Environmental Factors Affecting Natural Regeneration of Engelmann Spruce in the Central Rocky Mountains

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ABSTRACT. Natural regeneration success of Engelmann spruce in clearcut openings, with adequate seed, is controlled by weather and aspect and modified by seedbed conditions. Small clearcut openings of 1–2 hectares can be successfully regenerated on north exposures with mineral soil seedbeds and shade. However, successful natural regeneration in openings on south aspects is not possible, and shade is *absolutely* essential for any survival. Drought was the most serious cause of mortality, but significant losses also resulted from heat girdle, frost heaving, and clipping by birds. FOREST SCI. 23:420–429.

ADDITIONAL KEY WORDS. *Picea engelmannii, Abies lasiocarpa,* clearcutting, seedling ecology.

THE UNCERTAINTY OF ENGELMANN SPRUCE (*Picea engelmannii* (Parry)) natural regeneration in spruce-subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.) forests is a major management problem in the central Rocky Mountains. Past observations and research indicate that, of the three basic requirements for natural regeneration success—(1) a large supply of viable seed, (2) favorable seedbed conditions, (3) an environment compatible with germination and survival—environmental factors most often limit Engelmann spruce regeneration (Roe and others 1970). Consequently, this study was designed to identify limiting factors and determine what modifications in cultural practices are needed to provide a suitable environment for spruce regeneration.

STUDY AREA DESCRIPTION

Field observations were made from 1967 to 1972 on the Fraser Experimental Forest, located in the subalpine zone of the central Colorado Rocky Mountains. Two study areas, approximately 7.2 km apart, were selected; one on a north and one on a south aspect at 3,230 m elevation. Both areas were 1.5 ha, spruce-fir clearcuts, approximately 121 m on a side, with an average slope of 12 percent. Dominant understory vegetation was whortleberry (*Vaccinium myrtilis* L. and *V. scoparium* Leiberg).

Climate of the area is cold and humid (Haeffner 1971). Mean annual temperature is 0.6°C with extremes of –34° to 32°C. Annual precipitation varies from 46 to 86 cm, with an average of 58 cm. Approximately two-thirds of the precipitation falls as snow.

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Soils on the two areas are similar (Retzer 1962). They are gravelly, sandy loams that develop in place under spruce-fir or mixed, spruce-fir and lodgepole pine (*Pinus contorta* Dougl.), stands from coarse-textured material weathered from mixed gneisses and schists. Average combined depth of A and B horizons is 30 to 60 cm, including an 8- to 10-cm layer of organic matter. Soil moisture contents at tensions of ⅓ and 15 bars are 18 and 9 percent.

Methods

Study methods were the same for both aspects, unless otherwise noted.

Experimental Design

The design was a two by two factorial replicated in time—5 years on the north site and 4 years on the south site—in randomized blocks. A set of twelve 1 m-square seedbeds, comprised of four seedbed treatments replicated three times, was prepared each year. These 1 m-square seedbeds were the sampling units for all analyses using percentage data and arc-sin transformations based on number of viable seed per seedbed. Each aspect was studied independently. Appropriate replication times treatment mean squares were used for error term.

Seedbed Treatments

The four seedbed treatments were (1) scarified-shaded, (2) scarified-unshaded, (3) unscarified-shaded, and (4) unscarified-unshaded. Scarification was by hand removal of all organic matter to mineral soil. Wooden frames, made from 5 cm-wide slats elevated 22 cm above the ground on metal framing, provided overhead shade. Slats of the shade frames were aligned in a north–south direction to provide alternate 1-hour periods of shade and sunlight.

Seeding

In late September of each year an estimated 125 viable seeds, collected locally, were evenly sown on the surface of each seedbed. This corresponded to 1¼ million seed per ha, which could be expected from a heavy natural seed crop (Roe and others 1970). The actual number of seeds sown per seedbed each year varied from 165 to 190, depending on viability determined from laboratory germination tests.

Environmental Measures

Air temperatures and relative humidities were recorded from mid-June to October for each year, using hygrothermographs and maximum-minimum thermometers enclosed in standard Weather Bureau shelters. These data were used to compute vapor pressure deficits. In addition, air temperatures were measured periodically in full sunlight at the standard height of 1.4 m with thermistors and a circuit bridge. Wind velocities and patterns, at 1.8 m heights, were measured with recording anemometers; precipitation was measured gravimetrically with standard rain gages. Total horizontal incident radiation was measured with a pyroheliometer located in a level opening between the two aspects but at a slightly lower elevation. These data were adjusted for slope and aspect using tables by Frank and Lee (1966) to obtain potential solar irradiation expressed as langleys.

Seedbed temperatures were measured at the surface with an infrared field thermometer and at 2.5, 5, 10, and 20 cm above and below the surfaces with thermistors and a circuit bridge with switchbox. Data from 18 of the high temperature days were used in the final tabulation.

Biological Measurements

Germination, survival, and causes of mortality were recorded twice weekly beginning in mid-June when plots were first clear of snow, and ending about mid-October with reappearance of winter snow cover. Newly germinated seedlings were marked to show date of germination.

Results

North Aspect

Environmental Factors. The average maximum, minimum, and mean for the five weather factors measured were—

	Maximum	*Minimum*	*Mean*
Precipitation (cm)	28.7	16.4	20.4
Air temperature (°C)	19.0	0.4	9.3
Net radiation (ly/day)	862.0	188.0	530.0
Vapor pressure deficit (mm Hg)	16.5	2.5	9.1
Wind (km/hr)	59.5	0.0	3.4

The mean summer air temperature varied less than 0.1°C annually, and was 0.1°C above the long-term average of 9.2°C. The maximum air temperature recorded was 24°C and the minimum –12°C. Annual summer precipitation averaged 2.5 cm below the normal of 22.9 cm. Rainfall was distributed best in 1969, with 24 storms averaging 1.20 cm per storm, and poorest in 1971 which averaged 0.54 cm in 25 storms. No long-term records of net radiation, vapor pressure deficits, or wind velocity were available for comparisons. The wind had a flow pattern typical of mountain areas—slow, downslope, cold-air drainage during the night, and a morning upslope reversal, generally followed by gusty afternoon winds.

Seedbed Temperature. Average maximum seedbed temperatures were highest on unscarified-unshaded seedbeds—surface temperature was 55.0°C, soil temperature at the 2.5 cm depth was 25.3°C, and air temperature at the 2.5 cm height was 32.5°C. Scarified-shaded beds had the lowest average maximum surface temperature, 31.1°C when shaded and 39.0°C when exposed to the sun. However, at 2.5 cm above and below the surface, unscarified-shaded seedbeds had the lowest average maximum temperatures, 25.0°C air and 16.7°C soil (Table 1, A).

Germination. Total germination was 7.1 percent with a range of 12.3 on scarified-unshaded beds to 1.4 percent on unscarified-unshaded seedbeds (Table 2). Germination was improved significantly by scarification but not by shade. There were no significant differences in germination among years, despite a range of 12.7 percent in 1968 to 0.9 in 1971.

Survival. Total survival was 1.5 percent of the viable seed sown, with a range from 3.6 on scarified-shaded seedbeds to 0.2 percent on unscarified-unshaded beds (Table 2). Survival was significantly improved by both scarification and shade. There were no significant interactions, but differences in survival between years were significant.

Mortality. Seventy-nine percent of the seedlings that germinated eventually died. Most losses occurred within 3 months after germination (Fig. 1). Ten factors were

TABLE 1. A profile of average maximum seedbed temperatures (°C) recorded at the surface and at four distances above and below the surface on two aspects.

A. North Aspect

Profile position[1] (cm)	Scarified-shaded	Scarified-unshaded	Unscarified-shaded	Unscarified-unshaded
20.0 +	22.5	28.9	22.2	27.0
10.0 +	22.5	29.4	21.7	28.6
5.0 +	22.8	30.3	22.8	30.0
2.5 +	24.4	31.4	25.0	32.5
0.0 U	39.0	43.0	48.9	55.0
0.0 S[2]	31.1	—	42.7	—
2.5 –	21.1	22.8	16.7	25.3
5.0 –	17.8	22.2	13.9	21.1
10.0 –	15.0	17.5	13.1	17.2
20.0 –	12.8	15.6	11.1	13.6

B. South Aspect

Profile position[1] (cm)	Scarified-shaded	Scarified-unshaded	Unscarified-shaded	Unscarified-unshaded
20.0 +	23.6	30.0	22.8	31.7
10.0 +	23.9	30.6	23.3	31.7
5.0 +	23.9	31.7	24.7	32.5
2.5 +	25.9	33.3	25.9	35.3
0.0 U	50.0	51.0	51.0	>60.0[3]
0.0 S[2]	43.3	—	43.5	—
2.5 –	23.6	29.4	20.3	26.4
5.0 –	21.1	25.6	17.0	22.2
10.0 –	17.0	21.1	13.9	16.7
20.0 –	16.7	15.0	13.3	14.2

[1] Air temperatures are indicated by (+), soil temperatures by (–), and shaded and unshaded surface temperatures by U and S, respectively.

[2] The lath structure in the shade treatments provided alternate areas of 1-hour duration of shade and sunlight.

[3] Maximum surface temperatures on unscarified-unshaded seedbeds exceeded the range (60°C) of the instrument being used.

recognized as causes of mortality (Table 3) with drought (30 percent), frost heaving (23), and clipping (22) accounting for most mortality.

South Aspect

Environmental Factors. The average maximum, minimum, and mean for the five weather factors measured were—

	Maximum	*Minimum*	*Mean*
Precipitation (cm)	34.4	19.3	24.9
Air temperature (°C)	20.0	2.5	10.0
Net radiation (ly/day)	862.0	206.0	557.0
Vapor pressure deficit (mm Hg)	18.3	3.1	10.2
Wind (km/hr)	67.6	0.0	3.7

TABLE 2. Percent germination and survival of Engelmann spruce seeds on the north aspect, by seedbed treatment and year.

	Scarified-shaded		Scarified-unshaded		Unscarified-shaded		Unscarified-unshaded		Total	
Year	Germination	Survival	Germination	Survival	Germination	Survival	Germination	Survival	Germination	Survival
1968	15.7	3.7	28.0	0.8	5.1	0.8	1.9	0.0	12.7	1.3
1969	21.1	7.5	12.8	3.2	4.5	1.3	.8	.0	9.8	3.0
1970	12.5	5.1	7.2	1.6	4.5	.3	1.3	.5	6.4	1.9
1971	1.1	.5	2.1	1.1	.0	.0	.5	.3	.9	.5
1972	6.7	1.1	11.2	.8	1.6	.3	2.4	.3	5.5	.6
Total	11.4*	3.6**	12.3*	1.5**	3.1	0.5**	1.4	0.2	7.1	1.5

* Germination—scarification significant (0.95 percentile); shade not significant.

** Survival—scarification significant (0.99 percentile); shade significant (0.90 percentile).

Mean summer air temperature varied less than 0.1°C annually, but was 0.8°C above the long-term average. Maximum temperature was 25.6°C and the minimum −12°C. Rainfall averaged 2.0 cm above the seasonal average of 22.9 cm. Rainfall was best distributed in 1969, with 25 storms averaging 1.38 cm per storm, whereas only 20 storms were recorded in 1971, averaging 0.96 cm. The wind flow pattern was the same as previously described for the north aspect.

Seedbed Temperature. The highest seedbed temperatures were recorded on unscarified-unshaded seedbeds, which had average maximum of >60°C on the surface, 35.3°C at 2.5 cm above the soil surface, and 26.4°C at 2.5 cm below the soil surface. Scarified-shaded seedbeds had the lowest average maximum surface temperatures, 43.3°C when shaded and 50.0°C when unshaded. Average maximum temperatures 2.5 cm above the surface were lowest on scarified-shaded seedbeds, 25.9°C, and 2.5 cm below the surface were lowest on unscarified-shaded seedbeds, 20.3°C (Table 1, B).

Germination. Total germination was 5.0 percent and ranged from 8.7 on unscarified-shaded seedbeds to 3.2 percent on scarified-unshaded beds (Table 4). In contrast to the north aspect, germination on the south aspect was improved significantly by shade, but not by scarification. There were no significant interactions, but years were significantly different. Germination ranged from 14.5 percent in 1972 to 0.02 in 1970.

TABLE 3. Percentage of total spruce seedling mortality on the north aspect, by cause and seedbed treatment.

Mortality cause	Scarified-shaded	Scarified-unshaded	Unscarified-shaded	Unscarified-unshaded	Total
Drought	10.0	9.5	6.2	4.5	30.2
Clipping	11.2	9.5	1.2	.0	21.9
Frost heaving	6.4	16.2	.0	.0	22.6
Heat girdle	.5	1.0	.0	.0	1.5
Others[1]	6.9	12.0	4.2	.7	23.8
Total	35.0	48.2	11.6	5.2	100.0

[1] Others included light injury, freezing, washing, damping-off, snow mold, and unknown.

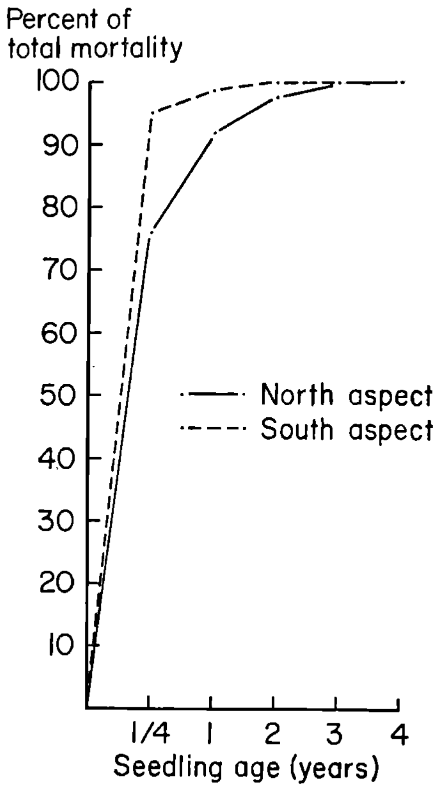

FIGURE 1. Percent of total mortality compared to seedling age on two aspects.

Survival. Total survival was 0.4 percent of the viable seed sown, ranging from 0.8 percent on unscarified-shaded beds to 0.0 on unscarified-unshaded seedbeds (Table 4). Shading the seedbeds significantly improved survival, but scarification did not. There were no significant interactions and no significant differences among years.

Mortality. Ninety-two percent of the seedlings that germinated died, and 95 percent of that mortality occurred before seedlings were 3 months old (Fig. 1). Of the 10 factors causing seedling mortality, drought (53 percent), clipping (25) and heat girdle (14) accounted for more than 90 percent of all mortality (Table 5).

Discussion and Conclusions

Figure 2 summarizes important factors influencing natural regeneration of Engelmann spruce in the central Rocky Mountains, based on this study and a review of literature (Noble 1974).

Regeneration success depends on the probability of viable seeds falling in favorable microsites for germination and survival. In this study, variability in seed viability was eliminated by artificial seeding in order to concentrate on factors affecting the microsites. Although our equipment could not adequately measure the microsite environment of individual seeds or seedlings, it was possible to measure the microenvironment of seedbeds, which in turn reflected conditions of the microsites. Three factors were identified as having a major effect on the seedbed—(1) weather, (2) aspect, and (3) cultural treatments. Biotic factors, while not directly affecting seedbed environment, did affect regeneration success.

REGENERATION CONDITIONS

FAVORABLE		UNFAVORABLE
> 600,000 seed/ha	-SEED CROP-	< 60,000 seed/ha
North	-ASPECT-	South
Ambient air > 0°C night and < 25°C day; maximum surface < 30°C	-TEMPERATURES-	Ambient air < 0°C night and > 25°C day; maximum surface > 30°C
> 1.0 cm/week	-PRECIPITATION-	< 1.0 cm/week
Light textured, sandy-loam	-SOIL-	Heavy textured, clay-loam
50 percent exposed mineral soil	-SEEDBED-	10 percent or less exposed mineral soil
40-60% dead shade		10% or less dead shade
Duff and litter < 5 cm		Duff and litter > 10 cm
Light vegetative cover		Heavy vegetative cover
Seedlings > 12 weeks old by mid-Sept.	-SURVIVAL-	Seedlings < 12 weeks old by mid-Sept.
Low population of birds and rodents that eat seeds and seedlings		High population of birds and rodents that eat seeds and seedlings
Protection from trampling		No protection from trampling
Snow cover when frost-heaving conditions exist		No snow cover when frost-heaving conditions exist

FIGURE 2. Conditions favorable and unfavorable to the natural regeneration of Engelmann spruce.

WEATHER

Threshold temperatures and precipitation in figure 2 are good guides; however, distribution of rainfall and time and duration of temperature extremes are equally important.

Temperature and precipitation generally work in consort, but not always. A single intense rainstorm can wash seeds and seedlings away, and unusually cold temperatures in midsummer can cause frost damage to both new and established seedlings. Both conditions occurred, but caused only minor damage. Their potential for serious damage, however, should not be overlooked (Roe and others 1970).

TABLE 4. Percent germination and survival of Engelmann spruce seeds on the south aspect, by seedbed treatment and year.

Year	Scarified-shaded		Scarified-unshaded		Unscarified-shaded		Unscarified-unshaded		Total	
	Germination	Survival	Germination	Survival	Germination	Survival	Germination	Survival	Germination	Survival
1968	—	—	—	—	—	—	—	—	—	—
1969	6.7	0.3	2.1	0.0	6.9	1.9	2.4	0.0	4.5	0.5
1970	.0	.0	.0	.0	.8	.3	.0	.0	.02	.1
1971	1.6	.5	1.3	.0	.3	.0	.6	.0	1.0	.1
1972	10.9	1.9	9.6	.5	26.9	1.1	10.7	.0	14.5	.9
Total	4.8*	0.7**	3.2	0.1	8.7*	0.8**	3.4	0.0	5.0	0.4

* Germination—shade significant (0.99 percentile); scarification not significant.

** Survival—shade significant (0.95 percentile); scarification not significant.

Temperature and precipitation interactions that caused drought and frost heaving were more serious. Drought, resulting from below-normal rainfall and high air temperatures for several weeks, may occur anytime during the growing season. It was most damaging to spruce regeneration during the 6 weeks following spring snowmelt. In high-elevation spruce-fir forests, high air temperatures may not contribute as much to drought as below-normal or poorly distributed rainfall. For example, 1971 was a poor year for germination on both aspects—0.9 percent on the north site and 1.0 on the south site—and rainfall was below average and poorly distributed. During the 6 weeks after the snowmelt, the north site received 3.8 cm of rain in 8 storms compared to the average of 8.4 cm in 11 storms; the south aspect received 4.8 cm of rain in 6 storms—3 storms and 4.5 cm blow average. Average maximum temperatures for the period were about 1°C above normal on the north area, and near normal on the south area. In contrast, 1972 was a good year for germination on the south aspect (14 percent) and an average year on the north aspect (6 percent). The south site received 9.3 cm of rain in 14 storms and the north site 7.3 cm in 9 storms. Air temperature on both areas averaged about 1°C below normal for the first 6 weeks following spring snowmelt.

Frost heaving, resulting from the interaction of moisture and temperature, was a serious cause of seedling mortality. This phenomenon occurred when soil moisture was at or near field capacity, there was no vegetative or snow cover, and day-night temperatures were alternately above and below 0°C. Seedling losses from frost heaving were recorded every year, but during the fall of 1968 conditions were particularly bad, and nearly half of the 190 germinated seedlings were lost. Frost heaving is most likely to occur during the 2–3 weeks following spring snowmelt, and again just prior to permanent snow cover in the fall.

The effects of other weather factors—radiation, vapor pressure deficits (VPD's), and wind—became more apparent when considered with aspect.

Aspect

This study was specifically planned to describe the regeneration environment of a north and a south aspect. The study areas were only 7.2 km apart, in the same major drainage, and at the same slope and elevation. Because of local topography, the south site received slightly more precipitation per season; however, the distribution patterns were very similar and no differences were found in wind pattern and velocity, which led to the conclusion that the same major air mass generally covered both aspects. Therefore, effects of net radiation, VPD, and temperature on regeneration success are more related to aspect.

TABLE 5. Percentage of total spruce seedling mortality on the south aspect, by cause and seedbed treatment.

Mortality cause	Scarified-shaded	Scarified-unshaded	Unscarified-shaded	Unscarified-unshaded	Total
Drought	9.0	11.1	20.8	12.5	53.4
Clipping	9.3	.7	13.6	1.4	25.0
Frost heaving	.4	.7	.0	.0	1.1
Heat girdle	1.4	2.5	6.4	3.9	14.2
Others[1]	2.2	1.8	1.8	.4	6.2
Total	22.3	16.8	42.6	18.2	99.9

[1] Others included light injury, freezing, washing, damping-off, snow mold, and unknown.

Surface temperatures on all four seedbed treatments averaged from 4.5°C to >11.2°C higher on the south aspect than on the north, despite the fact that air temperatures measured either in the open or in the weather shelters at 1.4 m height averaged only about 1°C warmer on the south aspect. The higher surface temperatures caused the air and soil temperatures, at 2.5, 5.0, 10.0, and 20.0 cm above and below the surface, to be higher on the south aspect. These higher temperatures, plus VPD's averaging 12 percent higher, increased evapotranspiration rates and created a drier environment, resulting in poor germination and high seedling mortality from drought and heat girdle. Snowmelt was also 7–10 days earlier in June on the south exposure, and unless rain fell in those critical first weeks, the seedbeds rapidly changed from too cold and wet to too hot and dry for germination and survival.

The greater net radiation of at least 5 percent on the south aspect was largely responsible for the higher seedbed temperatures and vapor pressure deficits.

Seedbed Treatments

Scarification and shading improve the microenvironment of seedbeds for regeneration by increasing available moisture and decreasing temperatures. Eis (1970) found that available water at a depth of 5 cm was substantially higher in mineral soil than in humus, while Day (1963) reported that shade reduced water loss from both spruce seedlings and the soil. Results from our study agreed with this earlier work. The layer of organic matter on the south aspect averaged less than 5 cm thick, reducing the need for scarification, whereas the organic matter on the north aspect was 7 cm or more thick, and scarification was more effective in increasing available moisture. Heavier layers of organic matter on north aspects are typical of the spruce-fir zone of the central Rockies.

The fact that shade was essential for survival of any regeneration on the south aspect, and significantly improved regeneration success on the north aspect, reemphasizes the importance of reducing evapotranspiration in cleared openings.

Biotic Factors

The only significant biotic factor affecting regeneration was the clipping of cotyledons on newly germinated seedlings. At first, we believed that rodents were doing the damage; however, by periodic trapping inside the exclosures, and from visual and photographic evidence, we determined that gray-headed juncos (*Junco caniceps*, Woodhouse) were responsible (Noble and Shepperd 1973).

Other biotic factors causing seed or seedling loss, such as insects, damping-off fungi, snow mold, and needlecast, were not limiting to regeneration success.

The basic conclusion from this study is that 1- to 2-ha clearcut openings on north exposures in the spruce-fir type in the central Rockies can be successfully regenerated naturally from seed with the aid of cultural treatments. However, similar openings on south exposures would be difficult to regenerate naturally from seed even with such treatments. Openings on south aspects will have to be regenerated with advanced reproduction or by planting.

Literature Cited

Day, R. J. 1963. Spruce seedling mortality caused by adverse summer microclimate in the Rocky Mountains. Can Dep For, For Res Branch No. 1003, 36 p.

Eis, S. 1970. Root growth relationships of juvenile white spruce, alpine fir, and lodgepole pine on three soils in the interior of British Columbia. Can Dep Fish and For, Can For Serv Publ No. 1276, 10 p.

FRANK, ERNEST C., and RICHARD LEE. 1966. Potential solar beam irradiation on slopes: Tables for 30 to 50 degrees latitude. USDA Forest Serv Res Pap RM-18, 116 p. Rocky Mt Forest and Range Exp Stn, Fort Collins, Colo.

HAEFFNER, ARDEN D. 1971. Daily temperatures and precipitation for subalpine forest, central Colorado. USDA Forest Serv Res Pap RM-80, 48 p. Rocky Mt Forest and Range Exp Stn, Fort Collins, Colo.

NOBLE, DANIEL L. 1974. Natural regeneration of Engelmann spruce in clearcut openings in the central Rockies as affected by weather, aspect, seedbed, and biotic factors. Ph D dissertation, Colo State Univ, Fort Collins. Diss Abstr 35(6):2530-B.

NOBLE, DANIEL L., and WAYNE D. SHEPPERD. 1973. Grey-headed [Gray-headed] juncos important to first season mortality of Engelmann spruce. J For 71:763–765.

RETZER, J. L. 1962. Soil survey of Fraser alpine area, Colorado. Soil Surv Ser 1956, No. 20, 47 p. US Dep Agric, Forest Serv and Soil Conserv Serv, Colo Agric Exp Stn, US Gov Print Off, Washington, D C.

ROE, ARTHUR L., ROBERT R. ALEXANDER, and MILTON D. ANDREWS. 1970. Engelmann spruce regeneration practices in the Rocky Mountains. US Dep Agric Prod Res Rep 115, 32 p. US Gov Print Off, Washington, D C.

Seasonal Variation in Foliar Nutrient Concentrations of Black Cherry

Note by T. W. Bowersox and W. W. Ward

ABSTRACT. Leaf samples were collected at four times during the 1974 growing season from black cherry trees growing on the Allegheny Plateau of Pennsylvania. Foliar concentrations of N, P, K, and Mg were dependent on sampling date. Variability of foliar Ca was such that no sampling date difference could be detected. N, P, and K levels declined during the growing season. Late August appears to be the best time to collect leaf samples from black cherry trees growing in the region. FOREST SCI. 23:429–432.

ADDITIONAL KEY WORDS. *Prunus serotina*, foliar sampling, foliar N, P, K, Ca, and Mg.

FOLIAR ANALYSIS is often used to estimate the potential of trees to utilize nutrients present in the soil. However, concentration of foliar nutrients varies with crown position, morphological maturity, and physiological stage. In sampling deciduous species, general practice has been to collect mature leaves from the upper crown before they begin discoloration. This practice attempts to minimize variation in nutrient concentrations that are time dependent. The logistical "best time" for a set of nutrients may not be the optimum time to measure individual nutrients in the set; therefore, knowledge of seasonal variation of foliar nutrients is essential. This paper reports on seasonal variation in the concentration of N, P, K, Ca, and Mg in leaves of black cherry (*Prunus serotina* Ehrh.) trees growing on the Allegheny Plateau of Pennsylvania.

PROCEDURE

Leaf samples were collected from 53 black cherry trees growing in fully stocked, even-aged stands in Elk County, Pennsylvania. Average age was 31 years, and average site

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The authors are Assistant Professor of Silviculture and Professor of Silviculture, respectively, School of Forest Resources, The Pennsylvania State University. They wish to thank Arthur Bennett and Texasgulf, Inc., for their assistance on this project. This research was supported by funds from McIntire-Stennis allotments. Paper No. 5209 in the Journal Series of the Pennsylvania Agricultural Experiment Station. Authorized for publication on December 10, 1976. Manuscript received January 11, 1977.

[1] Defler, Sam E. 1937. Black cherry: characteristics, germination, growth, and yield. M. F. Thesis, Syracuse Univ., Syracuse, N.Y.