, soil water storage, and aeration, and increased runoff and erosion.

Changes in chemical and physical properties of soil also affect microorganisms, but these interactions are not well understood. Some studies have found increases in ectomycorrhizal populations following fire, while others have found decreases (Schoenberger and Perry 1982). Pilz and Perry (1984) found that soil temperatures and light levels on cleared and burned sites in the western Cascades were more important influences on the formation of major ectomycorrhizal types than were changes in soil chemistry or biology. Pathogenic fungi are stimulated by fire in some cases and inhibited in others (Wells et al. 1979).

Long-term Silvicultural Benefits of Intensive Site Preparation

As the cost of site-preparation treatments rises, the need to evaluate the long-term benefits of site preparation becomes increasingly important. High interest rates and the long period of time over which reforestation costs must be carried make it imperative that the gain in stand growth attributable to site preparation be considerable and predictable.

Some of the longest-term studies that assess the effects of intensive site preparation are located in the southeastern United States. Studies with loblolly and slash pines in the Coastal Plain of Florida and Louisiana found that early increases in growth rate were not sustained throughout the rotation (Haywood 1983, Pehl and Bailey 1983). A study with loblolly pine in the Georgia Piedmont found that disking was the only treatment resulting in greater height growth after 10 years (Pehl and Bailey 1983). The authors predicted that a modest increase in site index (base age 25) of 2 ft would occur if the growth gains due to disking were maintained. A study in the Upper Coastal Plain of Alabama compared six different site-preparation treatments (Whipple and White 1965). After 22 years, the survival and growth of loblolly pine on all of the treated plots was significantly greater than on the control plots (Glover et al. 1981). The control plots supported only 23 ft^3 of wood/acre, while the treated plots supported 1,652 to 3,886 ft^3/acre.

Several studies (summarized by Roy 1981) in northern California illustrate the long-term impact that brush can have in ponderosa pine plantations. One study compared the growth of pines planted at five different spacings with and without competition from shrubs. The study area was prepared for planting by carefully pushing logging debris into windrows outside the plots. Half of each spacing main plot was kept brush-free with a combination of chemical and manual treatments. After 14 growing seasons, cubic foot volume losses due to brush competition ranged from 31 to 57 percent, depending on initial spacing. Another study considered the effects of brush density on the survival and growth of planted pines. Prior to planting, the brushfield was windrowed by crawler tractors. Windrows were not burned. The plantation was then used to test a variety of herbicide applications which resulted in a broad range of brush densities. After 19 growing seasons, the percentage of dead or suppressed trees ranged from 3 percent where trees were growing free of brush competition to 46 percent where brush biomass was greatest. Differences in volume growth converted to lost growing time ranged from 4 years with light brush cover to 10 years under heavy brush cover.

Without appropriate stocking control to minimize intraspecific competition throughout a rotation, the early growth advantages associated with site preparation could be reduced or lost completely by the time of harvest. A 25-year-old site-preparation study conducted in southeast Georgia investigated the interaction between tree spacing and site-preparation method on tree growth (Sarigumba 1985). At the 6 ft x 6 ft spacing, trees growing on harrowed plots produced 6 cords/acre more wood by age 14 than the trees growing in control plots, but by age 25 this growth advantage had completely disappeared. At the 6 ft x 12 ft spacing, harrowed plots had a 13 cords/acre advantage over the controls at age 14; this advantage increased to 15 cords/acre by age 20, and then declined to 10 cords/acre by age 25. At the 12 ft x 12 ft spacing, harrowed plots had a 11 cords/acre advantage over controls at age 14, which increased continuously to 17 cords/acre by age 25. Apparently, intraspecific competition eliminated the benefit of site preparation by age 25 at the closest spacing, reduced the benefit at the intermediate spacing, and was a minor factor at the widest spacing.

The fact that some studies have shown significant increases in wood production up to 25 years after site preparation, while other studies have observed no long-term increase, indicates a need for a better understanding of the effects of site preparation and other silvicultural practices on site productivity and stand yield. Data available currently are scattered among many different geographic locations, weed and crop tree species, soil types, climates, site conditions, and methods of site preparation (Stewart et al. 1984).

CONCLUSION

The ponderosa pine forests of southcentral Oregon are generally less productive than forests in more favorable environments. However, the productivity of these lands can be enhanced, at least in the short term, through effective control of undesirable vegetation. The effects of competing vegetation on crop tree performance are most important during regeneration. Excessively weedy plantations may fail completely or have survival and juvenile growth rates well below their biological potential. Cost-effective methods that control undesirable vegetation and minimize adverse impacts on site productivity need to be developed. Furthermore, site preparation and release treatments must be integrated with other silvicultural practices to meet the landowners' objectives.

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APPENDIX: English-to-metric Conversion Factors and Abbreviations

Length
inch x 2.54 = cm (centimeter)
ft (foot) x 0.305 = m (meter)
breast height (4.5 ft) = 1.4 m

Volume – solid
ft^3 x 0.0283 = m^3
ft^3/acre x 0.07 = m^3/ha
bd ft[a] (board foot) x 0.00236 = m^3
cord[b] x 3.62 = m^3
cord[b]/acre x 8.96 = m^3/ha

Mass
lb (pound) x 0.454 = kg (kilogram)
lb/acre x 1.12 = kg/ha

Miscellaneous
acre x 0.405 = ha (hectare)
bar x 100 = kPa (kilopascal)
degree Fahrenheit (°F):
5/9 (°F – 32) = degree Celsius (°C)

[a] Based on nominal measurement (1 inch x 1 ft x 1 ft), not actual measurement derived from scaling.
[b] Based on 128 ft^3 of stacked roundwood (4 ft x 4 ft x 8 ft).

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This report focuses on the effects of site-preparation treatments on the performance of planted pines. It is based primarily on literature dealing with ponderosa pine in southcentral Oregon, although information is drawn from similar geographic regions and other pine species as well. Methods to control undesirable vegetation during plantation establishment are discussed in relation to expected silvicultural benefits and possible adverse effects of treatments on long-term site productivity. Mechanical treatments are emphasized, since these are the most widely used methods of site preparation in southcentral Oregon.

KEYWORDS: site preparation, effects of vegetative competition, ponderosa pine, Pinus ponderosa, lodgepole pine, Pinus contorta, pine forests of southcentral Oregon, vegetation management, weed control, pine response to vegetation management, impacts of site-preparation treatments.

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