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Title: EFFECT OF SNOWBRUSH ON THE ESTABLISHMENT AND GROWTH OF DOUGLAS-FIR SEEDLINGS

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Six, recent clear cut areas were selected in the Douglas-fir zone of the Western Cascade Range of Oregon to determine the environmental and nutritional effects that snowbrush has on the establishment and growth of Douglas-fir seedlings.

One thousand eighty milacre sample plots on the six clear cuts were used to determine the survival, total height growth and browsing damage of Douglas-fir seedlings. The nutrient status of the seedlings growing in association with snowbrush and in the open was also determined on the six clear cuts. Needles on the current year's growth were analyzed at three times during the year, for nitrogen, calcium, magnesium, potassium and phosphorus. The nutrient levels of the seedlings were then related to their position relative to snowbrush. The percent total nitrogen and the exchangeable calcium, magnesium and potassium in the soil under snowbrush and in the open

were analyzed.

Three of the six clear cuts were selected and soil moisture in the open, along the edge and under snowbrush was measured with Colman fiberglas moisture blocks and gravimetrically. In all, 33 moisture stations were used. Moisture was measured at 2, 6 and 24 inches. At each moisture station, the maximum soil surface temperature was determined with a maximum reading mercury thermometer. In addition to the mercury thermometers, six continuous recording thermometers were used to determine the number of consecutive days on which high soil temperature occurred.

Precipitation through the growing season, both in the open and under snowbrush, was determined with home-made rain gauges.

Survival and growth of planted Douglas-fir seedlings were better under snowbrush than in the open. The milacre stocking under snowbrush was 48% greater than in the open. The total height was 2.5 feet greater on nine-year-old seedlings, whereas, the yearly height growth was as much as 5.1 inches greater on seedlings associated with snowbrush, than those in the open.

Browsing damage was greatly reduced by brush cover. Only 28.3% of the seedlings under snowbrush were damaged, compared to 69.0% and 73.5% damaged in the open and along the edge, respectively.

Throughout the growing season, soil moisture in the top six inches contained more moisture under snowbrush than in the open. At 24 inches, less water was available under the brush than in the open. The soil moisture consumption suggests that a newly planted or germinating seedling will have more moisture available to it under brush cover, than in the open, however, the seedling will eventually have to compete with the brush for moisture as its roots penetrate the soil to about 24 inches.

Lethal soil surface temperatures were encountered in the open. Soil surface temperatures in the open reached levels high enough to cause death to first year seedlings and at least some damage to planted stock, whereas, under the brush, soil surface temperatures never reached the lethal limit, even during the extremely hot, dry summer of 1967.

Lower soil surface temperatures under snowbrush are probably one of the most important factors in maintaining higher soil surface moisture levels under the brush.

The concentration of nitrogen, calcium, magnesium and potassium in current year's Douglas-fir needles is greater in seedlings growing in association with snowbrush than in those growing in the open. The concentration of phosphorus in needles, however, did not appear to be related to snowbrush cover.

The concentration of all nutrients tested, except phosphorus, declined as the growth rate increased. Seedlings growing in association with snowbrush did not have as marked a decrease, particularly in the case of nitrogen,as did seedlings in the open. The effect of snowbrush on the declining nutrient content was more marked on poorer sites, than on better sites. The effect of snowbrush appeared most pronounced during periods of high nutrient stress.

The nutrient content of the soil under a stand of snowbrush was higher in terms of total nitrogen and exchangeable calcium, magnesium and potassium than the soil in the adjacent opening. It would appear that snowbrush is not only capable of increasing nitrogen through fixation, but is also instrumental in maintaining more cations in the surface soil, through re-cycling in the litter.

Snowbrush in the Western Cascades appears to be instrumental in creating a more favorable microenvironment as well as a more favorable nutrient regime for newly establishing Douglas-fir seedlings.

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EFFECT OF SNOWBRUSH ON THE ESTABLISHMENT AND GROWTH OF DOUGLAS-FIR SEEDLINGS

I. INTRODUCTION

The problems of establishing a tree crop following logging are many and varied. Each geographic region has problems unique to it. These problems must first be recognized and then dealt with if a successful tree crop is to be obtained.

The ecological niche which a species occupies may vary considerably throughout its range. A species which is, for example, shade intolerant on the Coast may be shade demanding in the interior part of its range. Similarly, the requirements of a species may change with age, that is, in the juvenile stages a species may require the protection of a nurse crop, but in later stages it may have to be the dominant tree in order to survive.

The role of brush species as a nurse crop for Douglas-fir (Pseudotsuga menziesii, Mirb. Franco) has been considered in certain areas. In the Western Cascade Range in Oregon, Douglas-fir is found in pure or mixed stands. In a mature stand, Douglas-fir is the dominant species. During the seedling stage, however, some protection is required for survival and initial growth. The protection required during the initial growth stages of Douglas-fir seedlings may be provided by a brush species. Ideally the brush would provide the required protection from unfavorable growth factors and yet allow the seedling to penetrate and eliminate the brush once the seedling is firmly established.

Snowbrush (Ceanothus velutinus, Dougl.) occurs throughout the Cascade Range in Oregon. On the west side of the range, the species occurs only as a pioneer following clear cutting, burning or wildfires. The snowbrush is usually shaded out of an area in 15 to 20 years by invading tree species. The brush is, therefore, only a temporary member of the forest community on the west flanks of the Cascade Range.

Snowbrush is a species which may be ideally suited to serve as a nurse crop for Douglas-fir regeneration in this region. The species occupies clear cuts most prolifically after burning, is eliminated by shading and has the added advantage of being capable of fixing atmospheric nitrogen, thus increasing the nitrogen content of the ecosystem.

The objectives of this field investigation were to determine some of the beneficial and detrimental effects which snowbrush may have on Douglas-fir regeneration. To determine the effects of the brush species on seedlings, the effects of the snowbrush on both the microenvironment and nutrient status of the area were considered. More specifically, the envirionmental effects which were considered were the soil surface temperature and the available soil moisture in the seedling rooting zone. Similarly, the nutrient level in the rooting zone and in the seedlings themselves was used to attempt to evaluate the effect of the association with the brush on the availability of nutrients to Douglas-fir seedlings.

II. LITERATURE REVIEW

Environmental Relationships

The successful establishment and growth of a Douglas-fir plantation is dependent on many factors. Wilde (1958) stated that unsatisfactory survival and growth of planted trees may be caused by adverse conditions of soil and climate, biotic agencies, poor quality of planting stock and poor planting techniques. Youngberg (1955) considered texture and structure characteristics of the soil as they affect moisture and aeration; depth to the ground water table; content of soil organic matter; chemical properties, including soil fertility and the occurrence of layers high in soluble salts and toxic substances as the important edaphic characteristics, which influence the establishment and survival of both planted and natural Douglas-fir seedlings on the slopes adjacent to the Willamette Valley.

Although many factors are recognized as affecting the establishment of conifer seedlings, available soil moisture and temperature, particularly soil surface temperature,are the most critical. Isaac (1938) considered the major loss of seedlings as caused by heat and drought. Vaartaja (1949) emphasized the effect of temperature, but the soil surface temperature as influenced by the water and air content of the soil, as the major factor in seedling mortality. The soil surface temperature and moisture are particularly critical during the first year. Baker (1929) pointed out that soil temperatures were less favorable on dark colored soil as compared to light colored soils and the major cause of mortality was heat injury of the young seedling. Silen (1960) found that mortality of one-year-old Douglas-fir seedlings was correlated with type of seed bed, amount of soil moisture and soil surface temperature.

Whether lack of moisture or soil temperature is the chief cause of seedling mortality has been discussed by many workers. Isaac (1938) concluded that although high soil temperatures may be the major factor in the survival of young Douglas-fir seedlings, frequently death is the result of a combination of causes. Seedlings weakened by heat injury are often more susceptible to drought.

Investigations of heat injury to first year seedlings by high soil surface temperatures have been carried out by many workers. The majority of investigators tend to agree that injury to young seedlings occurs between 122°F and 131°F. The extent of injury is determined by several factors, namely; moisture content of the soil, duration of exposure, and age of the seedling.

Silen (1960) found that soil temperatures of over 150°F were needed if mortality is to occur in the early part of the growing season, when soil moisture is high, whereas, in late summer, when soil moisture is low, death of seedlings occurred when temperatures reached 138°F.

Duration of high soil temperatures determines the extent of injury received. Keijzer and Hermann (1966) found that 12-week-old seedlings could survive 130°F temperatures with no mortality for 60 minutes, however, the same aged seedling exposed to 140°F for five minutes had 100% mortality. Isaac (1938) found that several consecutive days at 123°F would kill newly germinated Douglas-fir seedlings. Toumey and Neething (1923) found that conifer seedlings were able to survive two to three hours at 125.6°F, but died quickly when soil temperatures were increased to 129-132°F. Silen (1960), working on the H. J. Andrews Experimental Forest, found that on yellow mineral soils no injury occurred to first year Douglas-fir seedlings at temperatures below 125°F.

With increasing age, the conifer seedlings become less susceptible to heat damage. Keijzer and Hermann (1966) reported 100% mortality of six-week-old seedlings exposed to 135°F for 15 minutes, but no mortality of 12-week-old seedlings, when subjected to the same exposure.

Planted seedlings, though influenced by the same environmental factors as natural seedlings, are affected to a different extent. Baker (1934) stated that initial survival of planted trees centers about their water relations. The relative importance of transpirational loss and moisture supply is, however, less easily determined. Wahlenberg (1930) believed that planted seedling losses were the result of transpiration as much as poor moisture supply. Youngberg (1959) concluded that soil moisture was the most critical factor influencing survival of planted Douglas-fir seedlings in non-forested openings in the Willamette Valley foothills. The role of competing vegetation in moisture depletion was suggested. In the southeast, Wakely (1954) considered drought the most important factor in the establishment of southern pine plantations.

Shading by herbaceous and shrub vegetation has been found beneficial to the establishment of planted seedlings. Brush not only reduces soil temperature, but also prevents loss of water from the soil surface. Wallenberg (1930) found more favorable moisture conditions under snowbrush in Montana. As a result of the more favorable moisture regime, survival of yellow pine was 36% higher under the snowbrush than in the open. Similarly, Baker (1934) reported better survival of northern white pine in the shade. Jack pine and Scotch pine, on the other hand, showed better survival in the open. Maguire (1955) found that 20% of 2-0 ponderosa pine seedlings survived in the open, whereas, 80% survived under shade. In general, therefore, it appears that survival of planted stock is increased by shading even though root competition is involved.

Heat injury, even though more significant on newly geminating seedlings ,does occur on planted stock. Rudolf (1939) found that heat injury occurred at the stem ground contact on planted jack pine seedlings. Eighty percent of two to six-year-old trees were injured by high temperatures, whereas, approximately 50% of the 10 to 13-year-old trees were similarly damaged. Maguire (1955) confirmed heat injury on 2-0 ponderosa pine by protecting the stem ground contact of the seedlings with cottonbatten. Eighty-two percent of the seedlings so protected in the open survived.

McWilliams (1949) found that 50% of the mortality of Douglas-fir seedlings planted on the coast of British Columbia was caused by poor planting with unfavorable weather conditions and browsing damage accounting for most of the rest. Rudolf (1939) also reported 30% greater mortality of jack pine when improperly planted.

The effect of browsing damage on seedlings is not clearly established. Gemmer (1941) reported that cattle grazing reduced the number of loblolly pine seedlings by 50% in the first year, however, in subsequent years, the mortality resulting from grazing is negligible. Thames (1962) showed that size of seedling, amount browsed and amount of moisture influenced the survival of year-old loblolly pine seedlings following a clipping, simulating browsing. Of the largest seedlings, only 10% survived severe clipping, 43% survived moderate to light clipping and 67% survived a moderate clipping. Driscol (1963) in a study on browsing repellents reported that 75% of 2-0 ponderosa pine seedlings died of causes other than browsing. The remaining 25% mortality was directly the result of browsing damage.

Water may be lost from a soil by two major pathways, transpiration and evaporation. The effect of vegetation on soil moisture is twofold. The vegetative cover protects the soil surface from high temperature, thus reducing evaporation. Vegetation, however, causes a loss of water through transpiration. The amount of water in the soil is, therefore, determined by the balance between these two effects.

Hide (1954) in attempting to determine the factors influencing the evaporation of soil moisture concluded that the vapor pressure differences between the layer from which water is evaporating, the atmosphere and the resistance to vapor flow are the most important factors in controlling evaporation. He considered three phases in evaporation from the soil; saturated, wet due to capillary conductivity and surface dry diffusion through soil air. To reduce the losses, Hide (1954) suggested the following: (1) decrease the amount of water that can move to the surface, (2) decrease the temperature of the upper soil, thus reducing the vapor pressure gradient and (3) increase the thickness of the static air layer, thus increasing the resistance to evaporation.

A cover of vegetation, particularly brush cover, has been shown to effectively reduce soil surface temperature and reduce evaporation from the soil surface. Brawand and Kohnke (1952) reported the evaporation of water from a meadow ranged from 17.76 to 1.80 inches per year, whereas, the loss of water from bare ground was 28.48 to 2.17 inches per year. Walhenberg (1930) found that during the dry summer weather, evaporation was less, relative humidity greater, soil temperatures lower and soil moisture greater under snowbrush than in the adjacent open areas. The result of these more favorable conditions was a higher survival of ponderosa pine seedlings under the brush than in the open. Youngberg (1965) working in central Oregon found that soil temperatures under snowbrush and manzanita were 20-30^{o}F cooler than in the open. He also found that the permanent wilting point was reached one to three weeks sooner in the open than under the brush. Maguire (1955) found temperature differences of 62^{o}F between the shade and adjacent open areas.

Maguire (1955) found that temperatures under brush were more favorable in the late fall. Soil temperatures were as much as 17^{o}F warmer under the brush than in the open. The brush cover may, to some extent, delay early frost damage to seedlings.

Soil Moisture Measurements

Determination of soil moisture content with Colman fiberglas moisture units has certain problems and disadvantages as well as some advantages. Colman introduced the units in 1946. The fiberglas units have long life, good range of sensitivity and also have the added feature of measuring soil temperature. Horton (1955) found that the fiberglas blocks were useful for frequent readings over long periods of time. He also found in areas of high salt content or where fertilizer is used, the blocks would not give accurate readings.

The fiberglas moisture block may be calibrated in the field or in the laboratory. The laboratory procedure is difficult and time consuming. Undisturbed cores must be used if a proper calibration curve is to be obtained. Field calibration is generally preferred, since it eliminates the necessity of duplicating actual field conditions in the laboratory.

Horton (1955) found that field calibration varied as much as 10% from the laboratory calibration curve. Carlson (1954) reported a 2.8% variation in field and laboratory calibration. He recommended field calibration in preference to laboratory calibration because of more erratic readings obtained in the laboratory. Hendrix and Colman (1951) reported that the first drying cycle had resistance readings higher than subsequent drying cycles. They also found that the fiberglas blocks tended to over-estimate the moisture content at the wet end of the range and underestimate moisture content of the soil at the dry end (near permanent wilting point). Thames (1959), on the other hand, found that blocks could reproduce the drying cycle with fair accuracy, however, they were unreliable during the wetting cycle. Horton (1955) found that even with mass field calibration, a shift occurred each season. The reason for the shift was unknown. He also noted marked wetting differences in the spring and fall. Both Thames (1959) and Horton (1955) reported that reliable moisture trends could be obtained from the fiberglas blocks, even though calibration was difficult or impossible.

Nutritional Effects

Snowbrush is one of the many nonleguminous species, which is capable of fixing atmospheric nitrogen. The nitrogen fixing capacity has been demonstrated through the use of N^{15}. The N^{15} work is well summarized by Webster (1968).

The ability of snowbrush to add nitrogen to the ecosystem has been demonstrated by a number of workers. Wollum and Youngberg (1964) grew nodulated snowbrush in pots of soil low in nitrogen for nine months. After removing the snowbrush tops, the pots were planted to Monterey pine. Growth of the pine was equivalent to growth of pine in pots of the same soil supplied with 35 ppm mineral nitrogen. Zavitkovski and Newton (1968) were able to show an increase in total nitrogen in the biomass and upper two feet of soil of a snowbrush stand. In 15 years the total turnover of nitrogen in a snowbrush stand was 1,436 kg/ha, of which 61% may have been fixed. This is equivalent to a rate of fixation of 58 kg/ha/year. Wollum and

Youngberg (1964) and Delwiche (1965) reported similar nitrogen fixing rates, namely 70 lbs/ac/year and 60 kg/ha/year respectively.

Snowbrush is not only capable of fixing nitrogen, but is also a prolific litter producer. Zatvitkovski and Newton (1968) found as much as 50% more nitrogen in snowbrush litter, when compared to the best of any other species. Youngberg (1965) found that in central Oregon the litter under snowbrush contained 1.20% nitrogen, whereas, under manzanita the litter only contained 0.72% nitrogen.

The type of litter and the nutrient content of the litter may be a factor in the decomposition and rate of nutrient cycling. Mikola (1958) working with Alnus incana and A. glutinosa found that these species were the only ones of a group of seven species which had sufficient nitrogen in the litter (1.5%) to allow decomposition without using nitrogen already present in the soil. All other species tested had less than 1.5% in the litter, thus used soil nitrogen in the microbial decomposition of the litter. Thus, the more favorable nitrogen content of snowbrush litter will allow more nitrogen to be released into the soil, rather than tying-up nitrogen in microbial decomposition.

The use of foliar analysis in determining the nutrient status of crops and soils has been carried out in agricultural crops for many years. Lundegardh (1943) stated that the fundamental concept of foliar analysis was that the amount of nutrient absorbed by the plant reflects the amount of available nutrient in the soil. Shear et al. (1946) concluded that the foliar analysis was an integration of all the circumstances involved in growth, but that deficiencies were more a result of an unbalance, rather than an actual lack.

Nutrient content of the foliage is not constant. Lavender and Carmichael (1967) found that the nutrient concentration of Douglas-fir needles varied with age of the foliage, position on the crown and season. Foliar samples must, therefore, be taken from the same position on a tree crown, same age and at the same time, if meaningful comparisons are to be made. Steenbjerg (1951) and Krueger (1967) show that the nutrient concentration after bud burst declines as the leaf expands and then the concentration increases as growth slows down in late summer. To evalute nutrient deficiencies in Douglas-fir, the foliar samples should be taken in the fall, when the concentration of nutrients is not subject to rapid changes (Gessel, et al., 1960).

Krueger (1967), Gessel et al. (1960) and Youngberg (1958) have presented data summarizing the nutrient content of Douglas-fir needles on nursery grown seedlings and forest trees in the fall, after dormancy. The nutrient ranges as given by these workers generally agree. Krueger's (1967) are generally at the upper end of the range as suggested by Gessel et al. (1960) and Youngberg's (1958) are at the lower end of this range.

III. DESCRIPTION OF THE STUDY AREA

Location

The study areas are located in the Western Cascade Range of Oregon, approximately 40 miles east of Eugene in the McKenzie River drainage system. Sample plots are located on Foley Ridge, with the exception of one, which was between Scott and Boulder Creeks. All sample areas are located in Twp 16S, R6E and R7E, W. M. Lane County, Oregon.

Geology

The Cascade Range in Oregon is formed chiefly from volcanic rocks of Cenozoic age and may be conveniently subdivided into two major sequences: the western part called the Western Cascade Range and the eastern part called the High Cascade Range. The Western Cascade Range is composed of slightly deformed and altered volcanic rocks of Eocene to Miocene age. The High Cascade Range is composed of sequences of undeformed and unaltered andesitic and basaltic flows of Pliocene to Recent age. The Western Cascade Range is highly dissected by streams and consists of narrow stream valleys, whose altitudes range from 500 to 2,000 feet above sea level (Thayer, 1936; Peck *et al*. 1964). The valleys are separated by long, acute ridges, the crests of which are at altitudes of 3,000 to 5,000 feet above sea level.

The volcanic rocks of the Western Cascades have been divided into five formations by Peck, et al. (1964). The formations which have affected the study area are the Little Butte Volcanic Series of Oligocene to Miocene Age, the Sardine Formation of late Miocene Age and the Boring Lavas from the High Cascades, which have covered these older formations and now form the uppermost strata of rock, forming Foley Ridge. The younger lavas may be distinguished from the older lavas by the degree of weathering. The recent flows are fresher in appearance. Olivine, for example, is more conspicuous, in contrast to the olivine in the older rocks which is altered to a green clay.

During the Pleistocene Epoch, the area was glaciated. The glaciers were local alpine glaciers and not connected to the main continental ice sheets (Baldwin, 1964). Glaciers apparently advanced and retreated over the area several times. In places a more indurated till sheet is in evidence, whereas in many other locales, poorly sorted outwash gravels may be found.

Soils

The soils on Foley Ridge have been influenced by at least three geologic events. The first was the deposition of the Boring Lavas, which covered the older formations in the late Pliocene and

Pleistocene Epochs. The second event was the alpine glaciation and the third event was the distribution of ash and pumice. The parent materials from which the soils on Foley Ridge have developed are mixtures of weathering andesite and basalt flows, glacial materials from the east, and ash and pumice.

The soils range from shallow stony soils developed mainly on steeper terrain with poorly developed, often truncated profiles to deep, reasonably well developed profiles occurring on benches and on the lower parts of gentle slopes. Textures range from coarse gravelly sandy loam to clay loam. The sandy textured soils are generally found near the tops of the ridges. The soils frequently contain lenses of gravels, cobbles and boulders. This coarse material is definite evidence of glacial activity in the area. At lower elevations and particularly on benches, the soil is deep and fine textured, with occasional lenses of coarse material, namely gravels, cobbles and boulders. The lenses of coarse material may be entirely subsurface or may crop out onto the surface.

The surface, as well as the profile as a whole, is usually quite porous. The soils have high water holding capacities and are well drained. The water holding and drainage characteristics appear to be enhanced by the presence of appreciable amounts of pumice and ash.

The soils have been identified and classified to the west of Foley

Ridge on the H. J. Andrews Experimental Forest by Stephens (1964). They have been classified as Reddish Brown Lateritic, Yellowish Brown Lateritic and Regosols. The soils on Foley Ridge resemble those on the H. J. Andrews Experimental Forest. They are very similar to the Carpenter series which Stephens (1964) described. The Carpenter soils are formed in glacial till derived primarily from the rocks of the Cascade andesites. These formations are composed predominantly of basaltic and olivine andesites. In the Carpenter series a discontinuous A2 horizon (0 to 1/2" thick) was reported, however, this horizon was lacking on Foley Ridge. The colors of the remaining horizons were quite similar to those in the Carpenter Series. The surface horizons were dark reddish brown (5YR 3/3 moist) and generally a sandy loam texture. The B horizons were a reddish brown to brown (5YR 4/4 and 7.5 YR 4/4 moist) color and a sandy loam to a clay loam texture. (See Appendix I.) The B horizon in the soils on Foley Ridge was usually identified on the basis of color and structural changes, rather than a textural change. The soils may be classified using the 7th Approximation as Inceptisols.

Climate

The climate of the area is characterized by warm dry summers and cool wet winters. The area is dominated by warm moist air masses moving in from the Pacific Ocean. The Coast Range in Oregon, being relatively low allows moist air to penetrate to the Cascades. The west side of the Cascade Range is then subject to warmer temperatures and higher rainfall than would be expected from its geographic position. The climate may be classified as a Cbs (after Thornthwaite, Trewartha, 1954). This is a cool marine climate.

The average precipitation at the McKenzie Bridge Station is 90.03 inches of rain annually. At an elevation of 1600 feet on the H. J. Andrews Forest, the temperature ranges from near $0^{o}F$ to brief periods of $100^{o}F$ in the summer. The mean annual temperature was $49.1^{o}F$ with a January mean of $35.0^{o}F$ and a July mean of $69.2^{o}F$. The extremes of temperature were $-3^{o}F$ and $110^{o}F$ in January and July respectively (Rothacher _et al._, 1967).

The relative humidity is generally high during the winter. Maximum relative humidity is approached daily throughout the year. Mid-summer relative humidities generally range from 30 to 50% during the day. The humidity may drop to 10% under the influence of an easterly wind. Similarly, humidities may drop to 40% in the winter when the area is affected by an easterly wind.

The potential evapotranspiration (P.E.) on the H. J. Andrews Forest was reported as 24.4 inches annually by Rothacher _et al._ (1967). The pattern of precipitation in the area is the reverse of temperature, and therefore, the reverse of potential evapotranspiration, since the evapotranspiration is based on temperature. As a result of the difference between precipitation and temperature patterns, a large excess of precipitation occurs from September to mid-May, followed by a deficiency during the summer months. An estimate of the difference between potential and actual evapotranspiration showed a range of 2.3 to 4.3 inches per year greater potential than actual evapotranspiration. The greater potential indicates a drought or stress condition under which the vegetation in the area must exist during the growing season.

Vegetation

The dominant species in the area are Douglas-fir (*Pseudotsuga menziesii* (Mirb) Franco var. *menziesii*) and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) with some grand fir (*Abies grandis* (Dougl.) Lindl.) and western red cedar (*Thuja plicata*, Donn.). The lower slopes and benches are occupied by nearly pure stands of Douglas-fir with an understory of vine maple (*Acer circinatum*, Pursh.), Pacific dogwood (*Cornus nuttallii* Aud.) and some hazel (*Corylus cornuta* Marsh. var *Californica* (A.DC.) Sharp.). The lesser vegetation consists of vanilla leaf (*Achlys triphylla* (Sm.) DC.), twin flower (*Linnaea borealis* L. var. *americana* (Forbes) Rehd.), pathfinder (*Adenocaulon bicolor*, Hook.), bunch berry

(Cornus canadensis L.), sword fern (Polystichum munitum (Kaulf.) Presl.) and at least three moss species. Western red cedar is more prominent on these areas in depressions, while incense cedar (Libocedrus decurrens Torr.) and golden chinkapin (Castanopsis chrysophylla (Dougl.) A.D.C.) occur in association with the Douglas-fir on poorer, drier sties. The productivity in terms of Douglas-fir is good on the benches. The site class is generally II and the site index ranges from 160 to 170.

The vegetation at higher elevations on Foley Ridge contains less Douglas-fir and more western hemlock. The shrub layer consists of vine maple, salal (Gaultheria shallon, Pursh.) rhododendron (Rhododendron macrophyllum D. Don.), Vaccinium spp., and ocean spray (Holodiscus discolor (Pursh) Maxim). The lesser vegetation frequently has large amounts of Oregon grape (Berberis Aquifolium, Pursh.), vanilla leaf, bunchberry and prince's pine (Chimaphila umbellata (L.) Nutt. var. occidentalis (Rydb.) Blake). The productivity in terms of Douglas-fir is lower than on the benches. Site quality classes are usually III and IV with site index ranging from 120 to 150.

IV. METHODS AND MATERIALS

Field Methods

In the summer of 1967, a reconnaissance was made of Foley Ridge and the adjacent country. The purpose of the survey was to locate suitable clear cuts, which had been logged no more than 10 or 15 years previously and were stocked to some degree with either planted or natural Douglas-fir regeneration. A logged area would also have to be relatively homogeneous, in terms of soil and have a cover of 50% snowbrush. It was seldom possible to find areas with less than 60% cover of snowbrush that had a reasonable number of Douglas-fir seedlings growing on them.

Six areas were selected for the study. Five were on Foley Ridge and one farther east on Scott Creek. Of the five areas on Foley Ridge, two were at approximately 3,800 feet elevation and the remaining three were between 2,400 and 2,800 feet elevation. The area on Scott Creek was selected, because it was the only one which had not been planted and was thus suitable for studying the influence of snowbrush on natural regeneration.

Description of Units

The three units at the lower elevations on Foley Ridge were selected because they occurred on benches where the soil was generally deep. The first unit designated Northwest Foley No. 2 (N.W.F. 2) is on the north side of the ridge at 2,700 feet. The soil is deep and the productivity good, having a site class II and a site index of 160 (McArdle, 1949). N.W.F. 2 was logged in 1959, burned that fall and planted in 1960 with 2-0 Douglas-fir stock. The unit has two benches; the upper bench with a 70% snowbrush cover was selected for the study area. The lower bench with only 25% snowbrush cover had very few surviving seedlings and was replanted in 1965.

The second unit was at 2,800 feet elevation and was on a larger bench on the south side of the ridge. On the basis of data from the adjacent timber, the area is a site class II with a site index of 170. The unit is designated Southwest Foley No. 2 (S.W.F. 2). The soil is deep and the topography is very gently undulating. The original area of 67 acres was logged in 1959, burned that fall and planted with 2-0 Douglas-fir stock in 1960. The area was salvage logged after the slash fire burned adjacent timber, thus the clear cut area is about 120 acres. The unit has about a 70% cover of snowbrush.

The third unit at the lower elevations was Southwest Foley No. 1 (S.W.F. 1). This clear cut is on the south side of the ridge at 2,800 feet. The soils are shallower and a large outcropping of rock is in one corner of the logged area. The productivity is a site class

III and a site index 140 to 150. The unit was logged in 1959, but was not burned and was planted with 2-0 Douglas-fir stock in 1960, 1965 and 1966. The unit has a 35% cover of snowbrush.

The two units at 3,800 feet elevation are designated as Foley Trail Cabin No. 1 and No. 2 (F.T.C. 1 and F.T.C. 2). Foley Ridge at this elevation is a series of minor ridges trending east-west. The clear cuts occupy the south slope of one ridge and the north slope facing on the adjacent ridge. The soils are shallower, and coarser textured with large pockets of coarse, boulder-sized glacial outwash material. Productivity is lower, with site class III and IV and site indexes ranging from 120 to 150. F.T.C. 1 was cut in 1959-60, burned in the fall of 1960 and planted in 1963. The unit has a 40% cover of snowbrush. F.T.C. 2 was logged in 1961, burned in 1962 and planted in 1963 with 2-0 Douglas-fir stock. Snowbrush cover is approximately 65%.

The last unit, located on Scott Creek, is designated Scott Creek No. 3 (S.C. 3). It is at 3,100 feet on a west facing slope. The area is site class III with a site index of 150. The area was logged in 1959-60, burned in 1960 and left for natural regeneration. Snowbrush cover is presently over 80%.

Establishing and Measuring Sample Plots

Within each of the clear cut units, the most uniform part with respect to soil type was selected. In each area, two or three small pits were dug and the soil was examined. The number of stumps and the rate of tree growth as measured by a ring size were also used in the selection of a uniform area. On each area, a systematic grid, one chain by one chain was established. The number of stations and milacre plots varied depending upon the size and homogeneity of each clear cut. On N.W.F. 2, 200 milacre samples on 10 acres were established; on S.W.F. 1, 120 milacre plots on six acres; on S.W.F. 2, 200 milacre plots on 10 acres; on F.T.C. 1, 340 milacre plots on 17 acres; on F.T.C. 2, 132 milacre plots on 6.6 acres and on S.C. 3, 120 milacre plots on six acres. A total of 1,112 milacre sample plots on six units were established in the summer of 1967.

Prior to any measurements, a systematic grid was established using a hand compass and chain. In each case, the perimeter of the sample area was staked at one chain intervals as well as one or two intermediate lines. The remainder of the grid was then established by compassing and pacing and using the established stakes as guides.

At each stake, that is at each one chain interval, two milacre sample plots were established. Each milacre was laid out with a 6.6 foot stick. In the event that a sample fell in an unsuitable location, such as a road, slash pile or cold deck pile, the sample was moved ahead or back 6.6 feet. If the new location was still unsuitable, the sample was discarded.

On each sample location the following information was collected and recorded: number of seedlings by species, height and age of each seedling and position of each seedling in relation to snowbrush (open, edge and under). In addition to the above information, the following were recorded: browsing damage, presence of other herbs and shrubs, slope and aspect, slash accumulation and the general health and vigor of the Douglas-fir seedlings.

The height of each seedling was determined to the nearest 0.1 foot. The age was estimated by counting whorls and by cutting two or three at ground level and counting the rings. The ring count merely served to definitely identify the age of very severly browsed seedlings, since the height was seldom proportional to the age in these seedlings.

Six cover classes of snowbrush were recognized. The classes were evenly distributed from zero snowbrush to 100% cover (Table 1).

Table 1. Percent of milacre covered by snowbrush.

Range Percent	Cover Class
0	0
1 - 20	1
21 - 40	2
41 - 60	3
61 - 80	4
81 - 100	5

The relationship of each seedling to the brush was noted. Three positions were considered, open, edge and under. The seedling in the open is in general four to five feet from the outer edge of the snowbrush crown. Those along the edge are presently growing so that the outer crown of the brush and the seedling are in contact. Those seedlings classed as under, germinated or were planted within 18 to 24 inches of the stem of the snowbrush. The "under" class of seedling is, therefore, influenced by the snowbrush to some extent all the time. The seedlings along the edge were, in many cases, in more exposed conditions at an earlier stage in their growth.

Soil Moisture Determinations

The amount of moisture in the soil at the end of the 1967 growing season was estimated from 60 gravimetric samples. Each sample consisted of soil taken from three depths: 2, 6 and 24 inches. Samples were taken on N.W.F. 2, S.W.F. 2, F.T.C. 1 and 2. Three seedling positions relating to snowbrush were sampled.

Electrical Method

The 1967 soil moisture samples served as a guide in determining the location of soil moisture stations the following year. From the original six units, only three were selected to continue the study. Units finally selected were S.W.F. 2, a near level site at low elevations, and F.T.C. 1 and 2, both with north and south aspects.

Based on the previous summer's experience, areas in the open and adjacent areas under snowbrush were selected within each of the grid areas. The open areas, in this case, were devoid of any snowbrush cover, however, they were not devoid of all vegetation. A reasonably uniform cover of bracken fern and some grasses and herb species cover these areas. In all cases, the open areas were confined to this type of cover, thus eliminating, at least partly, differences which might be created by various other cover types in their moisture consumption.

Four moisture stations were established in each of the conditions; open, edge and under snowbrush on S.W.F. 2. F.T.C. 1 and 2 were considered as one unit and were subdivided on the basis of aspect, that is, north and south facing slopes. Four soil moisture stations were established on north and south slopes in the open and on south slopes under brush, whereas, only three were placed along the edge on both slopes and under brush on the north slope. Thus, 33 moisture stations were established on the three units.

Each of the moisture stations consisted of a stack of three fiber glass moisture units. The units were placed 2, 6 and 24 inches below the mineral surface. In each case a pit was dug about 30 inches deep. The top eight inches was removed as a unit, then the next 10 inches and finally from 18 inches to near 30 inches was removed. The soil materials which had markedly different characteristics at these depths were kept separate and replaced in the order removed. The units were first saturated with water, then placed on edge into the wall of the pit. A good contact between the soil and block was made before covering the pit. The lead wires were in every case led deeper into the pit, then returned to the surface. The soil was returned to the pit and compacted to approximate the original density (Reinhart, 1953).

The moisture stations were established in the first two weeks of May, before growth had started. Growth on the snowbrush was first evident on May 12, with bud burst on Douglas-fir occurring on May 25. Soil moisture readings were taken twice a week from the end of May through June and once a week in July, August and September. The measurements were made with a Beckman A-C ohmmeter, model 300. The meter gave readings in milliamps, these readings were then converted to ohms resistance and then to soil moisture tension in atmospheres, using appropriate graphical calibration curves. A more detailed procedure is given by Colman (1947).

Gravimetric Method

Soil moisture was also determined gravimetrically. The purpose of the gravimetric determinations was to establish a field correlation between the gravimetric and the resistance method. The gravimetric samples would also serve as a second independent means of estimating the soil moisture throughout the growing season. A detailed procedure on field correlation is outlined by Colman (1947) and Carlson (1954) and will not be presented here.

The gravimetric moisture samples were obtained by digging a small hole close to the moisture blocks. The fiberglas moisture blocks were usually placed so that at least two stations were close together, thus facilitating the correlation between the two methods (Thames, 1959). Gravimetric samples were taken about once a week throughout the growing season. The samples had to be obtained with a shovel, since it was not possible to penetrate through the roots and stones to a depth of 24 inches with an auger. Each moisture sample was placed in a seamless, stainless steel can (about 250-300 g of moist soil) sealed with masking tape and a wet weight was taken within 24 hours.

Soil Surface Temperature

Maximum soil surface temperatures were estimated with a maximum recording mercury thermometer. Thermometers were placed just beneath the soil surface and a light covering of soil applied. The thermometer is five mm thick, thus the temperature recorded is actually an "average" between the surface and five mm.

In 1967, 44 temperature stations were established during the first week in August. Maximum temperatures were recorded at least once a week until the third week in September. Temperatures were taken only in the open and under conditions.

In 1968, a maximum recording thermometer was placed with each moisture station. The maximum soil surface temperature was, therefore, recorded each time the moisture was determined. In addition to the mercury thermometers, six seven-day, continuous recording thermometers were installed in the open and under snowbrush on south, north and flat aspects. The recording thermometers were used basically to determine the number of days and the length of time soil surface temperatures remained above critical levels.

Precipitation

Rainfall throughout the summer of 1968 was measured both in the open and under snowbrush. Homemade rain gauges were employed. The rain gauges were made from No. 10 cans, which are six inches in diameter. A funnel was made from heavy gauge aluminum foil to fit the cans. A calibrated, two-inch plastic tube sealed at one end was used to estimate the inches of rainfall. A detailed description of the rain gauge and the calibration is given by Berry and Berg (1955).

Rainfall measurements were made concurrently with the soil moisture and temperature readings.

Height Growth Measurements

The 1967 and 1968 height on undamaged Douglas-fir seedlings was measured. Strips, 6.6 feet wide along the stake lines, established the previous summer were used as the basis for sampling. All Douglas-fir seedlings within the 6.6 foot strip, which had not been browsed for at least four years prior to measurement, were measured. Height growth in 1967 and 1968 was measured to the nearest 1/4 inch and the position of the seedling in relation to snowbrush was recorded.

Only three of the six original units were used in the height growth study; these were S.W.F. 2, representing the good sites and F.T.C. 1 and 2, representing the poorer sites.

Soil Samples

Two soil pits on each unit were dug and the soil profiles described. In order to evaluate the possible influence of snowbrush on soil properties one pit was located in the open and one under snowbrush. Descriptions of the soils are included in Appendix I.

Soil samples were also collected at 2, 6 and 24 inches. Forty soil samples at each depth were collected in the open and under snowbrush, for nutrient analysis.

Undistributed core samples were taken from three locations on S.W.F. 2, F.T.C. 1 and 2. Since cores could not be obtained using a regular core sampler, they were obtained using the following technique. The surface adjacent to the pit was removed to about 1.5

inches below the mineral surface. Brass rings were then carefully pushed into the soil. A block of soil was then cut out around the brass ring, with a knife. The excess soil was carefully trimmed away and the bottom of the core was covered by a piece of cheesecloth, which was held in place by a rubber band. Each core was then placed in a small moisture can, sealed with masking tape and labeled. The surface adjacent to the pit was then removed to five inches and finally to 23 inches, each time taking 10 undisturbed cores.

The brass rings used for core sampling were all five cm in diameter. The heights were 1, 2 and 3.5 cm. The one and two cm cores were used to determine the soil moisture content at two and five atmospheres on the pressure membrane and 0.1 and 0.3 atmospheres on the pressure plate, respectively. The 3.5 cm cores were used to determine the bulk density. Additional bulk samples were collected at 2, 6 and 24 inches for determination of soil moisture at 10 and 15 atmospheres tension.

Foliar Samples

In sampling foliage from Douglas-fir seedlings the lateral branches from the top whorl were taken. Foliar samples were collected in October 1967, July 1968 and October 1968. In October 1967, 110 seedlings were sampled on the six units. Undamaged seedlings were sampled randomly along the milacre sampling strips previously established. The seedlings were classified as to their position in relation to snowbrush. In the first sampling, the density of snowbrush was also noted (Table 1), but since no difference could be detected in the nutrient content, only the three positions were recorded in subsequent samplings.

The first samples were taken when the seedlings were dormant. The second sampling in July was aimed at determining the foliar concentration at a time when nutrient demand was at a high level. The July sampling date occurred at the time when height growth was just being completed. The samples were taken just as the terminal buds began to form. Seedlings on lower units started forming buds the first week in July and on the higher units they began forming buds about four to five days later. A total of 81 samples were obtained on four units in July. The third sampling was in October, 1968, after the seedlings were once again dormant. A total of 41 samples were obtained at this time.

V. LABORATORY ANALYSIS AND METHODS

Soil Moisture Tension Curves

Curves relating soil moisture tension to percent moisture were developed for S.W.F. 2 and for F.T. C. 1 and 2. The moisture tension curves for F.T.C. 1and 2 were so similar that only one set was needed. Curves were constructed for the 2, 6 and 24 inch depths. In ease case, the undisturbed cores were allowed to become fully saturated by standing in water for 8 to 12 hours before being put on a pressure plate. For each depth, the soil moisture content at 0.1, 0.3, 2 and 5 atmospheres tension was determined. Moisture content at 0.1 and 0.3 tensions was determined on a porous plate and at two and five atmospheres tension on pressure membrane (Collins, 1952; Richards, 1941 and 1949). Equilibration time on the porous plate was 72 hours and on the pressure membrane was 48 hours. Reference samples were always included on each run.

The higher soil moisture tensions were determined with bulk samples rather than with cores (Broadfoot, 1954). Samples were screened with a two mm sieve, thus removing the larger pebbles, roots and other undesirable material. The moisture content at 10 and 15 atmospheres was also determined on the pressure membrane. An equilibration time of 48 hours was employed.

Graphs of percent of moisture for each moisture tension and at the three depths were then constructed. They are presented in Appendix V. Using these curves, it was then possible to convert percent moisture to atmospheres tension. It also made possible a comparison of gravimetric and electrometric soil moisture determinations.

Foliar Analysis

Foliar samples were dried in a forced air oven at 70°C for at least 60 hours. The samples were placed in the oven within 12 hours after collection (Lavender, 1968; White, 1958). Needles were separated from the twigs after drying and then the needles were ground in a Wiley Mill to pass through a 20 mesh screen. The samples were stored in manilla coin envelopes, until needed for analysis.

Prior to analysis, samples were placed in the 70°C oven for 24 hours. Appropriate amounts of material were then weighed out for the various analyses.

Nitrogen

Total nitrogen content of the needles was determined by a Micro-Kjeldahl procedure as outlined by Jackson (1958). A 0.5 gram sample was digested using sulfuric acid and a copper sulfate-selenium catalyst. After digestion, the distilled ammonia was titrated with

0.1 N HCl.

Preparation of Samples for Ca, Mg, K and P Determinations

A one gram sample of dry material was weighed out and placed in a 125 ml Erlenmeyer flask. Ten ml of concentrated nitric acid and a few boiling chips were added to each flask. The solution was allowed to stand 12 hours (usually overnight). The solution was then slowly heated until brown NO_2 fumes stopped coming off. The samples were allowed to cool, six ml of 70% perchloric acid were added. The samples were returned to the hot plate and digested for 10 minutes after dense white fumes were coming off. The flasks were cooled and approximately 20 ml of water were added. The solution was then filtered through a No. 50 Whatman filter paper, into a 100 ml volumetric flask. The volumetric flasks were allowed to cool and brought to volume. Aliquots of this stock solution were then taken for analysis.

Calcium and Magnesium

Calcium and magnesium were determined on the Perkin-Elmer Atomic Absorption Spectrophotometer, Model 303. A 1/2500 dilution of the standard digest was made. Five ml per 50 ml of a 15,000 ppm $SrCl_2$ were added to the aliquot to prevent interference from aluminum and phosphorus. The calcium was determined at a wavelength of 211 mμ and the magnesium at 285 mμ.

Standard curves were formed for both calcium and magnesium. Concentration ranging from 1 to 9 ppm calcium and 0.3 to 2.5 ppm magnesium were used to form the standard curve for these elements. The concentration of these elements in the plant sample was then determined by comparing the instrument reading obtained for that sample with the appropriate standard curve.

Potassium

Potassium was determined by diluting the standard digest solution 1/500. The analysis was carried out on the Beckman D.U. Flame Photometer at a wave length of 760 mμ. A standard curve was developed and plotted allowing graphical interpolation of samples between the standards. The standard curve was based on concentrations of potassium from 0 to 100 ppm.

Phosphorus

Phosphorus content of the plant samples was determined using the vanadomolybdophosphoric method. Ten ml of the standard digest were diluted to 50 ml (1/500). The determination was done on a Bauch and Lomb Spectronic 20 at a wavelength of 420 mμ. The readings were compared to a standard curve formed over a range from 0 to 7 ppm phosphorus (Jackson, 1958).

Soil Analysis

Soil samples collected from the study area were air dried, then screened through a coarse screen to remove the rocks, pebbles and large pieces of organic debris. Part of each sample was ground and screened through a 20 mesh screen. The soil samples were then analyzed for total nitrogen and exchangeable calcium magnesium and potassium.

Nitrogen

Total nitrogen was determined using a Macro-Kjeldahl procedure. The method used is partly described by Jackson (1958) and Alban and Kellogg (1959).

Ten grams of air dried soil was digested, using sulfuric acid and a catalyst of Na_2SO_4, $CuSO_4$ and Se. After digestion, a piece of mossy zinc was used to aid in the distillation of the ammonia into a boric acid solution. The ammonia, thus trapped in the boric acid was titrated with 0.1 N HCl.

Exchangeable Calcium, Magnesium and Potassium

Calcium, magnesium and potassium were determined by extracting with 1N ammonium acetate. A two gram sample of soil was extracted with 100 ml of ammonium acetate applied in 10 ml increments.

The samples were extracted over a period of three hours to insure complete removal of the cations by the ammonium. The resultant extract was then diluted and a 15,000 ppm $SrCl_2$ solution was added at the rate of 5 ml per 50 ml.

All three of the elements were determined on the Perkin-Elmer Atomic absorption Spectrophotometer, Model 303. A wave length of 211 mμ, 285 mμ and 383 mμ was used for calcium, magnesium and potassium respectively. A standard curve was constructed for each element. The ranges of 0 to 10 ppm, were used for both calcium and potassium, while 0 to 2.5 ppm was used for magnesium (Jackson, 1958; Alban and Kellogg, 1959; David, 1960).

VI. RESULTS AND DISCUSSION

Whenever more than one organism occupies the same area, competition is inevitable. Despite the fact that competition occurs between organisms, an organism may still benefit from the presence of another organism in the same area. An association may be considered beneficial, if gains outweigh the loss due to competition.

It has been known for a number of years that certain leguminous and nonleguminous species are capable of fixing atmospheric nitrogen. Farmers have used legumes to increase the nitrogen content of their land and thus benefit succeeding crops. A number of workers have shown that nonleguminous species, particularly alder and snowbrush, increase the nutrient content of the soils on which they grow (Tarrant et al., 1969; Zavitkovski and Newton, 1968; Wollum and Youngberg, 1964).

Douglas-fir regeneration may benefit as a result of an association with snowbrush. The benefit is, in part, lost by competition between the seedling and the brush. The benefits obtained, however, exceed the losses. Douglas-fir gains by the more favorable nutritional and environmental conditions provided by snowbrush. The benefit of the association is clearly demonstrated by the survival, growth rate and nutrient content of those seedlings growing in association with snowbrush, as compared to those seedlings growing in the open.

Milacre Stocking

The beneficial effects or lack of beneficial effects of snowbrush on Douglas-fir seedlings can only be measured by determining the numbers and growth characteristics of seedlings growing under the brush as compared to seedlings in the open. Data from 1,080 milacre sample plots indicated that the average stocking of Douglas-fir seedlings on the six units was 46.6%. Under snowbrush cover, stocking was 52.9%, while in the open it was only 36.5%. Stocking under snowbrush varied from 30.8% to 63.8%. Stocking on the poorer sites averaged 42.0%, while on the better sites it averaged 67.1%. In the open stocking ranged from 25.0% on poor sites to 46.2% on the good sites.

Since all the areas were planted with 2-0 Douglas-fir seedlings after harvest, the initial number of seedlings per acre on both the poor and good sites was the same. The open areas on two of the units, S.W.F. 1 and F.T.C. 2, were replanted. In spite of the replanting, the stocking is higher under the protection of brush than in the open (Table 2).

F.T.C. 1 is the only unit which has a higher percent stocking in the open than under brush. The majority of the unit is on a 40% north facing slope and the slash was only slightly burned. Large accumulations of unburned slash may have provided enough protection for some seedlings to survive.

Table 2. Percent Milacre Stocking of Douglas-fir Seedlings Related to Snowbrush Cover

Unit No.	Total Number of Milacres	Number of Milacres Stocked	Percent Stocking	OPEN Total Number of Milacres	OPEN Number of Milacres Stocked	OPEN Percent Stocking	CLOSED Total Number of Milacres	CLOSED Number of Milacres Stocked	CLOSED Percent Stocking
N.W.F. 2	196	119	60.7	52	24	46.2	144	95	66.0
S.W.F. 2	197	122	61.9	52	23	44.2	145	99	68.3
Total Good Sites	393	241	61.4	104	47	45.2	289	194	67.1
S.W.F. 1	115	43	37.4	72	22	30.6	43	21	48.8
F.T.C. 1	327	109	33.3	187	66	35.3	140	43	30.8
F.T.C. 2	125	57	45.6	34	12	35.3	91	45	49.5
S.C. 3 *	120	53	44.2	20	5	25.0	100	48	48.0
Total Poor Sites	687	262	39.1	313	105	33.5	374	157	42.0
TOTAL All Units	1,080	503	46.6	417	152	36.5	663	351	52.9

* Natural regeneration only

F.T.C. 1 and S.W.F. 1 have the lowest percent cover of snowbrush, with 40% and 35% respectively. They also have the poorest stocking with 33.3% and 37.4% respectively (Table 2). This suggests strongly that snowbrush is important in providing protection for Douglas-fir seedlings.

Stocking on all the units is generally poor. The poor overall stocking (46.6%), may be the result of a number of factors. Seedlings were planted on the clear cuts soon after slash burning, while the areas were still essentially devoid of vegetation. The exposed conditions, particularly during the first year, were undoubtedly responsible for a large percentage of seedling loss. In succeeding years, snowbrush provided protection for some of the seedlings, thereby, reducing mortality. Areas where snowbrush failed to germinate and grow suffered greater mortality. Percent stocking strongly suggests that conditions for germination and survival were more favorable under snowbrush cover than in the open.

Total Height Growth

The fact that more seedlings survived under snowbrush than in the open may not in itself be significant. The questions which arise are: (1) which seedlings are growing better and (2) what are the factors contributing to better growth? If snowbrush created such severe competition for moisture, light and nutrients that Douglas-fir seedlings were weakened and their growth rate reduced, then the better initial survival would be nullified.

To definitely establish the effect which snowbrush has on the vigor of Douglas-fir seedlings, the total height was measured. The height growth in each case was related to the position of the seedling relative to snowbrush cover.

Total height growth of Douglas-fir seedlings growing under snowbrush was greater than that of seedlings in the open. The relationship between seedling position relative to snowbrush cover, height growth and age is presented in Table 3. The total height of nine-year-old Douglas-fir seedlings was greater under snowbrush than in the open. Differences were, on the average, 2.5 feet on good sites and 1.3 feet on poor sites. The difference in total height growth decreases to 0.5 feet with the younger age classes. The smaller difference is expected, since the initial growth rate is slower on younger seedlings.

An analysis of variance shows that the difference in the average height between those seedlings in the open and those under snowbrush is significant at the one percent level for each age from four to nine years, on the good sites. On the poor sites, the difference in total height was significant at the five percent level for the seven and eight-year-old seedlings. The height difference on the younger seedlings was, however, not statistically significant. A summary of the

Table 3. Average Total Height in Feet of Douglas-fir Seedlings Related to the Position of the Seedling Relative to Snowbrush Cover

Age (Years)	9			8			7			6			5-4		
Position to Snowbrush	Open	Edge	Under	Open	Edge	Under	Open	Edge	Under	Open	Edge	Under	Open	Edge	Under
N. W. F. 2	3.8	4.7	5.6				2.4	3.2	4.2				1.3	1.8	2.6
S. W. F. 2	2.5	3.4	4.4												
Average of Good Sites	2.7	3.9	5.2				2.4	3.2	4.2				1.3	1.8	2.6
S. W. F. 1	1.7	2.8	3.0							1.3	1.4	1.8	0.6	-	0.7
F. T. C. 1				2.3	3.2	3.6				1.0	1.3	1.5	0.6	0.7	0.8
F. T. C. 2							1.3	1.9	2.3	1.0	0.9	1.1	0.5	1.1	1.3
S. C. 3				3.0	2.9	-				1.9	-	2.1	-	1.0	1.3
Average of Poor Sites	1.7	2.8	3.0	2.4	3.1	3.6	1.3	1.9	2.3	1.2	1.3	1.8	0.6	1.0	1.1

analysis of variance is given in Appendix II, Tables 1 through 5.

An analysis of variance was not carried out on the S.C. 3 seedling height data. The area was not planted and all regeneration has been by natural seeding. Essentially all the seedlings in the open were eight years old in 1967, and all the seedlings under snowbrush were in the four to six-year-old classes. Although distribution of seedlings was not well suited for an analysis of variance, the data from this unit does show that the majority of seedlings have become established under the protection of snowbrush.

Seedling Damage

Total height growth of Douglas-fir seedlings may not prove conclusively that snowbrush provides a more favorable environment for the growth of the young seedling. The amount of browsing damage, which was evident on all units except S. C. 3, may be an important cause of greater total height of seedlings under snowbrush.

The extent of browsing and mechanical damage of Douglas-fir seedlings on the six study units is shown in Table 4. The percentage of seedlings browsed in the open and along the edge was 69.0% and 73.5% respectively, while under the snowbrush only 28.3% were damaged. The percentage browsed in the open ranged from 33.3% on S.C. 3 to 88.0% on S.W.F. 2. S.C. 3 had very light browsing damage because of the heavy snowbrush cover (80%) and its position

Table 4. Browse and Mechanical Damage on Douglas-fir Seedlings Related to the Position of the Seedling Relative to Snowbrush Cover

Unit No.	OPEN				EDGE				UNDER			
	DAMAGED		NOT DAMAGED		DAMAGED		NOT DAMAGED		DAMAGED		NOT DAMAGED	
	Number of Seedlings	Percent	Number of Seedlings	Percent	Number of Seedlings	Percent	Number of Seedlings	Percent	Number of Seedlings	Percent	Number of Seedlings	Percent
N. W. F. 2	48	66.6	24	33.4	29	67.4	14	32.6	27	30.3	62	68.7
S. W. F. 1	55	86.0	9	14.0	5	55.6	4	44.4	3	33.3	6	66.7
S. W. F. 2	51	88.0	7	12.0	47	94.0	3	6.0	12	27.9	31	72.1
F. T. C. 1	50	53.2	44	46.8	9	52.1	8	47.1	5	25.0	15	75.0
F. T. C. 2	25	75.7	8	24.3	15	65.3	8	34.7	7	30.4	16	69.6
S. C. 3	7	33.3	14	66.7	6	66.7	3	33.3	9	23.0	30	77.0
All Units	236	69.0	106	31.0	111	73.5	40	26.5	63	28.3	160	71.7

in relation to roads. The unit is surrounded on three sides by major haul roads, which serve to keep deer out of the area. S.W.F. 1 and 2 had exceedingly high percentages of seedlings browsed in the open. S.W.F. 1 had only 35% snowbrush cover. The light brush cover on this unit may explain the heavy browse damage. S.W.F. 2 had a high incidence of browse, because former skid trails were being used by deer. The seedlings along the edge of snowbrush have nearly the same incidence of browse damage as those in the open. The mechanical protection from browsing afforded by snowbrush is very apparent when the incidence of damage to seedlings under snowbrush is compared with that of those growing along the edge or in the open.

Current Height Growth

Since approximately 70% of the seedlings in the open have been browsed,the difference in total height could be the result of mechanical protection. The question is then, can the entire height difference be accounted for by browsing or does snowbrush produce an environment more suitable for the growth of Douglas-fir seedlings? It would appear that current height growth of seedlings that had not been damaged for the past four or five years would be a good measure of the effects which snowbrush might have on seedling growth. Height growth for 1967 and 1968, was measured on undamaged seedlings in the three positions relative to snowbrush.

Table 5 shows the relationship between yearly height growth and the position of the seedling relative to snowbrush by age class from five through 10 years. These data are from only three units, F.T.C. 1, F.T.C. 2, and S.W.F. 2. The latter represents the better sites, while the other two units are representative of the poorer sites. The 10-year-old seedlings under snowbrush grew, on the average, 2.7 inches more in 1967 and 1.3 inches more in 1968, than the seedlings in the open. The seedlings along the edge of the snowbrush showed the greatest difference in height growth. In 1967, the seedlings along the edge grew 3.8 inches more than those in the open and in 1968 5.1 inches more. Similarly, the remaining ages show the same trend as the 10 year old seedlings, that is, a greater growth rate along the edge and under snowbrush, than in the open.

An analysis of variance, Appendix III, Tables 1-6, shows that the differences in yearly height growth of eight to ten-year-old seedlings growing in the open, along the edge and under snowbrush are significant at the one percent level, with the exception of 1967 height growth of eight and nine-year-old seedlings on F.T.C. 2. The six to seven-year-old trees show the same trend in height growth as the 10-year-old trees. Greater variation in the height growth among individuals, plus fewer numbers of seedlings in these ages, reduced the statistical significance. Height growth was greater in 1968 than in

Table 5. Average 1967 and 1968 Height Growth of Douglas-fir Seedlings Relatedto the Position of the Seedling Relative to Snowbrush Cover

Age (in years)	10			9-8			7			6-5		
Position of Seedling	Open	Edge	Under	Open	Edge	Under	Open	Edge	Under	Open	Edge	Under
					1967 Height Growth (in inches)							
S. W. F. 2	9.7	13.5	12.4									
F. T. C. 1				7.2	10.5	11.6	4.8	5.2	--			
F. T. C. 2				7.3	7.9	8.5				4.6	5.0	6.3
Average of All Units	9.7	13.5	12.4	7.3	8.4	9.1	4.8	5.2	--	4.6	5.0	6.3
					1968 Height Growth (in inches)							
S. W. F. 2	12.2	17.3	13.5									
F. T. C. 1				7.8	14.9	12.8	5.8	7.2	--			
F. T. C. 2				8.0	9.9	11.7				6.2	6.2	8.9
Average of All Units	12.2	17.3	13.5	7.9	11.6	11.9	5.8	7.2	--	6.2	6.2	8.9

1967. The difference in growth was probably the result of differences in weather between these two years (Appendix IV, Table 1). The year 1968 was wet and cool and, as a result, the period of height growth extended approximately two weeks later into the season than in 1967.

Along the edge of snowbrush, older seedlings exhibited better growth than they did either in the open or under snowbrush. The difference in the height growth between seedlings along the edge and those under brush cover may be in part the result of less competition with the brush. Seedlings along the edge benefit from the protection of the brush, but may not have to compete with the brush to the same extent as seedlings growing under the brush.

If total height of seedlings is compared with yearly height growth, it is apparent that total height of seedlings under snowbrush is greater for all ages, up to 10 years old, than either in the open or along the edge. The yearly height growth of older seedlings suggests that the seedlings along the edge have the better growth. The fact that seedlings along the edge are not the tallest may in part be explained by the amount of browsing damage. The incidence of browsing was as high along the edge as in the open, thus even though a seedling may grow more rapidly, because of reduced competition in any one year, the overall total height is still reduced by browsing.

Environmental Effects of Snowbrush

It appears from the data presented that both survival and growth of Douglas-fir seedlings in the Western Cascade Range is favored by snowbrush cover. In order to have better survival and growth rates under snowbrush, the brush cover must modify, at least, the environmental conditions in such a way as to produce more favorable conditions for growth of the seedlings. In addition to affecting the microclimate, the snowbrush is capable of fixing atmospheric nitrogen, and thereby affecting the nutrient regime.

A number of other workers have observed such effects on the growth and survival of conifer seedlings. Wahlenberg (1930) found that the survival of planted yellow pine seedlings was greater under the brush than in the open. Show (1924) working in northern California, found that brush cover increased survival. It has been shown that conifer seedlings grown with nitrogen fixing species, such as alder and snowbrush, have better growth rates than the same seedlings in the open. Wollum and Youngberg (1964), Youngberg (1965) and Tarrant (1961) are just a few of the workers that have reported increased conifer growth, when associated with either alder or snowbrush.

A number of environmental factors influence the establishment and growth of Douglas-fir seedlings. Isaac (1938) considered temperature and moisture as the two most critical factors in seedling establishment. Temperature has a twofold effect on seedling establishment. High temperatures kill the living tissue and also cause more rapid loss of water from the soil. The effect of snowbrush cover on temperature and moisture has been reported by a number of workers. Walhenberg (1930) noted a more favorable soil moisture regime beneath snowbrush. Youngberg (1965) reported temperatures at the two inch depth 30 degrees cooler under brush than in the open and periods up to two weeks longer before surface soil reached permanent wilting point. Isaac (1938) found that there was 37% less evaporation from the soil surface under brush than in the open.

In the present study, the environmental factors considered were soil surface temperature and soil moisture to a depth of two feet as influenced by brush cover.

Soil Surface Temperatures

The effect of snowbrush cover on soil surface temperature was considered for two reasons. First, soil surface temperatures are more critical for young seedlings than air temperatures, since most of the damage resulting from high temperatures occurs at the contact of the seedling with the soil surface. Second, soil temperature directly effects the rate of evaporation from the soil surface and, therefore, the amount of water available for the seedling.

In 1967, temperature measurements were made only in August and September. In the open, maximum soil surface temperatures ranged from 129° to 177°F in August. The average August maximum soil surface temperatures in the open were 153.3, 159.6 and 147.1°F on north, south and level aspects respectively. During the same period, the average soil surface temperatures under snowbrush were 101.2°F on a north aspect, 102.0°F on a south aspect and 101.4°F on the level area (Table 6).

Table 6. Average maximum soil surface temperature °F related to position of snowbrush cover in 1967.

Date	NORTH		SOUTH		LEVEL	
	Position Relative to Snowbrush					
	Open	Under	Open	Under	Open	Under
Aug 10	154	117	177	101	138	104
14	157	106	163	122	150	100
17	170	100	174	100	129	104
21	154	103	161	112	151	106
25	148	99	156	115	146	102
28	151	110	155	112	148	107
Avg. Aug	153.3	101.2	159.6	102.0	147.1	101.4
Sept 6	146	98	161	102	143	103
11	136	89	126	97	137	96
18	116	85	122	97	109	92
Avg. Sept	133.1	90.4	141.2	96.9	130.5	97.1

Soil surface temperatures were 15 to 20°F lower in September than in August. Temperatures in the open were 133.1, 146.2 and 130.5, while under the brush they were 90.4, 96.9 and 97.1 on north, south and level aspects. In September, the brush reduced temperatures by 30 to 50°F. It is also evident that the brush cover reduced soil surface temperature in August, 1967, by approximately 45 to 60°F, depending on the aspect.

Weather records at the McKenzie Bridge Ranger Station show that August was the hottest month in 1967, with a maximum air temperature of 106°F on August 15, 1967. Soil surface temperatures were undoubtedly the highest in August also. Table 6 shows that the highest maximum soil surface temperature was 117°F under snowbrush. The thermal death point for most conifers has been reported to be 122 to 131°F (Baker, 1929). Hare (1961) working with 20 species, not all conifers, reported that death occurred from 133 to 139°F. Silen (1960) reported that no Douglas-fir seedling mortality occurred until after soil surface temperatures reached 125°F and 100% mortality occurred after 150°F. With maximum soil surface temperatures during the hottest month being only 117°F under snowbrush, it is doubtful if any seedling mortality would have occurred as a result of high temperature under the brush cover. Temperatures in the open from August through September 11, 1967 were in all cases sufficient to cause death of young seedlings.

The 1968 soil surface temperatures were much cooler than in 1967. The only month with an average maximum temperature over 125°F was July. Temperatures in the open averaged 142.7 and 135.7°F on south and level aspects respectively. Table 7 shows the maximum average soil surface temperature attained from May through September, 1968. The difference in maximum soil surface temperatures between open areas and brush covered areas were 35 to 49°F in the early part of the season. In July, the difference between open and under reached a maximum of 73° on south aspects, 45°F on north aspects and 64°F on level areas. The difference diminishes with the season, as would be expected, and by September is between 30 and 40°F.

The generally lower soil surface temperatures in 1968 are the result of an abnormally cool summer. Appendix IV, Table 1, gives a summary of the rainfall and temperature in 1967 and 1968. Air temperatures in June, July, August and September, 1968, were 3 to 5°F cooler on the average than during the previous year. The precipitation in all four months was well above normal. Average maximum August soil surface temperatures were 30° to 50°F higher in 1967 than in 1968 (Tables 6 and 7).

The absolute maximum temperature attained is perhaps not as important as the duration of high temperatures. Hare (1961), Silen (1960), and Keijzer and Hermann (1966) all found that the duration of

Table 7. Average Maximum Soil Surface Temperature °F Related to Position of Snowbrush Cover in 1968

	NORTH			SOUTH			LEVEL		
	Position Relative to Snowbrush								
	Open	Edge	Under	Open	Edge	Under	Open	Edge	Under
Date									
May 12	-	-	-	-	-	-	125	-	-
19	-	-	-	-	-	-	126	-	94
25	-	-	-	-	-	-	88	-	72
30	87	78	60	93	-	67	106	80	71
May Average	87	78	60	93	-	67	111.2	80	79.0
June 2	97	82	63	96	74	70	116	84	74
6	86	84	60	94	82	75	105	78	70
9	95	79	64	107	70	67	110	78	68
13	109	82	62	106	75	77	108	84	68
16	119	89	70	126	87	70	140	88	70
20	113	93	74	138	86	82	139	89	72
23	100	86	66	132	80	75	130	88	69
27	104	82	69	135	81	73	117	89	72
30	87	68	60	104	61	62	102	69	62
June Average	101.1	82.8	65.3	115.3	77.3	72.3	118.6	83.0	69.4
July 3	111	79	69	131	81	70	120	85	71
10	118	87	70	151	83	76	153	88	79
14	123	84	68	150	81	71	142	82	76
18	104	74	61	132	73	64	136	74	64
23	110	75	72	138	79	66	121	76	66
28	125	89	77	154	89	69	142	84	78
July Average	115.2	81.3	69.5	142.7	81.0	69.3	135.7	81.5	72.3
August 1	131	88	75	156	97	73	150	90	79
8	109	92	72	138	80	73	133	85	75
15	114	92	73	136	82	73	135	85	70
22	83	68	59	95	68	61	95	70	52
28	80	70	59	84	60	60	89	66	62
August Average	103.4	82.0	67.6	121.8	77.4	68.0	120.4	79.2	67.6
September 6	-	-	-	-	-	-	106	82	71
12	110	87	69	102	79	68	117	76	69
26	93	76	66	111	76	70	112	74	66
September Ave.	101.5	81.5	67.5	106.5	77.5	69.0	111.7	77.3	69.7

exposure to high temperatures is important. Exposure to somewhat lower temperatures (125-130°F) require a long time before death or injury occurs, whereas, exposure to higher temperatures (150°F or over) for only a few minutes causes mortality. Silen (1960) found that the type of seed bed and moisture content of the soil influenced the duration of time required to cause seedling mortality at a given temperature. In peat it required 240 minutes at 128°F to kill 12-week-old seedlings, whereas, in yellow mineral soil the temperature could be raised to 137°F for the same time before death occurred. Silen (1960) also noted that at a given temperature there was less mortality when the soil was high in moisture as compared to a soil low in moisture.

Table 8 indicates the number of days each month that soil surface temperature reached 125°F or over in the open. It is evident that the cool wet weather in 1968 greatly reduced soil surface temperature. The soil surface reached a temperature in excess of 125°F for only 12 consecutive days in August and 16 consecutive days in July. In 1967, soil surface temperatures in excess of 125°F occurred every day in August and the first 11 days in September. The duration of the maximum temperatures each day varied. Generally, the higher temperatures (140°F and over) lasted at the most one to two hours each day, whereas, the lower temperatures (near 125°F) often lasted four hours each day.

Table 8. Number of Consecutive Days the Maximum Soil Surface Temperature Remained Above 125°F in the Open From May to September 1968 and From August to September 1967

Aspect	NORTH			SOUTH			LEVEL		
	Number of Consecutive Days	Total Number of Days	Average Maximum Temperature	Number of Consecutive Days	Total Number of Days	Average Maximum Temperature	Number of Consecutive Days	Total Number of Days	Average Maximum Temperature
August	21	21	153	21	21	160	21	21	147
September	11	11	142	11	11	146	11	11	140
May							0	3	126
June	0	2	125	0	4	138	0	3	140
July	16	17	132	16	16	154	6	11	153
August	6	7	131	12	12	156	4	5	150
September	0	0	-	0	0	-	0	0	-

The magnitude and duration of the soil surface temperatures in the open clearly indicate the possibility of 100% mortality of first year seedlings. In 1968, the temperatures under snowbrush never exceeded 82^{o}F. At this temperature there is no possibility for seedling mortality caused by excessive heat.

Minimum temperature reached each night under snowbrush cover and in the open are summarized in Table 9. Temperatures under brush cover early in the season and late in the season are up to 8^{o}F warmer than in the open. The May and September averages indicate this difference. It would appear, therefore, that the snowbrush cover not only keeps the temperature below lethal level in the summer, but also aids in preventing frost damage.

Table 9. Average minimum monthly soil surface temperature ^{o}F related to position of snowbrush cover in 1968.

	NORTH		SOUTH		LEVEL	
	Position Relative to Snowbrush					
Date	Open	Under	Open	Under	Open	Under
May	40.0	36.4	41.6	42.1	39.0	40.2
June	49.2	48.6	50.6	48.2	45.8	46.3
July	59.3	53.7	60.3	52.1	59.5	54.2
August	59.6	51.3	58.1	53.5	59.1	53.3
September	57.9	51.3	52.1	54.4	50.7	53.2

The use of mercury thermometers in place to thermocouples may introduce some errors into the values reported. The errors are not, however, of such magnitude as to negate the relationships given. Vaartaja (1949) found that the difference between the thermocouple and thermometer reading may be 10 degrees. Toumeys and Neething (1923) quoted by Vaartaja (1949) reported a difference of 0.5 to 1.5°F between thermocouple and thermometer readings. The great variation is the result of a very steep temperature gradient from the surface to depths in the soil. The gradient will be greater in the open than under brush cover. Temperatures measured in the open with a mercury thermometer will be subject to more error than those under the snowbrush. The soil surface temperatures recorded in the open in this study are probably too low. The difference reported between the soil surface temperature in the open and under brush may, therefore, be too small.

Soil Moisture

The second environmental effect of snowbrush cover is related to soil moisture. The amount of moisture available in the soil to a large degree determines the amount of growth. The moisture in the soil also has a direct influence on the soil temperature. Soils which are wet will be able to absorb more heat and transfer this heat downward into the soil. In a dry soil, the heat transfer is slow, thus surface temperatures increase more in a dry soil than a wet soil with the same amount of solar radiation. Silen (1960) reported that mortality of Douglas-fir seedlings was much lower prior to July when the soil moisture was high as compared to mortality after July 1 when soil moisture began to decrease.

The amount of moisture in the root zone of a seedling will determine the growth of that seedling. Stransky and Wilson (1964) found that height growth of loblolly and short leaf pine seedlings was inhibited by two atmospheres soil moisture tension and would stop if the tension reached 3.5 atmospheres. Sands and Rutter (1958) reported that tensions of 1.5 atmospheres suppressed height growth of three year old *Pinus sylvestris* L. seedlings. Fisher and Stone (1968), Glerum and Pierpoint (1968), Lotan and Zahner (1963) and Zahner (1958) all reported that height growth of various coniferous species is retarded by increasing soil moisture tension, but that the effect varied with age.

Since the soil moisture tension greatly affects the height growth, the effect of snowbrush on soil moisture may be significant. Youngberg (1965) reported that in central Oregon surface soils reached the permanent wilting point two weeks later under brush cover than in open areas. He also found more moisture in the seedling rooting zone (top 12 inches) under brush than in the open.

Reports concerning the influence of snowbrush on Douglas-fir regeneration in the Western Cascades are based on casual observations and are at best conflicting. During the latter part of the 1967 growing season and through the entire 1968 growing season, soil moisture was determined under snowbrush, in the edge position and in the open. Determinations were made using Colman fiberglas moisture blocks and by gravimetric sampling or by both methods. In order to facilitate comparisons between the gravimetric and electrometric moisture determinations, a calibration curve and soil moisture tension curves had to be established.

Six soil moisture tension curves were developed for the three units on which the moisture study was conducted. The curves are shown in Appendix V, Figures 1 and 2. A set of three curves, one for 2, 6 and 24 inch depths were developed for the deep soils at lower elevations. Similarly, three curves were developed for poor sites at higher elevations. The curves were based on soil moisture remaining after an undisturbed core was allowed to equilibrate at a given tension. The moisture tension curves made it possible to convert percent moisture to soil moisture tension in atmospheres.

Field calibration of the Colman fiberglas blocks proved impossible. The fluctuating wet and dry weather pattern in 1968 did not permit enough time to establish a good relationship between soil moisture determined gravimetrically and electrometrically.

The values presented in this study show trends, rather than definite values. Horton (1955) found that laboratory prepared soil moisture tension curves were seldom within 10% of the moisture tension curve based on field samples. He also concluded that in excessively rocky soils, moisture blocks could give reliable trends even in the absence of a calibration curve. Hendrix and Colman (1951), Carlson (1954) and Horton (1955) found that moisture determined with fiberglas blocks generally was higher at the wet end and lower at the dry end of the moisture range than when determined gravimetrically. The moisture units, at least in part, followed this same trend during the course of this study.

Moisture trends on three of the six units were followed throughout the summer of 1968. These units are representative of three aspects, south, north and level. Only the moisture trends on the level area, S.W.F. 2, will be considered in detail since trends on the north and south slopes are similar to those on the level area.

Growth of Douglas-fir seedlings started during the last week in May. Snowbrush had been growing for about one week prior to bud burst on Douglas-fir seedlings. Soil moisture data is reported from June 1, 1968.

From late April through June 2, 1968, 4.07 inches of rain fell on the area. This was about three inches above normal. This rain kept soil moisture tension below one atmosphere. The remainder of the summer, though not as wet as May, was nevertheless, well above the seasonal average. Appendix IV, Table 1, shows that from June to September, the rainfall in 1967 was only 3.98 inches, whereas, in 1968 rainfall during the same period was 10.82 inches.

Soil moisture tensions in June remained low for all depths, except the two inch depth in the open. Moisture tensions remained between 0.5 and 2 atmospheres (Figures 1, 2 and 3). The top two inches in the open varied from 0.9 to 5.0 atmospheres tension. The 5.0 atmospheres tension was attained by June 20, but 0.95 inches of rain fell between the 20th and the 23rd, bringing soil moisture tensions back to one atmosphere. Soil moisture tension at 24 inches under snowbrush cover started to increase slowly, from 0.9 to 1.5 atmospheres during June (Figure 3). Soil moisture tension at 24 inches in the open and along the edge of the snowbrush cover remained constant at 0.9 atmospheres throughout June.

From July 3, to August 8, except for July 31, when 0.70 inches of rain fell, soil moisture tensions increased. The most rapid increases in soil moisture tension occurred in the top two inches in the open and along the edge of the snowbrush. Soil moisture tension increased from 2.2 atmospheres on July 14th to 31.0 atmospheres by August 8th in the open, and along the edge from 2.2 atmospheres to 14.7 atmospheres. Tensions at the 24 inch depth increased steadily from July 3 to August 8. Moisture tension at six inches increased from 1.1 atmospheres to 14.5 atmospheres in the open and from

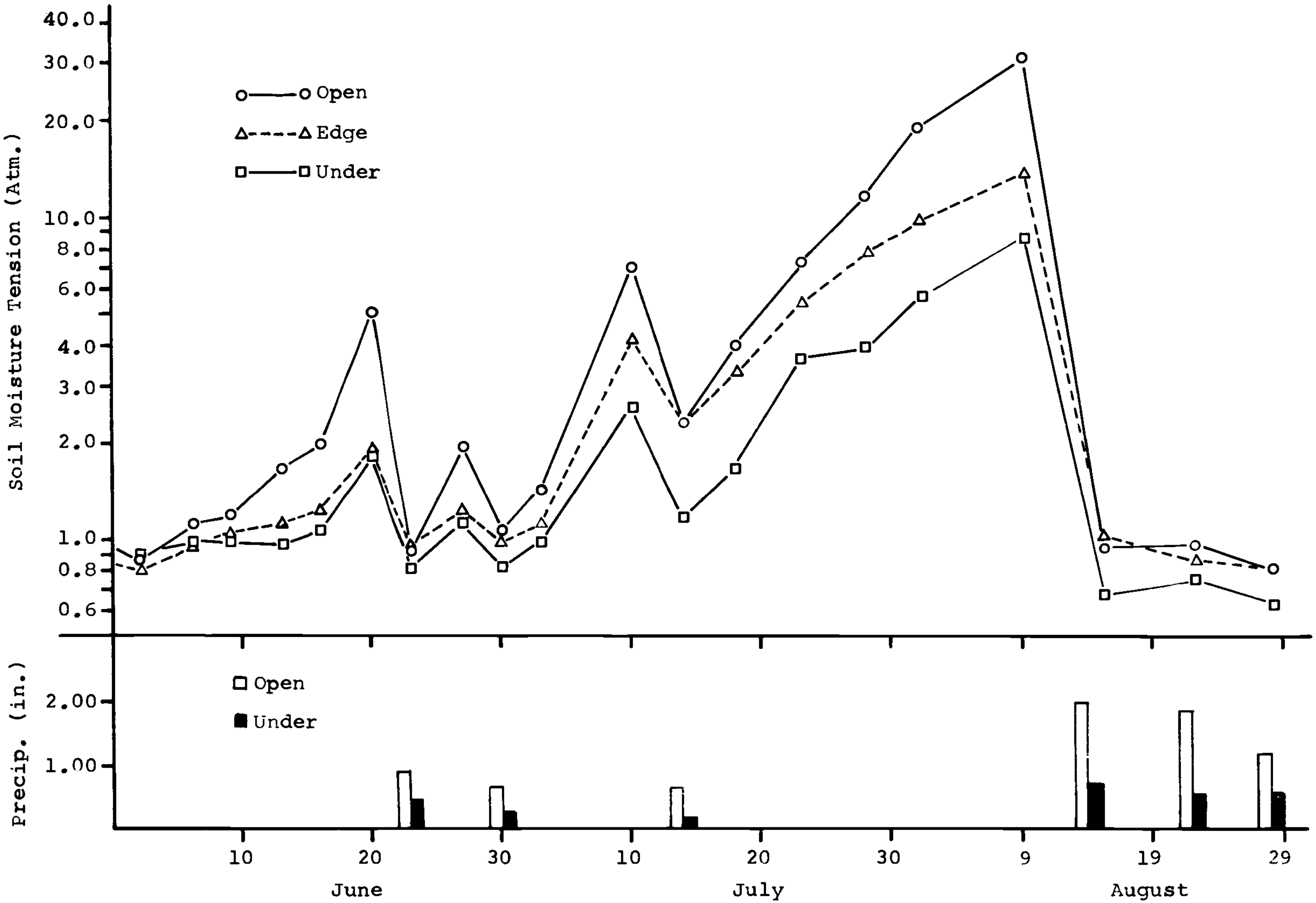

Figure 1. Soil-moisture tension in atmospheres at the 2 inch depth and precipitation in inches related to snowbrush cover.

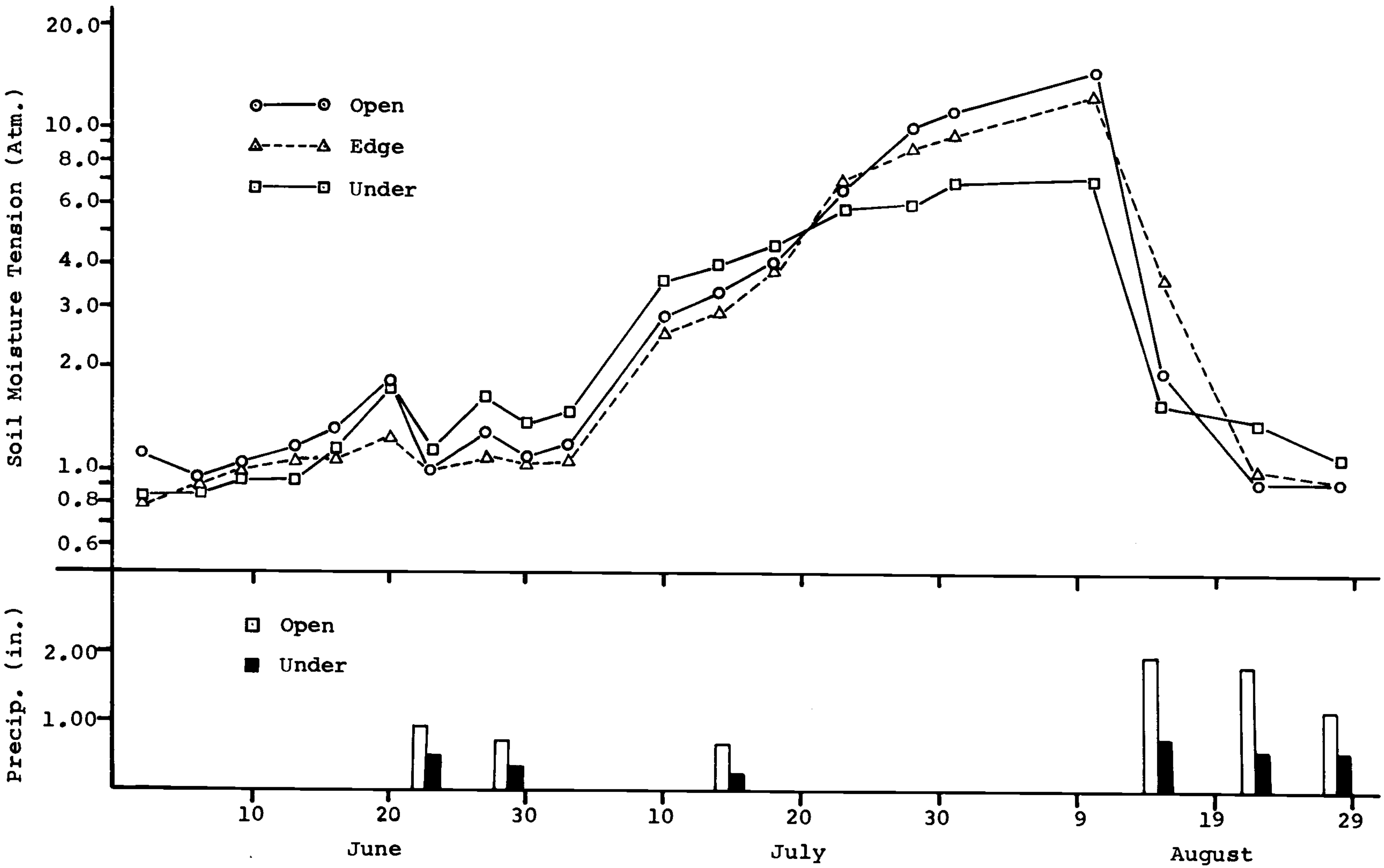

Figure 2. Soil-moisture tension in atmospheres at the 6 inch depth and precipitation in inches related to snowbrush cover.

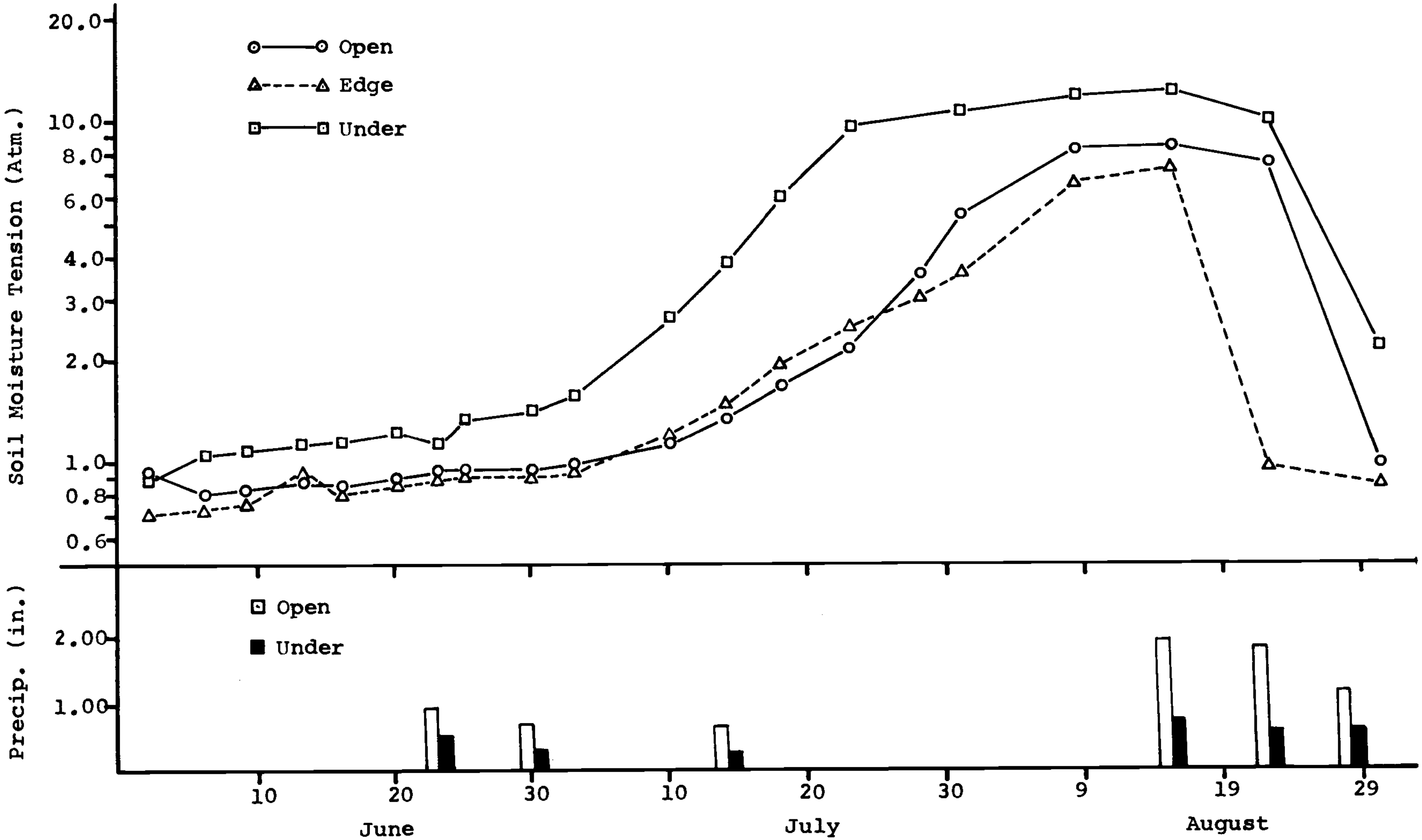

Figure 3. Soil moisture tension in atmospheres at the 24 inch depth and precipitation in inches related to snowbrush cover.

1.0 to 12.2 atmospheres along the edge from July 3 to August 8, 1968. Under snowbrush at six inches moisture tension only increased from 1.4 to 7.0 atmospheres during the same period (Figure 2).

By August 8, at the end of the driest period of the summer, it was apparent that the soil moisture tension in the open in the top six inches was generally above the permanent wilting point. At the same time, six inches under snowbrush cover was only at a maximum of nine atmospheres tension. The situation at 24 inches was, however, almost the reverse of the surface. Under snowbrush, the soil moisture tension was 12.2 atmospheres, while in the open and along the edge, soil moisture tension at 24 inches was 7.9 and 9.0 atmospheres respectively.

Table 10 summarizes soil moisture tensions on August 8, 1968, for all aspects and for both gravimetric and electrometric determination. It is apparent that gravimetric determinations are lower than the block measurements. The gravimetric samples do, however, show the same trend, that is, lower soil moisture tensions in the top six inches under snowbrush, than in the top six inches in the open.

Soil moisture tension data for north and south aspects are unfortunately complicated by slope and slope position. The only areas on south facing slopes which had openings were on the lower third of the slope. Since the moisture stations in the open were near the bottom of the slope, the edge and under positions were also on the lower one third of the slope adjacent to the openings. Moisture content is thus influenced by seepage waters. A comparison of soil moisture tensions on the level aspect and the south facing slope indicate that more moisture was available on the south slope, particularly at the 6 and 24 inch depths (Table 10). Moisture determinations on the north slope were made on the middle one third of the slope. The soil moisture tensions at 6 and 24 inches are generally higher than on the south slope, because of moisture seepage.

More important than the actual moisture tension is the trend. If each aspect is considered independently, it is apparent that the surface in the open is at a higher moisture tension than under brush cover and the 24 inch depth is at higher tensions under brush cover than in the open (Table 10).

Table 11, gives a summary of soil moisture tensions in the last week in August, 1967. The soil moisture samples were taken after 90 days without rain. From Table 11, it is obvious that the moisture tension in the open in the top six inches was higher than under snowbrush and similarly, the highest moisture tension at 24 inches was under snowbrush. On the level aspect, moisture tension trends were similar in 1967 and 1968 (Tables 10 and 11). The north and south aspects are unfortunately confounded by the slope and

Table 10. Soil moisture tension in atmospheres as determined by Colman moisture blocks and gravimetrically on August 8, 1968 (end of longest dry period), related to position of snow-brush.

Aspect & Method	2 inch depth			6 inch depth			24 inch depth		
	Open	Edge	Under	Open	Edge	Under	Open	Edge	Under
Level (S.W.F. 2)									
Moisture Block	31.0	13.7	8.7	14.5	12.2	7.0	7.9	9.0	12.2
Gravimetric	31.0	13.5	9.0	6.3	5.6	4.8	4.5	8.2	9.2
South Slope									
Moisture Block	33.0	3.6	4.2	8.4	4.9	3.9	3.8	4.8	4.5
Gravimetric	11.5	11.0	6.3	5.0	5.2	4.5	2.0	4.4	4.0
North Slope									
Moisture Block	26.5	9.1	9.1	6.4	5.4	7.2	1.3	5.6	6.2
Gravimetric	-	-	-	-	-	-	-	-	-

Table 11. Summary of soil moisture tensions in atmospheres at the end of August, 1967 related to snowbrush cover (gravimetric determinations).

	2 inch depth			6 inch depth			24 inch depth		
Site	Open	Edge	Under	Open	Edge	Under	Open	Edge	Under
Level	32.0	18.0	11.5	9.8	7.1	5.0	6.2	5.8	12.0
South	19.0	11.6	7.6	4.9	3.2	4.1	1.9	4.0	4.5
North	17.0	10.5	4.4	3.6	3.7	1.3	0.6	1.7	1.0

position on the slope, but the 1967 trends are very similar to those in 1968.

Snowbrush cover plays a vital role in the moisture economy of the surface six inches of soil. Since the surface 6 to 12 inches of soil is the rooting zone of newly planted or germinating seedlings, the snowbrush cover is helpful where dessication is likely to occur.

Because of the faster drying out of the surface in the open, growth would be retarded in the open sooner than under the brush cover. Youngberg (1965) found that the growth of yellow pine seedlings stopped as much as two weeks earlier in the open as compared to seedlings under the cover of snowbrush. It is apparent from Figures 1 and 2, that soil moisture tensions would have been high enough by June 20th in the open to retard height growth. The rainfall pattern, unfortunately, disrupted the drying cycle, thus on the basis of the moisture trends, it is not possible to show when moisture would have actually caused growth to stop in a more normal summer. The trends, however, suggest that growth of Douglas-fir seedlings cease sooner in the open than under snowbrush because of lack of moisture.

Moisture consumption at 24 inches clearly indicates that as a seedling grows older, it must undergo a period of competition with the snowbrush. The competition will come, however, at a time when the seedling is better prepared in terms of more extensive rooting and more stored nutrients. If Douglas-fir seedlings begin growth concurrently with the snowbrush or even one or two years after the brush is established they will be 10 to 15 years old before competition with the brush will be critical. After 15 years snowbrush becomes overmature and decadent (Zavitkovski and Newton, 1968). At 10 years Douglas-fir seedlings are beginning the period of most rapid and vigorous growth, thus, the competition created by the snowbrush is not too extreme.

The oldest seedlings on the study areas are probably just at the stage when they will be competing with snowbrush for moisture. The 10-year-old seedlings are just now breaking out of the canopy formed by snowbrush. The evidence for competition at this stage is perhaps indicated by the fact that height growth under snowbrush for 10-year-old Douglas-fir seedlings is less than height growth along the edge, where root competition has probably been less severe (Table 5).

It would appear from the moisture data that the snowbrush sends its main root system deep, thereby leaving a zone directly under its canopy where root competition is less severe. The canopy provides shade, thus reducing evaporation and keeping soil surface temperatures more favorable for growth than in the open. Douglas-fir seedling growing under the canopy can benefit from the more favorable moisture and temperature regimes created by the brush and, at the same time, be reasonably free from severe competition for moisture during the initial critical period of becoming established.

Nutritional Effects of Snowbrush

The nutrient content of Douglas-fir seedlings varied with a number of factors. The factors which were the most obvious in this area were: site quality, climate during the growing season, time at which the samples were taken and position of the seedling relative to snowbrush cover. The nutrient content of a seedling is, therefore, the net effect of all factors interacting with each other. To attempt to separate individual effects is often artificial and misleading, but some separation is necessary if the effects are to be evaluated.

The primary concern of this discussion will be the effect which snowbrush has on nutrient availability for Douglas-fir seedlings. Other factors will be considered, but in somewhat less detail.

Snowbrush is one of the many nonleguminous plants capable of fixing atmospheric nitrogen. The ability of the species to fix nitrogen has been studied and reported by a number of workers, Wahlenberg (1930), Wollum (1962), Wollum and Youngberg (1965), Delewiche, *et al.* (1965), and Zavitkovski and Newton (1968). The amount of nitrogen added to the system has been variously estimated to be from 20 to over 100 Kg per hectare per year. The growth rate of associated coniferous species has been shown to increase as a result of the added nitrogen. Wollum (1962) and Wollum and

Youngberg (1964) showed that the nitrogen added by snowbrush nodules increased the growth rate of potted Monterey pine seedlings.

Zavitkovski and Newton (1968) stated that snowbrush is a prolific litter producer and that the amount of nitrogen contained in the biomass of snowbrush may be as much as 50% more than in other brush species. Heavy litter production, coupled with the more favorable moisture and temperature regime under snowbrush than in the open, results in conditions favoring rapid organic matter decomposition and nutrient mineralization. The rapid cycling, caused by these more favorable conditions, should increase the available nutrient content under snowbrush.

Based on the concept that the amount of a nutrient found in a plant reflects the amount of nutrient available in the soil, an analysis of the nutrient content of Douglas-fir seedlings growing in the open and under snowbrush should reflect the nutrient status of the soil under these conditions (Lundegradh, 1943). Any difference in this status could be attributed to the snowbrush, since the soil on each of the units was relatively uniform.

The relationship between the nutrient content of Douglas-fir seedlings and their position relative to brush cover is given in Figures 4 through 8 and in Appendix VI, Tables 1 through 6. It is apparent that the higher nutrient content in the seedlings is, in part, caused by the effect of snowbrush on nutrients in the soil.

In order to interpret the nutrient content of the Douglas-fir seedlings in terms of growth responses, deficiency and optimum levels must either be known or established. For the purposes of this study, the nutrient range in Douglas-fir needles as reported by Gessel et al. (1960) will be used. These are summarized in Table 12, for current year needles collected in September-October.

Table 12. Elemental composition of Douglas-fir needles.

Element	Range (Percent)
Nitrogen	0.6 - 2.3
Phosphorus	0.1 - 0.25
Potassium	0.3 - 1.0
Calcium	0.2 - 0.75
Magnesium	0.05 - 0.15

The range, as given, goes from minimum or deficiency levels to optimum or above. Position of the seedling related to snowbrush cover is not the only factor determining the level of nutrients in them. Differences in the weather during the growing season can cause a difference in nutrient level. The 1967 growing season was typified by a hot dry summer. The rain fall from May to September totalled 5.67 inches, with no rain occurring in July and August. The 1968 growing season was wet and cool with 14.60 inches of rain falling during the same period with no dry months. Growth was, therefore, able to continue for a longer period. One result of the longer, more favorable growing season was an increase in the nutrient levels in all seedlings. A comparison of the nutrient levels in October, 1968 (Figures 4 through 8), with those in October 1967, clearly illustrates the effect of weather factors during the growing season. Regardless of the weather influence, seedlings growing in association with snowbrush still displayed a higher nutrient level than those in the open. The influence of weather has not negated the effect of the brush.

Time of the year in which the sample is collected affects the nutrient level. Tissue sampled in July had the lowest nutrient content. Differences in nutrient levels between foliage sampled in October and July are caused mainly by differences in the stage of growth of the seedlings.

The amount of any nutrient required by a plant is a function of its growth rate. The faster the plant grows, the greater is the demand placed on the nutrient supply. A plant does not grow at a constant rate throughout the growing season, therefore, the amount of a nutrient required for optimum growth will vary throughout the season. If the supply of nutrient in the soil is just sufficient to supply a species at a slow rate of growth, then a deficiency will occur, when the growth rate increases. The deficiency may not be evident in the early or late part of the growing season, when growth rate is slow, but may occur when growth rate is at a maximum.

Waring[1] found that the nitrogen content of current Douglas-fir needles decreased steadily from bud burst and reached the lowest level 60 days after bud burst, then increased again in the fall. He concluded that the demand for nitrogen increased with the growth rate, reached a maximum, then decreased with decreased growth rate in late summer. The nutrient content of seedlings in the study area followed the same pattern. The nutrient levels dropped in July, when growth rate was rapid. The demand placed on the nutrient supply at this time was much higher than later in the season (Figures 4-8). Nitrogen and calcium (Figures 4 and 5) showed the greatest reductions. Levels of the other nutrients were not reduced to the same extent.

The effect that snowbrush has in reducing nutrient stress is shown by the difference between the nutrient content of seedlings under the brush and in the open. The difference is greatest in July (Table 13) and least in the October, 1968 sampling. The difference is most apparent in nitrogen content. The smaller difference in 1968, compared to 1967, is in all probability a reflection of the weather conditions during the growing season.

Nutrient levels in foliage also reflect site differences. This is emphasized most markedly at the time when the stress is high. The

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[1] Personal communication.

Table 13. The difference between the percent nutrient in seedlings under snowbrush and in the open at different times of the year.

	NITROGEN (Site)			CALCIUM (Site)			MAGNESIUM (Site)			POTASSIUM (Site)		
Date	Good	Poor	Avg.	Good	Poor	Avg.	Good	Poor	Avg.	Good	Poor	Avg.
Oct. '67	0.22	0.21	0.22	0.05	0.09	0.07	0.01	0.02	0.01	0.28	0.10	0.21
July '68	0.26	0.39	0.31	0.06	0.06	0.07	0.01	0.01	0.01	0.16	0.21	0.18
Oct. '68	0.20	0.16	0.16	0.04	0.10	0.06	0.02	0.03	0.03	0.01	0.10	0.05

largest difference between nutrient content under brush cover and in the open occurred on the poor sites (Table 13). This result is to be expected, since on poor sites a seedling would experience greater nutrient stress than on good sites. The beneficial effect of snowbrush is, therefore, relatively greater on poor sites than on good sites.

Nitrogen

The nitrogen content of Douglas-fir needles collected in September and October varies from 0.6 to 2.3% (Gessel et al., 1960). At 0.6% severe deficiency exists. The deficiency at these low levels may be severe enough to prevent the full development of some organs. Deficiency symptoms are no longer evident when foliar nitrogen content reaches 1.1%, however, optimum growth is not obtained until the nitrogen levels reach approximately 1.6%.

In this study, the nitrogen content of Douglas-fir needles sampled in October ranged from 1.17 to 1.57%. This variation was due primarily to two factors: position of the seedling relative to snowbrush and weather conditions during the growing season. It is impossible to separate the effects entirely, but in each case the nitrogen content of seedlings associated with snowbrush was greater than that of seedlings in the open.

The cooler and wetter weather in 1968 (Appendix IV, Table 1) resulted in a longer growing period. Increased nitrogen uptake during this period of more favorable growth conditions is reflected in not only a higher foliar nitrogen concentration in 1968 than in 1967, but also in more total dry matter production in 1968 than in 1967 (Table 5).

The nitrogen content of seedlings in the open in October, 1967, averaged 1.19%, which is just above deficiency levels. In October, 1968, seedlings in the open averaged 1.38% nitrogen, which is well above deficiency levels. Seedlings along the edge and under snowbrush also showed an increase in foliar nitrogen in October, 1968. The increase in nitrogen between October, 1967 and October, 1968, was less in seedlings under snowbrush than those in the open. The increase in nitrogen was 0.19, 0.17 and 0.13% in the open, edge and under, respectively. The larger increase in the open condition is probably a reflection of a stronger influence of favorable weather conditions on nitrogen uptake by seedlings in the open, than on those in the edge or under positions. Nitrogen uptake by seedlings in the edge and under positions was undoubtedly influenced by more favorable weather conditions, but the smaller increases reflect the ameliorating influence of brush on environmental conditions.

This interaction between the influence of snowbrush cover and the weather on the amount of foliar nitrogen is perhaps better shown by the difference in percent nitrogen between seedlings under snowbrush and in the open. The difference in nitrogen content between seedlings under snowbrush and in the open in October, 1967, was 0.22, while in October, 1968, it was 0.16 (Table 13). The larger difference in 1967 suggests that during periods of extreme drought conditions, the influence of snowbrush may be more important in the nitrogen nutrition of Douglas-fir seedlings than during periods when environmental stresses are low.

The effect of snowbrush cover on the nitrogen content of Douglas-fir seedlings is presented in Appendix VI, Table 1, and Figure 4. On all sites, and regardless of sampling time, seedlings associated with snowbrush had higher foliar nitrogen than those seedlings growing in the open. Seedlings in the open contained 1.15 to 1.41 percent nitrogen, whereas, seedlings under snowbrush contained from 1.39 to 1.57% nitrogen.

An analysis of variance (Appendix VII, Tables 1 and 2) indicates that differences in nitrogen content on the good sites are significant at the one percent level of probability, except in October, 1968, when the significance fell to ten percent. The difference in nitrogen content of seedlings associated with snowbrush and those in the open on poor sites was significant at five percent in October, 1967, and one percent in July, 1968, but there was no significant difference in October, 1968.

The analysis of variance appears to support the conclusion that

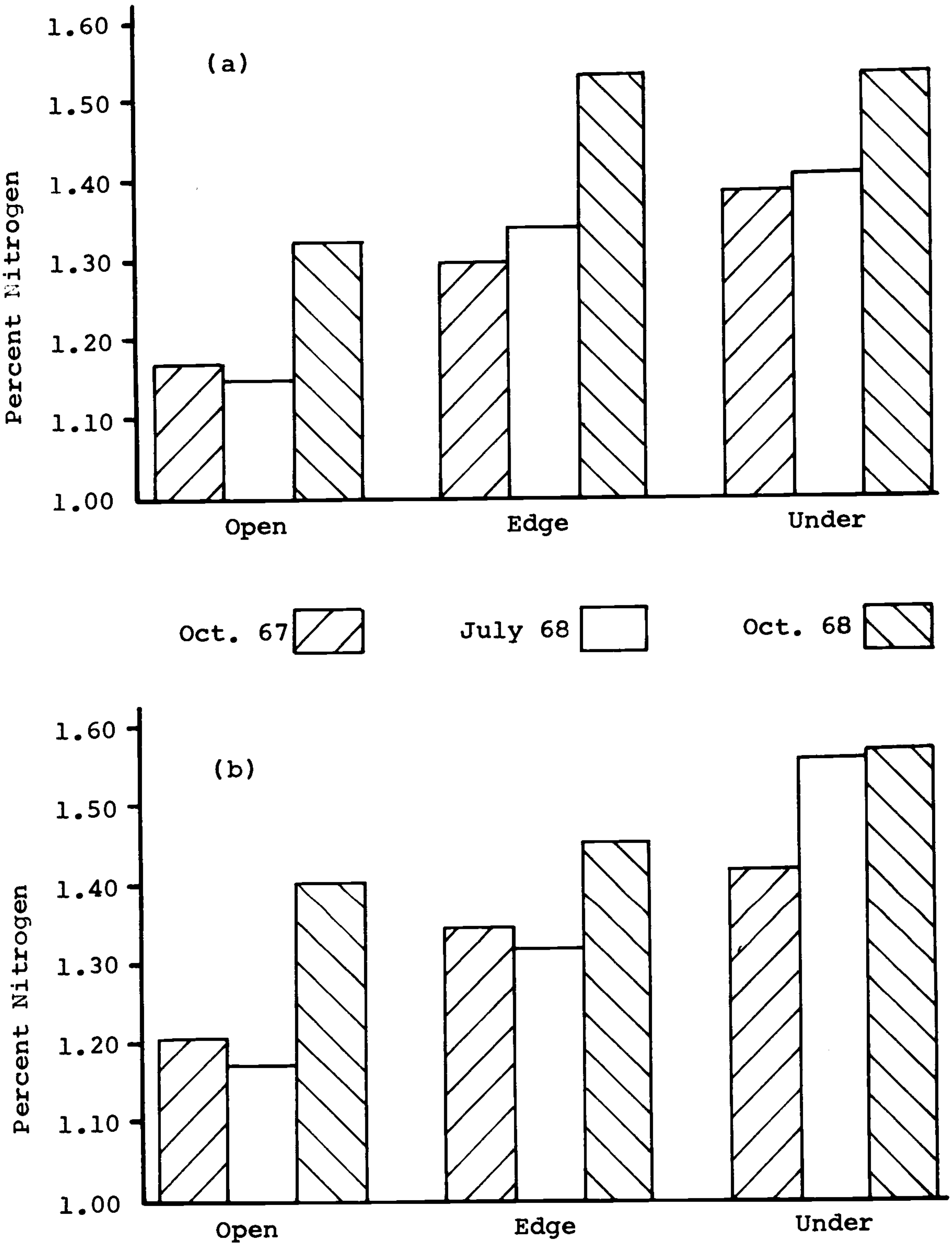

Figure 4. Relationship between percent nitrogen in Douglas-fir needles and the position of the seedling to snowbrush cover on (a) good sites and (b) poor sites.

snowbrush is more important in the nitrogen nutrition of Douglas-fir seedlings during periods of high environmental stress, than during periods of relatively low environmental stress. The fact that in October, 1967, the nitrogen content of the seedlings was significant with relation to brush position, whereas, in October, 1968, the nitrogen content was not significantly different may be the result of the weather and length of the growing season.

The effect of snowbrush cover on the nitrogen content of Douglas-fir seedlings was most significant in July. On both poor and good sites, the difference in nitrogen content of seedlings related to brush cover was significant at the one percent level of probability (Appendix VII, Tables 1 and 2). The nitrogen content in the needles of seedlings in the open dropped to their lowest average value of 1.16%, while under snowbrush, the average nitrogen content was 1.47% (Appendix VI, Table 1).

The drop in nitrogen content in the first week of July is the result of the rapid growth rate. Nutrient stress will be at a maximum during the period of most rapid growth. Snowbrush appears to have the most significant effect on the nitrogen content of seedlings at this time. The effect of snowbrush on reducing nutrient stress is greatest on poor sites. Table 13 shows the difference between the nitrogen content of seedlings in the open and under the brush. The greatest difference, 0.39, occurs on the poor sites in July. As the nutrient stress diminished toward the end of the growing season the difference between the under and open conditions decreased to 0.16.

It would have been interesting to compare nitrogen contents at the end of height growth in 1967 with the 1968 values, since a more severe environmental stress occurred in 1967. The environmental stress in 1968, was by no means severe. Such a comparison may have better shown the influence of snowbrush on the nitrogen nutrition of Douglas-fir seedlings.

Calcium, Magnesium and Potassium

Foliar calcium, magnesium and potassium levels have been influenced by many of the same factors which influenced the nitrogen content of Douglas-fir seedlings. The presence of these cations was generally well correlated with snowbrush cover, but the relationship was not as pronounced as with the nitrogen. The three cations are kept in the rooting zone of Douglas-fir seedlings by rapid recycling. Snowbrush, growing much faster than Douglas-fir seedlings, occupies a larger volume of soil, thus the roots gather the nutrient from a larger volume of soil. Nutrients are returned to the soil through leaf fall and decomposition. Seedlings growing under snowbrush, therefore, have more calcium, magnesium and potassium available to them than those in the open.

The weather during the growing season affected the amount of cations absorbed. The longer growing period in 1968, gave the seedlings more time to absorb the nutrients. Appendix VI, Table 2 and Figure 5, show that the foliar calcium level was approximately 0.10% higher in October 1968, than in October 1967. The magnesium content of seedlings associated with snowbrush showed a general increase as a result of the weather, however, seedlings in the open showed no increase between the October 1967 and 1968 levels (Figure 6 and Appendix VI, Table 3). Potassium also showed an increase generally, however, the increase was very small (Figure 7 and Appendix VI, Tabe 4). The rather small increase in potassium may be due to the low potassium levels in the soil.

An analysis of variance (Appendix VII, Tables 5 and 6) indicates that there was no significant difference between the magnesium content of the Douglas-fir seedlings in the open and under snowbrush. The calcium content of the seedlings was not significantly different on the good sites, but was significantly different in both October 1967 and 1968, on the poor sites (Appendix VII, Tables 3 and 4). The potassium content (Appendix VII, Tables 7 and 8) was not significantly different between the open and under condition, except in October, 1967. In general, the effect of snowbrush on the cation content during periods of low stress was minimal. The July sampling, however, shows that the cation content of the seedlings is strongly related to their position relative to snowbrush cover. The

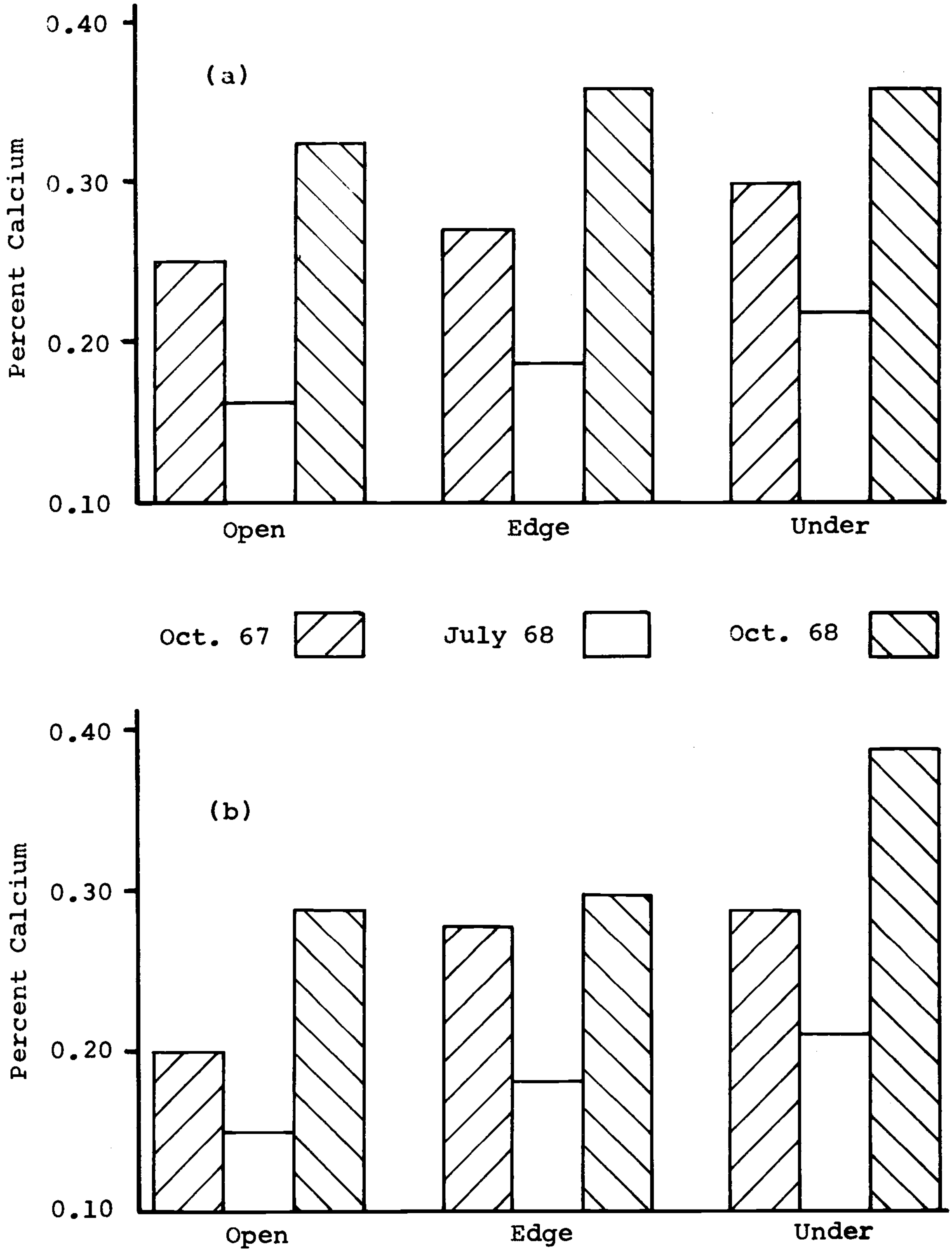

Figure 5. Relationship between percent calcium in Douglas-fir needles and the position of the seedling relative to snowbrush cover on (a) good sites and (b) poor sites.

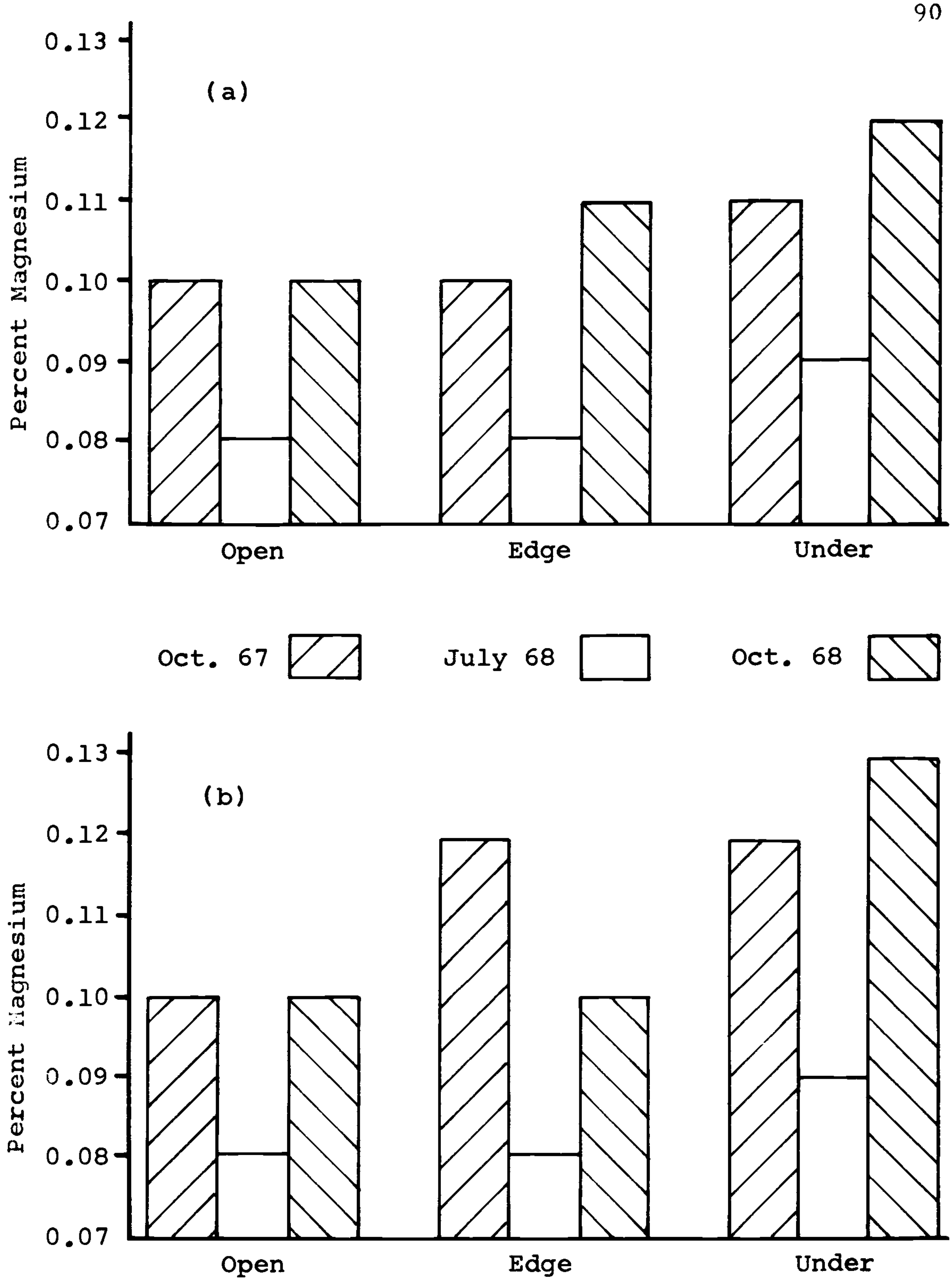

Figure 6. Relationship between percent magnesium in Douglas-fir needles and the position of the seedling relative to snowbrush cover on (a) good sites and (b) poor sites.

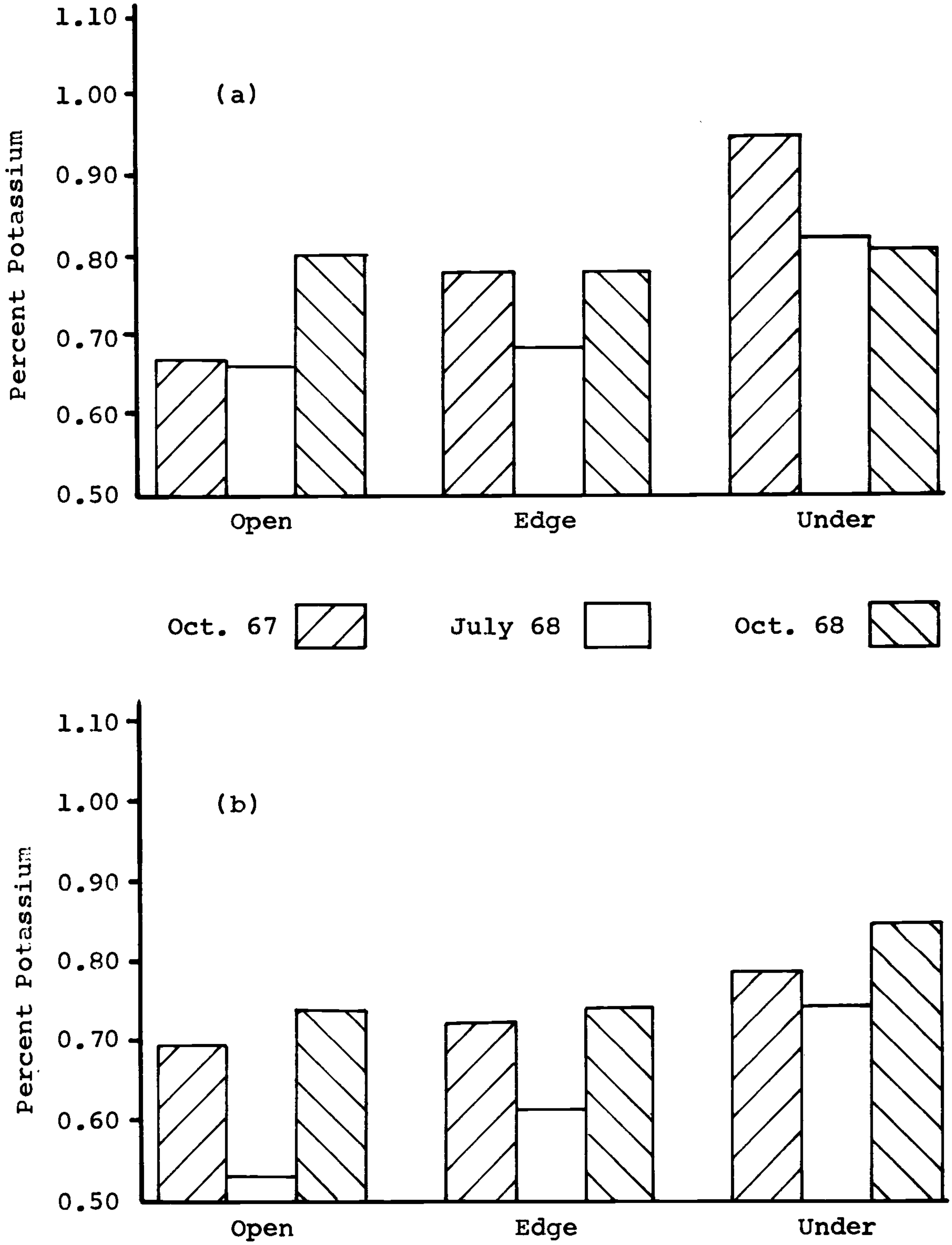

Figure 7. Relationship between percent potassium in Douglas-fir needles and the position of the seedling relative to snowbrush cover on (a) good sites and (b) poor sites.

differences in calcium and potassium content were significant at the one percent level of probability, whereas, the magnesium difference was significant at ten percent on the poor sites and at the five percent level of probability on the good sites. The fact that the cation content was related to snowbrush cover in July and was not strongly related in October suggests that snowbrush is in more influential position in periods of high nutrient stress.

Based on Gessel et al. (1960), the only cation which was low was calcium. Appendix VI, Table 2, shows that in October, 1967, the calcium content of seedlings in the open on the poor sites was 0.20%. Table 12 indicates that the minimum level of calcium is about 0.20%. The magnesium and potassium were both sufficient. Gessel et al. (1960) suggest that the magnesium content be between 0.05 and 0.15% and the potassium should be 0.3 to 1.0%. Appendix VI, Tables 3 and 4, show that the minimum content of potassium was 0.67 and the maximum 0.95, while magnesium ranged from 0.08 to 0.13%. Levels of both potassium and magnesium were well into the sufficiency range.

Phosphorus

Phosphorus content was only determined on seedlings sampled in October, 1967. The range in phosphorus was from 0.18 to 0.25% on a dry weight basis (Appendix VI, Table 5). Gessel et al. (1960)

give the range of phosphorus in Douglas-fir foliage as 0.1 to 0.25%. The phosphorus content of the samples thus fall within this range. No relationship was evident between the position of the seedling relative to snowbrush cover and phosphorus content (Figure 8). An analysis of variance (Appendix VII, Tables 9 and 10) shows that no significant difference occurred between the mean concentration of phosphorus in the trees under snowbrush and those in the open.

Because of the lack of any trend, further phosphorus determinations were omitted. It is doubtful if even in July, when all the other nutrients are subjected to maximum demands, that phosphorus would show the same trends as the other nutrients. The majority of the phosphorus requirement is taken up early in the growing season, thus at the end of height growth, the stress on phosphorus may not be as great as on the other nutrients.

Nutrient Content of the Soil

If snowbrush is actively contributing to the nutrient level of the soil by nitrogen fixation and by recycling through litter fall, the soil under snowbrush should have higher levels of nutrients. Youngberg (1965) found higher levels of nitrogen and calcium under snowbrush and manzanita in both the litter and soil in central Oregon. An analysis of the soils on Foley Ridge in the open and under snowbrush indicated that nitrogen, calcium, magnesium and potassium levels

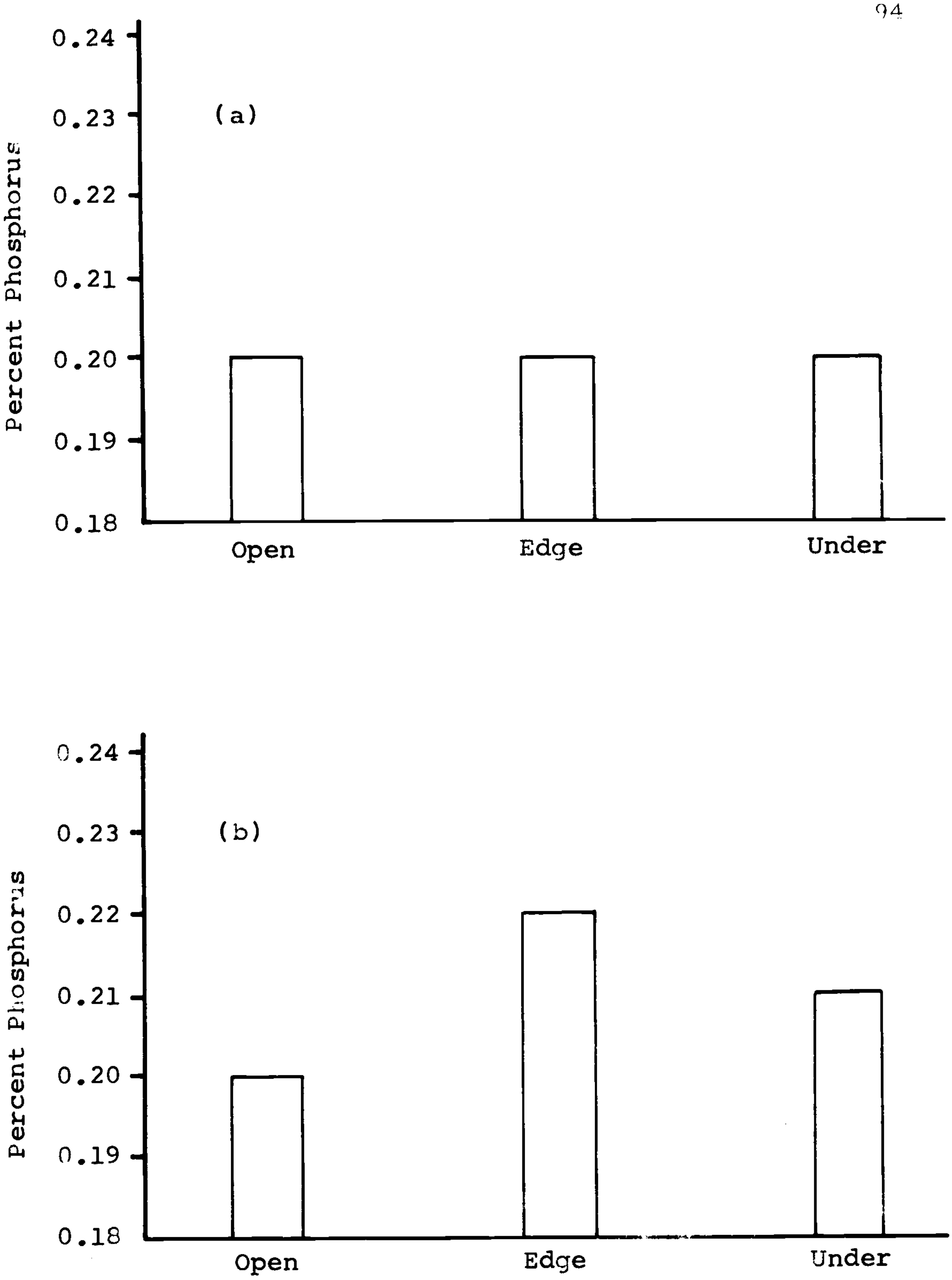

Figure 8. Relationship between percent phosphorus in Douglas-fir needles and the position of the seedling relative to snowbrush cover in October, 1967 on (a) good sites and (b) poor sites.

are higher under snowbrush than in areas devoid of snowbrush (Tables 14 and 15).

The total nitrogen content of the soil was higher under snowbrush then in the open. The difference diminished with depth and at 24 inches, there was no difference. The nitrogen content under the snowbrush averaged 0.16% at two inches at 0.10% at six inches. In the open, the soil nitrogen content averaged 0.12 and 0.09% at two and six inches respectively (Table 14).

Gessel et al. (1960) suggested that a soil nitrogen content of 0.1% would be sufficient to prevent nitrogen deficiency in Douglas-fir. The soils on the study area were at or above this level. The nitrogen content of Douglas-fir needles, even in the open, was never below 1.1%. Also, no serious visible nitrogen deficiency symptoms were observed during the course of the study.

An analysis of variance on nitrogen content in the soil did not show a significant difference between soils in the open and soil under brush. The nitrogen content of the seedlings under the snowbrush was, however, significantly higher than that of those in the open, definitely indicating that the nitrogen supply associated with snowbrush is probably higher.

Exchangeable calcium, magnesium and potassium levels were higher under snowbrush than in the open. The greater supply of these nutrients in the soil is probably the result of the recycling activity of the brush. Snowbrush, with its extensive rooting system gathers nutrients from a large volume of soil. The heavy litter production, along with more favorable temperature and water regime under the brush enhances rapid release of nutrients to the soil. The soil is thus enriched and seedlings growing under the brush may then benefit from this increased nutrient supply.

Table 14. Percent nitrogen in the soil related to snowbrush cover.

Position to Snowbrush	Open		Under	
Depth (in.)	2	6	2	6
N.W.F. 2	0.12	0.07	0.16	0.06
S.W.F. 2	0.12	0.11	0.12	0.10
F.T.C. 1	0.11	0.09	0.14	0.09
F.T.C. 2	0.13	0.10	0.20	0.13
Average of all Units	0.12	0.09	0.16	0.10

Exchangeable calcium varied from 0.30 to 18.31 meq per 100 grams of soil. The calcium content under the brush averaged 5.77 and 4.38 meq/100g at two and six inches respectively. In the open, calcium averaged 1.77 and 1.03 meq/100g at two and six inches respectively (Table 15).

Exchangeable magnesium and potassium were also higher in

Table 15. Exchangeable Calcium, Magnesium and Potassium in the Soil Related to Snowbrush Cover

Nutrient meg/100 g.	CALCIUM				MAGNESIUM				POTASSIUM			
Position to Snowbrush	OPEN		UNDER		OPEN		UNDER		OPEN		UNDER	
Depth (inches)	2	6	2	6	2	6	2	6	2	6	2	6
N. W. F. 2	4.80	2.06	17.36	18.31	0.48	0.48	2.10	4.51	0.95	1.03	1.30	1.14
S. W. F. 2	1.48	0.98	4.48	2.84	0.28	0.28	0.44	0.64	0.29	0.25	0.38	0.33
F. T. C. 1	0.77	0.45	0.92	0.30	0.18	0.16	0.25	0.18	0.19	0.23	0.24	0.20
F. T. C. 2	1.06	0.96	6.12	3.02	0.23	0.31	0.60	0.44	0.19	0.13	0.21	0.12
Average of All Units	1.77	1.03	5.77	4.38	0.27	0.29	0.65	0.99	0.27	0.26	0.42	0.35

the soil under the brush, than in the open. The magnesium increased slightly with depth to six inches (Table 15).

The potassium content of the soils, especially on the poor sites (F.T.C. 1 and 2) was quite low. Even with the low potassium level, there did not appear to be a potassium deficiency evident in the Douglas-fir seedlings.

The more favorable fertility level of the soil associated with snowbrush doubtlessly creates more favorable growing conditions for Douglas-fir seedlings. The higher fertility along with more favorable moisture and temperatures is reflected in better growth of seedlings growing in association with snowbrush.

VII. SUMMARY AND CONCLUSIONS

On the basis of the data in this study, it is possible to state that the beneficial effects of snowbrush cover exceed the detrimental effects on the survival and growth of Douglas-fir seedlings.

Snowbrush provided a more favorable environmental and nutritional regime in which seedlings can become established and grow. Soil surface temperatures under the brush remained well below the lethal point, whereas, in the open the temperatures were usually well above lethal levels. During the extremely hot summer of 1967, soil surface temperatures under the brush never exceeded $117^{\circ}F$. Soil surface temperatures in the open in 1967 reached as high as $177^{\circ}F$ and were frequently above $150^{\circ}F$ in the latter part of the summer. Since damage to newly established seedlings occurs as low as $125^{\circ}F$ the benefit of shade protection is immediately apparent.

Soil moisture tension in the top six inches of soil under snowbrush cover remained below the permanent wilting point in both 1967 and 1968. The surface six inches of soil in the open reached tensions well above the permanent wilting point. At 24 inches consumption of moisture was greater under brush cover than in areas devoid of snowbrush. Even though soil moisture tensions did not go above the permanent wilting point at the 24 inch depth, seedlings with roots penetrating to this depth would experience competition for available moisture. The extent to which a seedling would be affected by such competition was not investigated. It is doubtful if the competition would cause severe mortality, since the competition would occur after a seedling is well established and growing vigorously. Another reason for the limited effect which the competition has on Douglas-fir seedlings is that competition occurs when the seedlings are starting their most vigorous growth stage and snowbrush is starting to decline in vigor, because of maturity.

The increased nutrient supply available to a seedling under snowbrush may be the result of nitrogen fixation and the large amount of litter produced by the species. Decomposition of the litter and mineralization of nutrients is favored by cooler temperature and more moisture available under the brush cover. The increased nutrient supply as a result of the snowbrush is apparent in the soil. The total nitrogen in the surface six inches is greater under snowbrush than in the open. Similarly, exchangeable calcium, magnesium and potassium are at a higher level under brush than in the open. The difference in nutrient level is attributable to snowbrush.

As a result of higher soil nutrient level seedlings associated with snowbrush have higher nutrient contents throughout the growing season than those in the open. Seedlings growing under snowbrush had near optimum levels of nitrogen, calcium, potassium and magnesium, whereas,those in the open were at or near the deficiency level for these nutrients. The only exception to this trend was the phosphorus content, which did not appear to be related to the snowbrush cover.

Snowbrush appeared to have the greatest influence on nutrient levels in the seedlings during the period of high nutrient demand. In July, when the height growth was just ending and nutrient stress was near maximum, the difference in nutrient content, particularly nitrogen, between seedlings in the open and under snowbrush was the greatest. Statistical treatment of the data revealed that nutrient differences in July were significant at the one percent level of probability, while in October, nutrient differences, though present, were usually less significant. Clearly then, snowbrush is influential in reducing the nutrient stress placed on a seedling.

The effects of more favorable soil surface temperatures, moisture supply and nutrient supply in the seedling rooting zone under snowbrush cover are better survival and growth rates of Douglas-fir seedlings.

Milacre stocking and hence survival of planted Douglas-fir seedlings is definitely improved by the presence of snowbrush cover. On Foley Ridge, 53% of the milacres with snowbrush cover were stocked, while those with no snowbrush cover were only 36% stocked.

The total height of seedlings was greater under brush as compared to seedlings in the open. Nine-year-old seedlings were 2.5

feet higher under the brush than in the open. The total height growth is not only a reflection of better growing conditions, but also of the mechanical protection afforded the seedling. Sixty-nine percent of the seedlings in the open and 73.5% along the edge were browsed, while only 28.3% of the seedlings under brush were damaged by browsing. The difference in browsing, doubtlessly accounts for some of the difference in the height of the seedlings, however, not the entire amount. The 1967 and 1968 height growth of seedlings, which were not browsed also indicates better growth under the protection of the brush than in the open.

Clearly then, the snowbrush provides more favorable conditions for the establishment and growth of Douglas-fir seedlings on the western flanks of the Cascade Range. It and other related species should be considered in the management of forest lands in this region.

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APPENDICES

APPENDIX I

Soil Descriptions

Soil developed on the lower benches:

Horizon	Depth (inches)	Description
L-H	$2\frac{1}{2}$ - 0	Litter of snowbrush leaves and twigs, some conifer needles.
A1	0-5	Dark reddish brown (5YR 3/3 moist) gravelly loam of fine granular structure; loose to very friable when moist; lower boundary clear; pH 6.5
A3	5-16	Reddish brown (5YR 4/4 moist) clay loam of moderate-medium subangular, blocky structure; firm when moist; lower boundary gradual; pH 6.5
B2	16-29	Brown (10YR 4/3 moist) clay loam of moderate-medium subangular, blocky structure; firm when moist; pH 7.0
B3	29-40	Brown (10YR 4.5/4 moist) clay loam of moderate-fine subangular, blocky structure; firm when moist; lower boundary clear; pH 6.5
C	40-45	Dark reddish brown (5YR 3/4 moist) clay loam of moderate fine to very fine subangular, blocky structure; friable when moist; lower boundary clear; pH 6.5
IIC	45-58	Yellowish brown (10YR 5/4 moist) loam of moderate medium to fine subangular, blocky structure; very firm when moist; pH 6.0

Soil developed at high elevations:

Horizon	Depth (inches)	Description
L-H	$\frac{1}{2}$ - 0	Leaves, twigs, needles
A1	0-7	Dark reddish brown (5YR 3/4 moist) gravelly sandy loam of weak, very fine granular structure; very friable moist; lower boundary clear; pH 6.1
A3	7-15	Dark reddish brown (5YR 3/4 moist) gravelly loam of weak fine subangular structure; very friable when moist; lower boundary abrupt; pH 5.9
B2	15-27	Reddish brown (5YR 4/4 moist) loam of moderate-medium subangular, blocky structure; firm when moist; pumice particles evident; lower boundary clear; pH 5.2
B3	27-37	Brown (7.5 YR 4/4 moist) sandy loam of moderate-medium subangular, blocky structure; firm when moist; 40% stones, cobbles, gravel; lower boundary abrupt; pH 5.2
C	37-48	Dark brown (7.5 YR 3/2 moist) gravelly loam of weak fine subangular blocky structure; friable when moist; 90% rock highly weathered

APPENDIX II

Table 1. Analysis of variance for total height of Douglas-fir seedlings on N.W.F. 2.

Source of Variation	Degrees of Freedom	Sum of Squares
	Nine-year-old seedlings	
Total	69	235.19
Treatment	2	39.46**
Error	67	195.73
	Seven-year-old seedlings	
Total	64	128.86
Treatment	2	39.26**
Error	62	89.60
	Six-year-old seedlings	
Total	23	24.98
Treatment	2	9.78**
Error	21	15.20
	Five-year-old seedlings	
Total	28	16.31
Treatment	2	7.68**
Error	26	8.63

**F value significant at 1% level.

Table 2. Analysis of variance for total height of Douglas-fir seedlings on S. W. F. 1.

Source of Variation	Degrees of Freedom	Sum of Squares
	Eight and nine-year-old seedlings	
Total	36	31.20
Treatment	2	8.04**
Error	34	23.16
	Six-year-old seedlings	
Total	36	8.49
Treatment	2	0.63
Error	34	7.86

**F value significant at 1% level.

Table 3. Analysis of variance for total height of Douglas-fir seedlings on S. W. F. 2.

Source of Variation	Degrees of Freedom	Sum of Squares
	Nine-year-old seedlings	
Total	93	242.55
Treatment	2	64.74**
Error	91	177.81

**F value significant at 1% level.

Table 4. Analysis of variance for total height of Douglas-fir seedlings on F.T.C. 1.

Source of Variation	Degrees of Freedom	Sum of Squares
	Eight-year-old seedlings	
Total	53	126.15
Treatment	2	14.47*
Error	51	111.68
	Six-year-old seedlings	
Total	40	8.86
Treatment	2	0.78
Error	38	8.08

*F value significant at 5% level.

Table 5. Analysis of variance for total height of Douglas-fir seedlings on F.T.C. 2.

Source of Variation	Degrees of Freedom	Sum of Squares
	Seven-year-old seedlings	
Total	43	31.17
Treatment	2	4.38*
Error	41	26.79

*F value significant at 5% level.

APPENDIX III

Table 1. Analysis of variance for 1967 height growth of Douglas-fir seedlings on S.W.F. 2.

Source of Variation	Degrees of Freedom	Sum of Squares
	Ten-year-old seedlings	
Total	310	5764.11
Treatment	2	874.56**
Error	308	4889.55

**F value significant at 1% level.

Table 2. Analysis of variance for 1967 height growth of Douglas-fir seedlings on F.T.C. 1.

Source of Variation	Degrees of Freedom	Sum of Squares
	Nine-year-old seedlings	
Total	43	423.04
Treatment	2	153.81**
Error	41	269.23

**F value significant at 1% level.

Table 3. Analysis of variance for 1967 height growth of Douglas-fir seedlings on F.T.C. 2.

Source of Variation	Degrees of Freedom	Sum of Squares
	Eight-year-old seedlings	
Total	109	765.29
Treatment	2	29.55**
Error	107	753.74

Continued on next page

Table 3 Continued.

Source of Variation	Degrees of Freedom	Sum of Squares
	Five and six-year-old seedlings	
Total	53	258.60
Treatment	2	33.89*
Error	51	224.71

*F value significant at 5% level.

Table 4. Analysis of variance for 1968 height growth of Douglas-fir seedlings on S.W.F. 2.

Source of Variation	Degrees of Freedom	Sum of Squares
	Ten-year-old seedlings	
Total	346	9026.06
Treatment	2	1625.81**
Error	344	7400.25

**F value significant at 1% level.

Table 5. Analysis of variance for 1968 height growth of Douglas-fir seedlings on F.T.C. 1.

Source of Variation	Degrees of Freedom	Sum of Squares
	Nine-year-old seedlings	
Total	44	1069.88
Treatment	2	418.03**
Error	42	651.85

**F value significant at 1% level.

Table 6. Analysis of variance for 1968 height growth of Douglas-fir seedlings on F.T.C. 2.

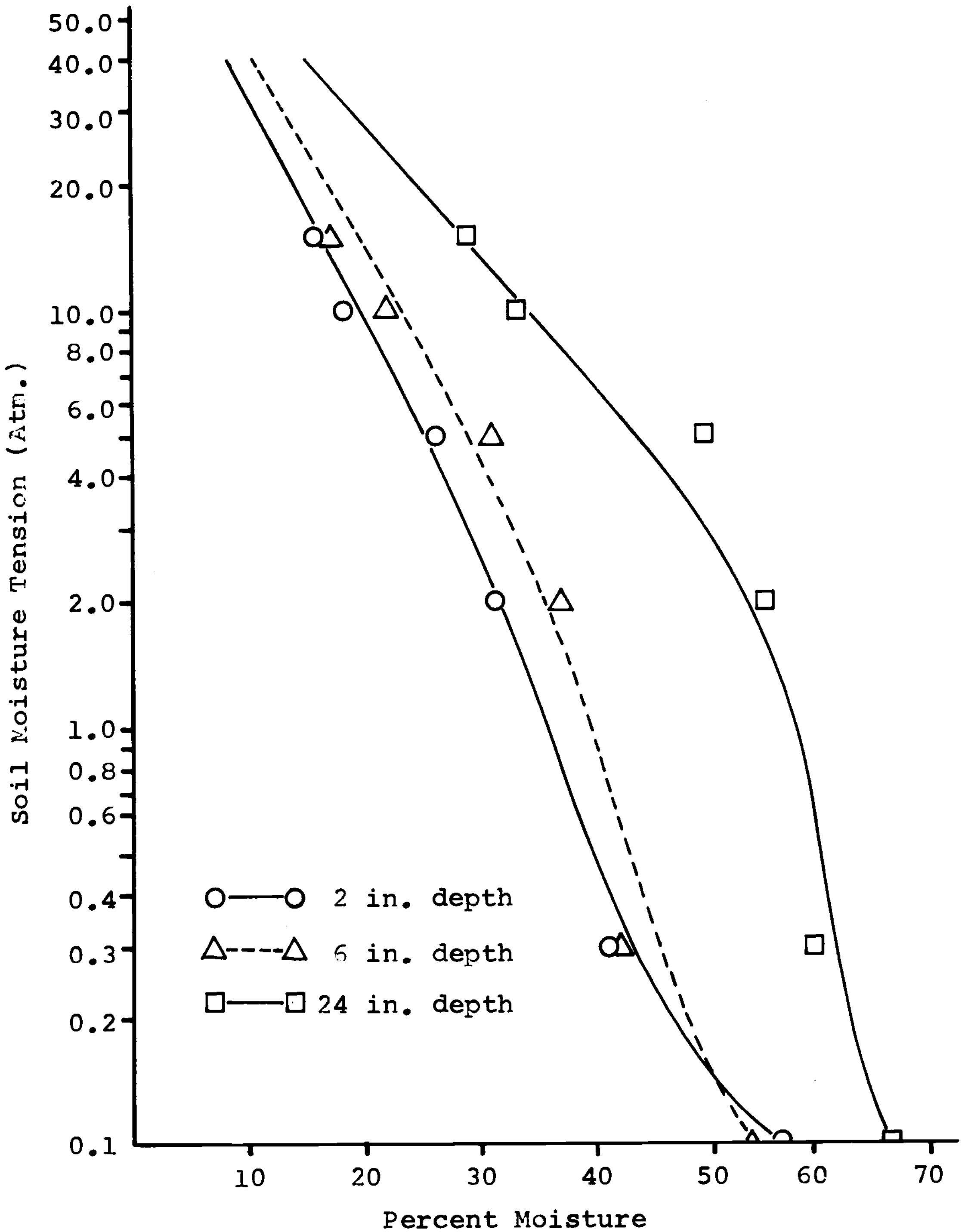
Source of Variation	Degrees of Freedom	Sum of Squares
	Eight-year-old seedlings	
Total	113	1877.53
Treatment	2	274.95**
Error	111	1602.58
	Five and six-year-old seedlings	
Total	54	562.40
Treatment	2	99.31**
Error	52	463.09

**F value significant at 1% level.

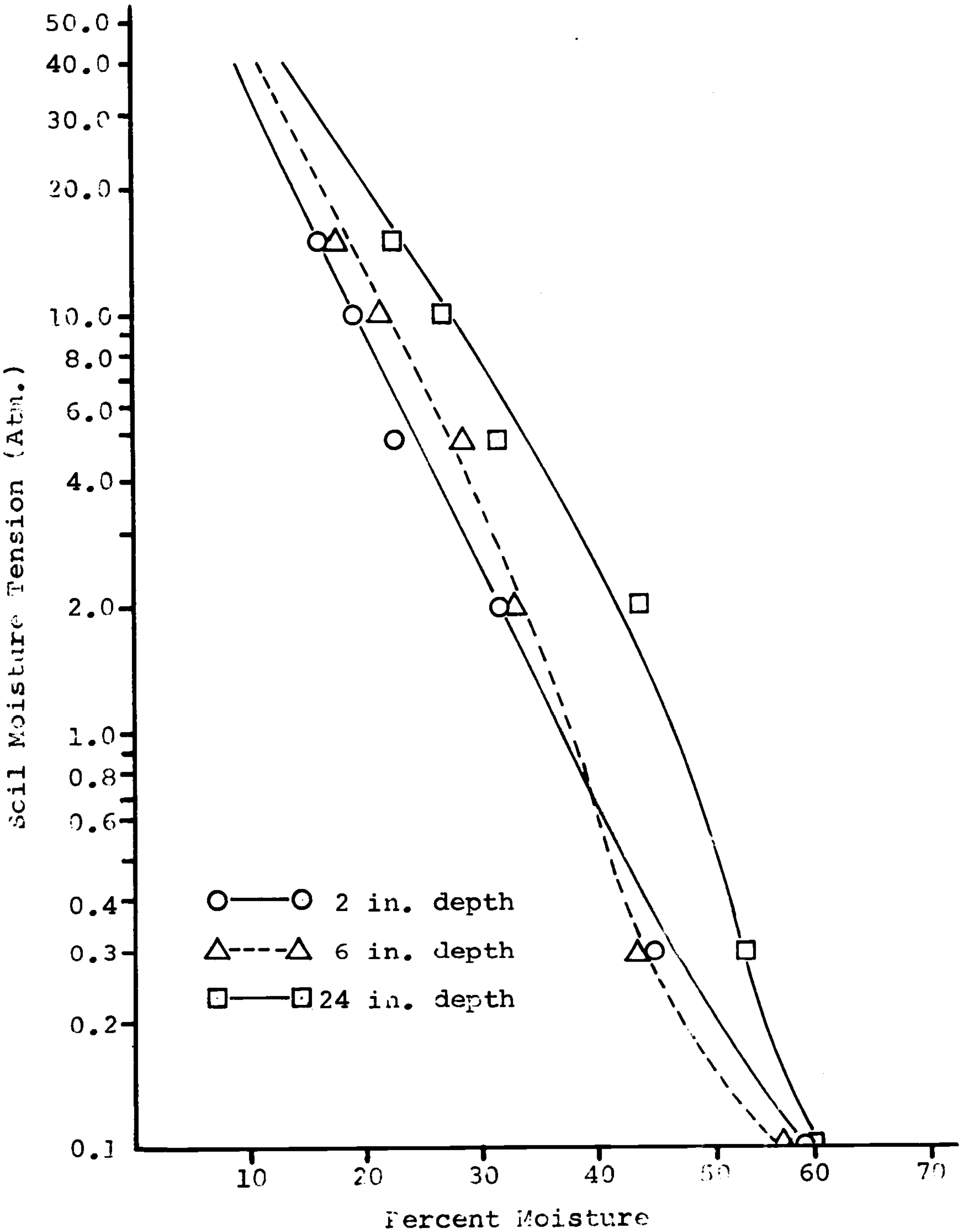
APPENDIX IV

Table 1. Average Monthly Temperature and Precipitation in Inches for 1967 and 1968 at McKenzie Bridge, R. S.

MONTH	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual Total	Deviation from Average
							1967							
Precipitation In Inches	14.15	4.11	5.69	3.21	1.69	1.24	0.00	0.00	2.74	9.83	5.29	7.15	55.37	-14.47
Temperature Fahrenheit	41.9	43.4	44.0	45.8	55.3	63.2	67.9	70.7	64.8	53.9	47.7	38.3	53.0	-----
Hottest Day: August 15, 106° F.														
							1968							
Precipitation In Inches	7.32	9.68	3.89	3.11	3.78	1.90	0.76	4.80	3.36	7.79	12.35	12.71	71.45	+ 1.01
Temperature Fahrenheit	39.7	48.5	48.8	48.4	54.6	61.4		65.1	61.8	52.5	46.9	38.6	52.8	----
Hottest Day: July 31, 100° F.														



Appendix V: Figure 1. Soil moisture tension curves for soil developed on lower benches.



Appendix V: Figure 2. Soil moisture tension curves for soil developed at higher elevations.

APPENDIX VI

Table 1. Percent Nitrogen in the Current Year's Needles of Douglas-fir Seedlings Related to the Position of the Seedling Relative to Snowbrush Cover

Position of Seedling	OPEN			EDGE			UNDER		
Month Sampled	Oct. 67	July 68	Oct. 68	Oct. 67	July 68	Oct. 68	Oct. 67	July 68	Oct. 68
Good Sites	1.17	1.15	1.33	1.30	1.34	1.53	1.39	1.41	1.53
Poor Sites	1.21	1.17	1.41	1.35	1.32	1.45	1.42	1.56	1.57
Average of All Sites	1.19	1.16	1.38	1.33	1.33	1.50	1.41	1.47	1.54

Table 2. Percent Calcium in the Current Year's Needles of Douglas-fir Seedlings Related to the Position of the Seedling Relative to Snowbrush Cover

Position of Seedling	OPEN			EDGE			UNDER		
Month Sampled	Oct. 67	July 68	Oct. 68	Oct. 67	July 68	Oct. 68	Oct. 67	July 68	Oct. 68
Good Sites	0.25	0.16	0.32	0.27	0.19	0.36	0.30	0.22	0.36
Poor Sites	0.20	0.15	0.29	0.28	0.18	0.30	0.29	0.21	0.39
Average of All Sites	0.23	0.15	0.31	0.27	0.18	0.34	0.30	0.22	0.37

Table 3. Percent Magnesium in the Current Year's Needles of Douglas-fir Seedlings Related to the Position of the Seedling Relative to Snowbrush Cover

Position of Seedling	OPEN			EDGE			UNDER		
Month Sampled	Oct. 67	July 68	Oct. 68	Oct. 67	July 68	Oct. 68	Oct. 67	July 68	Oct. 68
Good Sites	0.10	0.08	0.10	0.10	0.08	0.11	0.11	0.09	0.12
Poor Sites	0.10	0.08	0.10	0.12	0.08	0.10	0.12	0.09	0.13
Average of All Sites	0.10	0.08	0.10	0.11	0.08	0.11	0.11	0.09	0.13

Table 4. Percent Potassium in the Current Year's Needles of Douglas-fir Seedlings Related to the Position of the Seedling Relative to Snowbrush Cover

Position of Seedling	OPEN			EDGE			UNDER		
Month Sampled	Oct. 67	July 68	Oct. 68	Oct. 67	July 68	Oct. 68	Oct. 67	July 68	Oct. 68
Good Sites	0.67	0.66	0.80	0.78	0.68	0.78	0.95	0.82	0.81
Poor Sites	0.69	0.53	0.74	0.72	0.61	0.74	0.79	0.74	0.85
Average of All Sites	0.68	0.60	0.77	0.77	0.65	0.78	0.89	0.78	0.82

Table 5. Percent phosphorus in the current years needles of Douglas-fir seedlings related to their position relative to snowbrush cover in October, 1967.

Position of Seedling	Open	Edge	Under
Good Sites	0.20	0.20	0.20
Poor Sites	0.20	0.22	0.21
Average of all Units	0.20	0.21	0.20

APPENDIX VII

Table 1. Analysis of variance for nitrogen in Douglas-fir needles on good sites.

Source of Variation	Degrees of Freedom	Sum of Squares
	October 1967	
Total	59	3.146
Treatment	2	0.860**
Error	57	2.286
	July 1968	
Total	44	2.402
Treatment	2	0.526**
Error	42	1.876
	October 1968	
Total	23	0.837
Treatment	2	0.179+
Error	21	0.658

**F value significant at 1% level.
+F value significant at 10% level.

Table 2. Analysis of variance for nitrogen in Douglas-fir needles on poor sites.

Source of Variation	Degrees of Freedom	Sum of Squares
	October 1967	
Total	49	2.608
Treatment	2	0.438*
Error	47	2.170
	July 1968	
Total	35	2.375
Treatment	2	0.913**
Error	33	1.462

Continued on next page

Table 2 Continued.

Source of Variation	Degrees of Freedom	Sum of Squares
	October 1968	
Total	17	0.454
Treatment	2	0.078
Error	15	0.376

**F value significant at 1% level.
*F value significant at 5% level.

Table 3. Analysis of variance for calcium in Douglas-fir needles on good sites.

Source of Variation	Degrees of Freedom	Sum of Squares
	October 1967	
Total	58	0.319
Treatment	2	0.023
Error	56	0.296
	July 1968	
Total	43	0.123
Treatment	2	0.030**
Error	41	0.093
	October 1968	
Total	23	0.064
Treatment	2	0.009
Error	21	0.005

**F value significant at 1% level.

Table 4. Analysis of variance for calcium in Douglas-fir needles on poor sites.

Source of Variation	Degrees of Freedom	Sum of Squares
	October 1967	
Total	48	0.245
Treatment	2	0.072**
Error	46	0.173
	July 1968	
Total	35	0.108
Treatment	2	0.024*
Error	33	0.084
	October 1968	
Total	17	0.110
Treatment	2	0.035+
Error	15	0.075

**F value significant at 1% level.
*F value significant at 5% level.
+F value significant at 10% level.

Table 5. Analysis of variance for magnesium in Douglas-fir needles on good sites.

Source of Variation	Degrees of Freedom	Sum of Squares
	October 1967	
Total	58	0.0203
Treatment	2	0.0012
Error	56	0.0191
	July 1968	
Total	43	0.0067
Treatment	2	0.0013*
Error	41	0.0054

Continued on next page

Table 5 Continued.

Source of Variation	Degrees of Freedom	Sum of Squares
	October 1968	
Total	23	0.0152
Treatment	2	0.0012
Error	21	0.0140

*F value significant at 5% level.

Table 6. Analysis of variance for magnesium in Douglas-fir needles on poor sites.

Source of Variation	Degrees of Freedom	Sum of Squares
	October 1967	
Total	38	0.0214
Treatment	2	0.0016
Error	36	0.0198
	July 1968	
Total	35	0.0100
Treatment	2	0.0016+
Error	33	0.0084
	October 1968	
Total	17	0.0108
Treatment	2	0.0026
Error	15	0.0085

+F value significant at 10% level.

Table 7. Analysis of variance for potassium in Douglas-fir needles on good sites.

Source of Variation	Degrees of Freedom	Sum of Squares
	October 1967	
Total	59	4.279
Treatment	2	0.840**
Error	57	0.439
	July 1968	
Total	43	0.743
Treatment	2	0.225**
Error	41	0.517
	October 1968	
Total	22	0.266
Treatment	2	0.003
Error	20	0.263

**F value significant at 1% level.

Table 8. Analysis of variance for potassium in Douglas-fir needles on poor sites.

Source of Variation	Degrees of Freedom	Sum of Squares
	October 1967	
Total	38	2.205
Treatment	2	0.076
Error	36	2.129
	July 1968	
Total	35	0.806
Treatment	2	0.249**
Error	33	0.557
	October 1968	
Total	17	0.434
Treatment	2	0.047
Error	15	0.387

**F value significant at 1% level.

Table 9. Analysis of variance for phosphorus in Douglas-fir needles on good sites in October, 1967.

Source of Variation	Degrees of Freedom	Sum of Squares
Total	59	0.0783
Treatment	2	0.0002
Error	57	0.0781

Table 10. Analysis of variance for phosphorus in Douglas-fir needles on poor sites in October, 1967.

Source of Variation	Degrees of Freedom	Sum of Squares
Total	48	0.1228
Treatment	2	0.0022
Error	46	0.1206