AN ABSTRACT OF THE THESIS OF

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Reforestation of Sites Near Mount St. Helens

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The 1980 eruptions of Mount St. Helens damaged or destroyed vegetation on more than 66,100 hectares (270,000 acres) within the Gifford Pinchot National Forest. The effects of the eruption on planting sites and seedling performance were unknown. Regeneration of "cut over" lands near Mount St. Helens has historically been limited by high soil-surface temperatures in the summer; a short growing season; and young, easily erodible, nutrient deficient, volcanic soils. Reforestation following the 1980 eruptions was expected to be far more difficult and exacting than pre-eruption reforestation.

This study monitored survival and growth of seedlings planted on sites to the east and northeast of Mount St. Helens in the devastated, blowdown, scorch, and ashfall zones. Seven conifer species were planted with shading and fertilization treatments on six "low elevation" sites (685 to 1097 m 2250 to 3600 ft. elevation) and five "high elevation" sites (1067 to 1280 m 3500 to 4200 ft. elevation).

First- and second-year survival and growth results were as good as or better than those for undisturbed sites. Seedling second-year survival rates were high: averaging 85 percent on the low elevation sites and 75 percent on the high elevation sites. Raval damage was the most common cause of seedling mortality, especially when slopes exceeded 60 percent.

Known autecological differences among the species tested were maintained on the post-eruption sites. Lodgepole pine (_Pinus contorta_ var. _murrayana_ Dougl.) survived best and Douglas-fir (_Pseudotsuga menziesii_ (Mirbel) Franco.) exhibited the fastest height growth at elevations below 1100 m (3600 ft). Western white pine (_Pinus monticola_ Dougl.), lodgepole pine, and Engelmann spruce (_Picea Englemanii_ Parry) survived equally well on the high elevation sites, but lodgepole pine grew faster. Lodgepole pine and Engelmann spruce had the highest survival rates on the harshest, exposed sites near the volcano. Ravel caused mortality was severe on the steepest site, especially when slopes exceeded 60 percent.

Fertilization usually increased seedling growth rates but reduced first-year survival by as much as 15 percent. Lowered survival rates with the fertilization treatment were most extreme for true fir (_Abies_ spp.) seedlings.

Although the growth of shaded seedlings was slower than that of fertilized seedlings, survival rates of the former were significantly higher. Shading was most effective in reducing drought or heat stress on south and southwest facing sites in the low elevation study. Two-year survival for shaded trees in this experiment was 21 percent higher than that of fertilized trees.

The high survival and growth rates for planted seedlings on all planting sites were much better than expected. The good one- and two-year survival and growth results on the extensively damaged sites in the devastated areas suggested that site conditions were not as harsh as they initially appeared. This study indicated that reforestation procedures used for pre-eruption regeneration should be adequate for successful reforestation of most of the damaged and ash impacted forestland near Mount St. Helens. Shading may be beneficial on hot exposed sites or southerly aspects but fertilization is not recommended.

Post-Eruption Species Selection and Planting Trials for Reforestation of Sites Near Mount St. Helens

by

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INTRODUCTION

The 1980 eruptions of Mount St. Helens damaged vegetation and wildlife on more than 66,100 hectares (270,000 acres) of forest land on the Gifford Pinchot National Forest. Nearly 8,100 hectares (20,000 acres) of forest stands were totally destroyed by the initial blast or buried in mud and debris flows (U.S.D.A. Forest Service, 1981). The initial blast scorched or blew down forest stands on an additional 15,000 to 17,000 hectares (37,000 to 42,000 acres). Forests and plantations in the remaining 81,000 hectares (200,000 acres) of the ashfall zone were damaged or buried by ash and tehpra material.

Large acreages of these disturbed lands on what is now the Mount St. Helens National Monument as well as on state and privately owned land required reforestation. The lack of reforestation experience on sites such as those at Mount St. Helens made the prescription of planting procedures, species selection and seedling size criteria difficult.

This planting study was conducted to determine which of seven native conifer species would survive and grow best on a variety of disturbed sites on National Forest land east and northeast of Mount St. Helens within the blast and ashfall zones of the 1980 eruptions. Fertilization and shading treatments at planting were also tested.

Douglas-fir (*Pseudotsuga menziesii* (Mirbel) Franco) and noble fir (*Abies porcera* Reinder), the species most widely used in reforestation near Mount St. Helens , were planted at suitable elevations. Five conifer species not commonly used in pre-eruption plantings were also tested: 1) lodgepole pine (*Pinus contorta* var. *murrayana* Dougl.); 2) western white pine (*Pinus monticola* Dougl.); 3) Pacific silver fir (*Abies amabilis* (Dougl.) Forbes); 4) grand fir (*Abies grandis* (Dougl.) Forbes); and 5) Engelmann spruce (*Picea Englemanni* Parry).

Environmental conditions were monitored at planting and during the summer of 1982. These data were analyzed to clarify the relevant relationships among sites, species, and treatments and tp aid in the understanding of the variations in seedling survival and growth.

Seedling morphological characteristics were measured at planting to determine if performance was related to initial size. Initial seedling size was examined to determine if the variance in species performance was attributable to specific adaptive responses or initial morphology.

All of the species tested performed well. One- and two-year survival and growth rates were high on all but the steepest site. Shading increased survival on south- and southwest-facing slopes and fertilization reduced survival rates.

The results of this study may be useful in planning reforestation of similar areas where young volcanic soils, severe climatic conditions or disturbance present special regeneration problems.

LITERATURE REVIEW

Background

Artificial reforestation of blast and ashfall zone sites on what is now the Mount St. Helens National Monument was expected to be extremely difficult. Similar harvested sites in the western Cascade Range (especially in the higher elevations of the Pacific silver fir zone) have historically been difficult to reforest (O'Toole 1976). Young, nutrient-deficient, volcanic soils and cold climatic regimes have often limited regeneration success (Brockway et al. 1983). These severe climatic and soil conditions have often required that special reforestation procedures be implemented. Scarification, shading, and seedling placement in protected microsites have all been used to ameliorate severe site conditions on plantations.[1/] Hardy, stress-tolerant, cold-adapted species have been most successful on the harshest sites (Brockway et al. 1983).

Heat, dessication, and frost damage, which have been the most common cause of poor growth and survival in the past, were expected to be magnified on the more disturbed sites. Seedling dessication has already been observed on windy exposed sites (Clark 1983).

Natural reforestation following volcanic eruptions has been studied on the ash at Katmai and Kodiak in Alaska (Griggs 1915, Griggs 1919a,

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[1/] Gene Sloniker, Silviculturist, Mount St. Helens National Monument, personnal communication.

Griggs 1919b and Griggs 1933), in southern Idaho (Eggler 1941), near Paricutin volcano in Mexico (Eggler 1959, Eggler 1963 and Eggler 1948) and at Lassen National Park (Griggs 1919c, Heath 1967 and Bailey 1963).

These researchers reported that natural revegetaion of severely disturbed sites occured quite slowly. Eggler (1959) speculated that it may take as long as 100 years for natural reforestation of some volcanic deposits. Slow seedling establishment and vegetative recovery was generally attributed to the unfavorable chemical and physical properties of the volcanic deposits. Eggler (1959) and Griggs (1919b and 1933) thought that nitrogen deficiencies retarded plant growth. They also suggested that erosion and tephra accumulation, the inpenetrable surface crust, and low water holding capacity and acidity of the deposits prevented seedling establishment.

Reforestation plantings on older volcanic deposits in central Oregon and New Zealand have been extensive. However, the results were not applicable to the reforestation effort at Mount St. Helens due to differences in climate, age of deposits, and the length of time elapsed between the eruptions and planting.

Results from the considerable reforestation research conducted on skeletal soils in southwestern Oregon where extreme temperature and moisture regimes prevail may be more applicable to reforestation at Mount St. Helens. Researchers have found that dry, rocky, southwest-facing slopes were the hardest to regenerate (Stein 1955). Special treatments, such as shading and mulching, and proper stock selection were tested and found to improve survival rates (Hobbs and Helgerson 1981, Hobbs 1982a, Hobbs 1982b, Helgerson et al. 1982, Hallin 1968 and Stein 1955).

Site Characteristics

A careful analysis of site characteristics is required to produce adequate reforestation prescriptions (Cleary and Kelpsas 1981), particularly on severely disturbed sites. Once critical site factors are identified, the optimum planting stock, site modification and planting techniques can be prescribed for that site.

Reduced tree growth and mortality in forest plantations in the Pacific Northwest has most often been attributed to summer drought (Brix 1978). Infrequent precipitation during the summer results in inadequate soil moisture levels and high seedling evaporative demands during the growing season (Brix 1978). Bledsoe et al. (1982) found that low soil fertility and desiccation injury during the first growing season were the most commmon causes of poor performance for Douglas-fir seedlings on dry sites.

The intensity and severity of summer droughts on nutrient-poor volcanic soils are extreme due to the physical and chemical properties of volcanic soils. Although volcanic soils have high water storage capacities and soil water is held at relatively low tensions, physical barriers and low nitrogen levels prohibit root growth and water absorption and slow soil water movement (Hermann 1970). Moisture stress may limit seedling establishment on sites with deep deposits at Mount St. Helens.

All plant physiological processes are regulated by water availability. Moisture stress affects seedling photosynthesis, respiration, transpiration and growth rates (Cleary 1970). The moisture status of a seedling is affectd by soil water and atmospheric conditions and the ability of the plant to control water loss (Glerum and Peirpoint 1968). Reduction in photosynthetic rates and growth occur when moisture conditions are unfavorable. When respiration of trees exceeds photosynthesis, growth stops, carbohydrate levels are lowered, and starvation may occur. Growth-limiting internal water deficits are most often attributed to insufficient soil moisture levels (Kramer and Kozlowski 1980).

Soil water availability depends upon the ability of the plant roots to absorb water with which they are in contact and the rate of water movement. These factors were found to be very important to moisture availability in the pumice soils of central Oregon (Hermann and Cochran 1971). The limited contact between the large, non-plastic pumice particles and seedling roots resulted in slow moisture flow to the roots. The poor root growth which was observed in pumice soils was attributed to low soil fertility, mechanical obstruction and abrasion by the large pumice particles and slow moisture flow (Cochran 1971). Hermann (1970) found that root damage, not physiological drought, was the major cause of seedling mortality on pumice soils in central Oregon.

Klock (1980) also observed lower available water levels and restricted root movement on the high bulk density, coarser ash deposits tested in a seedling germination pot study on Mount St. Helens deposits. He suggested that reforestatinm would be most difficult on the coarser deposits.

Although high soil surface temperatures do not usually cause direct heat damage to established seedlings or mature trees, heat induced increases in evaporative demand may promote drought damage (Halverson and Emmingham 1982). Cleary et al. (1978) reported that thin-barked species and seedlings with small stem diameters are susceptible to stem damage when soil surface temperatures exceed 54^{0}C (130^{0}F).

Light inhibition of photosynthesis and solarization damage can occur on exposed sites where light intensities are high (Ronco 1972). Photosynthetic activity is reduced when critical enzymes are denatured by high air temperatures. Water-stressed seedlings with high leaf temperatures and low food reserves are most susceptible to solarization damage (Ronco 1972).

Drought or heat-caused damage is common on steep, south-facing xeric plantations in the Oregon and Washington Cascades (Hobbs 1982a). Shading has been successful in preventing mortality on sites with high soil and air temperatures and limited soil moisture (Cleary et al. 1978, Berntsen 1958, Peterson 1982, Franklin and Hermann 1973, Hobbs 1982b and Lewis et al. 1978).

Shading can reduce heat and drought stress in planted seedlings by reducing air and soil temperatures. The lowering of temperatures can reduce evaporation and transpiration, prevent internal water stress and slow rates of soil water use. Shading also prevents frost damage by reducing nighttime radiant heat loss from seedlings and soil. Since soil surface temperatures and light intensities were expected to be high in the severely disturbed areas, I chose to examine the effect of shading on seedling survival. Since shading has been necessary on severe sites near Mount St. Helens in the past it was selected as a planting treatment in this study.

Seedling Characteristics

The easiest way to maximize reforestation success is to produce planting stock with phenotypic, genotypic, and physiological characteristics best suited to site environmental conditions (Cleary and Kelpsas 1981). This matching of seedling to site is one of the most cost effective managements strategies.

Seedling morphological characteristics are often closely related to first-season field performance. The survival of planted seedlings depends in part on the size of its shoot and root and the ability of the roots to grow and supply enough water to meet transpirational demands (Cleary et al. 1978).

Lopushinsky and Beebe (1976) found that the size characteristics of Douglas-fir planting stock were most important on dry, pumice soils in north central Washington. Douglas-fir seedlings with large roots and a low shoot-to-root ratio exhibited better root and shoot growth and survival than larger seedlings with small roots and higher shoot-to-root ratios. Brix (1978) found that seedlings with small roots were more susceptible to drought injury.

Drew and Ferrell (1979) reported that when shoot growth of Douglas-fir seedlings exceeded root growth under dry soil conditions, xylem pressure potentials were lowered and seedlings were more susceptible to desiccation injury. Drew (1983) postulated that Douglas-fir seedlings with large shoots and roots may be best suited to xeric sites. Hermann (1964) stated that Douglas-fir seedlings with high shoot-to-root ratios performed poorly on dry sites because transpirational losses from the large crowns were excessive. He also found that root growth potential at lifting affected the ability of seedlings to survive on xeric sites.

Hobbs and Wearstler (1983) reported that initial root and shoot size were not a factor in the growth or survival of Douglas-fir on droughty sites in southwestern Oregon. Hobbs (1983) later reported high plant moisture stress for seedlings exhibiting inadequate root growth on dry sites. He also hypothesized that good root growth on dry sites assured that the roots would remain in contact with receding soil moisture during the growing season. Cleary et al. (1978) also state that early and vigorous root regeneration after outplanting is essential for seedling survival on xeric sites. Several other researchers have noted that root condition and root growth potential (the physiological readiness of roots to grow) are far better indicators of seedling quality than root-to-shoot ratios (Hermann 1964, Jaramillo 1980 and Jenkinson and Nelson 1978).

Root growth potential is controlled by the physiological state and preconditioning of the seedling. This physiological readiness to grow is affected by the preconditioning and handling of the seedling. Maximum root growth potential can be obtained by producing seedlings with fibrous root systems and high levels of carbohydrate reserves and insuring that they are dormant during handling. Root growth rates are attributable to site conditions and planting procedures as well as seedling condition. Poor root growth can be caused by improper handling during planting, low soil temperatures and moisture, and soil compaction.

Planting Methods

Auger planting was used in this study because it has proven to be the best planting method on droughty sites and skeletal soils (Miller 1969, Hobbs 1982a and Cleary et al. 1978). Hobbs (1982c) and Miller (1969) found that auger planting reduced predawn moisture stress and mortality on sites where soil moisture was deficient. On pumice-dominated sites in eastern Oregon, Hermann (1970) and Barrett and Youngberg (1965) found that auger planting was essential for rapid seedling root elongation and development. Hermann (1970) recommended auger planting over shovel planting on sites where pumice deposits exceeded 20 centimeters. He found that the mixing and loosening of pumice and ash deposits allowed roots to grow through the infertile deposits to the more fertile residual soils below.

Auger planting also brings the nutrient-rich residual soil into the planting hole. McMinn (1982) reported that the soil mixing promoted by auger planting increased root growth by raising soil temperatures in the root zone and increasing nutrient turnover rates. Antos and Zobel (1985) stated that seedling establishment on volcanic deposits was facilitated by the mixing of the ash deposits and residual soil and organic matter.

Fertilization

Various types and formulations of slow release fertilizers have been applied at planting for more than 20 years to promote seedling growth and survival on unfavorable sites. Results from fertilization trials have been variable. Rothacher and Franklin (1964), Austin and Strand (1960), Carlson and Presig (1981), Strand and Austin (1966), Lewis et al. (1978) and Knight (1963) showed enhanced growth rates for fertilized Douglas-fir seedlings. Mullin (1981) reported lowered survival rates and no significant increase in height growth for fertilized white spruce (Picea glauca (Moench) Voss) and white pine (Pinus strobis L.) seedlings. Smith et al. (1966) and Landis (1976) observed slight reductions in growth rates for fertilized Douglas-fir seedlings. Landis (1976) found that fertilization in the nursery produced stunted and chlorotic lodgepole pine seedlings and in planting studies Winston (1974) found lower survival rates for fertilized lodgepole pine seedlings. Rothacher and Franklin (1964) and Lewis (1978) reported that fertilization did not affect survival of Douglas-fir but Smith et al. (1966) found lowered survival rates with fertilization.

These inconsistencies in experimental results may be attributed to differences in soil physical and chemical conditions (Gentle 1972), fertilizer form (Winston 1974), application method or seedling condition. Soil pH and cation exchange capacity may be the most important of these factors because they determine the rate of fertilizer release and the ability of the soil to adsorb nutrients after they are released (Gentle 1972). Radwan and Campbell (1981) reported that the volcanic deposits at Mount St. Helens can not retain nutrients because they have low cation exchange capacities.

Many hypotheses have been suggested to explain the poor survival of fertilized seedlings. Winston (1974) stated that seedling mortality with fertilization was caused by high levels of ammonia or exposure to biuret, a toxic compound which is formed when urea fertilizer (as used in this study) is manufactured. Crane et al. (1972) found that excess ammonium ions, such as those released after slash burning, are lethal to seedlings at low concentrations. Austin and Strand (1960) and Strand and Austin (1966) found that survival and growth were reduced when rapidly soluable fertlizers were used.

Root damage has been observed with strong fertilizer formulations or when fertilizer pellets are placed too closely to roots (Wilde 1960 and White 1963). White (1963) noted that roots were burned when they were in contact with relatively small quantities of soluable fertilizers. He found that a urea-formaldehyde, super-phosphate and potash fertilizer formulation (as used in this study) is most likely to cause root injury. However, the present-day, slow-release formulations have been found to be less damaging to roots than the formulations used in these preliminary studies.

The negative effects of fertilization are more severe and seedling response poorest on dry sites (Strand and Austin 1966 and Walters et al. 1961). On dry sites, Van den Driessche (1982) found that survival of nursery-fertilized Douglas-fir was 10 percent lower than that of non-fertilized seedlings but found no depression in survival rates on mesic sites. Cleary et al. (1978) also stated that fertilization increased the risk of root damage on sites with inadequate soil moisture. Strand and Austin (1966) found that the proximity of fertilizers to roots was not important in well-watered pot studies. They suggested that direct contact between the fertilizer and seedling roots should be avoided on droughty sites. Most researchers have concurred that a soil barrier between seedling roots and fertilizers is advisable (Winston 1974, White 1963, and Strand and Austin 1966).

Fertilization generally stimulates shoot growth more than root growth (Van Den Driessche 1982). This may lead to undesirable changes in shoot-to-root ratios and the physiological condition of the seedling (White 1963). Carlson and Presig (1981) found that for Douglas-fir seedlings fertilization increased the number of roots.

A report on the chemical properties of the Mount St. Helens ash and mud deposits by Radwan and Campbell (1981) indicated that the deposits were deficient in most plant macronutrients, especially nitrogen. These results and the recent success of several seedling fertilization studies encouraged me to test a slow release fertilizer in these initial plantings.

METHODS AND MATERIALS

Experimental Design, Treatments, and Plot Installation

Eleven sites located on what is now the Mount St. Helens National Monument were selected for this regeneration study. These sites were clearcut harvested and initially planted (except one unplanted) between 1965 and 1980. Environmental conditions and treatment histories for each site are presented in Tables A1 and A2. The sites were divided into low and high elevation experiments and examined separately.

The high elevation experiment consisted of five clearcut blocks ranging from 1067 to 1280 m (3500 to 4200 ft.) in elevation (Figure 1). The low elevation experiment included six blocks with elevations from 685 to 1097 m (2250 to 3600 ft.). This stratification of experiment plots allowed an analysis of species which perform well on relatively favorable lower elevation sites and species which can tolerate the more harsh environmental conditions at higher elevations. This design also eliminated variation in results caused by macroclimatic factors known to be associated with elevation. These elevationally controlled factors include length of growing season, snowpack depth and persistence, and frost and drought occurrence and severity.

The experimental design for this study was a randomized complete block (Figures 2 and 3). Each randomly assigned combination of species and treatment was considered to be an experimental unit.

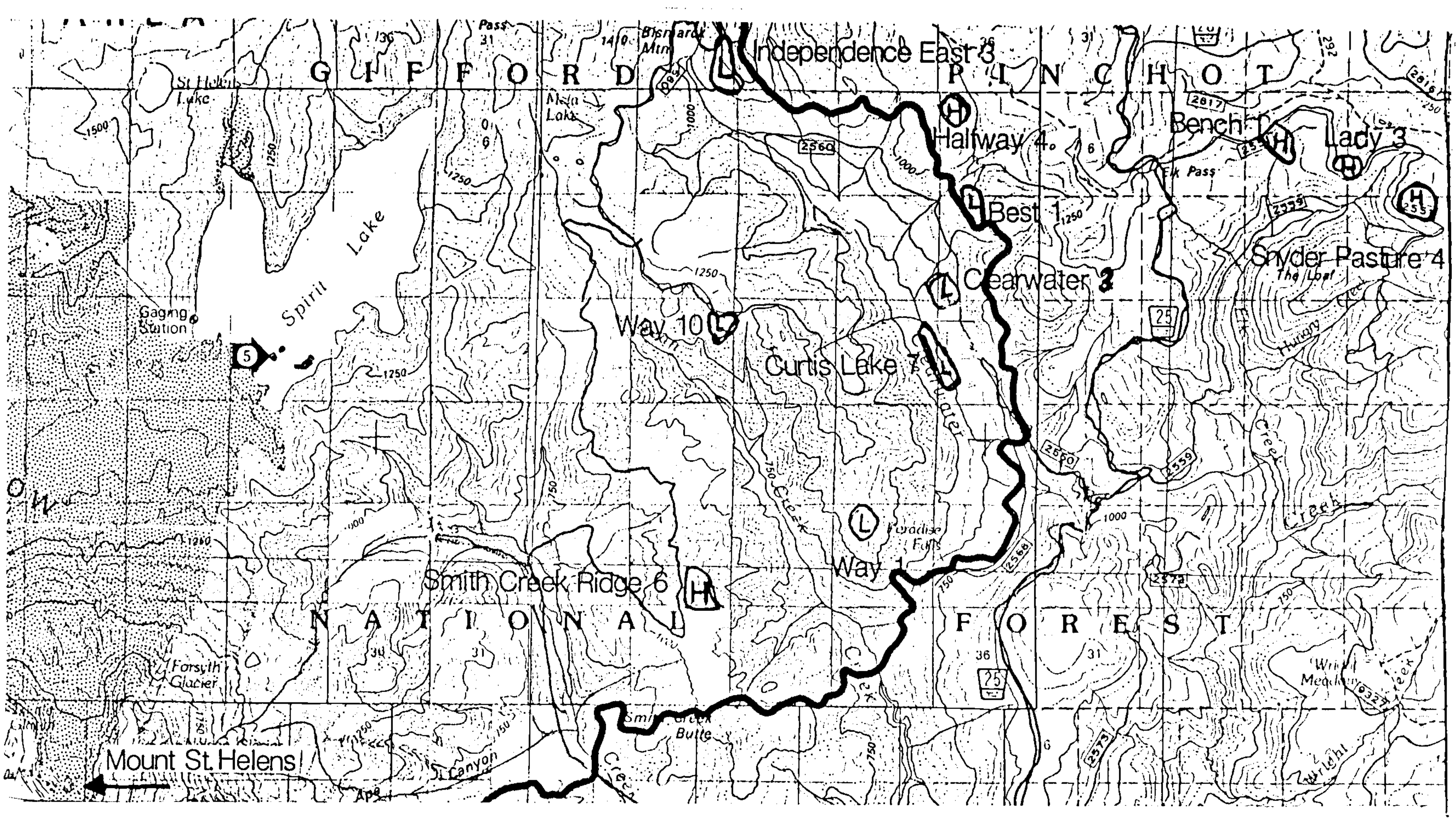
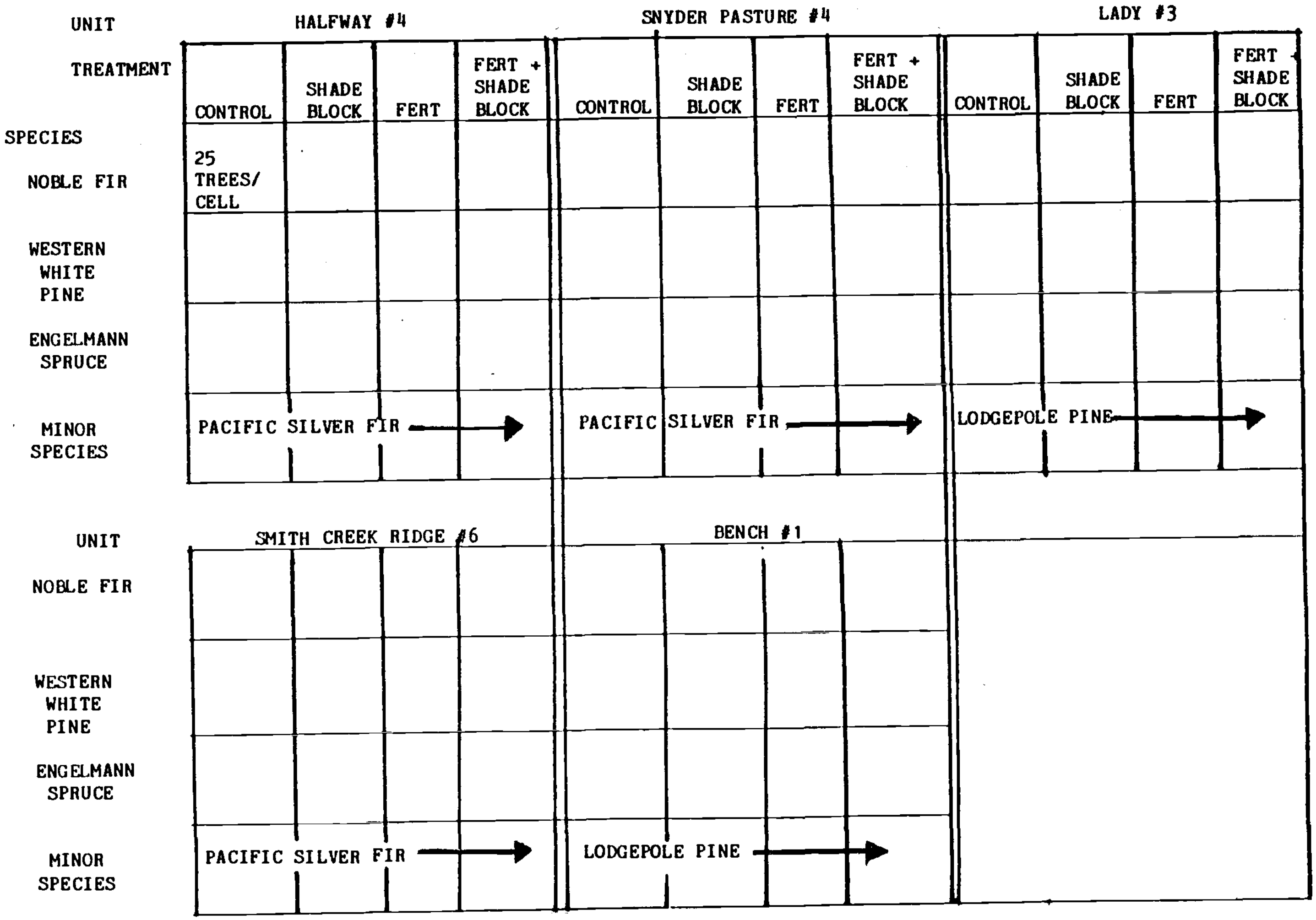


Figure 1. Location of Study Sites on St. Helens National Monument. H denotes high elevation sites and L denotes low elevation sites.



UNIT	HALFWAY #4				SNYDER PASTURE #4				LADY #3			
TREATMENT	CONTROL	SHADE BLOCK	FERT	FERT + SHADE BLOCK	CONTROL	SHADE BLOCK	FERT	FERT + SHADE BLOCK	CONTROL	SHADE BLOCK	FERT	FERT + SHADE BLOCK
SPECIES												
NOBLE FIR	25 TREES/ CELL											
WESTERN WHITE PINE												
ENGELMANN SPRUCE												
MINOR SPECIES	PACIFIC SILVER FIR →				PACIFIC SILVER FIR →				LODGEPOLE PINE →			

UNIT	SMITH CREEK RIDGE #6				BENCH #1			
NOBLE FIR								
WESTERN WHITE PINE								
ENGELMANN SPRUCE								
MINOR SPECIES	PACIFIC SILVER FIR →				LODGEPOLE PINE →			

Figure 2. Experimental Design for the High Elevation Experiment.

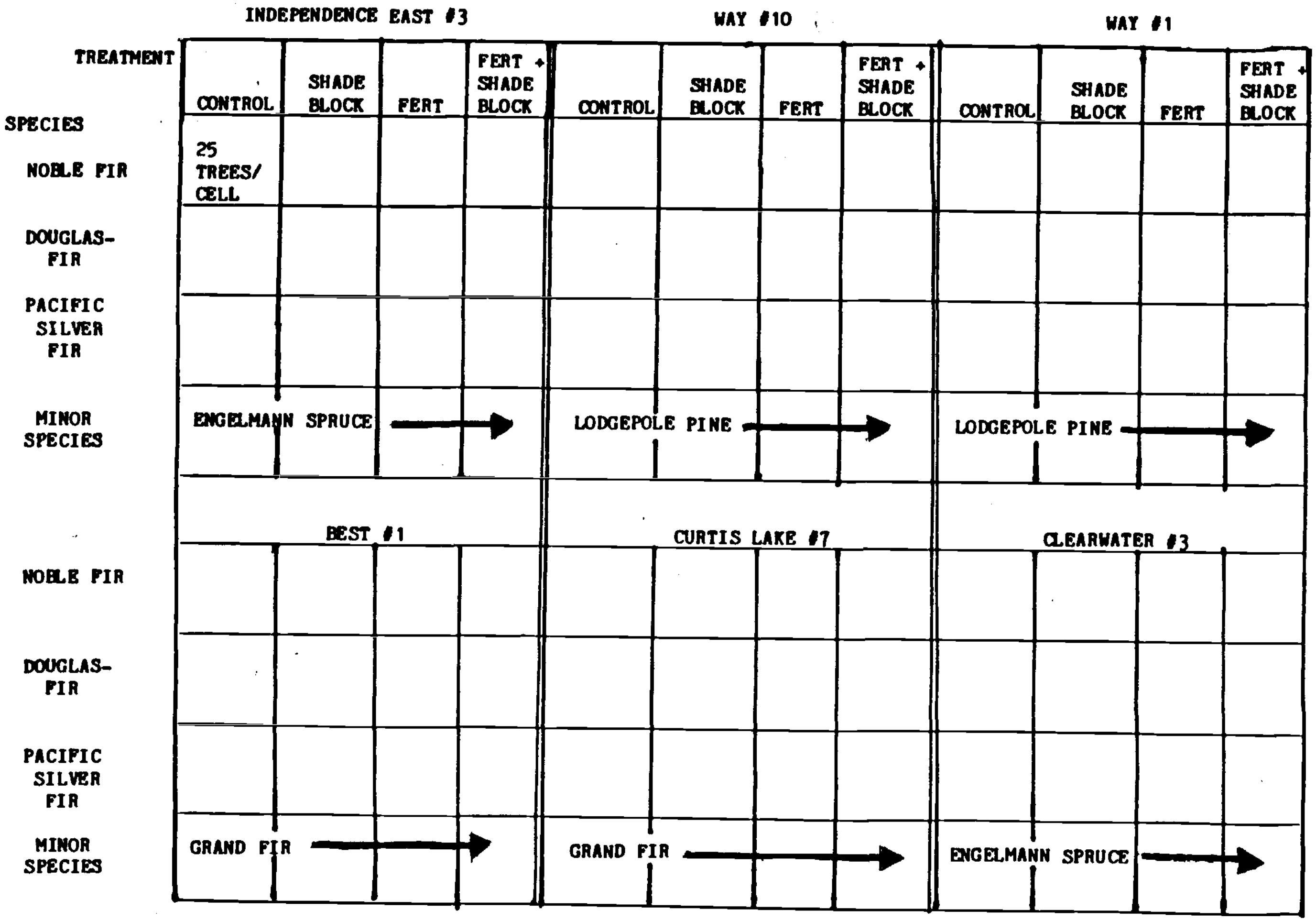


Figure 3. Experimental Design for the Low Elevation Experiment.

The sites were selected to examine varying site characteristics such as slope, aspect, distance from the volcano, tephra depth, and severity of disturbance. The sites were used as experimental replicates.

Three species were tested on all sites in an experiment and are referred to as major species. One of two additional species was planted in the high elevation experiment and one of three in the low elevation experiment and were designated as minor species. The fourth species, which varied from block to block, were not fully replicated. Planting these species on a few sites allowed me to test several species rarely used in pre-eruption reforestation at Mount St. Helens. I wished to compare the performance of these species to that of species commonly used for reforestation on non-impacted sites.

The major species selected for planting on the high elevation sites were noble fir, western white pine, and Engelmann spruce. The minor species were Pacific silver fir and lodgepole pine. Western white pine, Engelmann spruce, and noble fir were selected as major species because they are thought to be both frost-resistant and adapted to low water and nutrient environments (Brockway et al. 1983). They have been successful in reforestation of high elevation sites in the region.

The major tree species selected for study on low elevation sites were Douglas-fir, noble fir, and Pacific silver fir. Lodgepole pine, grand fir, and Engelmann spruce were planted as minor species. Each minor species was replicated on two units.

The 2-0 bareroot stock used was grown at Wind River Nursery near Carson, Washington. The seed was from the correct seed zone and elevation for the specific planting sites. Table A3 displays the seed source and distribution of planting stock in the study. Seedling roots were pruned to 15 cm (6 in.) and arrived in good condition. Normal reforestation practices such as keeping seedlings in cold storage prior to planting and dipping the roots in a vermiculite slurry before planting were followed. Site weather conditions were monitored during planting and are presented in Tables A4 and A5.

Rows of 25 trees were randomly assigned to one of the four treatment types and species on each site. This resulted in 16, 25-tree rows per site. The treatments were control (or no treatment), shading, fertilizer, and both fertilization and shading (referred to as the "both" treatment in the following text) (Figures 2 and 3).

One hundred test trees of each species were auger planted at a 2.4 m by 2.4 m (8 ft. by 8 ft.) spacing in May and June of 1981. The auger was driven into the residual pumice and soil and then pulled up to mix the old and new material. Cedar shingles measuring approximately 20 cm by 30 cm (8 in. by 15 in.) were placed on the southwest side of the shaded seedlings at the time of planting. The fertilized trees received a 10-gram pellet of Agriform® brand 20-10-5 (N-P-K) slow release fertilizer. The pellet was placed in the planting hole on the uphill side of the tree at a depth which was approximately half the length of the root. Care was taken to avoid placing the fertilizer in direct contact with the roots.

Site Monitoring

The site characteristics that were measured included slope, aspect, elevation, and ash depth and composition. These variables were chosen to quantify the major post-eruption environmental factors which most affect seedling survival and growth. Temperature regimes are most closely related to elevation. Elevation affects the coldness to which seedlings are exposed, the length of the growing season and the severity of snowpack, frost and summer drought. Slope steepness, aspect and topography can also control frost occurence, solar radiation intensity and temperature. Slope orientation affects the amount of incoming solar radiation received and influences the range of soil surface temperatures. The unblocked solar input and high heat reflectivity of the light-colored ash may contribute to heat stress on the disturbed sites.

The tradeoff between the amount of protection provided by and competition from residual and returning vegetation was of interest. I wished to compare seedling performance on severely disturbed sites where little residual vegetation remained and revegetation was occurring slowly with that of plantations where ash deposition was the only disturbance and residual vegetation was rapidly returning. An occular estimation of percent canopy cover of competing vegetation within 2 m (6 ft.) of each seedling was recorded.

During the summer of 1982, soil surface temperatures and plant moisture stress were monitored on selected units. The units were chosen to examine the extremes and patterns of heat and moisture stress during the dry season and to determine how heat and moisture differences affected tree survival and growth.

Four sites were selected for temperature monitoring. The amount of protection provided by vegetation, debris, or topographic position on each were used to rank exposure. The Way 10 site was an exposed site in the devastated area that had no residual vegetation. The Snyder Pasture 4 site was selected to represent the cold, high elevation, ashfall zone. The Curtis Lake 7 site was a low elevation, protected, flat site in the blowdown zone. The Best 1 site, also in the blowdown zone, was slightly more exposed than Curtis Lake 7 site.

Tempil® brand temperature-sensitive wax pellets ranging from 52° to 76°C (125°to 169°F) were placed on the open ash surface and behind neighboring shade blocks in three places on each unit. This allowed an assessment to be made of the effectiveness of the shade blocks in reducing surface temperatures and the effect of surface temperature variation on seedling performance. Each unit was checked weekly from June 26 to August 27. The highest temperature-rated pill that had melted was recorded.

Predawn plant moisture stress was measured by the Scholander pressure bomb with methods outlined by Waring and Cleary (1967). Measurements were taken four times at three-week intervals from June to August of 1982. Three sites representive of the most common types of post-eruption environments: blast, blowdown and ash fall (Way 10, Curtis Lake 7 and Lady 3, respectively) were selected for monitoring. Control and shaded noble fir were tested on each of the sites. Noble fir fertilization treatments were tested on three of the four mornings on Curtis Lake 7. Douglas-fir control and Pacific silver fir control treatments were tested on two low elevation sites, Way 10 and Curtis Lake 7. Lodgepole pine (on Way 10) and grand fir (on Curtis Lake 7), were also monitored on the low elevation sites. Lodgepole pine, Engelmann spruce and western white pine control seedlings were examined on Lady 3.

Data Collection at Planting

Data collected during planting included weather, site conditions, and individual tree and planting spot information. Planting conditions--relative humidity, air and soil temperatures, tree bag temperature, wind speed and solar input--were checked periodically (Tables A4 and A5). The general slope, aspect, elevation, and ash depth and composition of each site were recorded (Tables A1 and A2). Variables observed at each planting spot were aspect, slope, microtopography, seedling shoot height, and stem diameter at ground level.

Ocular estimates of percent canopy cover of tall (greater than 45 cm in height) and low (less than 45 cm in height) competing vegetation within 2 m (6 ft.) of the seedling were recorded at each planting spot during planting (Tables A6 and A7). A subsample of seedling root length and ash depth was obtained for every fifth planting spot. The presence of organic matter in the planting hole, protection provided by residual slash or stumps, and evidence of erosion were recorded.

Seedling Growth and Survival Surveys

Seedling mortality and condition for live trees were recorded after the first- and second-growing seasons. First-growing season measurements were made during the fall of 1981, approximately 5 months after planting. Second-year observations were made during the fall of 1982.

Total height and height growth data were collected for live trees in 1981 and 1982. Stem diameter measurements were taken in 1982. Diameter growth for the 2-year period was obtained by subtracting the initial stem diameter from the 1982 stem diameter. Mortality was recorded and percent survival was calculated as follows:

$$\%surv = 100 - (summort \times 4)$$

%surv = percent survival
summort = sum of dead trees per cell

Two subjective observations of tree vigor were collected to assess the reliability of first-season vigor as a predictor of second-season survival. The first was an estimate of crown ratio. The percentage of the seedling stem with green foliage was assigned to one of five vigor classes as follows:

1 = 100 - 75 %
2 = 74 - 50 %
3 = 49 - 25 %
4 = 24 - 0 %
5 = dead tree

The second vigor evaluation was a subjective estimation of overall tree condition. This vigor evaluation was rated on a scale of 1 to 3 as follows:

1 = Excellent
2 = Good
3 = Poor

The presence of ravel, sinking of trees into the planting hole due to subsidence of substrate material, percent cover of high and low competing vegetation and the presence of competing vegetation growing in the planting holes were recorded at each planting spot (Tables A6 and A7).

During the summer of 1982, five seedlings from each row were excavated to observe root growth and mycorrhizal fungus colonization following the second-growing season. Dr. Gary Hunt, research assistant at Oregon State University, examined root tissue obtained from both the upper and lower portions of all species planted on the low elevation units and western white pine and Engelmann spruce planted on the Smith Creek Ridge site from the high elevation experiment. The other four high elevation units were not examined because the ash deposits were less deep (ranging from 12 to 24 cm, 5 to 10 in.) and rapid fungal recolonization from the surrounding mature forest was expected. Both fertilized and unfertilized seedlings of each species were examined to determine if fertilization affected root growth or mycorrhizal colonization.

Data Analysis

Data from the high and low elevation sites were analyzed separately. All computer analysis was done with the Statistical Analysis System (SAS) statistical package (SAS Institute 1979).

An analysis of variance for seven measured seedling growth and survival characteristics was done for the three factors: species, treatment and site. When significant differences in means were observed for the main effects and no interaction effects occurred for species and treatments, multiple pairwise comparisons were made using Bonferoni's B procedure (Neter and Wasserman 1974). The equations used appear in Appendix 1 and Appendix 2.

Multiple regression was used to determine which site and initial seedling characteristics were most related to the observed variation in first-season survival. Environmental factors such as slope, aspect, amount of competing vegetation and ash depth were used as independent variables.

Means and standard deviations were calculated for all variables measured in each experimental unit (row of 25 trees) for species (Tables 1 and 2) and treatment (Tables 3 and 4). The three-factor fixed effects model analysis of variance was conducted using the SAS General Linear Models procedure (SAS Institute 1979). This analysis is appropriate because the inclusion of the minor species resulted in an unbalanced experimental design. Species, treatments and sites (as blocking units) were the factors analyzed. The analysis was designed to determine whether any of these main effects or the interaction of species and treatment had a significant effect on the magnitude of the mean values of the dependent variables.

Since many of the survival percentages fell between 80 and 100, a test of homogeneity of variance was conducted. The results showed that these data were binomially distributed. An arcsin square root of Y transformation (Snedecor and Cochran 1980) was used to normalize the survival percentage distribution.

Regression analysis was used to determine which seedling morphological and site characteristics best explained variation in second-year survival. Initial height, root length and diameters were used as independent variables. Site slope, total ash depth and seedling height and diameter growth were also used as independent variables. R-squared values were calculated for all possible multiple regressions.

Correlation analysis was done to examine the relationship between first- and second-year growing season survival and the vigor, competing vegetation and height growth variables.

RESULTS

First- and second-year survival and growth results were surprisingly good. All of the species tested performed well. Although fertilized seedlings grew faster than non-fertililzed seedlings, they had the poorest survival rates. Shading was most beneficial in reducing mortality on southerly facing sites.

Analysis of Variance

The means and standard deviations for survival, growth, and vigor for species and treatments on high elevation sites are presented in Tables 1 and 2. Similar means and standard deviations for the low elevation sites are presented in Tables 3 and 4.

The analysis of variance tables for the seven seedling variables are presented in Tables A8 through A14 for the high elevation experiment and Tables A15 through A21 for the low elevation experiment.

A summary of the results for the main effects and interaction effects from the three factor analysis of variance are presented in Table 5. $PR > F$ (the probability of obtaining calculated F values smaller than the tabular F values) values are the probabilities that the observed differences in mean survival and growth were actually due to chance rather than the treatments tested.

The sites were significantly different from each other ($PR > F$ less than .05) for all survival and growth variables investigated, except first- and second-year survival in the low elevation experiment and first-year height growth in the high elevation experiment.

TABLE 1. MEANS AND STANDARD DEVIATIONS FOR SPECIES SURVIVAL, GROWTH AND VIGOR ON HIGH ELEVATION STUDY SITES.

	NOBLE FIR (NF)	PACIFIC SILVER FIR (PSF)	ENGELMANN SPRUCE (ES)	LODGEPOLE PINE (LPP)	WESTERN WHITE PINE (WWP)
NUMBER OF SEEDLINGS	500	300	500	200	500
SURVIVAL					
FIRST-YEAR SURVIVAL	90[1]	83	97	98	97
(%)	(11)	(8)	(8.9)	(9.5)	(9.4)
SECOND-YEAR SURVIVAL	78	75	92	91	89
(%)	(24)	(16)	(10.5)	(10.2)	(19.6)
GROWTH					
FIRST-GROWING SEASON					
HEIGHT GROWTH (cm)	4.0	3.4	4.7	5.9	5.1
	(1.9)	(1.4)	(1.0)	(1.0)	(1.3)
TOTAL HEIGHT(cm)	19.4	11.0	20.7	20.7	11.5
	(3.1)	(1.4)	(4.7)	(2.5)	(1.7)
SECOND-GROWING SEASON					
HEIGHT GROWTH (cm)	5.7	4.3	8.9	11.2	8.9
	(2.5)	(1.0)	(3.3)	(3.5)	(2.1)
TOTAL HEIGHT (cm)	24.5	14.6	28.9	31.0	19.9
	(4.6)	(1.7)	(6.6)	(4.1)	(2.7)
DIAMETER (mm)	7.2	5.3	8.4	10.0	7.5
	(1.5)	(0.9)	(2.0)	(1.6)	(1.3)
TOTAL HT. GROWTH(cm)	9.7	7.7	13.6	17.1	14.0
	(3.2)	(1.7)	(3.8)	(3.5)	(2.8)
TOTAL DIA. GROWTH(mm)	3.0	1.8	4.0	5.3	3.2
	(1.2)	(0.3)	(1.0)	(1.3)	(1.0)

---

[1] MEAN ABOVE, STANDARD DEVIATION BELOW.

TABLE 1. Continued.

	NOBLE FIR (NF)	PACIFIC SILVER FIR (PSF)	ENGELMANN SPRUCE (ES)	LODGEPOLE PINE (LPP)	WESTERN WHITE PINE (WWP)
NUMBER OF SEEDLINGS	500	300	500	500	200
INITIAL CHARACTERISTICS					
SEEDLING QUALITY[2]	2.3	2.2	2.5	2.5	2.4
	(0.4)	(0.4)	(0.4)	(0.4)	(0.4)
DIAMETER (mm)	4.2	3.4	4.4	4.7	4.2
	(0.5)	(0.6)	(0.7)	(0.3)	(1.9)
HEIGHT (cm)	18.9	10.0	18.1	20.0	9.2
	(3.0)	(1.7)	(4.0)	(2.9)	(1.7)
ROOT LENGTH (cm)	20.6	16.7	20.0	20.1	20.6
	(2.5)	(2.6)	(2.4)	(1.8)	(1.9)
NUMBER OF SEEDLINGS	120	60	120	120	48
VIGOR					
1981 VIGOR RATING[3]	1.9	2.1	1.6	1.4	1.6
% LIVE CROWN	(0.8)	(0.5)	(0.5)	(0.4)	(0.75)
1981 SEEDLING [4]	1.9	1.9	1.6	1.6	1.5
CONDITION	(0.9)	(0.4)	(0.4)	(0.6)	(0.8)
1982 VIGOR RATING[3]	2.2	2.1	1.5	1.6	1.5
% LIVE CROWN	(0.4)	(0.1)	(0.4)	(0.5)	(0.4)
1982 SEEDLING [4]	1.6	1.8	1.4	1.5	1.4
CONDITION	(0.4)	(0.3)	(0.3)	(0.5)	(0.3)

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[2] SEEDLING QUALITY: 1 = POOR, 2 = GOOD, 3 = EXCELLENT.

[3] PERCENT LIVE CROWN: 1 = 75 TO 100, 2 = 50 TO 75, 3 = 25 TO 50, 4 = 0 TO 25, 5 = DEAD.

[4] SUBJECTIVE CONDITION RATING: 1 = EXCELLENT, 2 = GOOD, 3 = POOR.

TABLE 2. MEANS AND STANDARD DEVIATIONS FOR SPECIES SURVIVAL, GROWTH AND VIGOR ON LOW ELEVATION STUDY SITES.

	GRAND FIR (GF)	DOUGLAS-FIR (DF)	ENGELMANN SPRUCE (ES)	LODGEPOLE PINE (LPP)	PACIFIC SILVER FIR (PSF)	NOBLE FIR (NF)
NUMBER OF SEEDLINGS	200	600	200	200	600	600
<u>SURVIVAL</u>						
FIRST-YEAR SURVIVAL	80[1]	94	98	99	84	92
(%)	(15)	(13)	(7)	(2)	(24)	(9)
SECOND-YEAR SURVIVAL	75	86	90	99	70	85
(%)	(15)	(17)	(10)	(1)	(25)	(3)
	(15)	(17)	(10)	(1)	(25)	(3)
<u>GROWTH</u>						
FIRST-GROWING SEASON						
HEIGHT GROWTH (cm)	2.9	6.3	4.6	5.6	2.9	2.9
	(0.5)	(3.8)	(0.9)	(1.4)	(1.0)	(2.6)
TOTAL HEIGHT(cm)	25.0	32.4	21.4	20.2	10.5	23.2
	(3.2)	(3.5)	(3.7)	(3.5)	(1.4)	(5.2)
SECOND-GROWING SEASON						
HEIGHT GROWTH (cm)	8.3	11.3	7.7	11.0	5.0	5.9
	(2.1)	(5.0)	(3.0)	(3.7)	(2.1)	(2.6)
TOTAL HEIGHT (cm)	32.4	43.4	28.0	30.7	15.5	28.3
	(4.5)	(7.0)	(4.1)	(4.9)	(2.8)	(6.0)
DIAMETER (mm)	8.9	10.6	8.0	11.3	5.6	8.2
	(1.1)	(2.6)	(1.7)	(2.4)	(0.8)	(1.4)
TOTAL HT. GROWTH(cm)	11.5	17.9	12.4	16.7	8.3	8.9
	(2.1)	(6.8)	(3.8)	(3.8)	(2.8)	(3.0)
TOTAL DIA. GROWTH(mm)	4.3	6.2	4.1	7.0	2.4	3.7
	(0.8)	(2.7)	(2.0)	(2.0)	(0.9)	(1.5)

---

[1] MEAN ABOVE, STANDARD DEVIATION BELOW.

TABLE 2. Continued

	GRAND FIR (GF)	DOUGLAS FIR (DF)	ENGELMANN SPRUCE (ES)	LODGEPOLE PINE (LPP)	PACIFIC SILVER FIR (PSF)	NOBLE FIR (NF)
NUMBER OF SEEDLINGS	200	600	200	200	600	600
INITIAL CHARACTERISTICS						
SEEDLING QUALITY[2]	2.5 (0.6)	2.4 (0.5)	2.0 (0.1)	2.3 (0.5)	2.2 (0.4)	2.3 (0.4)
DIAMETER (mm)	4.6 (0.5)	4.3 (0.7)	3.8 (0.6)	4.3 (0.5)	3.1 (0.8)	4.5 (0.7)
HEIGHT (cm)	23.9 (2.9)	30.0 (2.7)	19.9 (4.4)	17.8 (2.8)	11.5 (1.5)	23.4 (4.8)
ROOT LENGTH (cm)	27.6 (0.9)	23.7 (1.9)	16.3 (2.8)	20.0 (2.4)	17.4 (1.8)	20.6 (2.4)
NUMBER OF SEEDLINGS	48	144	48	48	144	144
VIGOR						
1981 VIGOR RATING[3] % LIVE CROWN	1.8 (0.1)	1.9 (0.7)	1.6 (0.6)	1.0 (0.3)	2.5 (0.9)	1.9 (0.7)
1981 SEEDLING [4] CONDITION	1.5 (0.0)	1.7 (0.4)	1.7 (0.4)	1.9 (0.2)	1.9 (0.4)	1.8 (0.5)
1982 VIGOR RATING[3] % LIVE CROWN	2.0 (1.5)	1.8 (0.8)	1.6 (0.4)	1.2 (0.2)	2.3 (1.01)	1.9 (0.6)
1982 SEEDLING[4] CONDITION	1.7 (0.3)	1.5 (0.4)	1.4 (0.3)	1.3 (0.4)	1.7 (0.4)	1.6 (0.4)

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[2] SEEDLING QUALITY: 1 = POOR, 2 = GOOD, 3 = EXCELLENT.

[3] PERCENT LIVE CROWN: 1 = 75 TO 100, 2 = 50 TO 75, 3 = 25 TO 50, 4 = 0 TO 25, 5 = DEAD.

[4] SUBJECTIVE CONDITION RATING: 1 = EXCELLENT, 2 = GOOD, 3 = POOR.

TABLE 3. MEANS AND STANDARD DEVIATIONS FOR SURVIVAL, GROWTH AND VIGOR BY TREATMENTS ON HIGH ELEVATION STUDY SITES.

	CONTROL(C)	SHADE(S)	FERTILIZATION(F)	FERTILIZATION AND SHADE(B)
NUMBER OF SEEDLINGS	500	500	500	500
SURVIVAL				
FIRST-YEAR SURVIVAL (%)[1]	95 (14)	96 (11)	90 (23)	94 (15)
SECOND-YEAR SURVIVAL (%)	83 (20)	89 (18)	80 (22)	87 (15)
GROWTH				
FIRST-GROWING SEASON				
TOTAL HEIGHT(cm)	17.0 (6.1)	15.9 (4.7)	17.0 (5.8)	15.0 (4.9)
HEIGHT GROWTH (cm)	4.9 (1.9)	4.3 (1.6)	4.4 (1.2)	4.7 (1.4)
SECOND-GROWING SEASON				
HEIGHT GROWTH (cm)	6.6 (3.1	6.3 (3.2)	8.2 (2.8)	9.4 (3.6)
TOTAL HEIGHT (cm)	22.7 (7.8)	21.5 (5.6)	24.9 (7.3)	25.4 (6.7)
DIAMETER (mm)	7.6 (2.1)	6.6 (1.5)	8.2 (1.9)	7.9 (2.0)
TOTAL HT. GROWTH(cm)	11.5 (4.5)	10.6 (4.5)	12.7 (4.6)	14.1 (5.2)
TOTAL DIA.GROWTH(mm)	3.2 (1.6)	2.6 (1.2)	4.0 (1.7)	3.7 (1.9)

---

[1] MEAN ABOVE, STANDARD DEVIATION BELOW.

TABLE 3. Continued.

	CONTROL(C)	SHADE(S)	FERTILIZATION(F)	FERTILIZATION AND SHADE(B)
NUMBER OF SEEDLINGS	500	500	500	500
INITIAL CHARACTERISTICS				
SEEDLING QUALITY[2]	2.5 (0.5)	2.3 (0.3)	2.3 (0.4)	2.4 (0.4)
DIAMETER (mm)	4.3 (0.8)	4.0 (0.5)	4.2 (0.6)	4.2 (0.5)
ROOT LENGTH (cm)	20.5 (3.2)	19.7 (2.3)	19.2 (2.7)	19.8 (2.1)
HEIGHT (cm)	15.5 (6.0)	14.2 (5.3)	15.6 (5.5)	11.8 (4.8)
VIGOR				
1981 VIGOR RATING[3] % LIVE CROWN	1.8 (0.6)	1.6 (0.6)	1.9 (0.8)	1.7 (0.6)
1981 SEEDLING[4] CONDITION	1.8 (0.4)	1.7 (0.4)	1.7 (0.4)	1.7 (0.4)
1982 VIGOR RATING[3] % LIVE CROWN	1.9 (0.8)	1.7 (0.7)	2.0 (0.9)	1.6 (0.6)
1982 SEEDLING[4] CONDITION	1.5 (0.4)	1.6 (0.3)	1.5 (0.4)	1.5 (0.3)

---

[2] SEEDLING QUALITY: 1 = POOR, 2 = GOOD, 3 = EXCELLENT.

[3] PERCENT LIVE CROWN: 1 = 75 TO 100, 2 = 50 TO 75, 3 = 25 TO 50, 4 = 0 TO 25, 5 = DEAD.

[4] SUBJECTIVE CONDITION RATING: 1 = EXCELLENT, 2 = GOOD, 3 = POOR.

TABLE 4. MEANS AND STANDARD DEVIATIONS FOR SURVIVAL, GROWTH AND VIGOR BY TREATMENTS ON LOW ELEVATION STUDY SITES.

	CONTROL	SHADE	FERTILIZATION	FERTILIZATION AND SHADE
NUMBER OF SEEDLINGS	600	600	600	600
SURVIVAL				
FIRST-YEAR SURVIVAL (%)[1]	92	96	80	93
	(18)	(14)	(20)	(9)
SECOND-YEAR SURVIVAL (%)	80	91	70	87
	(21)	(14)	(22)	(11)
GROWTH				
FIRST-GROWING SEASON				
TOTAL HEIGHT(cm)	22.3	23.0	29.9	31.4
	(8.5)	(8.5)	(11.7)	(12.2)
HEIGHT GROWTH (cm)	3.6	4.2	4.2	4.5
	(1.7)	(1.8)	(4.0)	(1.8)
SECOND-GROWING SEASON	6.4	6.8	8.4	9.8
HEIGHT GROWTH (cm)	(3.2)	(4.2)	(4.4)	(4.2)
TOTAL HEIGHT (cm)	28.1	28.2	29.9	31.4
	(10.3)	(11.1)	(11.7)	(12.2)
DIAMETER (mm)	8.4	7.7	9.0	8.8
	(2.4)	(2.5)	(3.0)	(2.7)
TOTAL HT. GROWTH (cm)	9.9	10.9	12.6	14.3
	(4.6)	(5.2)	(7.1)	(5.6)
TOTAL DIA.GROWTH (mm)	4.2	3.7	5.1	4.7
	(2.2)	(2.5)	(2.7)	(2.5)

---

[1] MEAN ABOVE, STANDARD DEVIATION BELOW.

TABLE 4. Continued

	CONTROL	SHADE	FERTILIZATION	FERTILIZATION AND SHADE
NUMBER OF SEEDLINGS	600	600	600	600
INITIAL CHARACTERISTICS				
SEEDLING QUALITY[2]	2.2 (0.3)	2.2 (0.4)	2.2 (0.4)	2.5 (0.5)
DIAMETER (mm)	4.1 (0.8)	4.0 (0.9)	3.9 (0.9)	4.1 (0.9)
ROOT LENGTH (cm)	20.7 (2.9)	20.3 (3.7)	19.9 (3.4)	20.4 (3.4)
HEIGHT (cm)	22.0 (8.0)	21.2 (7.2)	21.4 (7.5)	20.8 (7.9)
VIGOR				
1981 VIGOR RATING[3] % LIVE CROWN	9.0 (0.8)	1.7 (0.6)	2.3 (1.0)	2.0 (0.6)
1981 SEEDLING [4] CONDITION	1.8 (0.3)	1.8 (0.4)	1.8 (0.5)	1.7 (0.4)
1982 VIGOR RATING[3] % LIVE CROWN	2.0 (0.8)	1.6 (0.6)	2.3 (0.9)	1.7 (0.5)
1982 SEEDLING[4] CONDITION	1.7 (0.4)	1.6 (0.4)	1.5 (0.4)	1.4 (0.3)

---

[2] SEEDLING QUALITY: 1 = POOR, 2 = GOOD, 3 = EXCELLENT.

[3] PERCENT LIVE CROWN: 1 = 75 TO 100, 2 = 50 TO 75, 3 = 25 TO 50, 4 = 0 TO 25, 5 = DEAD.

[4] SUBJECTIVE CONDITION RATING: 1 = EXCELLENT, 2 = GOOD, 3 = POOR.

TABLE 5. SUMMARY TABLE FOR THREE FACTOR ANALYSES OF VARIANCE: LEVELS OF SIGNIFICANCE FOR SEVEN DEPENDENT SEEDLING VARIABLES

HIGH ELEVATION

	UNIT PR>F[1]	SPECIES PR>F	TREATMENT PR>F	SPECIES BY TREATMENT INTERACTION PR>F
FIRST SEASON'S HEIGHT GROWTH	.1825	.0026	.5122	.8596
SECOND SEASON'S HEIGHT GROWTH	.0001	.0001	.0001	.2185
TOTAL HEIGHT GROWTH	.0001	.0001	.0001	.5854
DIAMETER GROWTH	.0001	.0005	.0002	.2890
TOTAL HEIGHT	.0001	.0001	.0008	.1036
FIRST YEAR SURVIVAL (1981)	.0001	.0001	.0286	.7533
SECOND YEAR SURVIVAL (1982)	.0001	.0001	.0189	.9192

LOW ELEVATION

	UNIT PR>F	SPECIES PR>F	TREATMENT PR>F	SPECIES BY TREATMENT INTERACTION PR>F
FIRST SEASON'S HEIGHT GROWTH	.0217	.0001	.4878	.9817
SECOND SEASON'S HEIGHT GROWTH	.0001	.0001	.0001	.9467
TOTAL HEIGHT GROWTH	.0001	.0001	.0001	.9294
DIAMETER GROWTH	.0001	.0001	.0048	.6051
TOTAL HEIGHT	.0001	.0001	.0297	.7618
FIRST YEAR SURVIVAL (1981)	.1779	.0001	.0001	.1108
SECOND YEAR SURVIVAL (1982)	.0904	.0001	.0001	.0491

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[1] PROBABILITY THAT THE OBSERVED DIFFERENCES WERE DUE TO CHANCE (OBTAINING CALCULATED F VALUES SMALLER THAN THE TABULAR VALUE).

Species means were significantly different from one another at the .01 level for all seven attributes in both experiments. First-season height growth means by treatment were not significant in either experiment. Treatment means were significantly different from one another at the .01 level for all variables except first- and second-year survival in the high elevation experiment and total height in the low elevation experiment. However, they were significantly different at the .05 level. The only significant species by treatment interaction effect was for second-year survival in the low elevation experiment ($PR > F$ of .04).

Since significant differences in sample means were shown for all variables except first-season height growth for treatments, Bonferroni's method was used for multiple pairwise comparisons of all other means to determine where the differences occurred.

Bonferoni Multiple Pairwise Comparison for High Elevation Sites

The results of the Bonferoni multiple pairwise comparisons for all seedling variables on the high elevation sites are presented in Table 6.

Height Growth by Species

Lodgepole pine, western white pine and Engelmann spruce demonstrated equally good height growth after the first-growing season (Figure 4).

TABLE 6. RESULTS OF MULTIPLE PAIRWISE COMPARISON OF SPECIES AND TREATMENT MEANS FOR SEVEN SEEDLING ATTRIBUTES USING BONFERONI METHOD - HIGH ELEVATION EXPERIMENT

GROWTH	SPECIES					TREATMENT			
1981 Height Growth (mean in cm)	LPP	WWP	ES	NF	PSF[1]	CONT	BOTH	FERT.	SHADE
	5.8	5.1	4.7	4.0	3.4[2]	4.9	4.7	4.4	4.3
						NOT SIGNIFICANT			
1982 Height Growth (mean in cm)	LPP	ES	WWP	NF	PSF	BOTH	FERT.	CONT.	SHADE
	11.2	8.9	8.9	5.7	4.3	9.4	8.2	6.6	6.3
Total Height Growth (mean in cm)	LPP	WWP	ES	NF	PSF	BOTH	FERT.	CONT.	SHADE
	17.2	14.0	13.6	9.7	7.8	14.1	12.7	11.5	10.6
Total Height (mean in cm)	LPP	ES	NF	WWP	PSF	BOTH	FERT.	CONT.	SHADE
	31.1	28.9	24.5	19.9	14.6	25.4	24.9	22.7	21.5
Diameter Growth (mean in mm)	LPP	ES	WWP	NF	PSF	FERT.	BOTH	CONT.	SHADE
	5.2	4.0	3.3	3.0	1.8	4.0	3.7	3.2	2.6
SURVIVAL									
1981 Survival	LPP	WWP	ES	NF	PSF	SHADE	CONT.	BOTH	FERT.
Mean Percent	98	97	97	90	83	96	95	94	90
1982 Survival	ES	LPP	WWP	PSF	NF	SHADE	BOTH	CONT.	FERT.
Mean Percent	92	91	89	78	75	89	87	83	80

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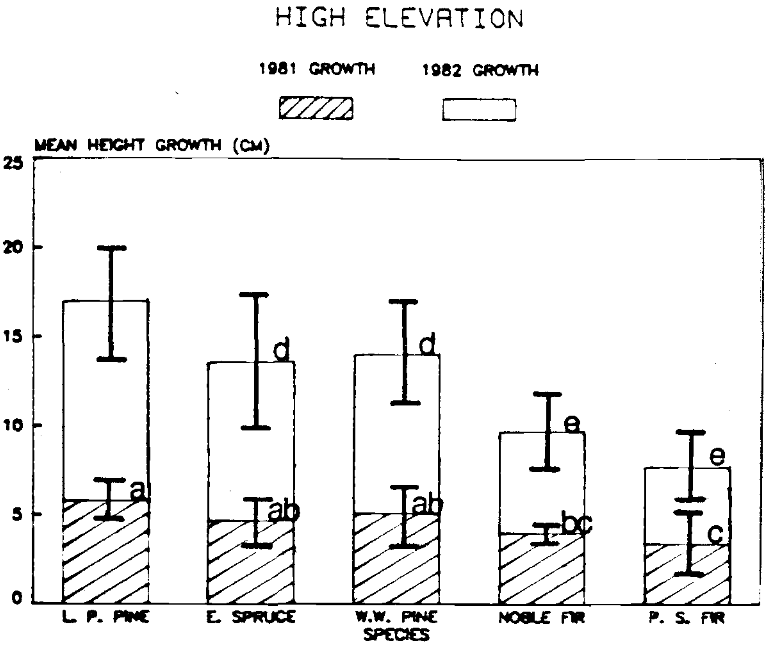
[1] RANKED HIGH TO LOW

[2] UNDERLINED VALUES ARE NOT STATISTICALLY DIFFERENT AT .05 LEVEL OF SIGNIFICANCE.



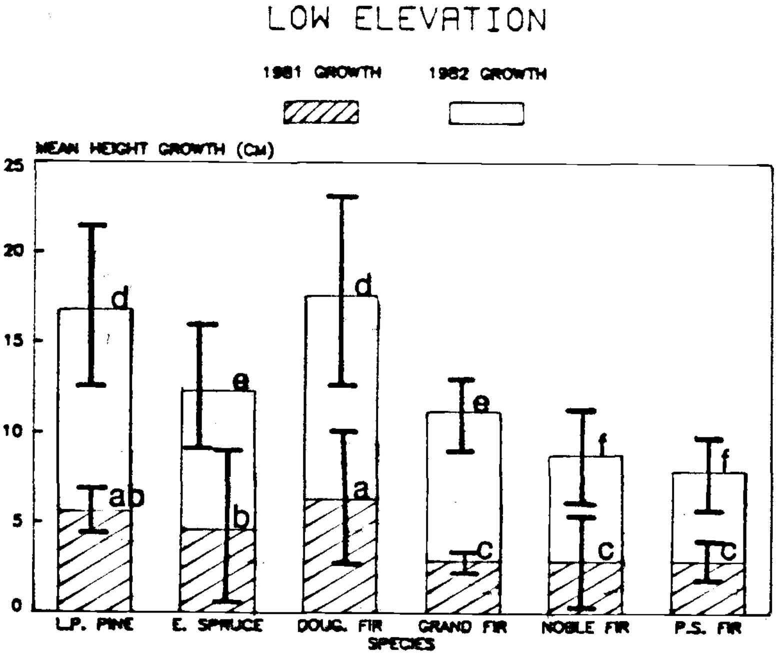


Figure 4. Height Growth Comparisons by Species on High and Low Elevation Sites. Bars are ± 1 standard deviations about the mean. Species mean values with similar letter designations are not statistically different at the .05 level.

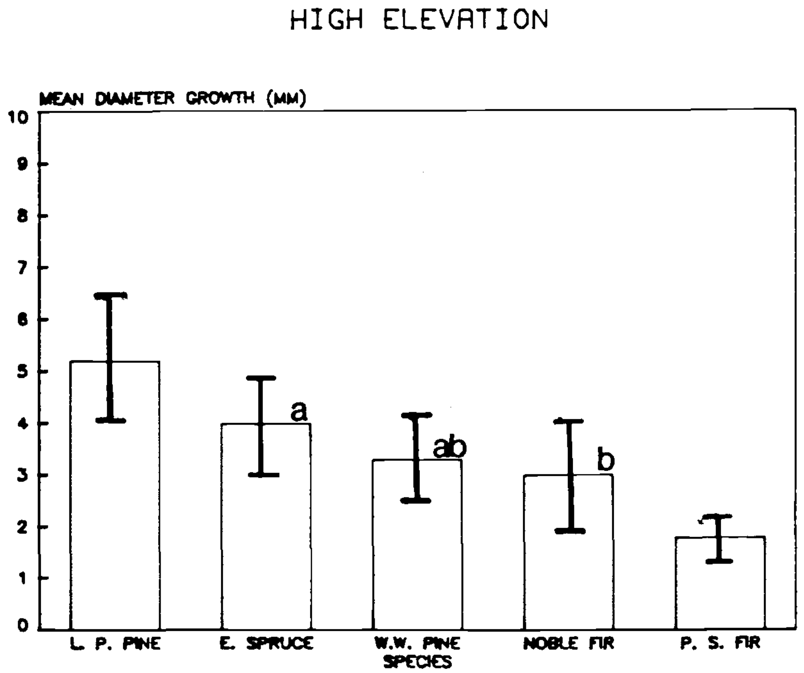
Noble fir and Pacific silver fir were the slowest growing species in 1981 and 1982. Noble fir height growth was not significantly different from that of western white pine and Engelmann spruce in 1981.

There was a 2.4 cm difference between first-season height growth between the slowest-growing species (Pacific silver fir at 3.4 cm) and the fastest-growing species (lodgepole pine at 5.8 cm). The difference in height growth between the fastest- and slowest-growing species was 9.4 cm after the second-growing season. Lodgepole pine exhibited the greatest height growth and total height at the end of the study. Engelmann spruce and western white pine had equal second-year growth and total growth.

Total height after two growing seasons was significantly different for all species, except lodgepole pine and Engelmann spruce. These species were 4.5 cm taller than the next tallest species, noble fir. Noble fir was 5 cm taller than western white pine and 10 cm taller than Pacific silver fir after two growing seasons. A contributing factor to the total height differences was initial planting height which was greater for noble fir (18.9 cm) than white pine (9.2 cm).

Diameter Growth by Species

Total diameter growth for lodgepole pine (5.2 cm) was significantly larger than that of any other species (Figure 5). Engelmann spruce diameter growth (4 cm) was significantly smaller than lodgepole pine but not significantly larger than western white pine (3.3 cm). Noble fir diameter growth (3 cm) was the next highest but statistically



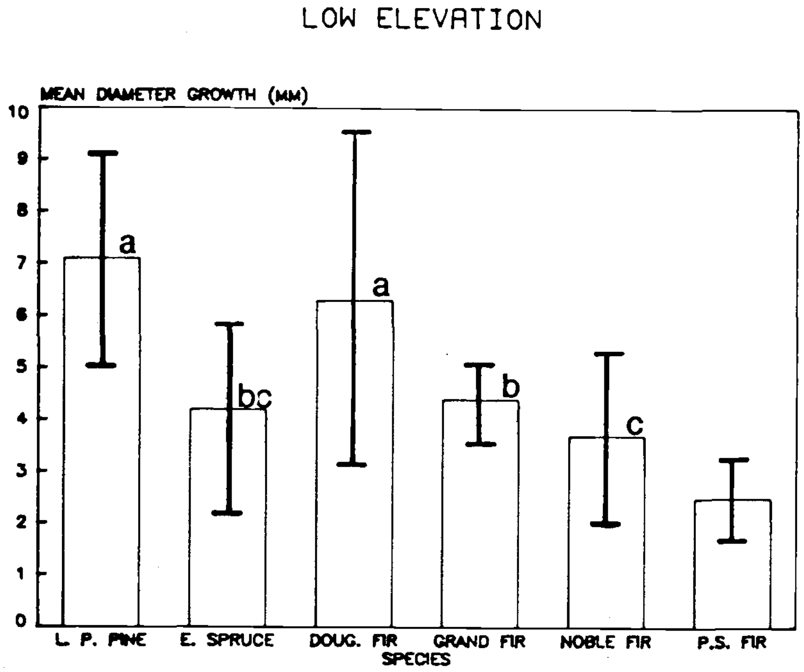


Figure 5. Two-year Diameter Growth Comparisons for Species on High and Low Elevation Sites. Bars are ± 1 standard deviations about the mean. Species ~~mean~~ values with similar letter designations are not statistically different at the .05 level.

different from that of western white pine. Pacific silver fir had significantly slower diameter growth (1.8 cm) than any other species.

Survival by Species

First-year survival of lodgepole pine, western white pine and Engelmann spruce were very similar (97 to 98 percent) and significantly greater than that of noble fir and Pacific silver fir (Figure 6). Noble fir and Pacific silver fir survival percentages were lower than the other three species (90 and 83 percent, respectively) but not significantly different from one another.

Trends of survival after 2 years were similar to those recorded during the first year. Engelmann spruce survival was best (92 percent), but not significantly different from lodgepole pine (91 percent) and western white pine (89 percent). Pacific silver fir survival (78 percent) was similar and not significantly different from that of noble fir (75 percent).

Height Growth by Planting Treatment

Results of Bonferoni multiple pairwise comparisons for treatments on the high elevation sites are presented in Table 6. Since mean first-year (1981) height growths by treatment were not significantly different from one another in the analysis of variance, this variable was not analyzed any further.

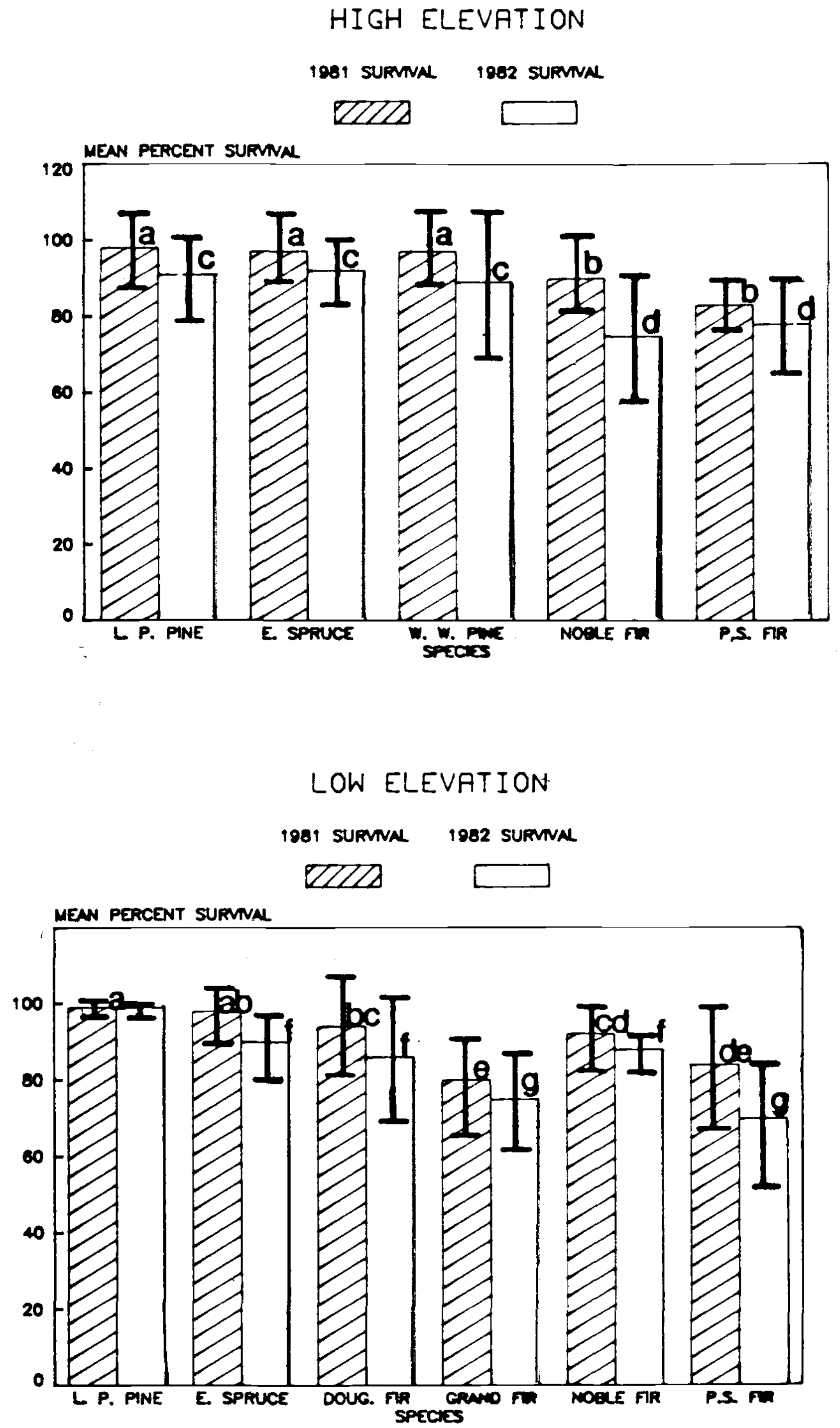


Figure 6. Comparison of Survival Percentages by Species on High and Low Elevation Sites. Bars are ± 1 standard deviations about the mean. Species mean values with similar letter designations are not statistically different at the .05 level.

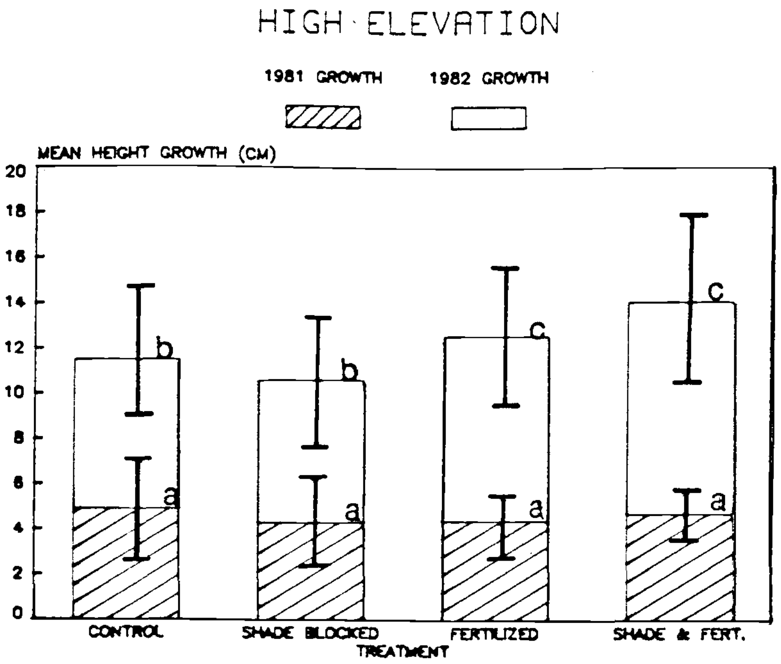
After the second-growing season, the surviving shaded plus fertilized ("both") seedlings and fertilized seedlings grew significantly better than the shaded and nontreated seedlings (Figure 7). Means for second-season height growth for "both" (9.4 cm) and fertilized (8.2 cm) treatments were not significantly different. Height growth for the control and shading treatments was similar and significantly less than for the "both" and fertilized treatments.

Total height growth after 2 years was best when "both" treatments were applied (25.4 cm) (Table 6). Fertilized trees produced slightly less but not significantly different total height growth (24.9 cm) than those with both. Control and shade (21 cm) treatments had the lowest growth rates. They were not significantly different from one another. The fertilized trees always had significantly higher growth rates than the shade treatment; however, when shade was combined with fertilization, height growth and diameter growth were better than or equal to that of the fertilized trees.

As would be expected, results of the statistical tests for total height growth for two growing seasons were similar to those for second-season height growth. The only difference was that total height growth for the "both" treatment was not significantly greater than growth for the fertilized trees.

Diameter Growth by Planting Treatment

Two-year diameter growth for the fertilizer and "both" treatments were not statistically different (4.0 mm versus 3.7 mm). Fertilization produced the greatest diameter growth rates (Figure 8). Application


HIGH ELEVATION

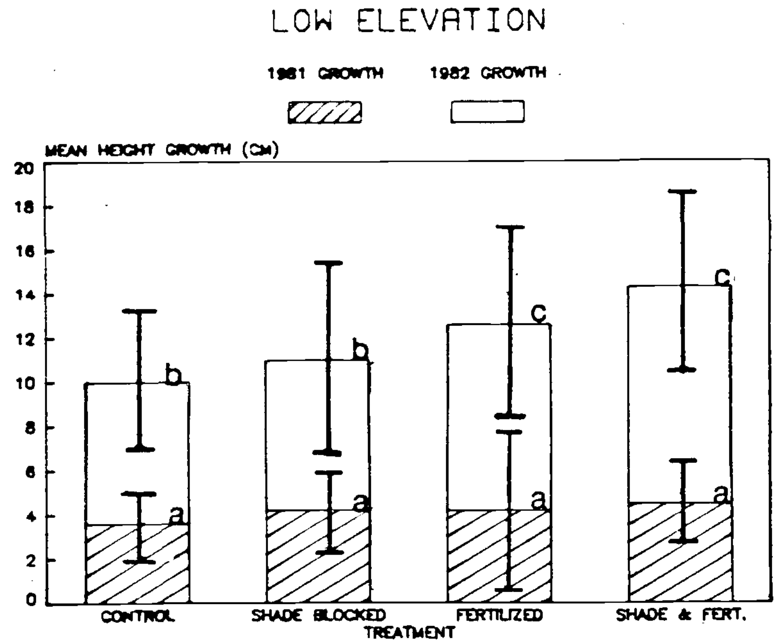

LOW ELEVATION

Figure 7. Height Growth Comparisons for Planting Treatments on High and Low Elevation Sites. Bars are ± 1 standard deviations about the mean. Treatment mean values with similar letter designations are not statistically dlfffercnt at the .05 level.

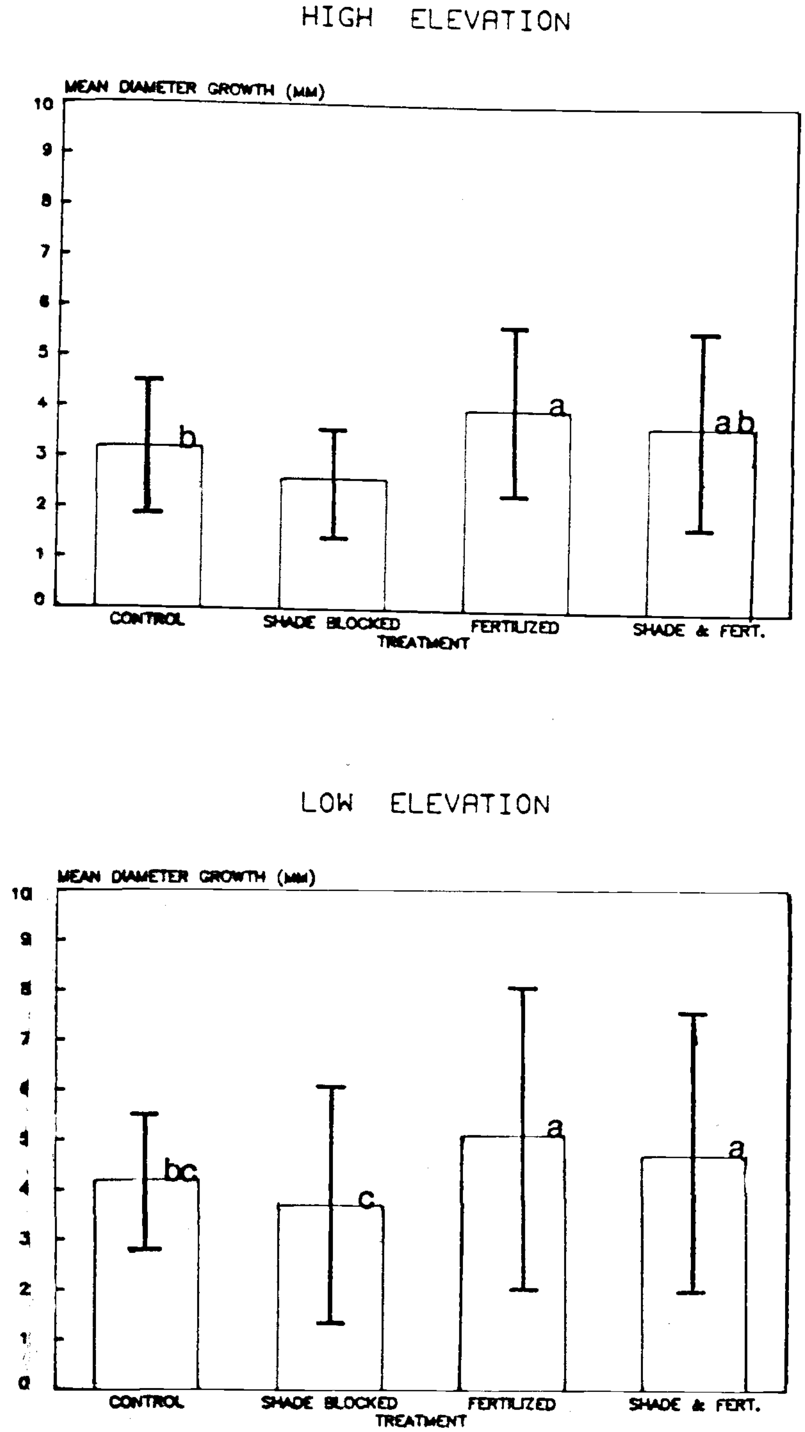


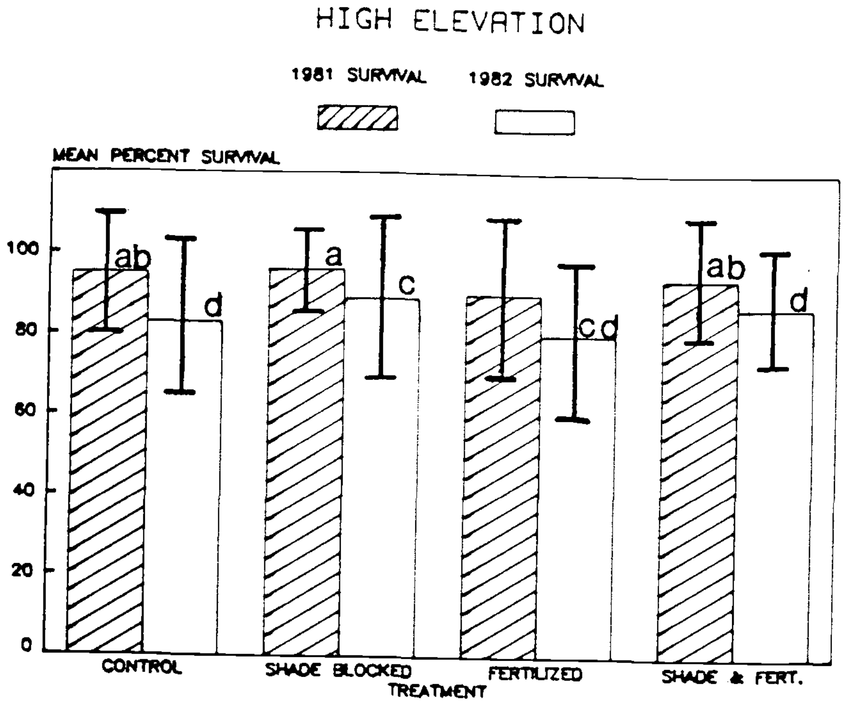
Figure 8. Two-year Diameter Growth Comparisons for Planting Treatments on High Versus Low Elevation Sites. Bars are ± 1 standard deviations about the mean. Treatment mean values with similar letter designations are not statistically different at the .05 level.

of both treatments was not significantly different from the control treatment (3.7 mm versus 3.2 mm). Diameter growth of the shaded seedlings was slowest (2.6 mm).

Survival by Planting Treatment

The differences in treatment means for both first- and second-season survival were small (Figure 9). The only statistically significant difference in first-year means was between the highest, shade treatment (96 percent), and the lowest, fertilization (90 percent).

For second-year survival, the shade treatment mean (89 percent) was significantly larger than that of the control (83 percent) and fertilization (80 percent) but not different from the both treatment (87 percent). Survival means for the "both," control and fertilization treatments were not significantly different.



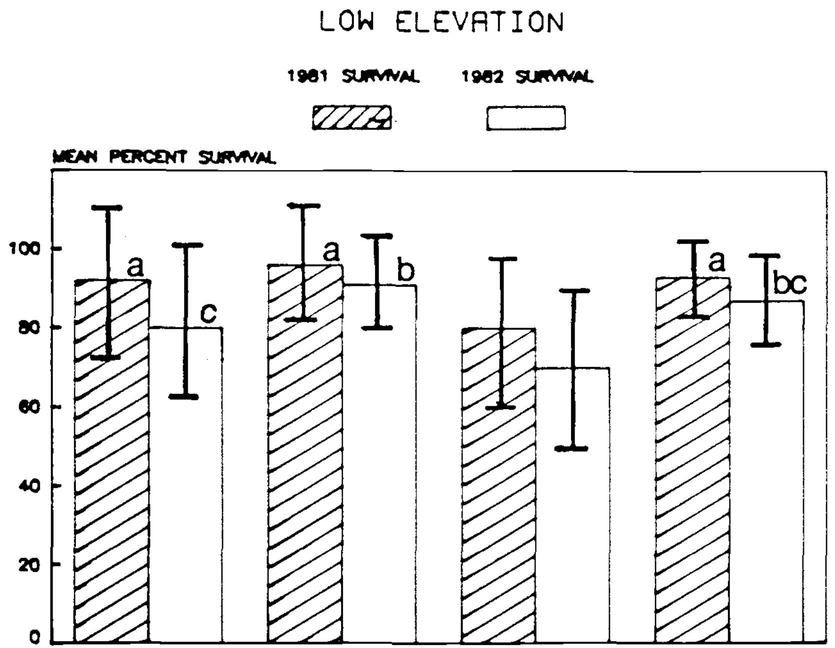


Figure 9. Comparisons of Survival Percentages for Planting Treatment on High and Low Elevation Sites. Bars are ± 1 standard deviations about the mean. Treatment mean values with similar letter designations are not statistically different at the .05 level.

Bonferoni Multiple Pairwise Comparisons
Low Elevation Sites

Results of Bonferoni multiple pairwise comparisons for low elevation seedling variables by species are presented in Table 7.

Height Growth by Species

Douglas-fir and lodgepole pine had the fastest first- and second-season growth rates (Figure 4). Douglas-fir (11.3 cm) mean second-season height growth was the largest of any species in both experiments. Engelmann spruce height growth was similar to that of lodgepole pine in 1981 but slower in 1982. First-season height growth for Pacific silver fir, grand fir and noble fir averaged 2.9 cm each. Mean second-year height growth for grand fir (8.3 cm) and Engelmann spruce (7.7 cm) mean growth were not significantly different, but significantly greater than that of noble fir and Pacific silver fir. Noble fir and Pacific silver fir growth rates were the slowest of any species (5.9 and 5.0 cm, respectively) and not significantly different from one another.

Total height growth patterns for all species were the same as 1982 height growth rankings (Table 7). Total height growth for Douglas-fir (17.9 cm) and lodgepole pine (16.7 cm) were the largest total height growths recorded in both experiments.

Total height after two-growing seasons was greatest for Douglas-fir (43.4 cm). The next tallest species, grand fir and lodgepole pine (32.4 and 30.7 cm,) were not significantly different from one another.

TABLE 7. RESULTS OF MULTIPLE PAIRWISE COMPARISON OF SPECIES AND TREATMENT MEANS FOR SEVEN SEEDLING ATTRIBUTES USING BONFERONI METHOD - LOW ELEVATION STUDY

GROWTH	SPECIES						TREATMENT			
								NOT SIGNIFICANT		
1981 Height Growth (mean in cm)	DF	LPP	ES	GF	PSF[1]	NF	BOTH	SHADE	FERT.	CONT.
	6.3	5.6	4.6	2.9	2.9	2.9[2]	4.5	4.2	4.2	3.6
1982 Height Growth (mean in cm)	DF	LPP	GF	ES	NF	PSF	BOTH	FERT.	SHADE	CONT.
	11.3	11.0	8.3	7.7	5.9	5.0	9.8	8.4	6.8	6.4
Total Height Growth (mean in cm)	DF	LPP	ES	GF	NF	PSF	BOTH	FERT.	SHADE	CONT.
	17.9	16.7	12.4	11.5	8.9	8.3	14.3	12.6	10.9	9.9
Total Height 1982 (mean in cm)	DF	GF	LPP	NF	ES	PSF	BOTH	FERT.	SHADE	CONT.
	43.4	32.4	30.7	28.3	28.0	25.5	31.4	29.9	28.2	28.1
Diameter Growth (mean in cm)	LPP	DF	GF	ES	NF	PSF	FERT.	BOTH	CONT.	SHADE
	7.1	6.3	4.4	4.2	3.7	2.5	5.1	4.7	4.2	3.7

---

[1] RANKED HIGH TO LOW

[2] UNDERLINED VALUES ARE NOT STATISTICALLY DIFFERENT AT .05 LEVEL OF SIGNIFICANCE

TABLE 7. Continued.

SURVIVAL

1981 Survival	LPP	ES	DF	NF	PSF	GF	SHADE	BOTH	CONT.	FERT.
Mean percent	99.0	98.0	94.0	92.0	84.0	80.0	96.0	93.0	92.0	80.0

1982 Survival	LPP	ES	DF	NF	GF	PSF	SHADE	BOTH	CONT.	FERT.
Mean percent	99.0	90.0	86.0	85.0	75.0	70.0	91.0	87.0	80.0	70.0

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[1] RANKED HIGH TO LOW

[2] UNDERLINED VALUES ARE NOT STATISTICALLY DIFFERENT AT .05 LEVEL OF SIGNIFICANCE

Total heights of lodgepole pine (30.7 cm), noble fir (28.3 cm) and Engelmann spruce (28.0 cm) were not significantly different from one another. Pacific silver fir total height (25.5 cm) was equal to that of Engelmann spruce and noble fir but significantly smaller than all the other species.

Diameter Growth by Species

Lodgepole pine and Douglas-fir exhibited the greatest diameter growth of any species in this experiment after two growing seasons (7.1 mm and 6.2 mm, respectively) (Figure 5). Grand fir (4.4 mm) and Engelmann spruce (4.2 mm), which had the next largest diameter growth rates, were not statistically different from one another. Engelmann spruce diameter growth was not statistically greater than noble fir (3.7 mm). All of the species had significantly greater diameter growth than Pacific silver fir (2.5 mm).

Survival by Species

First-year survival results were variable (Figure 6). There was no significant difference in first-year survival for the best surviving species, lodgepole pine (99 percent) and Engelmann spruce (98 percent). However, Engelmann spruce survival was not significantly greater than that of Douglas-fir (94 percent). Douglas-fir survival was not significantly different from that of noble fir (92 percent). Noble fir survival was not significantly different than that of Pacific silver fir (84 percent). First-year survival of Pacific silver fir was not significantly greater that of the poorest surviving species, grand fir (80 percent).

Two-year survival of lodgepole pine remained at 99 percent. This was significantly greater than the 2-year survival for all other species. Two-year survival of Engelmann spruce, Douglas-fir and noble fir were not significantly different from one another (90, 86 and 85 percent, respectively). Grand fir and Pacific silver fir, the poorest surviving species (75 and 70 percent, respectively) were not statistically different from one another.

Height Growth by Planting Treatment

As in the high elevation experiment, the analysis of variance for first-year height growth showed that treatment means were not significantly different from one another. This variable was not included in the multiple pairwise comparison analyses. The largest 1982 height growth rate observed in this experiment was that of the "both" treatment (9.8 cm) (Figure 7). However, the shaded and fertilized seedlings were not growing significantly faster than fertilized seedlings (8.4 cm). Two-year height growth for the shade (6.8 cm) and control (6.4 cm) treatments were lower and not significantly different from each other.

As in the species analysis, total height growth patterns were exactly the same as for second-year height growth (Table 7). Total height for this experiment was greatest for the "both" treatment (31.4 cm). The "both" treatment mean was significantly greater than all others, except fertilization (29.9 cm). Fertilization, shade (28.2 cm) and control (28.1 cm) treatment means were not significantly different.

Diameter Growth by Planting Treatment

Seedlings in the fertilization and "both" treatments had the largest and statistically equal 2-year mean diameter growth (5.1 and 4.7 mm, respectively) (Figure 8). The control treatment had the next largest mean diameter growth (4.2 mm) but was not statistically different from the "both" or the shade treatment. The mean diameter growth for the shade treatment (3.7 mm) was not significantly different from that of the control treatment.

Survival by Planting Treatment

First-season survival percentages for the shade (96 percent), "both" (93 percent) and control (92 percent) treatments were not statistically different, and all had significantly higher first-year survival rates than fertilized seedlings (80 percent) (Figure 9).

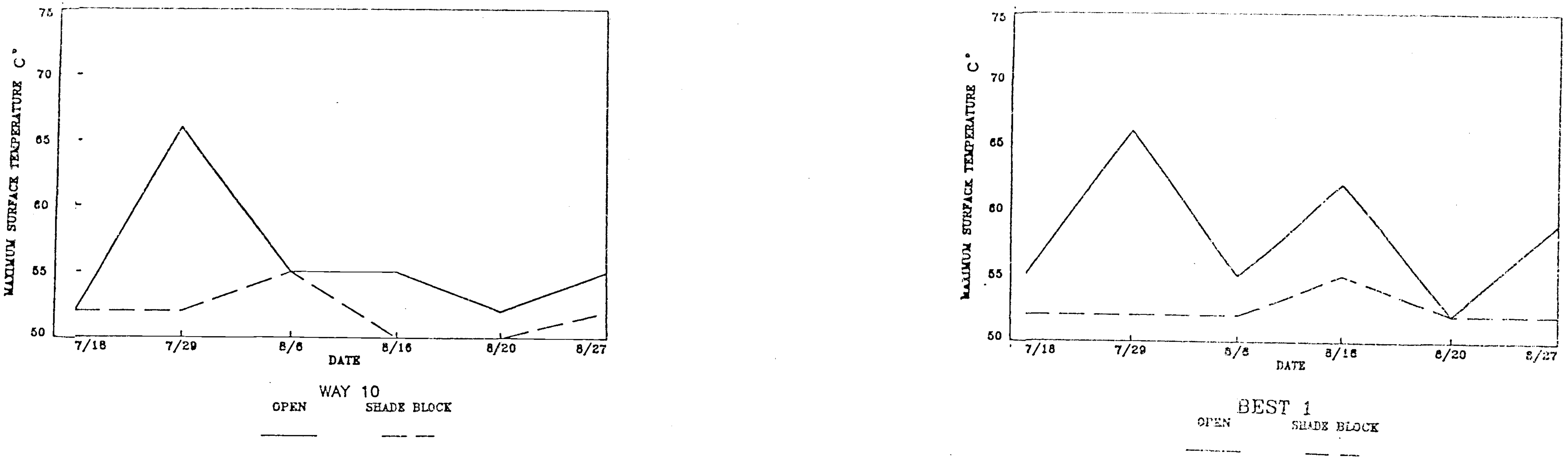
Two-year survival rates for the shaded trees were highest 91 percent). However, 1982 survival for shaded trees was not statistically greater than the 87 percent survival of trees receiving both treatments. Second-year survival for the "both" and control treatments (87 and 80 percent, respectively) were not significantly different. The 70 percent 2-year survival of the fertilized trees was significantly less than that of the other treatments.

Site Monitoring

Soil Surface Temperature

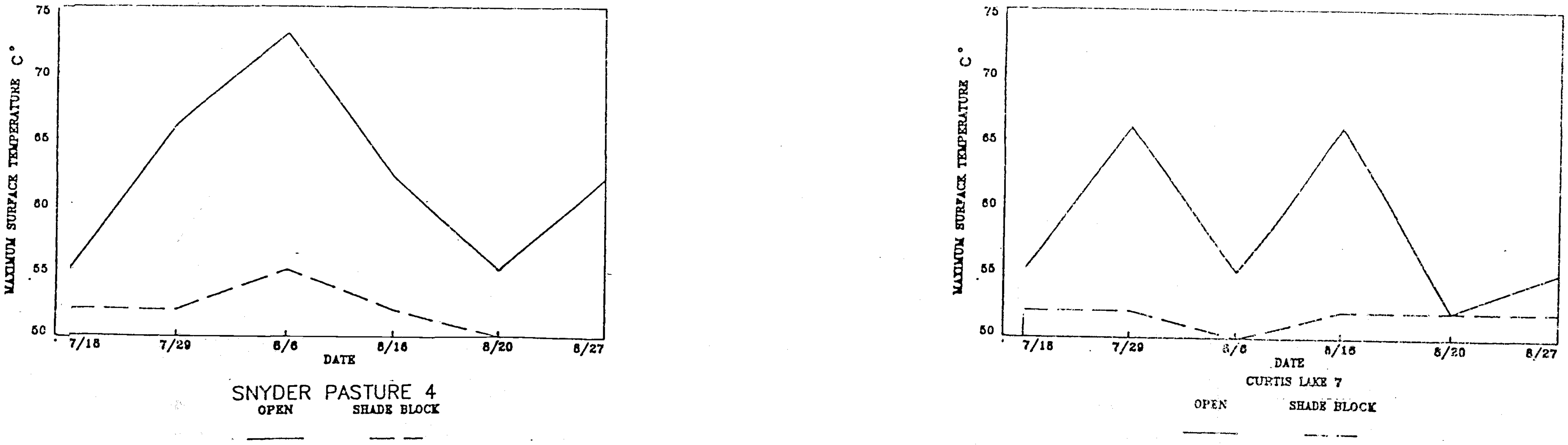
Mean maximum surface temperatures recorded biweekly for three shaded and unshaded replications on four sites during the summer of 1982 are presented in Figure 10. The mean maximum surface temperatures in the open were consistently higher than in the shade on all sites. The largest differences in temperature between the replications was observed during July. At this time, the maximum temperature recorded for shaded replications was 55°C (131°F) compared to the 73°C (163°F) for unshaded replications. Surface temperatures of 62°C (144°F) and 66°C (150°F) were not uncommon in the open replications during July and August.

The trends for the open replications were similar for the Curtis Lake, Way 10 and Best sites. Mean maximum surface temperatures for these sites were highest at the end of July and in mid-August (66°C, 150°F) but rarely exceeded 55°C (131°F). With the exception of the early August period, the hottest maximum surface temperatures were recorded on the open replications on the Snyder Pasture site. Surface temperatures for shaded replications were always lower than those in the open, never exceeding 55°C (131°F). Although these surface temperatures were the lowest for the study, they are relatively high.



WAY 10

BEST 1



SNYDER PASTURE 4

CURTIS LAKE 7

Figure 10. Maximum Soil Surface Temperatures on Shaded and Unshaded Areas of Four Sites, July-Aug. 1982.

Predawn Plant Moisture Stress

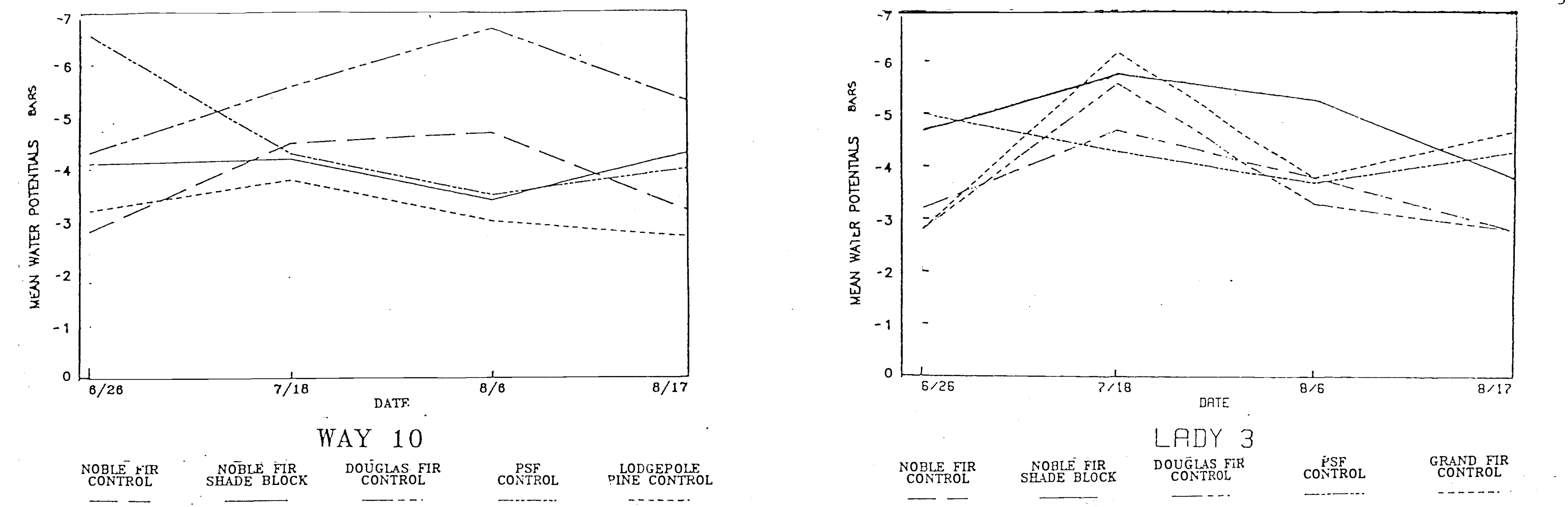
Monitoring of predawn plant moisture stress was done during the summer of 1982 (Figure 11). Mean predawn plant moisture stress readings ranged from 2.3 to 6.7 bars over the summer.

Noble fir control seedlings were used as a baseline for comparisons of moisture stress among the three sites monitored. Readings for noble fir on the most mesic lowest site (Curtis Lake 7) were generally the lowest. Noble fir on Way 10 had intermediate readings and predawn plant moisture stress was almost always highest on the the high elevation site, Lady 3

Of the species monitored, lodgepole pine seedlings exhibited the least moisture stress. Noble fir seedlings generally had the next lowest readings. Contrary to my expectations, the shaded noble fir seedlings often had higher plant moisture stress readings than did the unshaded seedlings. The difference was especially evident on the Lady 3 site. The shaded noble fir that were checked on two dates on Curtis Lake 7 had the lowest moisture stress readings recorded for those dates (2.3 and 2.7 bars).

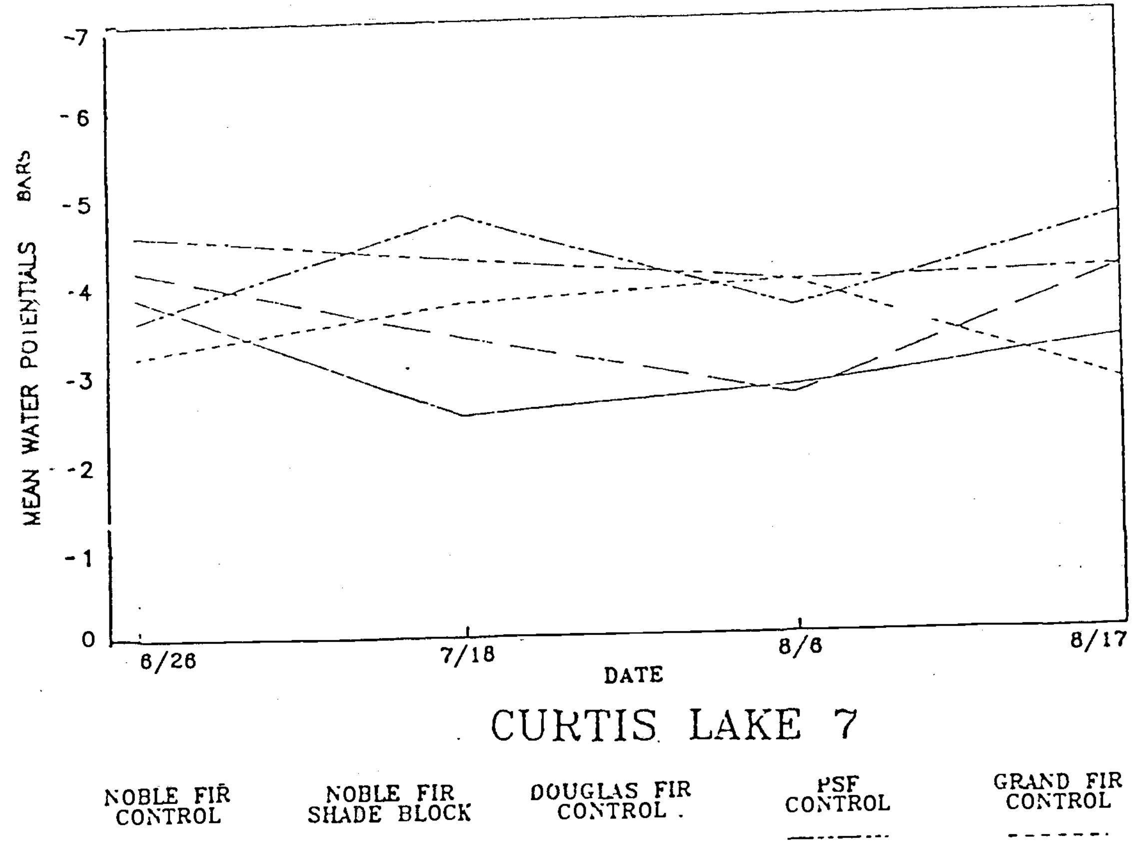
Correlations for Site Characteristics and Survival

The correlation coefficients for percent cover of high vegetation within 2 m (6 ft.) of the planting spot at planting and subsidence are presented in Table 8. Of the measurements of competing vegetation, the cover of high vegetation at planting was the most highly correlated to survival. The vigor ratings were the only variables more highly



WAY 10

LADY 3



CURTIS LAKE 7

Figure 11. Mean Predawn Plant Moisture Stress for Each Species on Three Sites, June-August, 1982.

Table 8. CORRELATION COEFFICIENTS FOR FIRST- AND SECOND-GROWING SEASON SURVIVAL AND SELECTED VIGOR RATINGS, PERCENT HIGH VEGETATION AT PLANTING AND SUBSIDENCE.

	SURVIVAL	
	First-Growing Season	Second-Growing Season
Crown Ratio (% live crown) First-Growing Season	-0.74	-0.71
Subjective Condition Vigor Rating First-Growing Season	-0.22	-0.35
High Vegetation at Planting	-0.28	-0.35
Subsidence	-0.09	-0.02

correlated with survival. High vegetation at planting was found to be consistently negatively correlated with survival. The correlation coefficients for percent cover of initial vegetation taller than 45 cm (18 in.) and first-and second-year survival were -.28 and -.35, respectively.

Correlations for Vigor Ratings and Survival

Data from the two experiments were combined for the correlation of vigor ratings and first- and second-year survival (Table 8). The vigor assessment based on percent live crown ranked seedlings from one to five, with one being seedlings with the largest live crown percentages and five the smallest. The subjective vigor rating ranked seedling condition from one to three with one being excellent and three being poor. Thus, low ratings indicated better vigor.

The only variable which appeared to be correlated to first- and second-season survival was first-season crown ratio rating. Correlation coefficients for first-season crown ratio rating, (-0.74 for first-season survial and -0.71 for second season survival) were much higher than those of the other variables analyzed. Correlation coefficients for first-season subjective condition ratings were very low (-0.22 and -0.35).

Mean first-season crown vigor ratings by species appeared to be a very good indicator of second-year survival potential, especially on the low elevation sites. Lodgepole pine, Englemann spruce, and western white pine which had the best vigor ratings (between 1.0 and 1.6) had the highest second-season survival rates in both experiments (Tables 1 and 2). Pacific silver fir, grand fir, and noble fir which had the had the poorest crown ratio ratings (between 1.8 and 2.5) and lowest 2-year survival rates.

Multiple Regression of Initial Seedling Morphological Characteristics and Slope and Ash Depth on Second-Season Survival

The regression analysis for initial seedling size characteristics on second-year survival showed that these variables were poor predictors of survival (Table 9). R^2 values for all possible multiple regressions of initial seedling root length, height and diameter on second-season survival were very low. The low R^2 values also indicate that the variability in species characteristics may have been more important to second-season survival than initial seedling size. Better results may have been obtained if the samples had been stratified by species.

The best R^2 values obtained (0.10 for the high elevation sites and 0.8 for the low elevation sites) were for initial diameter. The R^2 values for the other initial morphological characteristics in both experiments were quite low.

The best R^2 values obtained for the environmental variables were for the regressions of slope percent (0.25) and total ash depth (0.21) on the high elevation sites. The regressions for slope and ash depth in the low elevation experiment were quite low (0.01 and 0.004, respectively).

TABLE 9. R^2 (SQUARE OF THE MULTIPLE CORRELATION COEFFICIENT) VALUES FOR REGRESSIONS OF INITIAL SEEDLING MORPHOLOGICAL CHARACTERISTICS AT PLANTING AND SLOPE AND ASH DEPTH ON TWO-YEAR SURVIVAL.

Independent Variables	R^2 for Two-Year Survival High Elevation	R^2 for Two-Year Survival Low Elevation
Initial Root Length	.02	.004
Initial Height	.04	.01
Initial Diameter	.10	.08
Slope	.25	.01
Ash Depth	.21	.004

Mycorrhizal Root Tip Percentages for Fertilized and Unfertilized Sample Trees

The results of the examination of seedling roots from five of the sites are presented in Table 10. In 50 percent of the comparisons of fertilized seedlings, by site, fewer mycorrhizal root tips were found on fertilized Pacific silver fir and noble fir seedlings. Fertilized seedlings of these species also had fewer mycorrhizal roots than corresponding unfertilized replications on the same site 50 percent of the time.

TABLE 10. ESTIMATES OF PERCENT MYCORRHIZAL ROOT TIPS OF SAMPLES FROM THE UPPER AND LOWER PORTIONS OF FERTILIZED AND UNFERTILIZED SEEDLINGS EXCAVATED ON FIVE SITES.

SPECIES	TREATMENT	WAY 1 UNIT 1		CURTIS LAKE 7 UNIT 3		CLEARWATER 3 UNIT 4		WAY 10 UNIT 6		SMITH CREEK RIDGE 6 UNIT 5	
		U[a]	L[b]	U	L	U	L	U	L	U	L
DOUGLAS-FIR	FERTILIZED	M[c]	M	M	M	M	S	M	M		
	NOT FERT.	S	M	M	M	M	F	M	M		
PACIFIC SILVER FIR	FERTILIZED	S	S	F	N	F	M	M	M		
	NOT FERT.	M	M	M	M	F	M	M	M		
NOBLE FIR	FERTILIZED	S	S	F	S	F	F	M	M		
	NOT FERT.	M	M	S	M	M	M	S	S		
GRAND FIR	FERTILIZED			M	S						
	NOT FERT.			M	S						
WESTERN WHITE PINE	FERTILIZED									M	F
	NOT FERT.									M	M
LODGEPOLE PINE	FERTILIZED	M	M					M	M		
	NOT FERT.	M	M					M	M		
ENGELMANN SPRUCE	FERTILIZED					M	M			M	M
	NOT FERT.					M	M			M	M

[a] U -- UPPER ROOTS

[b] L -- LOWER ROOTS

[c] MYCORRHIZAL TIPS ON UPPER AND LOWER ROOT SYSTEMS ARE CLASSIFIED AS:

F -- A FEW: LESS THE 5 PERCENT
S -- SOME: MORE THAN 5 PERCENT, LESS THAN 50 PERCENT

M -- MAJ: MAJORITY, GREATER THAN 50 PERCENT

DISCUSSION

Species Performance

Survival and Growth

All of the species tested in this study survived and grew equally well. The relative performance results for species were no different than those for species evaluated in pre-eruption planting trials (Dezellem 1981) and operational plantings near Mount St. Helens. Variations in survival for species exposed to harsh conditions have been attributed to specific differences in early growth habits and stress resistance (Hinckley et al. 1982). This seemed to be the case in my study.

Lodgepole pine, Douglas-fir and western white pine survived well on the most disturbed sites. These shade-intolerant species, which commonly dominate the early successional stages of stand development, are fast growing, stress resistant, are good water regulators, and can efficiently utilize site resources (Minore 1979). These early seral species make rapid physiological adjustments in response to the environment and are able to fully utilize limiting site resources such as light, nutrients, and water and avoid adverse conditions by responding quickly to the environment.

Late successional species, such as the true firs, respond slowly to the environment and tolerate stressful conditions rather than avoid them. They are less able to withstand extreme, long-lasting or rapidly changing conditions.

Noble fir, which regenerates well after logging and disturbances such as fire (Fowells 1965), did not perform as well as expected. Adverse moisture conditions may have prevented noble fir, the least drought resistant of the seral species (Hinckley et al. 1982), from surviving as well as Douglas-fir and lodgepole pine. The higher water potentials measured in August for noble fir seedlings (Figure 11) on the most disturbed site (Way 10) when surface temperatures were lowest (although still relatively high, Figure 10) indicated that noble fir seedlings may not have been able to withstand the extreme or extended periods of drought.

Lopushinsky and Klock (1974) found that species which were able to reduce transpiration rates through stomatal control in response to decreasing soil water potential were best able to avoid drought. They found that lodgepole pine seedling were most responsive to changes in soil water followed by Douglas-fir, grand fir and Engelmann spruce. Species which avoid drought by effectively regulating transpirational water loss through stomatal control are generally more drought resistant than those which do not (Hinckley et al. 1982). True fir species which have poor stomatal control of transpiration (Lopushinsky 1969) are restricted to well-drained sites where soil moisture is high and evapotranspirational demand is low (Powers 1981).

The plant predawn moisture stress readings for lodgepole pine were generally lower than those of the other species (Figure 11). This indicated that it was better able to reduce its rate of water loss or was more efficient at obtaining water than were the other species. Lodgepole pine also performs well in low nutrient environments and has higher root growth rates than any of the other species tested (Minore 1979). These characteristics may have allowed lodgepole pine seedlings to obtain water more effectively in the ash substrates and maintain rapid growth.

Several species, such as Douglas-fir and lodgepole pine, which have adapted to early seral conditions exhibited rapid juvenile growth rates. Seedlings of these species and grand fir grew much faster in this study than did the shade-tolerant Pacific silver fir and noble fir seedlings.

There were no significant differences among species first-season height growth in either experiment. For every species, second-season height growth rates exceeded those of the first-season. Differences among species growth rates were greatest in the high elevation experiment. Douglas-fir and lodgepole pine, known to have rapid juvenile growth rates, (Brockway et al. 1983) had the best second-year height (11 cm) and 2-year diameter (5-7 mm) growth. Engelmann spruce, western white pine and grand fir had moderate 2-year height (7-8 cm) and diameter (3-4 mm) growth rates.

Pacific silver fir and noble fir, known to have slower juvenile growth rates (Brockway et al. 1983 and Halverson and Emmingham 1982), had the lowest 2-year height (4-5 cm) and diameter (2-4 mm) growth. Diameter growth for each species on the low elevation sites was always greater than that of the same species on high elevation sites. The better diameter growth on the low elevation sites may have been the result of the longer growing season on these less harsh sites and lack of competition.

Comparison with other Mount St. Helens Planting Studies

All of the species tested in this study survived as well as or better than pre- and post-disturbance plantings near Mount St. Helens. Clark (1983) reported that survival of recent operational plantings averaged 75 to 80 percent, which are similar to the 80 percent overall second-year survival for all seedlings in my study. The excellent survival rates for the seedlings in my study may have been due in part to the favorable weather conditions at planting and the careful, closely monitored planting.

Although not strictly comparable, seedling survival on operational plantings by Burlington Northern Timberlands on a site near the Way 1 site in the low elevation experiment was much lower than that from my study (Swanson and Szumera 1982). Their site was closer to Mount St. Helens and had deeper ash deposits than most sites in my study.

Swanson and Szumera's (1982) first- and second-year survival percentages for 2-0 Douglas-fir were 66 percent and 48 percent, respectively. These were much lower than the 94 percent first-season and 86 percent second-season survival of Douglas-fir in my low elevation experiment. Second-year survival for their 1-0 noble fir was

94 percent, considerably higher than the 85 percent average second-year survival of noble fir in the low elevation experiment. Their first-year survival results for 2-1 Douglas-fir seedlings were quite high, 96 percent, but dropped to 58 percent after the second growing season.

I speculate that the differences in performance observed in these two studies may have been due in part to the different planting methods. Auger planting, used in my study, may have been more suited to post-eruption conditions than the shovel method used in the Burlington Northern planting.

Washington State Department of Natural Resources (DNR) operational plantings on the debris flow resulted in first-season survival rates of 89 percent for all species (Russell 1982) which were similar to the combined 90 percent first-season survival for all species on my low elevation ash-covered sites. However, DNR's combined second-year survival of 65 percent was much lower than my combined second-season survival rate of 83 percent. These differences in survival are not surprising, since the substrate conditions on the debris flow were very different and the sites were located in a different drainage and 20 miles to the west of my study sites.

The DNR's 85 percent 2-year survival for lodgepole pine was lower than the 99 percent 2-year survival recorded for the low elevation sites in my study. Western white pine second-season survival (65 percent) was significantly lower than the that from my study (89 percent). Grand fir survival was 75 percent for both studies.

The DNR attributed two-thirds of the 35 percent 2-year mortality to elk damage and one-third to drought. Eighty-five percent of the mortality in planted grand fir and 90 percent of the mortality in western white pine was drought caused. Thirty-five percent of the Douglas-fir and 20 percent of the lodgepole pine mortality was also caused by drought. The other two thirds of the mortality in Douglas-fir was caused by elk damage. Contrary to my results, lodgepole pine was found to be susceptible to ravel damage. This may have been due to differences in lodgepole pine planting stock or topograpy.

The Weyerhaeuser Company conducted reforestation studies northwest of Mount St. Helens at 1070 m (3500 ft.) (Stevens 1982). The ash deposits were fine in texture and generally not as deep as that on the sites in my study. Lodgepole pine survival (92 percent) was excellent as in the high elevation sites in my study (91 percent). Weyerhaeuser's 2-1 Pacific silver fir survival was 78 percent. This is equal to the survival of my 2-0 Pacific silver fir on the high elevation sites. Their 2-1 noble fir survival (69 percent) was slightly less than that of my 2-0 stock (75 percent). As in my study, they reported first- and second-growing season survival results for true fir species that were consistently lower than those of other species tested.

Total height and 1982 height growth for lodgepole pine in my high elevation study were comparable to those reported for seedlings which had all of the ash removed from the planting holes on Weyerhaeuser lands (Stevens 1982). However, the 11 cm of height growth for my control lodgepole pine seedlings was considerably greater than the 4.3 cm reported by Stevens.

Results from these various planting studies can only be compared in a general way. Differences in seedling performance may have been caused by variations in site conditions, planting stock, and planting procedures. The excellent performance for seedlings in my planting test may have been the result of the careful planting. Differences in performance on the Weyerhaeuser sites and my study sites may have been due to the greater amount of competing residual vegetation, and flooding and ponding problems on the Weyerhaeuser sites.

Seedling Size

The poor results for the regression of inital size variables on survival (when not classified by species as in the analysis of variance) indicated that the variability in seedling survival can better be understood by examining differences in species autecological characteristics. Of the seedling size variables analyzed, initial diameter had the highest R^2 values for second-year survival in both experiments. Initial diameter may have been important to survival in the high elevation experiment since it appeared that the large-diameter trees on the steep Bench site were ravel resistant. Average survival for all seedlings on this site was very low, 60 percent. The species which grew fastest and had the largest initial diameters and heights (Engelmann spruce and lodgepole pine) survived and grew best (Table 1).

Franklin and Rothacher (1962) and Berntsen (1958) found that larger seedlings survived best on steep, ravel-prone slopes. Franklin and Rochacher (1962) recommended a 3-0 seedling was best for planting on ravel-prone sites. I found, as did Cleary et al. (1978), that seedlings with large stem diameters were less susceptible to bending and ravel damage. Cleary et al. (1978) suggested that large diameter seedlings are better insulated from heat damage because heat is dissipated along and away from the stem.

Seedling Comparisons for the High and Low Elevation Sites

Survival and growth for species planted in both experiments in this study were similar. Height growth and total growth were slightly better for most species on the low elevation sites (Figure 4). However, height growth figures for the treatments were almost identical for both experiments (Figure 7). Diameter growth was consistently greater on low elevation sites (Figure 5).

The greatest difference between the two experiments was in second-year survival. Second-year survival for all seedlings on low elevation sites (85 percent) was higher than that of high elevation sites (75 percent). With the exception of Pacific silver fir and Engelmann spruce, species survival was 8 to 10 percent better on low elevation sites.

Noble fir performance on low elevation sites was slightly better than on high elevation sites. The very poor survival (43 percent) of noble fir on a single site, the high elevation steep site (Bench), may be the reason for this difference.

Lodgepole pine performed better than most species in both experiments. Engelmann spruce grew slightly faster and survived better on the high elevation sites, possibly because it is a very frost resistant species. Pacific silver fir survived better on the high elevation sites. This is not surprising since this species is most commonly found at elevations above 1070 m (3500 ft.) in natural stands. Difference in total height for the two experiments after two growing seasons was greatest for Pacific silver fir. Total height on low elevation sites was 25.5 cm, compared to 14.6 cm on high elevation sites. The greater transpirational demands of the larger seedlings on the lower sites may have increased drought related mortality.

Reforestation Environment

Temperature and Moisture Conditions

The high survival and growth rates indicated that the ashfall and devastated sites were not as harsh an environment for seedling establishment as they originally appeared. However, data from the soil surface temperature and moisture stress monitoring and from other planting trials results at Mount St. Helens suggest that some unfavorable climatic and soil conditions may limit future reforestation. Steep, south-facing slopes, pumice-dominated soils and large, unprotected areas may be droughty. The large amounts of solar radiation and range of soil surface temperatures on south or southwesterly-facing slopes may have been extreme. The high solar input and high heat reflectivity of the light-colored ash may have contributed to heat stress. The highest soil surface temperatures and plant moisture stresses were measured on the steepest, southwest facing unit (Way 10). Hallin (1961) also found that steeper, south-facing sites generally had higher soil surface temperatures.

Seedling predawn plant moisture stresses monitored in 1982 were rarely high but may have affected seedling growth (Figure 11). Plant moisture stresses between -5 to -10 bars can reduce photosynthesis (Emmingham and Waring 1977). Halverson and Emmingham (1982) suspected that the combination of plant moisture stress within this range and high soil surface temperatures could raise evaporative demands of poorly adapted seedlings, resulting in mortality.

Site Conditions and Seedling Performance

Although the R^2 values from the regression analysis (Table 9) were not high, ash depth and slope were fair predictors of second-year survival on the high elevation sites. Erosion, uprooting, and burial of seedlings by the unstable ash and tephra deposits was a major cause of mortality in both experiments. Ravel-caused damage was most prevalent on the sites with deeper ash deposits, especially on steeper slopes.

The lowest survival rates in the low elevation experiment were recorded on the unstable, erodable exposed sites in the blast zone. Survival rates were slightly higher on the less disturbed ash zone sites in the high elevation experiment. This indicates that the extent of disturbance, and depth of the ash deposits may be critical factors in determining the severity of the regeneration environment.

The depth and composition of the volcanic deposits determined how quickly seedlings had access to residual soil and decaying organic material and nutrients. Klock (1980) suggested that auger planting could eliminate all soil physical and chemical barriers to regeneration. Radwan (1981) conducted pot studies with Mount St. Helens ash and speculated that seedlings may survive only when planted in the residual soil rather than in mud or ash. He found that seedling root penetration was difficult in compacted volcanic ash or mud. Hermann (1970) found that seedlings planted on the pumice soils in Central Oregon begin to exhibit satisfactory growth only after their roots had reached the water and nutrient-rich residual soils. Upon extraction of the seedlings, we found that roots were concentrated in old organic materials, and trees having root contact with these materials were quite vigorous.

Trees not carefully placed in the planting holes, especially on the pumice deposits where the larger tephra particles led to improper soil packing around the roots, tended to sink into the planting holes. This subsidence in the planting holes appeared to be a problem. Subsidence was not however, found to be highly correlated (Table 8) with first- or second-year survival (correlation coefficients of -.09 and -.02, respectively). On sites where the subsidence was most evident (Smith Creek Ridge, Independence East, and Way 10), seedling survival rates were lower (Tables 6 and 7). These sites were also the most exposed and disturbed.

When the Weyerhaeuser Company (Stevens 1982) tried ash scalping on the fine ash deposits on their planting sites, they found that the depressions collected water and drowned seedlings. Stevens (1982) found that scalping reduced seedling survival but increased growth. Although not as common on pumice deposits, a similar situation may have occured when subsidence depressions were formed in augered planting holes.

Competing Vegetation

A study of plantation records from the Wind River Ranger District, just south of Mount St. Helens, showed that long intervals between site preparation and planting allowed competing vegetation to return (Dezellem 1981). First-year survival rates were significanlty lower when the interval between site preparation and planting was increased. I wished to determine if returning vegetation would cause a reduction in survival rates similar to those found by Dezellem (1981).

The correlation of survival and cover of vegetation was not particularly strong. The highest correlation coefficients were observed for high vegetation at planting (-.28 for first-season survival and -.35 for second-season survial). These results suggested that the negative effects of competition for moisture and nutrients may have been more important than the protection that the live vegetation provided. This is particularly true of the less disturbed sites in the areas which only received ash deposits.

Reforestation should proceed quickly to avoid moisture and light competition from the rapidly-recovering residual vegetation, especially on the less disturbed sites. Many sites in the ashfall zone were already being rapidly colonized by willow (*Salix spp*.) and vine maple (*Acer circinatum* pursh.) sprouts.

Treatment Effects

Fertilization

Fertilization, alone and fertilization with shading, resulted in greater second-year height growth, total height growth and diameter growth than did shading alone and control treatments. Differences in first-year height growth means for treatments were not found to be significantly different from one another. Other researchers have reported that the effects of fertilization are usually not evident until the second-growing season after application (Carlson and Presig 1981 and Nicholson 1968).

The fertilization treatment significantly reduced seedling survival, while the slower growing shaded trees had significantly higher survival rates. The fertilized seedlings had rapid second-year shoot growth rates but I speculate that they may not have maintained adequate root growth to meet the needs of rapidly growing shoots. I suspect that eventually the seedlings may not have been able to extract enough water from the rooting zone to meet transpirational needs.

These results agree with Lahiri's (1972) assertions that fertilization of water-stressed plants may not be beneficial. Nicholson (1968) indicated that adequate soil moisture is necessary for the best results with slow release fertilizers. He also reported no significant increases in height growth on dry south- or west-facing slopes. Second-year height and diameter growth of fertilized or fertilized and shaded seedlings was significantly greater than that of surviving unfertilized seedlings. Douglas-fir seedlings showed the greatest growth response to fertilization.

True fir seedlings were particularly sensitive to the fertilization treatment. Survival rates were lowest for the faster growing Pacific silver fir, noble fir and grand fir seedlings on the same sites. For these species, especially noble fir, slow growing seedlings seemed to survive better. In contrast, the fastest growing lodgepole and western white pine seedlings exhibited superior survival. The pines species were able to meet transpirational demands by initiating and maintaining adequate root growth.

Fertilized seedlings often had lower percentages of mycorrhizal root tips than non-fertilized seedlings. A reduction in number of mycorrhizal root tips with fertilization was evident for true fir seedlings. On all of the sites sampled, fertilized noble fir seedlings had fewer mycorrhizal root tips than non-fertilized seedlings. Fowells and Krauss (1959) found that seedlings fertilized with phosphorous and nitrogen had fewer mycorrhizal roots than seedlings grown in nutrient-poor substrates. Kramer and Kozlowski (1980) and Richards and Wilson (1963) also found that increasing soil nitrate levels slowed mycorrhizae development.

Seedling survival and growth may be aided by associations with mycorrhizal fungi. Mycorrhizal associations have been shown to be particularly benefical to seedling establishment on severely disturbed sites (Wilcox 1980). Mycorrhizal fungi are known to increase root surface area and may enhance water and nutrient uptake (Trappe and Fogel 1977). Of the seedlings observed in my study, Pacific silver fir and noble fir seedlings generally had the fewest mycorrhizal roots. Seedlings of all of the other species, which consistently performed better than Pacific silver fir and noble fir, usually had greater numbers of mycorrhizal root tips.

The Weyerhaueser Company tested various fertilizers in reforestation test plantings on deposits more than 25 cm deep (Stevens 1982). They found, as I did, that fertilized lodgepole pine seedlings were less susceptible to fertilizer-caused mortality than was noble fir. They tested six different formulations of fertilizers and found that mortality increased with the higher application rates. Clark (1983) attributed the mortality of seedlings planted directly in ash to a lack of nitrogen.

The height growth of the fertilized or fertilized and shaded seedlings was never more than 19 or 20 percent (3 cm) greater than that of the non-fertilized seedlings. Although these small height growth gains were statistically significant, the lower survival rates with fertilization may negate the benefits of better height growth. Other researchers have reported larger height gains with fertilization than observed in my study. Nicholson (1968) reported a 3 to 8 cm increase in height growth after fertilization of seedlings on the Mt. Hood National Forest.

Height and diameter growth rates of fertilized Douglas-fir and lodgepole pine were 18 percent greater than non-fertilized seedlings. The use of fertilization to hasten diameter growth may reduce ravel damage. Better survival and growth results may be achieved at Mount St. Helens by obtaining nursery stock with high mineral nutrient levels and high root growth potentials rather than with fertilization.

Shading

Shading generally aids seedling survival on harsh sites by reducing both heat and drought stress. It was particularly effective in my study on south- or southwest-facing sites and on exposed sites in the blast zone. Results of the temperature pill study (Figure 10) showed that maximum soil surface temperatures behind shade blocks were reduced as much as $20^{o}C$. I suspect that shading may have helped to lessen drought stress by lowering evaporation of soil moisture and reducing seedling transpiration.

I found, as did Ronco (1975), that shading was efficient in reducing mortality of the heat-sensitive, shade-tolerant species, Pacific silver fir, Noble fir, and Engelmann spruce. Shade had little effect on survival of shade-intolerant species, such as lodgepole pine and Douglas-fir. These results are also similar to those of Ronco (1975) who found that shade did not aid the survival of these species.

Shaded trees always exhibited slower growth rates than fertilized trees and in the high elevation experiment they grew slightly slower than the control trees. However, seedlings that received both shading and fertilization grew slightly faster (although not significantly) than the fertilized trees.

SUMMARY AND CONCLUSIONS

The species tested in this study survived and grew similarly . With this information, silviculturists may select the species best adapted to specific site characteristics. For instance, Engelmann spruce could be planted in frost pockets or lodgepole pine could be used for reforestation of ravel-prone areas.

Douglas-fir will perform best on sites below 914 m (3000 ft.) which are not frost-prone or exposed and windy. Lodgepole pine and Douglas-fir exhibited the best diameter and height growth rates. Where site conditions are severe, lodgepole pine, Engelmann spruce or noble fir may perform better.

On plantations above 914 m (3000 ft.), survival of all species tested was at least 75 percent. Lodgepole pine, western white pine and Engelmann spruce grew well. However, because of their fast growth and high value at harvest, noble fir and rust-resistant western white pine may be the best choices for reforestation.

On erosion-prone sites or where slope steepness exceeds 60 percent, large planting stock may be more ravel resistant. Fertilization or the use of rapid-growing species such as Engelmann spruce, lodgepole pine and Douglas-fir should be considered on steep slopes or exposed sites needing immediate revegetaion.

Shading will enhance survival on south or southwest-facing slopes, especially in the blast zone. Shading will most improve survival of true fir seedlings. Shaded trees generally had significantly slower growth rates than fertilized trees but when shaded trees were also fertilized, height growth was equal to or better than that of ferilized trees.

Fertilized trees exhibitied faster height and diameter growth and significantly lower survival rates than nonfertilized seedlings. The depression in survival rates was especially evident on droughty sites and for true fir seedlings. Western white pine, lodgepole pine and Douglas-fir seedlings responded best to fertilization. These species exhibited less of an increase in mortality and larger increases in growth rates. The increased growth rates of these species when fertilized may facilitate the regeneration of steep ravel-prone sites where larger fast-growing trees are most needed. However, the depression in survival observed for most species indicates that the fertilization will not be beneficial.

Adequate mycorrhizal infection of seedling roots was evident on the five sites I monitored. Seedling roots should be carefully handled and soil should be packed firmly around the roots in the planting hole. Planting should be done when soil and weather conditions are favorable.

Conifer regeneration on these disturbed sites must proceed as quickly as possible. Residual vegetation which may successfully compete with conifers on the less severly disturbed sites is recovering rapidly. On some of the wetter ashfall zone sites in this study, competing vegetation had rapidly outgrown the planted seedlings after two growing seasons. Conifer establishment on severly disturbed sites will aid slope stabilization efforts.

Every attempt should be made to produce and handle seedlings so that root growth potential is maximized. It is essential that planted seedlings be able to initiate root growth rapidly after planting, especially on the more severely disturbed sites. Seedlings which can maintain rapid root growth will obtain soil water and nutrients and avoid drought damage.

Successful reforestation at Mount St. Helens will be possible if site characteristics are carefully considered and healthy, well-adapted seedlings are carefully handled and planted.

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APPENDIX

APPENDIX 1. BONFERONI CALCULATIONS FOR DEPENDENT SEEDLING VARIABLES ON LOW ELEVATION

$$B = T_{(.05/2s)\ (df)} \bullet \sqrt{S^2_{(D)}}$$

FOR TREATMENT

$$S^2_D = \frac{2 \quad \text{mean square error}}{a \bullet n}$$

a = no. of species (6)
b = no. of treatments (4)
n = no. of blocks or units (6)
nt = total number of cells (96)
s = number of comparisons (6)

CALCULATION OF TABULAR VALUE

DEGREES OF FREEDOM $r = b = 4$
$v = nt - a \bullet b =$
$96 - 24 = 72$

$T_{(.05/12)\ (72)} = 2.6375$

TEST STATISTIC $B_{.05} = 2.6375 \times \sqrt{S^2_D}$

FOR SPECIES

$$S^2_D = \frac{2 \text{ mean square error}}{an}$$

a = no. of species (6)
b = no. of treatments (4)
n = no. of blocks or units (6)
nt = total number of cells (96)
s = no. of comparisons (15)

CALCULATION OF TABULAR VALUE

DEGREES OF FREEDOM $r = a = 6$
$v = nt - a \bullet b =$
$96 - 24 = 72$

$T_{(.05/30)\ (72)} = 2.93449$

TEST STATISTIC $B_{.05} = 2.93449 \times \sqrt{S^2_D}$

APPENDIX 2. BONFERONI CALCULATIONS FOR DEPENDENT SEEDLING VARIABLES ON HIGH ELEVATION SITES

$$B = T_{(.05/2s)\ (df)} \quad S^2_{(D)}$$

FOR TREATMENT

$$S^2_{(D)} = \frac{2 \text{ mean square error}}{a \bullet n}$$

a = no. of species levels (5)
n = no. of blocks or units (5)
b = no. of treatment levels (4)
nt = total number of cells (80)
s = no. of comparisons (6)

CALCULATION OF TABULAR VALUE

DEGREES OF FREEDOM $r = b = 4$
$v = nt - a \bullet b =$
$80 - 20 = 60$

$T_{(.05/12)\ (60)} = 2.6445794$
TEST STATISTIC $B_{.05} = 2.6445794 \times S^2_{(D)}$

FOR SPECIES

$$S^2_{(D)} = \frac{2 \text{ mean square error}}{a \bullet n}$$

a = no. of treatment levels (4)
n = no. of blocks or units (5)
b = no. of species levels (5)
nt = total number of cells (80)
s = no. of comparisons (10)

CALCULATION OF TABULAR VALUE

DEGREES OF FREEDOM $r = a = 4$
$v = nt - a \bullet b =$
$80 - 20 = 60$

$T_{(.05/20)\ (60)} = 2.814288$
TEST STATISTIC $B_{.05} = 2.814288 \times S^2_{D}$

APPENDIX III.

TABLE A1. MANAGEMENT HISTORY AND ENVIRONMENTAL CHARACTERISTICS OF HIGH ELEVATION STUDY SITES

	SMITH CREEK RIDGE #6	HALFWAY #4	BENCH #1	LADY #3	SNYDER PASTURE #4
SITE #	5	11	8	9	10
AREA					
HECTARES	19	14	13	17	23
IN ACRES	48	35	32	42	58
ELEVATION					
METERS	1159	1067	1219	1280	1280
FEET	3800	3500	3900	4200	4200
ASPECT	W(270)°	WNW(282)°	SE(140)°	SW(220)°	NNE(18)°
PERCENT SLOPE	20	8	60	21	15
YEAR HARVESTED	1964	1969	1972	1977	1963
YEAR PLANTED	1966 1978 1980	1974 1977	1974 1977 1980	1978 1979	1965 1973
YEAR CERTIFIED	1978	1979	1978	1979	1978
TREES PER ACRE	446	395	411	663	295
SITE INDEX	100	100	100	90	
SITE CLASS	IV	IV	IV	V	IV
SOIL RESOURCE INVENTORY CODE	55	55	21,56,57	57	21
TOTAL ASH DEPTH (cm)	48	24	12	15	15
ASH COMPOSITION (cm)					
FINE	4	5	1	3	3
PUMICE	21	15	9	7	9
BLAST	23	4	3	5	3

TABLE A2. MANAGEMENT HISTORY AND ENVIRONMENTAL CHARACTERISTICS OF LOW ELEVATION STUDY SITES

	CURTIS LAKE 7	CLEAR-WATER #3	BEST #1	WAY #1	INDEPENDENCE EAST #3	WAY #10
SITE #	3	4	2	1	7	6
AREA						
HECTARES	19	15	13	12	26	9
ACRES	47	37	33	31	65	22
ELEVATION						
METERS	685	731	829	1067	1067	1152
FEET	2250	2400	2720	3500	3500	3600
ASPECT	E(74)°	W(270)°	SW(240)°	SE(120)°	W(270)°	WSW(240)°
PERCENT SLOPE	4	10	15	30	20	35
YEAR HARVESTED	1969	1969	1973	1978	1969	1976
YEAR PLANTED	1976	1970, 1972	1978, 1979		1976	1979
YEAR CERTIFIED	1977	1978	1979		1977	1979
TREES PER ACRE	883	431	513		454	607
SITE INDEX		120	110			100
SITE CLASS	IV	IV	IV	IV	V	IV
SOIL RESOURCE INVENTORY CODE	55	55	21,56, 57	57	21	21
TOTAL ASH DEPTH (cm)	28	28	31	32	17	27
ASH COMPOSITION (cm)						
FINE	3	3	7	5	3	4
PUMICE	13	14	13	19	7	12
BLAST	12	11	11	8	7	11

TABLE A3. SEEDLING PLANTING STOCK INFORMATION BY SITE

UNIT #	SPECIES		STOCK # [1]
1	DF	(1)	205-03-440-01005-3.5-2-0
WAY 1	NF	(2)	022-03-440-03000-3.5-2-0
	PSF	(3)	011-03-440-08000-3.5-2-0
	LPP	(4)	017-03-652-03000-3.5-78
2	DF	(1)	205-03-440-01005-3.5-2-0
BEST 1	NF	(5)	022-03-440-01001-3.0-2-0
	PSF	(6)	011-03-440-08000-3.0-2-0
	GF	(7)	017-03-652-03000-3.0-2-0-78
3	DF	(8)	205-03-440-01002-2.5-2-0
CURTIS LAKE 3	NF	(5)	022-03-440-01001-3.0-2-0
	PSF	(6)	011-03-440-08000-3.0-2-0
	GF	(7)	017-03-652-03000-3.0-2-0-78
4	DF	(8)	205-03-440-01002-2.5-2-0
CLEARWATER 3	NF	(5)	022-03-440-01001-3.0-2-0
	PSF	(6)	011-03-440-08000-3.0-2-0
	ES	(9)	093-03-440-08302-3.0-2-0-78
5	NF	(12)	022-03-440-01005-4.0-2-0
SMITH CREEK RIDGE 6	WWP	(13)	119-03-652-03300-4.0-3-0
	ES	(14)	093-03-652-05000-4.0-2-0
	PSF	(15)	011-03-652-03000-4.0-2-0-78
6	DF	(1)	205-03-440-01005-3.5-2-0
WAY 10	NF	(2)	022-03-440-03000-3.5-2-0
	PSF	(3)	011-03-440-08000-3.5-2-0
	LPP	(10)	108-03-652-03010-4.0-2-0-78
7	DF	(1)	205-03-440-01005-3.5-2-0
INDEPENDENCE E	NF	(2)	022-03-440-03000-3.5-2-0
	PSF	(3)	011-03-440-08000-3.5-2-0
	ES	(11)	093-03-440-08000-3.5-2-0-78
8	NF	(12)	022-03-440-01005-4.0-2-0
BENCH 1	WWP	(13)	119-03-652-03300-4.0-3-0
	ES	(14)	093-03-652-05000-4.0-2-0
	LPP	(10)	108-03-652-03010-4.0-78

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[1] Seed code used by the Pacific Northwest Region, U.S.D.A. Forest Service.

TABLE A3. CONTINUED

UNIT #	SPECIES		STOCK #
LADY 3	WWP	(13)	119-03-652-03300-4.0-3-0
	ES	(14)	093-03-652-05000-4.0-2-0
	LPP	(10)	108-03-652-03010-4.0-2-0-78
10	NF	(12)	022-03-440-01005-4.0-2-0
SNYDER PASTURE 4	WWP	(13)	119-03-652-03300-4.0-3-0
	ES	(14)	093-03-652-05000-4.0-2-0
	PSF	(15)	011-03-652-03000-4.0-2-0-78
11	NF	(12)	022-03-440-01005-4.0-2-0
HALFWAY 4	WWP	(13)	119-03-652-03300-4.0-3-0
	ES	(14)	093-03-652-05000-4.0-2-0
	PSF	(15)	011-03-652-03000-4.0-2-0-78

TABLE A4. WEATHER CONDITIONS DURING PLANTING ON LOW ELEVATION UNITS

	CURTIS LAKE #7	CLEARWATER #3	BEST #1	WAY #1	INDEPENDENCE EAST #3	WAY #10
PLANTING DATA						
DATE	5/21	5/19	5/20	5/23	6/1	6/2
TIME	1115	1100	1120	1100	1300	1300
AIR TEMPERATURE °F	50	51	50	70	84	75
RELATIVE HUMIDITY %	63	82	69	48	36	70
WIND SPEED	8-10		CALM	3-8	0-2	3-8
WIND DIRECTION	NW			E/NE	W	SW
SOLAR INPUT		RAIN OVERCAST		SUNNY		
SOIL TEMPERATURE °F			54		64	68
BAG TEMPERATURE °F	55		49		56	54
TIME	1340	1700	1810	1505		
AIR TEMPERATURE °F	55	51	53	64		
RELATIVE HUMIDITY %	51	82	65	68		
WIND SPEED	5-10	0-5		5-9		
WIND DIRECTION	N	N				
SOLAR INPUT				OVERCAST		
SOIL TEMPERATURE °F	54	54	55	50		
BAG TEMPERATURE °F	55		54			

TABLE A5. WEATHER CONDITIONS DURING PLANTING ON HIGH ELEVATION UNITS

	SMITH CREEK RIDGE 6	HALFWAY 4	BENCH 1	LADY 3	SNYDER PASTURE 4
PLANTING DATA					
DATE	5/31	5/30	5/22	5/29	5/24
TIME	1000		1050	1104	1300
AIR TEMPERATURE °F	55	65	49	53	82
RELATIVE HUMIDITY %	72	55	80	100	39
WIND SPEED	2	8-10	2	2	0-2
WIND DIRECTION	SW	NW	SW		W
SOLAR INPUT	SUNNY	CLOUDY, SHOWERS	OVERCAST	DRIZZLE, OVERCAST	
SOIL TEMPERATURE °F	74	61			66
BAG TEMPERATURE °F		48			54
TIME	1420		1200	1300	1800
AIR TEMPERATURE °F	62			53	60
RELATIVE HUMIDITY %	92			100	74
WIND SPEED	15-20			2	
WIND DIRECTION	SW				
SOLAR INPUT				RAIN	
SOIL TEMPERATURE °F	70		46	58	
BAG TEMPERATURE °F					
TIME	1515		1635	1450	
AIR TEMPERATURE °F	59		61	55	
RELATIVE HUMIDITY %	74		66	100	
WIND SPEED	15-20		6	2	
WIND DIRECTION	SW				
SOLAR INPUT			CLOUDY		
SOIL TEMPERATURE °F	65			54	
BAG TEMPERATURE °F				53	

TABLE A6. PLANTING SPOT CHARACTERISTICS BY SITE FOR LOW ELEVATION SITES

	CURTIS LAKE 7	CLEARWATER #3	BEST #1	WAY #1	INDEPENDENCE EAST #3	WAY #10
SUBSIDENCE 1981[a]	40	37	30	40	121	120
SUBSIDENCE 1982	3	11	11	1	5	2
RAVEL 1981	0	4	0	142	200	267
RAVEL 1982	9	16	164	21	59	328
GREEN 1981	105	106	30	1	3	35
GREEN 1982	218	270	107	65	16	75
DUFF AT PLANTING	30	19	25	15	6	0
% VEGETATIVE COVER[b]						
INITIAL						
taller than 45 cm	0	0	0.5	0	0	0
shorter than 45 cm	3.5	2	1.1	0	2.7	0.8
FALL 1981						
taller than 45 cm	10.4	4.9	1.6	10.5	5	1.1
shorter than 45 cm	2.0	2.2	1.3	1.2	2.8	1.5
FALL 1982						
taller than 45 cm	6.5	18.2	4.6	8.6	4.0	2.3
shorter than 45 cm	2.9	3.1	2.9	2.2	12.1	1.3

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[a] NUMBER OF OCCURRENCES OUT OF 400 PLANTING SPOTS/UNIT.

[b] MEAN FOR 16 CELLS PER UNIT.

TABLE A7. PLANTING SPOT CHARACTERISTICS BY SITE FOR HIGH ELEVATION SITES.

	SMITH CREEK RIDGE #6	HALFWAY #4	BENCH #1	LADY #3	SNYDER PASTURE #4
SUBSIDENCE 1981[a]	143	33	4	9	38
SUBSIDENCE 1982	22	1	2	2	14
RAVEL 1981	167	1	239	51	60
RAVEL 1982	15	23	364	259	110
GREEN 1981	1	9	13	3	36
GREEN 1982	0	37	13	48	93
DUFF AT PLANTING	4	8	23	39	20
% VEGETATIVE COVER[b]					
INITIAL taller than 45 cm	0	1.1	9.8	4.5	14.1
shorter than 45 cm	0.5	2.9	6.1	3.1	9.7
FALL 1981 taller than 45 cm	1.6	9.0	14.4	4.2	26.0
shorter than 45 cm	1.0	2.4	6.7	1.6	11.4
FALL 1982 taller than 45 cm	7.6	19.4	24.6	18.5	37.3
shorter than 45 cm	1.8	5.5	12.7	4.8	18.9

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[a] NUMBER OF OCCURRENCES OUT OF 400 PLANTING SPOTS/UNIT.

[b] MEAN FOR 16 CELLS PER UNIT.

TABLE A8. ANALYSIS OF VARIANCE TABLE FOR 1981 SURVIVAL LOW ELEVATION STUDY

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR>F [1/]
MODEL	28	3.8059	0.1359	3.41	0.0001
ERROR	67	2.6727	0.0399		
BLOCK (UNIT)	5	0.3534		1.77	0.1296
SPECIES	5	1.4076		7.06	0.0001
TREATMENT	3	0.8908		7.44	0.0003
SPECIES X TREATMENT	15	0.1108		1.56	0.1108
TOTAL	95				

TABLE A9. ANALYSIS OF VARIANCE TABLE FOR 1982 SURVIVAL LOW ELEVATION STUDY

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR>F
MODEL	28	4.4252	0.1580	4.06	0.0001
ERROR	67	2.6055	0.0389		
BLOCK (UNIT)	5	0.3872		1.10	0.3700
SPECIES	5	1.6924		8.70	0.0001
TREATMENT	3	1.2820		6.23	0.0009
SPECIES X TREATMENT	15	1.0636		1.82	0.0491
TOTAL	95				

[1/] PROBABILITY THAT THE OBSERVED DIFFERENCES WERE DUE TO CHANCE (OBTAINING CALCULATED F VALUES SMALLER THAN THE TABULAR VALUE).

TABLE A10. ANALYSIS OF VARIANCE TABLE FOR TOTAL GROWTH LOW ELEVATION STUDY

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR>F
MODEL	28	2517.0251	89.8938	8.63	0.0001
ERROR	67	698.2682	10.4219		
BLOCK (UNIT)	5	622.9335		11.95	0.0001
SPECIES	5	1467.3187		28.16	0.0001
TREATMENT	3	182.0793		5.82	0.0015
SPECIES X TREATMENT	15	78.9725		0.51	0.9294
TOTAL	95				

TABLE A11. ANALYSIS OF VARIANCE TABLE FOR 1981 HEIGHT GROWTH LOW ELEVATION STUDY

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR>F
MODEL	28	298.1840	10.6494	2.32	0.0026
ERROR	67	307.0112	4.5823		
BLOCK (UNIT)	5	44.4317		1.94	0.0985
SPECIES	5	199.4644		8.71	0.0001
TREATMENT	3	2.9987		0.22	0.8826
SPECIES X TREATMENT	15	25.5370		0.37	0.9817
TOTAL	95				

TABLE A12. ANALYSIS OF VARIANCE TABLE FOR 1982 HEIGHT GROWTH LOW ELEVATION STUDY

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR>F
MODEL	28	1265.1731	45.1848	7.48	0.0001
ERROR	67	404.9822	6.0445		
BLOCK (UNIT)	5	395.1854		13.08	0.0001
SPECIES	5	620.7172		20.54	0.0001
TREATMENT	3	136.5445		7.53	0.0002
SPECIES X TREATMENT	15	42.7757		0.47	0.9467
TOTAL	95				

TABLE A13. ANALYSIS OF VARIANCE TABLE FOR TOTAL HEIGHT LOW ELEVATION STUDY

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR>F
MODEL	28	10839.8968	387.1391	21.50	0.0001
ERROR	67	1206.2031	18.0030		
BLOCK (UNIT)	5	999.5377		11.10	0.0001
SPECIES	5	9403.1973		104.46	0.0001
TREATMENT	3	122.0100		2.26	0.0882
SPECIES X TREATMENT	15	192.9898		0.71	0.7618
TOTAL	95				

TABLE A14. ANALYSIS OF VARIANCE TABLE FOR DIAMETER GROWTH LOW ELEVATION STUDY

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR>F
MODEL	28	438.3853	15.6567	8.59	0.0001
ERROR	67	122.1340	1.8229		
BLOCK (UNIT)	5	149.5516		16.41	0.0001
SPECIES	5	226.1255		24.81	0.0001
TREATMENT	3	25.1255		4.79	0.0045
SPECIES X TREATMENT	15	23.6490		0.86	0.6051
TOTAL	95				

TABLE A15. ANALYSIS OF VARIANCE TABLE FOR 1981 SURVIVAL HIGH ELEVATION STUDY

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR>F
MODEL	23	3.6513	0.1588	6.63	0.0001
ERROR	b	1.3407	0.0239		
BLOCK (UNIT)	4	2.4008		25.07	0.0001
SPECIES	4	1.2727		13.29	0.0001
TREATMENT	3	0.2481		3.45	0.0222
SPECIES X TREATMENT	12	0.1984		0.69	0.7533
TOTAL	79				

TABLE A16. ANALYSIS OF VARIANCE TABLE FOR 1982 SURVIVAL HIGH ELEVATION STUDY

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR>F
MODEL	23	5.0191	0.2182	8.11	0.0001
ERROR	56	1.5076	0.0269		
BLOCK (UNIT)	4	3.4949		32.45	0.0001
SPECIES	4	1.4948		13.88	0.0001
TREATMENT	3	0.2804		3.47	0.0217
SPECIES X TREATMENT	12	0.1545		0.48	0.9192
TOTAL	79				

TABLE A19. ANALYSIS OF VARIANCE TABLE FOR 1982 HEIGHT GROWTH HIGH ELEVATION STUDY

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR>F
MODEL	23	761.8206	33.1226	14.54	0.0001
ERROR	56	127.5560	2.2778		
BLOCK (UNIT)	4	232.3594		25.50	0.0001
SPECIES	4	193.7460		21.26	0.0001
TREATMENT	3	112.1107		16.41	0.0001
SPECIES X TREATMENT	12	36.8653		1.35	0.2185
TOTAL	79				

TABLE A20. ANALYSIS OF VARIANCE TABLE FOR TOTAL HEIGHT HIGH ELEVATION STUDY

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR>F
MODEL	23	3261.9342	141.8232	14.41	0.0001
ERROR	56	551.0659	9.8405		
BLOCK (UNIT)	4	568.6656		14.45	0.0001
SPECIES	4	1488.0792		37.81	0.0001
TREATMENT	3	151.5820		5.13	0.0034
SPECIES X TREATMENT	12	195.0594		1.65	0.1036
TOTAL	79				

TABLE A17. ANALYSIS OF VARIANCE TABLE FOR TOTAL GROWTH HIGH ELEVATION STUDY

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR>F
MODEL	23	1072.20156	46.6175	9.21	0.0001
ERROR	56	283.5600	5.0643		
BLOCK (UNIT)	4	243.4097		12.02	0.0001
SPECIES	4	351.1131		17.33	0.0001
TREATMENT	3	128.0108		8.43	0.0001
SPECIES X TREATMENT	12	52.5894		0.87	0.5854
TOTAL	79				

TABLE A18. ANALYSIS OF VARIANCE TABLE FOR 1981 HEIGHT GROWTH HIGH ELEVATION STUDY

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR>F
MODEL	23	70.0078	3.0438	1.49	0.1148
ERROR	56	114.7005	2.0482		
BLOCK (UNIT)	4	8.8147		1.08	0.3772
SPECIES	4	38.0275		4.64	0.0026
TREATMENT	3	4.4048		0.72	0.5494
SPECIES X TREATMENT	12	13.9233		0.57	0.8594
TOTAL	79				

TABLE A21. ANALYSIS OF VARIANCE TABLE FOR DIAMETER GROWTH HIGH ELEVATION STUDY

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR>F
MODEL	23	175.0235	7.6097	7.85	0.0001
ERROR	56	53.3160	0.9694		
BLOCK (UNIT)	4	71.2597		18.38	0.0001
SPECIES	4	22.6372		5.84	0.0005
TREATMENT	3	20.9451		7.20	0.0004
SPECIES X TREATMENT	12	14.2734		1.23	0.2890
TOTAL	79				