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REPORT

of

COMMITTEE ON THESIS

THE undersigned, acting as a committee of the Graduate School, have read the accompanying thesis submitted by Charles F. Bliss for the degree of Master of Science They approve it as a thesis meeting the requirements of the Graduate School of the University of Minnesota, and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science.

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June 1 1915

A STUDY OF REGENERATING ENGELMANN SPRUCE

ON SODDED BURNS

-O-

A THESIS

SUBMITTED TO THE FACULTY

OF THE

GRADUATE SCHOOL

OF THE

UNIVERSITY OF MINNESOTA

May 15, 1915

BY

CHARLES F. BLISS

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

FOR THE DEGREE OF

MASTER OF SCIENCE

-O-

A STUDY OF REGENERATING ENGELMANN SPRUCE ON SODDED BURNS

INTRODUCTION

In the southern part of its natural range the Engelmann spruce occurs at high altitudes, forming dense forests in mixture with Alpine fir. Throughout these forests, particularly in the state of Colorado, at elevations ranging from 10,000 to 12,000 feet, occur many open areas that are covered with a heavy grass sod. These areas or "sodded burns" are the result of forest fires that occurred many years ago. Although Engelmann spruce is an abundant reproducer, it is failing to reestablish itself satisfactorily on these burns. To inquire into the reasons for the lack of natural reproduction and to set forth the results of certain experiments to determine the best methods for reforesting these areas by artificial means, is the purpose of this study.

To present the subject as clearly as possible, the study is taken up in the following order:

(1) The botanical and silvicultural characteristics of Engelmann spruce and its relation to the physical and biotic factors of its range;

(2) The occurrence of sodded burns in Engelmann spruce areas and the absence of the natural reproduction of this species on them; and

(3) The description and results of experiments in artificially reforesting these areas satisfactorily by present methods.

The author acknowledges his indebtedness to Professor J. P. Wentling for suggestions offered in the course of the study of this subject, and to the United States Forest Service for pictures and material relative to the same.

Table of Contents

Page

GENERAL DESCRIPTION.

HISTORICAL:

Lewis and Clark, while crossing the Bitterroot Mountains on September 9, 1805, during their second trans-continental journey, found that the timber was "almost exclusively pine, chiefly of the long-leaved kind, with some spruce and a sprinkling of fir resembling the Scotch Fir." The spruce must have been Picea engelmanni. Here it made its first appearance in literature as well as being seen for the first time by white men. The fir "resembling the Scotch Fir" is without doubt the lodgepole pine.

TAXONOMICAL:

Engelmann spruce (Picea engelmanni) was first described by Dr. C. C. Parry who found it on Pikes Peak in Colorado in 1862. It was named for Dr. George Engelmann.

There are many confusing local names. It is called <u>balsam</u> in Utah; <u>white spruce</u> in Oregon, Utah, Colorado, and Idaho; <u>mountain spruce</u> in Montana; <u>Arizona spruce</u> in Arizona; and <u>white pine</u> in Idaho which is misleading with Idaho's white pine (Pinus monticola). In the market it is called western spruce, confusing it with the Sitka spruce (Picea sitchensis) which is also western.

<u>BOTANICAL</u>:

FLOWERS. Staminate; oblong-cylindrical, 5/8 inches long, 1/4 inch thick, purple anthers, raised on slender foot stock, 1/4 inch long when full grown. Pistillate; oblong-cylindrical, bright scarlet, 3/8 to 5/8 inch in length with pointed or rounded and more or less divided or entire scales, their bracts oblong and rounded, or acute to acuminate and denticulate at apex, or obovate oblong and abruptly acuminate.

LEAVES. Soft and flexible, four angled to tetragonal, acute, callous tip, slender, nearly straight, on vigorous sterile branches, stouter, shorter, more

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LEAVES. Soft and flexible, four angled to tetragonal, acute, callous tip, slender, nearly straight, on vigorous sterile branches, stouter, shorter, more curved on fertile branches, length 1 to 1-1/8 inches, each face marked with three to five rows of small stomata conspicuous on upper side, originally glaucescent to pale glaucous brown changing to dark blue green or pale steel blue during the first summer, in close-set spirals pointing forward and standing out from all sides or the branch, persistent four or five years, and with peculiar pole-cat odor on being bruised.

SUMMER BUDS. Conical, obtuse, about 1/8 inch long, with loosely imbricated pale reddish brown perulae.

WINTER BUDS. Conical to slightly obtuse, with pale chestnut brown scarious scales free or slightly reflexed at margin.

BRANCHLETS. Three to five mm. thick, slender to much thickened in high exposed places, with brown smooth bark which on young shoots is whitish and pubescent for three or four years. The pale greenish yellow color in youth turns to light or dark orange-brown, or a gray fringed with brown, during the first winter and then gradually becoming darker until the thin bark begins to

Fig. 1. A typical mature stand of Engelmann spruce running over 20,000 feet board measure per acre. The ground cover and habitat are typical of the forest.

separate into small flaky scales during the fourth or fifth year.

BRANCHES. At short intervals in regular tiers, the lower and middle branches long making the tree fusiform in shape, lower ones cast off in advancing age leaving the trunk bare for nearly its entire height (See Figure No. 1).

BARK. On young trees, thin unbroken bark with resin blisters similar to balsam and Douglas fir, but less conspicuous and numerous sometimes because of being deeply sunken. On trunk of older trees brown or scaly grayish or reddish- purple to light cinnamon red broken into large, thin, loose scales with sometimes deep furrows.

CONES. Elliptical, oblong, cylindrical or oval, sessile or nearly so, or on stems 1/4 to 3/4 inch long, gradually narrowed at both ends, 1 to 3 inches long, usually 2 inches, and 0.75 to 1 inch in diameter; scale bracts 4 to 6 mm. long, striate, thin, obovate-rhombic, with erose-dentate margin, slightly concave, truncate or spatulate tip, scales thicker and firmer than other species, reddish-brown when mature; cones originally horizontal and ultimately pendulous when full grown, in youth light green tinged with scarlet with scales spreading or oppressed, changing to light chestnut brown and lustrous at maturity. The side shoots of the laterals generally support the cones, but sometimes they are found sessile on main branches of small trees on which they occur on the upper quarter of the tree and in older trees the upper half. They drop off in a year or so after maturity.

SEED. Base obtuse, nearly black, generally half as broad as long with very oblique wing.

SILVICULTURAL:

RANGE. Engelmann spruce extends three thousand miles from Yukon territory to Arizona along the Rocky Mountains, beginning in the mountains of Alberta and British Columbia and distributed southward, eastward, and westward through Montana, Idaho, Washington, and Oregon. It forms the largest part of the forest of Alberta and those which overlook the valley of the

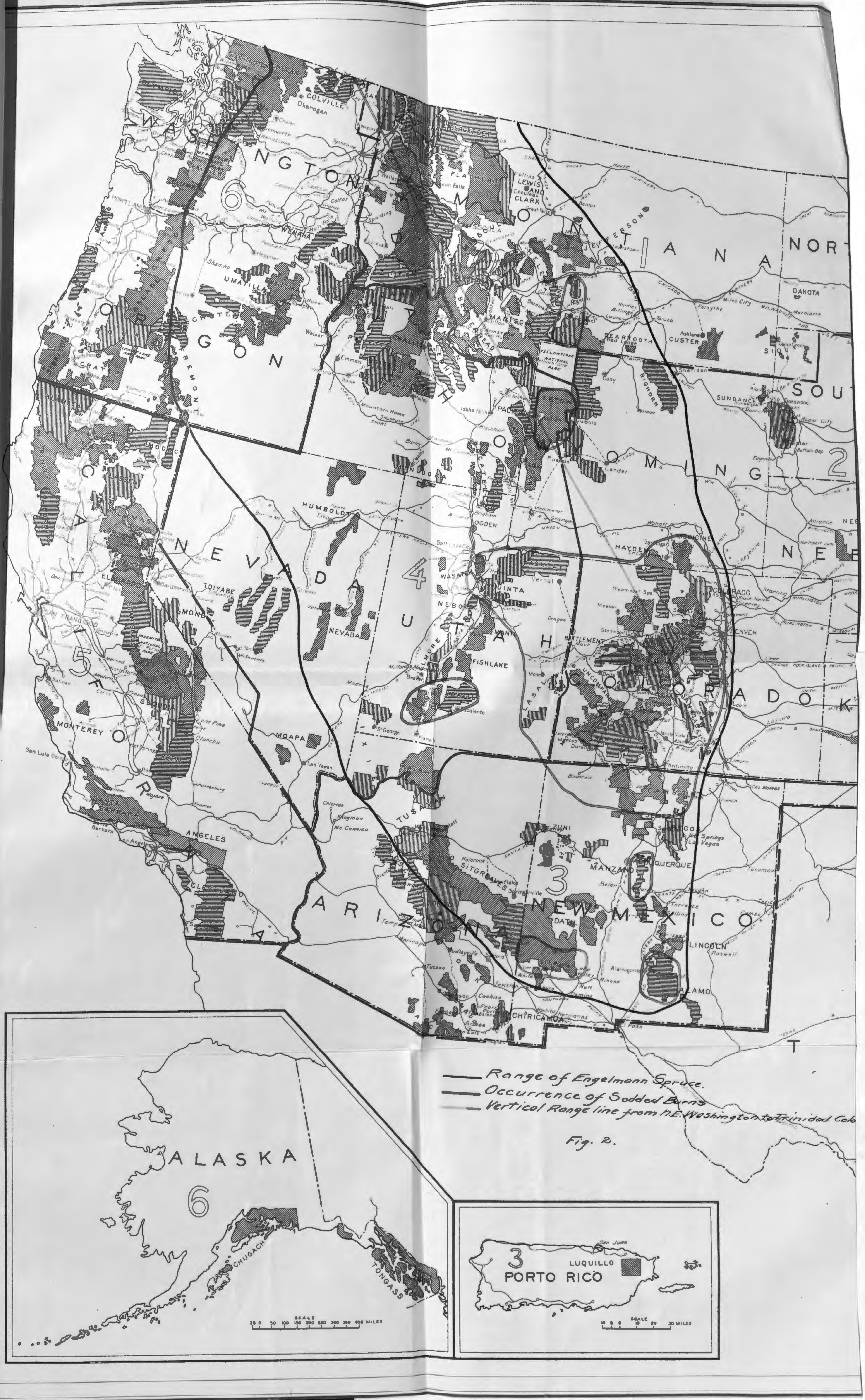

WASHINGTON
OREGON
CALIFORNIA
NEVADA
IDAHO
MONTANA
WYOMING
UTAH
COLORADO
ARIZONA
NEW MEXICO
ALASKA
PORTO RICO
Range of Engelmann Spruce.
Occurrence of Sodded Burns
Vertical Range line from N.E. Washington to Trinidad Colo

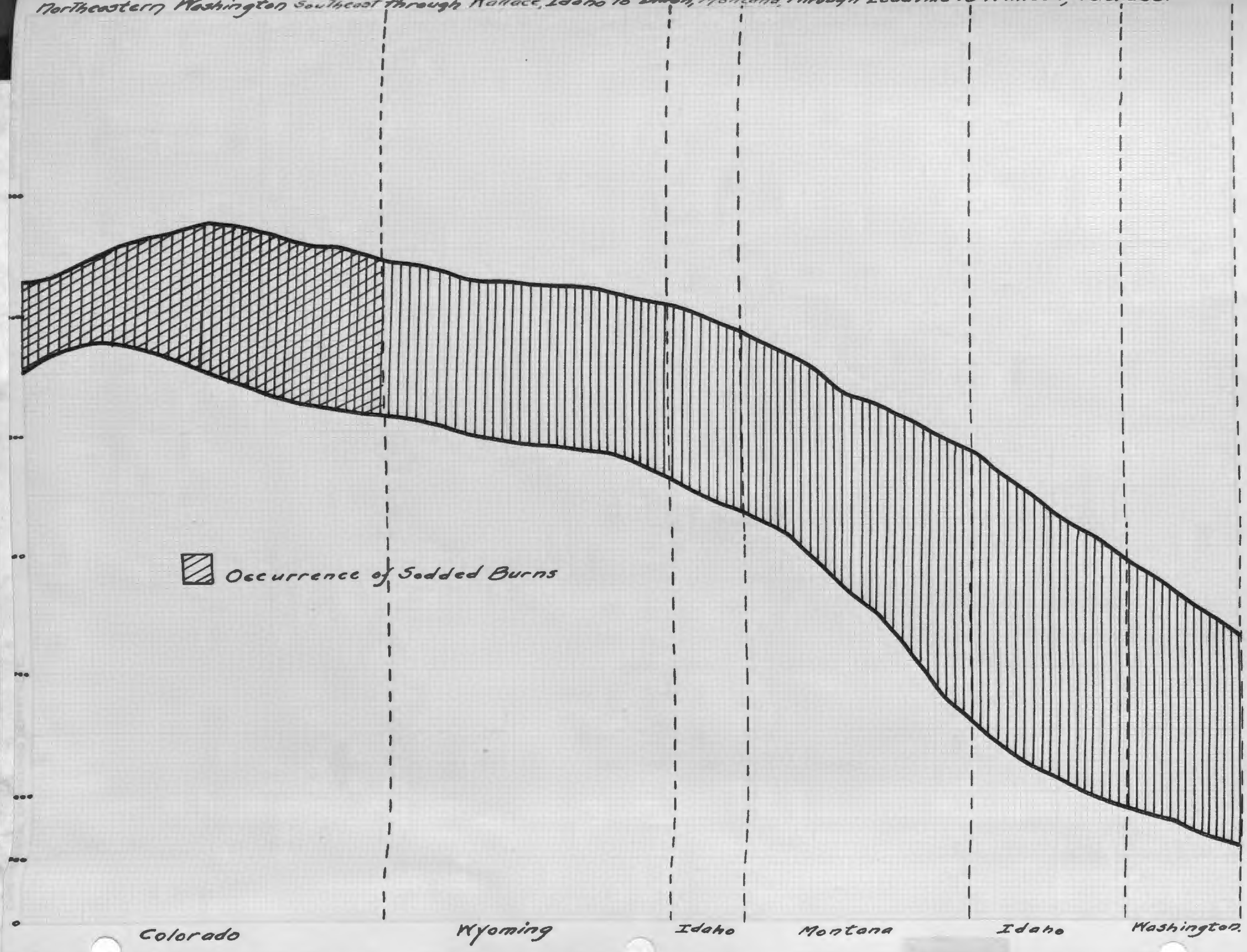
Fig. 2.

Columbia in British Columbia and the Selkirk Mountains. Immediately south of the boundary of the United States, it is found less extensive, but it is again a common tree in the forests of Montana and Idaho and ranges through the high mountains of northern Washington and southward along both slopes of the Cascade Mountains to southern Oregon and over the Powder River and Blue Mountains of eastern Washington and Oregon. It is quite abundant on the Yellowstone Plateau in northwestern Wyoming and southward on all mountain ranges about ten thousand feet above sea level. It is found in eastern Nevada on the Humboldt and Nevada National Forests, on the San Francisco Peaks in northern Arizona, as well as on Mount Graham and the Sierra Blanca and near the summit of the Mogollon Mountains in New Mexico. (See Figure 2).

The vertical range varies with the latitude. It reaches its greatest elevation in the states of Colorado and New Mexico (12,000 feet) and gradually descends to about 1,500 feet in the state of Washington. From data collected at 105 points between the states of New Mexico and Washington, the following table was compiled:

Figure. 3. Vertical Range of Engelmann Spruce.

Northeastern Washington Southeast through Wallace, Idaho to Dillon, Montana, through Leadville To Trinidad, Colorado.



State	Range
Washington	1500 to 3000 ft.
Idaho	2000 to 10000 ft.
Oregon	3000 to 7500 ft.
Montana	3000 to 9500 ft.
Wyoming	6000 to 9500 ft.
Utah	7000 to 11500 ft.
Colorado	8500 to 12000 ft.
Nevada	9000 to 11500 ft.
New Mexico	8500 to 12000 ft.
Arizona	8500 to 12000 ft.

These figures were taken from estimates made by Forest Supervisors of National Forests in their respective states. (See Figure No. 3).

CLIMATE. Following the same line as that in the vertical profile map of range from the extreme northeastern corner of Washington southeast through Wallace Idaho, to Hamilton and Dillon Montana, through southwestern Wyoming and through Leadville up to Trinidad, Colorado, the climatic features are found to be more or less uniform. In eastern Washington the precipitation is from 17 to 25 inches, the most of it coming in the fall, winter, and spring. Being sheltered only by the Rocky and the Bitterroot Mountains and not by the Cascades from cold waves that sweep down from the northwestern provinces of Canada, temperature extremes from 26 to 36 degrees below zero occur. The distance of the eastern part of the state from the Pacific Ocean and the intervening high mountain barrier give a climate, although tempered somewhat by the mild air currents from the ocean, that is continental in character.

In northern Idaho there is great diversity of climate. In general, however, the climatic conditions are similar to those of eastern Washington. In the valleys precipitation is from 20 to 30 inches, increasing to about 40 inches on the summits of the Coeur d' Alene Mountains. A large diurnal range in temperature with cooled nights is prevalent. Frost occurs in any of the summer months at the high elevations.

In western Montana similar conditions exist, but precipitation is greater than it is east of the

Continental Divide where Engelmann spruce is not found. The spring and summer rainy season or the first precipitation period begins about May 1, and extends well into July; the second precipitation period begins in November and ends in January. The driest months are April and August. The winter temperature on the whole is milder, the precipitation somewhat greater and differently distributed through the year, and cloudy weather is more prevalent than just east of the Continental Divide in Montana.

In southwestern Montana the annual range of temperature is lower than it is to the eastward. The summer is cool and the heat less intense. Rare atmosphere due to high altitudes, with low relative humidity and the absence of high winds, exercise a modifying influence. Precipitation is irregularly distributed, being lightest in autumn and winter. The wettest season is from April to June, inclusive. Precipitation is in the form of snow from October to April. Thunder storms are frequent but light. The prevailing wind is southwest with a velocity at Helena of about seven miles an hour. This part of the state lies south of the normal path of high and low pressure areas, and, as a result, it is comparatively free from sudden and extreme changes in temperature. However, in some of the narrow elevated valleys there are on the average only five to eight days without frost temperatures.

Southern Idaho, lying on the westward side of the Continental Divide, has a climate that is extremely varied. Exposure to the winds from the Pacific Ocean throughout the entire season, however, contributes materially to the mildness of the climate. The local "chinooks" play an important part. In the higher mountains the mean annual temperature is very similar to that experienced in northern Minnesota, but with less pronounced extremes. A high daily range in summer and a low one in the winter occurs. Precipitational distribution is governed by altitude to some extent. In the Seven Devils Mountains the annual precipitation is 40 inches. The precipitation minimum is in July and August and the maximum from November to May. Snow melts late in the summer. During the late spring, summer, and early fall months there is an abundance of intense sunshine, the intensity of which is increased by the impurity and dryness of the air. In the winter there are periods of considerable cloudiness with occasional fogs.

In western Wyoming is a section of high plateau interspersed with rugged mountain ranges, with elevations varying from 6,000 to 13,700 feet in the Wind River and the Teton Mountains. Average temperatures are known to be low. In the mountains frosts are common during all of the summer months and winter snows are heavy. A great number of drifts remain on the mountains until late in June, while some do not melt during the entire summer. The snows in the Sierra Madre Mountains show a depth of 180 feet and similar depths probably occur in the Wind River and Teton Mountains.

In the region drained by the Colorado River in Colorado, the climate is fairly uniform, due to the high mountains which deflect the course of the low pressure areas. Stprms approaching from the west will cross the Continental Divide, where the mountains are lower, either to the north or to the south of the state of Colorado. This forms a region of high control over the state with clear skies, light winds, moderately high and uniform daily temperature, and with nights that are cool but seldom excessively cold except when the ground is covered with snow and there is poor air drainage. Above 9,000 feet frosts are general throughout the growing season. Precipitation is as high as 40 inches in certain localities, but it varies with exposure to rain bearing winds which here are from west to southwest. Precipitation is greatest during the winter and the early spring. March and April have the most rainfall and droughts come in the early spring and summer. June is generally rainless. July to September constitutes the rainy season.

In the region drained by the Arkansas River in Colorado, conditions are similar to the above. Heading as the river does on the Continental Divide and flowing eastward into desert conditions around Pueblo, Colorado, great variations of mean temperature and precipitation may be expected. The temperature difference in the section may equal that found from southern Florida to Iceland. This difference in mean temperature may be as great as 35 degrees. The diurnal range in the wind movement is large in the mountains and the velocity is generally high in the afternoon, dying down at night. There is a decided movement of air down the valley in the early morning, and up the valley in the afternoon. The descending current of air, which is strongest at the hour when the lowest temperature would ordinarily be reached, is generally of such strength as to prevent the stratification of air necessary for the occurrence of excessive cold. The decrease of temperature with altitude is less due to these winds.

The climate of the zone frequented by Engelmann spruce, therefore, is, as a whole, more or less uniform in being continental in character. In this continental region there is found greater precipitation unevenly distributed throughout the year. The springs are wet in respect to soil on account of its saturation by water from melting snow drifts higher up on the mountains. The

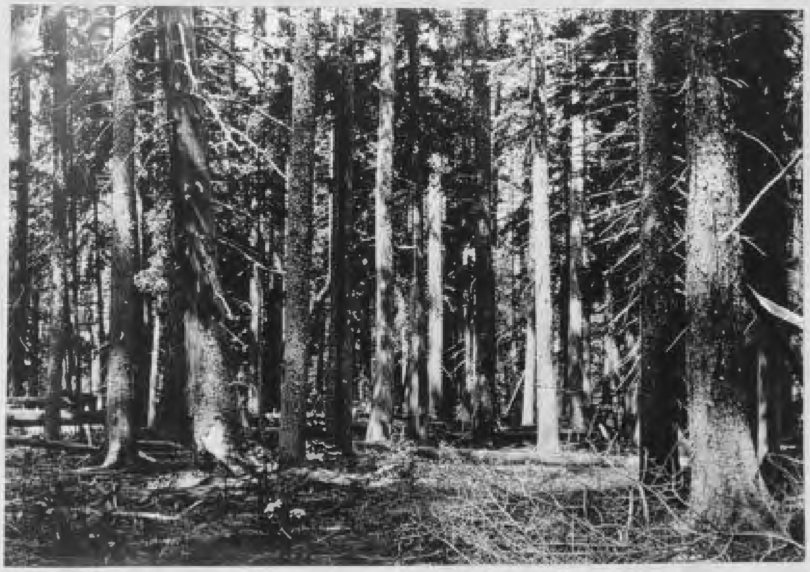


Fig. 4. A virgin stand of Engelmann spruce in southwestern Colorado. A fire damage is shown on the base of the large tree on the left.

month of June is dry. The greatest rainfalls come about the middle of July and in September. The altitude decreases the pressure and through it causes a low relative humidity. Great diurnal ranges of temperatures are common. Very high wind velocities also prevail.

FORM AND DEVELOPMENT. The average height of Engelmann spruce trees is about 90 feet, and the average diameter about 24 inches. Variations, as follows, are not uncommon: In Colorado trees, 130 feet high and 5 feet in diameter; in northern Idaho and Washington, 140 feet high and 3 feet in diameter; in Canada, 160 feet high and 5 feet in diameter. In the Rocky Mountains, in general, these extreme specimens are absent and in Colorado a mature tree seldom reaches a diameter over 22 inches.

From the examination of various tables on height and diameter growth, the rate of height growth is found to be the greatest between the 70th and 150th year; and the diameter growth between the 50th and the 120th years. After 200 years little or no growth is made and trees 300 years old are probably over matured.

Fig. 5. Semiprostrate specimens of Engelmann spruce on a wind swept ridge, on top of the Continental Divide.

BOLE. The development of the bole varies with situation. Generally, there is a heavy taper except in dense stands on good situations in deep, moist ravines, where the taper of the second or the third log is hardly noticeable. In Alpine situations the bole is shorter and tapers very rapidly. On extreme exposed sites it may be exceedingly prostrate in form as shown in Figure No.5.

VOLUME. A tentative volume table of Engelmann spruce in Colorado is as follows:

ENGELMANN SPRUCE

Tentative Volume Table

(Diameter, inside bark, of top - 6")

Volume - Board Feet, Full Scribner Rule

Diameter breast high	Height of Tree - Feet											
Inches	45	50	55	60	65	70	75	80	85	90	95	100
7	11	...	...	...	...	...	...	...	...	...	...	...
8	32	...	...	...	...	...	...	...	...	...	...	...
9	36	38	49	...	...	...	...	...	...	...	...	...
10	40	48	57	...	...	...	...	...	...	...	...	...
11	52	59	66	72	93	...	...	...	...	...	...	...
12	68	69	83	92	106	114	130	...	...	...	...	...
13	..	84	91	106	120	136	149	159	...	...	...	...
14	..	103	120	123	131	143	157	169	197	...	...	...
15	..	...	133	146	153	172	186	204	220	...	...	...
16	..	...	138	158	181	188	211	236	243	...	...	...
17	..	...	...	178	204	226	226	239	271	300	...	...
18	..	...	...	190	249	244	261	299	314	320	340	...
19	..	...	...	240	258	300	288	309	317	328	364	454
20	..	...	...	...	281	333	347	339	352	364	352	436
21	..	...	...	...	...	366	393	380	367	485	396	472
22	..	...	...	...	...	421	351	454	438	453	496	509
23	..	...	...	...	...	...	487	462	483	504	545	598
24	..	...	...	...	...	...	...	528	513	557	573	650

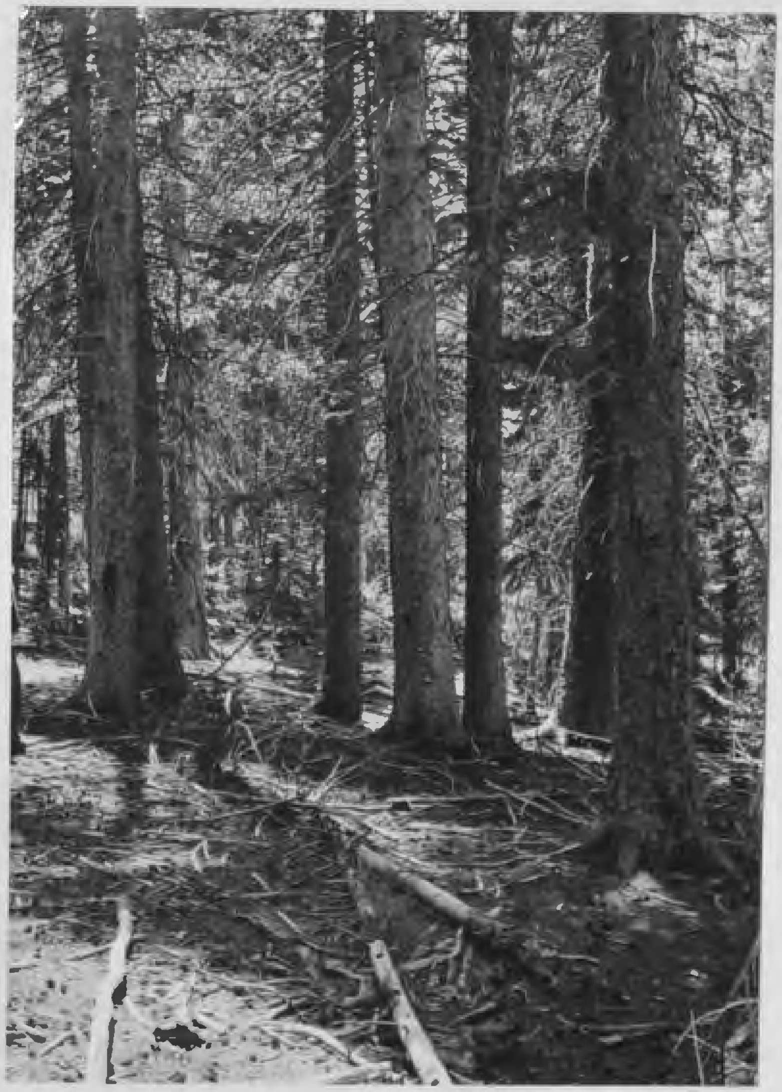


Fig. 6. An Engelmann spruce stand running about 20,000 feet board measure, in the vicinity of Pikes Peak, Colorado, and showing typical ground litter and humus conditions for the forest.

CROWN. The crown is heavy, spire-shaped, close and compact on good sites, but in mature and over mature stands and on poor sites, it becomes irregular. The branches gradually increase in length from the tip of the tree downward, for two-thirds the length of the crown, where they have a maximum length of six to eight feet. The lower third of the crown tapers to the base of the tree or maintains its full size, giving the cone or truncated cone shape to the tree. The upper branches are more or less erect, the middle horizontal and those of the base drooping. (See Figure No. 6).
In nearing maturity all branches droop as is common of conifers in regions of heavy snows. In case of injury to the terminal buds of branches, two laterals will usually increase in length almost equally, a fact which is true of the stem, but rarely in the latter for any length of time as one lateral will grow faster and take the lead, producing a crook instead of a fork.

ROOT SYSTEM. The root system of Engelmann spruce is very superficial. In youth a tap root is developed and maintained until the tree has reached a height of

Fig. 7. A cut-over area in an open, mixed Engelmann spruce and alpine fir stand. The ground cover is heavy enough here to preserve good soil moisture.

about 20 feet, when it ceases to elongate. Mature specimens usually have several strong laterals about two feet deep in a radius of twenty feet. An example was given in 1903 by F. W. Besley, Forest Agent, - - - "A tree was windthrown, exposing the root system. Observations showed it to be 16.4 inches in diameter breast high and 75 feet high. Two of the largest lateral roots were respectively 2.2 inches in diameter and 2.6 inches in diameter 14 feet from the trunk of the tree. There were numerous small roots extending diagonally downward that had been broken off, but none of them were over one-half inch in diameter. Many observed root systems show this strong lateral root development with numerous small short roots, penetrating downward. A seedling five years old 1.49 inches high showed a tap root 2.70 inches long, penetrating vertically downward with a few short rootlets. Another seedling four years old and 3.3 inches high showed a tap root 12.8 inches long."

TYPES. The broad range of the species gives rise to many mixtures. The most common species in

Fig. 8. Looking west from Marshall Pass, Colorado over a heavily sodded burned-over area in an originally Engelmann spruce stand in the foreground. A transitionary lodgepole pine stand lower down below the railroad, and a Douglas fir, lodgepole pine, and Engelmann spruce mixture below this.

association with Engelmann spruce and alpine fir (Abies lasiocarpa) and lodgepole pine (Pinus contorta). The former is less exacting as to seed bed, is as tolerant, and reproduces better. After fires lodgepole pine gets into Engelmann spruce stands, making in Colorado a transitionary type that generally has an understory of young spruce seedlings which ultimately replace the pine. At lower sites Douglas fir may be found on dry situations, making a distinct spruce-Douglas fir mixture. Bristle cone and limber pine are also found with it in the southern Rockies on dry ridges, but these species are less common and generally occur by themselves locally. In the northern part of its range in Idaho and northern Montana alpine larch (Larix lyallii) and white bark pine (Pinus albicaulis) mix with it on higher elevations. Lower down it is found with western white pine (Pinus monticola), lowland fir (Abies grandis), western larch (Larix occidentalis), western hemlock (Tsuga heterophylla), and great arbor vitae (Thuja plicata). In the State of Washington a few pure stands exist, although Engelmann spruce is

Fig. 9. Aspen forming an overstory to Engelmann spruce seedlings and saplings.

generally in mixture with other species of the higher altitudes of this region. In the Cascade range in Oregon it mixes with alpine (Abies lasiocarpa), noble (Abies nobilis), and white (Abies concolor) fir, mountain hemlock (Tsuga mertensiana), lodgepole (Pinus contorta), and Douglas fir (Pseudotsuga taxifolia). Aspen (Populus tremuloidis) is a general species in low spruce zones throughout the range. It is beneficial in forming an upper story (Figure 9). In the south the Engelmann spruce type proper occurs, but here also, mixtures in which alpine fir constitute from 20 per cent to 50 per cent are the usual occurrence. Probably pure stands of Engelmann spruce are very limited, occurring mostly at the head of ravines and on moist flats. In Colorado the density of the spruce stands varies greatly. An average stand is about 5000 feet board measure with extremes of from 20,000 to 50,000 feet board measure per acre. The latter are found at the heads of cool gulches on northern aspects. (Figures 1 and 6).

TOLERANCE. Engelmann spruce is more tolerant than any of its associates. A consecutive list from the most tolerant might be:

Engelmann spruce (Picea engelmanni)
Alpine fir (Abies lasiocarpa)
White fir (Abies concolor)
Great arbor vitae (Thuja plicata)
Western hemlock (Tsuga heterophylla)
Mountain hemlock (Tsuga mertensiana)
Sitka spruce (Picea sitchensis)
Douglas fir (Pseudotsuga taxifolia)
Lowland fir (Abies grandis)
Noble fir (Abies nobilis)
Western White Pine (Pinus monticola)
Blue spruce (Picea parryana)
Bristle cone pine (Pinus aristata)
Alpine larch (Larix lyallii)
Western larch (Larix occidentalis)
White bark pine (Pinus albicaulis)
Lodgepole pine (Pinus contorta)

The relative tolerance of Engelmann spruce is gained through its ability to withstand the increasing light requirements of trees at high altitudes, the increasing cold of soil and air temperatures, and the decreasing direct and diffused light with elevation. Even with direct sunlight increase, the light requirements of a species remain constant or become less at higher altitudes. Greater moisture and fertility of the soil help to increase the tolerance. The tolerance, in general, decreases with age and increases with greater vigor. In respect to origin, trees from seed are generally more tolerant than those from sprouts. Nursery grown transplants are more tolerant than trees from direct seeding methods. In reference to tolerance Dr. Clements found that Engelmann spruce and alpine fir are almost identical in tolerance and that no forest light which was measured was too weak for their fair reproduction.

SOIL AND SOIL MOISTURE. Engelmann spruce must have abundant soil moisture and a high relative humidity. If its occurrence does not bring it into the direct path of storms, as is the case in its northern distribution in Idaho and Washington, it depends on regions of lower temperature and pressure, and greater precipitation, all of which are found at higher altitudes. Aspect has a local distributional effect, due for instance to a lack of a conservation of moisture, a shallowness of the soil, or a higher temperature, of an area with the occurrence of a greater gradient and exposure. The physical character of the soil which necessarily affects drainage through texture has a greater effect than the composition. Swamps that are not sour are good. However, a cool, moist soil, fairly well drained, is much better in general for the germination and growth of the spruce.

REPRODUCTION. Engelmann spruce reproduction is almost wholly by seed. Some layer shoots do develop in local areas. In general, the development of seedlings is good in all localities presenting good moist mineral soil conditions, but on dry, exposed southern slopes, the species fails. Cool ravines, flats, and northerly slopes support the best reproduction in case a heavy humus layer does not act as a dry blanket between the seedling and the moisture beneath. In old stands ready for the saw, suppressed seedlings are found

GERMINATION RECORD.

Serial Test No. 119　　　　Till No. 38

Test of 500 (Number.) seed started in Soil (Soil or chamber.), Nov. 18 (Date.), 1913.

Test discontinued 1-2 (Date.), 1914.

~~Date or~~ days.	1	.								10		.			15
Germination ~~per cent.~~ no									1	41	72	57	28	14	11
Date or days.	16														30
Germination per cent. no	5	7	2	0	0	1	0	0	0	0	1	0	0	0	0
Date or days.	31													.	45
Germination ~~per cent.~~ no															
Date or days.	46														
Germination per cent. no	0	0	1	1	0	0	0	0	0	0	0	0		.	
Date or days.															
Germination per cent.															

REMARKS AND GERMINATION CURVE.

GERM. PER CENT.

NO. OF DAYS.

Form 489.
(Revised July 1, 1912.)

SEED TESTING.

8—1943

Sample No. I-1 Species Engelmann Spruce Cone Lot No. 1 Kiln Run No.

Shipped from Gunnison, Crawford (Forest.) (Post Office.) Sender's mark B.H. No. of lbs. of seed of which sample is representative 65

Collection: Date 1913 Place Black Mesa Altitude 9,500 Exposure Southeast

Forest type Mature Soil Moist loam

Method Collected from squirrel hoards

Age of trees 125-250 Size 14"-20" D.B.H. Character Heavy limbed at edge of parks

Condition Good

Kind of season Precipitation 19". Early frosts, first in July. (Precipitation, early or late frosts, dry winds, etc.)

Cones: Sun or kiln dried? Sun Kiln temps.

Wt. of uncleaned sample 3.94 (Grams.) Wt. of clean seed in sample 3.12 (Grams.) Purity per cent 79.25 Wt. ~~1,000~~ 1052 clean seed 3.12 (Grams.)

No. seed in lb. clean sample 152,300 No. seed in lb. uncleaned sample 121,050 Cutting test (Per cent.)

Germinative energy: Soil, 47.8 per cent germination in 22 days; Chamber, per cent germination in days.

Rapidity factor (days to germinate 50 per cent of total number germinated): Soil Chamber

Final germination: Soil, 48.4 per cent in 45 days; Chamber, per cent in days.

Real value: Number of seed per lb. of uncleaned sample multiplied by { germinative energy / final germination per cent }: From cutting test { }

From soil test { } From chamber test { } Vol. 1,000 seed (c.c.m.) Specific gravity

Notes :

GERMINATION RECORD.

Serial Test No. 294/96 Till No. 149

Test of 500 (Number.) seed started in Soil 1/4" (Soil or chamber.), 4/11/12 (Date.), 191 .

Test discontinued ______ (Date.), 191 .

~~Date or~~ days.	1														15
Germination ~~per cent.~~ No.			1	24	24	49	26	11	10	8	3	2	2	4	2
~~Date or~~ days.	16						22	= 166 33.2%							30
Germination ~~per cent.~~ No.	1	0	0	0	3	0	1	1	0	0	0	0	0	0	0
~~Date or~~ days.										40					
Germination per cent.	0	0	0	0	0	0	0	0	0	0	= 172		- 34.4%		
Date or days.															
Germination per cent.															
Date or days.															
Germination per cent.															

REMARKS AND GERMINATION CURVE.

GERM. PER CENT.

NO. OF DAYS.

8—1943

Form 489.
(Revised July 1, 1912.)

SEED TESTING.

8—1943

Sample No. .... Species Engelmann Spruce Cone Lot No. A-1 Kiln Run No. ....

Shipped from White River (Forest.) Pinnacle, Colo. (Post Office.) Sender's mark .... No. of lbs. of seed of which sample is representative ....

Collection: Date 10-1-10-15, 1911. Place .... Altitude 8000 Exposure Eastern

Forest type Mixed Soil ....

Method Squirrel hordes

Age of trees 150-250 Size Large Character Large crown

Condition Healthy

Kind of season Late fall. No drought (Precipitation, early or late frosts, dry winds, etc.)

Cones: Sun or kiln dried? Sun dried Kiln temps. ....

Wt. of uncleaned sample 2.38 (Grams.) Wt. of clean seed in sample 1.90 (Grams.) Purity per cent 79.85 Wt. 1,000 clean seed .... (Grams.)

No. seed in lb. clean sample 208,800 No. seed in lb. uncleaned sample 166,400 Cutting test .... (Per cent.)

Germinative energy: Soil, 33.2 per cent germination in 22 days; Chamber, ... per cent germination in .... days.

Rapidity factor (days to germinate 50 per cent of total number germinated): Soil .... Chamber ....

Final germination: Soil, 34.4 per cent in 44 days; Chamber, ... per cent in .... days.

Real value: Number of seed per lb. of uncleaned sample multiplied by {germinative energy / final germination per cent}: From cutting test { .... }

From soil test { .... } From chamber test { .... } Vol. 1,000 seed .... (c.c.m.) Specific gravity ....

Notes: 55,245 good seed per pound

in abundance, but in drier openings, in burned over areas and on dry slopes this advanced reproduction is lacking.

GERMINATION. A limited number (56) of seed tests on the germination of Engelmann spruce in Colorado and New Mexico were made. (Specimen record cards are inserted.) Although not conclusive, the following results are given. Taking all of the percentages of the tests of seed from various points in the central and southern Rockies with the elimination of the variations of the site, tree class, age, altitude, and years, an average by states is as follows:

Wyoming	32.5 per cent
Northern Colorado	43. 5 per cent
Central Colorado	39.3 per cent
Southwestern Colorado	40.6 per cent
New Mexico	63.3 per cent

These figures show a gradual increase in amount of good seed from northern to southern points. This percentage increase, does not conform to the results of a similar study of Douglas fir by J. P. Willis and

J. V. Hofmann. A low percentage of 65 was shown by them to be in the southern and 73 in the northern localities. The differences are attributed by them to the greater insect infestation of the seed in the southern regions. The uncertain effect of altitude on germination percentage, taking all tests to the elimination of all factors except altitude, is shown by the following sequence from highest to lowest percentage.

Elevation	Percentage
7,800	56.4
8,200	55.8
10,000	47.0
9,000	34.36
8,300	33.2
8,500	29.8
8,200	26.4
7,000	26.0
8,900	21.6

Individual variation in the germination percentages made of different tree classes of Engelmann spruce at elevations of 10,000 and 9,000 feet in northern and southwestern Colorado are as follows:

Northern Colorado

Engelmann Spruce 10,000 Feet

Percentage	Class of Tree Height	Crown
57.2	Dominant	Poor
54.2	Dominant	Fair
40.0	Codominant	Good
39.4	Intermediate	Poor
37.0	Codominant	Fair
34.4	Dominant	Good
31.8	Intermediate	Fair
8.6	Codominant	Poor

Southwestern Colorado

Engelmann Spruce 9,000 Feet

Percentage	Class of Tree Height	Crown
81.2	Oppressed	Stunted
73.2	Codominant	Fair
58.4	Dominant	Large
53.4	Suppressed	Runty
50.2	Dominant	Fair
49.0	Intermediate	Poor
23.4	Codominant	Good
22.0	Intermediate	Fair
1.0	Intermediate	Good

The relative quality of seed shows a great variation. It was expected that the intermediate thrifty trees would give the greatest germinative percentage, but they fall into the minor places. These figures are from tests covering one year only and are not conclusive.

There is little or no accurate knowledge on the periodicity of seed years of the species in the Rocky Mountains. The periods depend without doubt on fire and insect damage as well as on soil and physical factors, for all of these affect the excess of stored food material from which the seed production arises. In some favorable localities an examination of the age of seedlings would suggest that good years occur about every three to five years. In general, the age of the first production of seed of the spruce is much later than in its associated species, being near the 25th year. Although the species is an abundant seeder throughout its range, in portions of its area of distribution this abundance means comparatively little on account of the excessive destruction of the seed

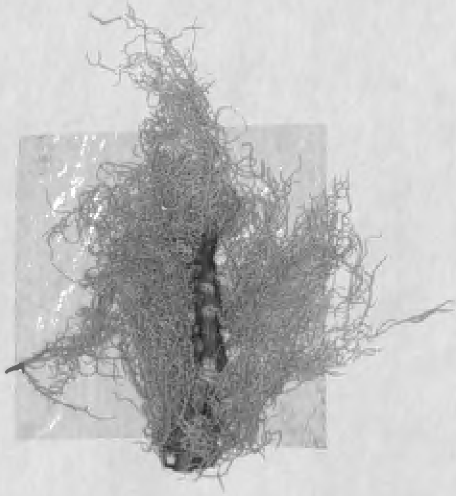


Fig. 10. Specimen of Usnea cavernosa.

by insects, which are described later under the proper heading in the consideration of biotic factors.

BIOTIC FACTORS:

Fungus. Two species of fungi occur in the southern part of the range:-Herpotrichia (nigra), identified in 1908 by Dr. Hedgcock, and Usnea cavernosa (Figure 10). The former is found on scattered groups of seedlings and saplings of both balsam fir and Engelmann spruce on all slopes at altitudes of from 9,000 to 11,500 feet. It occurs more frequently in regions of heavy snows. This occurrence means probably that an entrance is gained by the spores of the fungus through injuries caused by snow. It forms a brown, smutty, spongy mass over young leaves and branches which may be slightly compacted by its action. The evil effects came about through the fatal reduction of light and carbon dioxide gas so necessary to the needles in food making. The latter fungus (Usnea cavernosa) is a fruticose lichen. It branches profusely, is yellowish to grayish in color while young and turns darker later in life. It grows to be from six to twelve inches long. It is considered by many people to be a parasite, but is strictly a saprophyte, which attaches itself only at the base, and hangs and thrives on green branches which are dying and on dead limbs of Engelmann spruce, balsam fir, and lodgepole pine.

INSECTS. A species of Chermes is found that checks the year's growth by killing the lateral branches and branchlets. A crook in the stem develops as a new lateral takes the lead. A beetle (Dendroctonus engelmanni) described by Dr. Hopkins, a full description of which may be found in Bulletin 83, Part I, Bureau of Entomology, pp. 126-132, 1909 is found doing extensive damage throughout the range of Engelmann spruce, especially from central Idaho southward through the mountains of southern New Mexico. The beetle thrives best where there is considerable moisture, unlike the drier site loving pine beetles, and, consequently, finds a fine host in the Engelmann spruce in such localities. Snow, lightning, frost, and wind storms all produce injuries through which favorable entrance is made. The life history is simple. The over-winter forms which are passed in all stages of development in the inner bark, emerge in the months of May and June and settle on injured standing, healthy or recently felled trees. The adult deposits eggs from which the larvae develops and feeds on the cork cambium. The larvae girdle and kill the tree. The attacks of these insects are usually on medium to large trees. In some localities in the State of Colorado it is estimated that 20 per cent of the Engelmann spruce stands are beetle killed, while in other regions 95 per cent of the old burns are thought to have been formerly insect killed, due to the presence of charred channels in burned stumps.

Besides these two insects there is present a seed chalcidad, the adult of which is a small wasp. The eggs are deposited in the spring in undeveloped cones which continue to grow until mature in September. The feeding of the larvae at this point ceases. There is then a dormant stage until new cones are formed. The winter may be passed in the pith of the cone or in resinous masses among the scales, or from the study of other species the pupae may possibly be formed in the ground or in the debris on the surface. The general intermittent character of the life of the chalcidad makes it hard to eradicate. All of the broods do not come out the first spring after the first winter, but may lay dormant for some time, thus overlapping poor seed years which would otherwise cause its extermination through the lack of a food supply. A specific description of the life history of the species affecting Engelmann spruce in particular has not been published, but is in course of preparation by the Bureau of Entomology. The importance of the knowledge of its life history and and the means of eradication of the insect is emphasized by the facts that from 85 to 95 per cent of the cones are infested in southwestern Colorado by this insect which not only reduces the germination percentage, appreciably,but also destroys outright about 50 per cent of the seed.

WIND. The high continental region inhabited by Engelmann spruce subjects it to the mechanical and desiccating effects of winds. The direct compact produces prostate specimens with abnormalities on wind blown slopes and ridges, (Figure 5) and also causes windfalls when tornadoes or strong wind whirlpools occur at the heads of moist ravines. Even though wind may assist in a small way in the dissemination of the seed, it must be considered as generally detrimental on account of the above mentioned evil effects as well as the drying up of tender seedlings fresh from germination by high winds during the period of uneven distribution of summer precipitation.

FROSTS. Frosts not only make large frost cracks which permit the rapid entrance of the destructive dendroctonus and fungi, but play as important a role in heaving out of the ground seedlings and transplants. This is an important means of resisting natural, as well as all artificial, methods of reforestation. Engelmann spruce, in growing naturally at high altitudes, also unfolds its buds early in the spring. Consequently there is great damage that might be done to them by late severe freezing.

ANIMALS. Cattle and sheep do damage by rubbing off the bark of older saplings and by nibbling off and tramping out seedlings. The chief damage, however, occurs by the compaction of the soil which prevents reproduction in the beginning, and by the tramping out of a few seedlings directly year after year. Little reproduction may be expected, if an area which is being reforested, is heavily grazed. Only a few isolated and well protected seedlings are able to exist under such conditions. Rodents are important in the destruction of the seed as food. Engelmann spruce stands are frequented by the Rocky Mountain chipmunk (Eutamias quodrivitlatus), by the ground squirrel (Callospermophalus lateralis), by the white-footed mouse (Peromyscus moniculatus rufinus), and a western mole (Condylure cristata).
The first three eat the seed for food and the latter, by constantly stirring up the soil, limits the establishment of any plant life. This effect is probably more local than general, but its frequence in some localities is such as to cause a complete destruction

Fig. 11. A small snow slide in a ravine in an Engelmann spruce type, near Marshall Pass, Colorado.

of all seedlings from direct seeding methods. In the destruction of the seed the ever present and hungry birds, especially the snow bird (Junco hiemalis), is not to be under-estimated, since they may follow direct seeding work and pick up practically all of the seed sown. This is especially true in artificial work when the seed spot and the winter broadcasting on the snow methods are used.

SNOW SLIDES. Snow slides are not uncommon in Engelmann spruce mixtures, but are not frequent or extended over large areas. Their effect of denudation of parky areas is reciprocal in exposing a mineral soil on which the species may again reestablish itself in case biennial or annual slides do not occur. (Figure 11) shows a shallow ravine in which snow slides occurred in the years 1910 and 1914. The area of denudation is small in this particular picture, but in a region within a few miles snow slides large enough to wipe out a good sized mining town have occurred. The extent of the slides of 1910 may be estimated by noticing the ground leveled aspen in the left of the

Fig. 12. A heavily sodded burn at the head waters of Saguache Creek, fifty miles southwest of Saguache, Colorado. Few seed trees were left by the fire of 1894. The charred standing dead timber gradually falling and preventing the use of the area for cattle grazing. In a few years the tract will be entirely worthless unless reforested to preserve water for irrigation purposes for the farms along the Saguache Creek and for those in the San Luis Valley.

Fig. 14. Western slope of Marshall Pass, Colorado. Elevation 10,846 feet. A sodded burn that is not re-foresting naturally although seed trees are present.

Fig. 13. A typical sodded spruce burn in the vicinity of Wagon Wheel Gap, Colorado. Age about twenty-two years, and almost devoid of reproduction. Elevation 11,300 feet, aspect southerly.

Fig. 15. A spruce burn about twenty-two years old entirely devoid of reproduction, although seed trees are present on all sides. Elevation 11,000 feet and aspect easterly. Wagon Wheel Gap, Colorado.

picture. In the remnant, as well as at the edge of the deposited debris of the recent slide of 1914, may be seen uptorn seedlings of spruce and aspen. Denuded areas on northern exposures, similar to the one shown in the picture, reforest slowly but naturally on account of the better soil moisture present on such slopes.

FIRE. The species should be extremely susceptible to fire damage on account of its superficial root system and of its especially thin bark in youth. However, when Engelmann spruce is found mixed with lodgepole pine, Douglas fir, and limber pine, the latter shows the greatest destruction, and in general the needles of the spruce are scorched less under the same fire conditions. Good reproduction has been seen on very moist northern slopes, where fire has exposed the mineral soil and the site has retained sufficient moisture to make a favorable seed bed for germination. Fires are, nevertheless, responsible for vast parky or burned over areas, with or without seed trees, that are wholly without any seedlings or without any favorable indications for a rapid and successful natural reproduction. (Figures No. 12, 13, 14, 15).

Since the main point of the problem in this study is to find the best method of sowing or planting that will reforest these sodded burns in Engelmann spruce stands most cheaply and satisfactorily, it will be necessary to show now more definitely the occurrence of sodded burns and give the unfavorable conditions existing on them in order to explain the causes of this lack of natural reproduction, and the obstacles in reforestation which artificial methods must overcome.

SODDED BURNS DISCUSSION

OCCURRENCE OF SODDED BURNS.

The localizing of heavily sodded burns in the states of Colorado and New Mexico is probably due to some extent to the differences of the succession of plant life after fires in the northern portion of the range of the species as compared to the central and the southern portions. The more moist conditions existing in the deep forest humus in the Washington and Idaho forests, possibly prevents the complete destruction of all of the seed in the forest floor. Some seed will usually remain there to form a transitionary type that will furnish proper cover under which there is greater humidity and soil moisture for the development of Engelmann spruce seedlings. The severity of the climate of higher altitudes in Colorado and the repeated occurrence of fires over the same area also help to destroy any seed which may be buried in the humus since the ground cover is relatively thinner and drier on account of the prevalence of long dry windy periods.

From data of 105 reports from forest supervisors of the National Forests of the Rocky Mountains, a table of the estimates may be arranged in summations by states. In most cases the figures are purely approximations of the acreage of Engelmann spruce stands and the acreage of sodded burns not reforested within these stands. Nevertheless, the percentages of Engelmann spruce type of the total National Forest Lands of the respective states, and the acreage and percentage of this Engelmann spruce type which is now covered by sodded burns in each state, gives a better view of the occurrence of sodded burns than could be had otherwise.

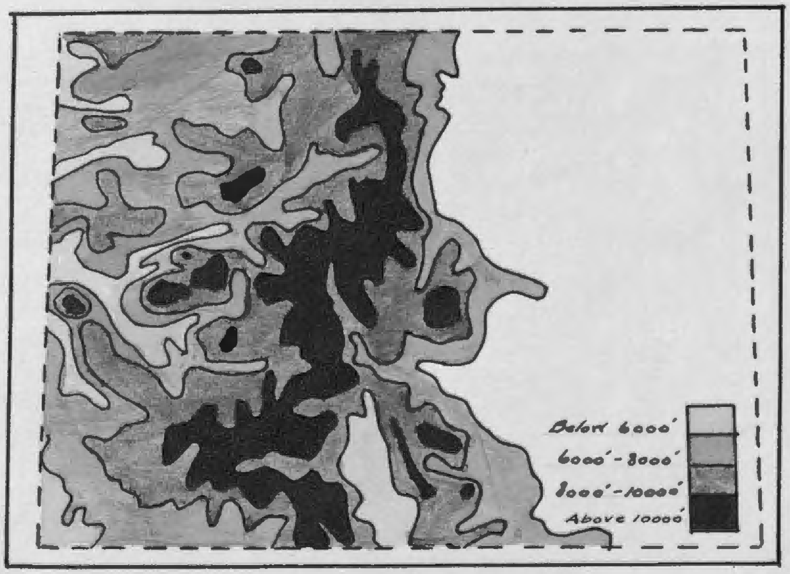
State	Type Area-acres	Net area Nat. Forest Lands	Percentage of type of National Forest Lands	Sodded Burns. Area-Acres	Sodded Burns. Percentage
Washington	28,000	9,828,826	.28		
Oregon	23,280	13,227,412	.17		
Idaho	585,900	17,712,666	3.30	40,500	7.0
Montana	481,500	16,272,230	2.96	5,700	1.1
Utah	695,490	7,472,694	9.20	23,700	3.4
Wyoming	301,175	8,413,846	3.57	20,000	6.3
Colorado	2,574,187	13,402,481	19.20	381,950	11.0
New Mexico	339,000	8,592,660	3.94	110,000	3.2
Total	5,028,532	94,922,815	5.29	581,850	11.4

In the above table the state of Colorado has the greatest area of Engelmann spruce type, the greatest percentage of the type in the National Forest lands, and the greatest acreage and percentage of sodded burned over areas within the Engelmann spruce type. It is also evident that sodded burns do occur from the central Rocky Mountains southward into New Mexico. The state of Colorado, however, presents the greatest acreage of sodded burns which need to be reforested. Consequently, the review of the climatic conditions and the results of natural and artificial reforestation will be confined to this portion of the range of Engelmann spruce where sodded burns are of the most importance.

GENERAL DESCRIPTION OF COLORADO. As the continental climate and physical factors of Colorado are quite universally carried up and down into adjacent northern and southern states, a detailed description of the conditions prevailing in Colorado will be given, assuming that ultimately conclusions on these factors may be applied more or less generally to sodded burns in the Rocky Mountains. In the application of the conclusions, however, an appreciation of the numerous local variations that come about with aspect, slope, drainage, and surrounding environmental conditions is absolutely necessary.

Area and Elevation. The area of Colorado is

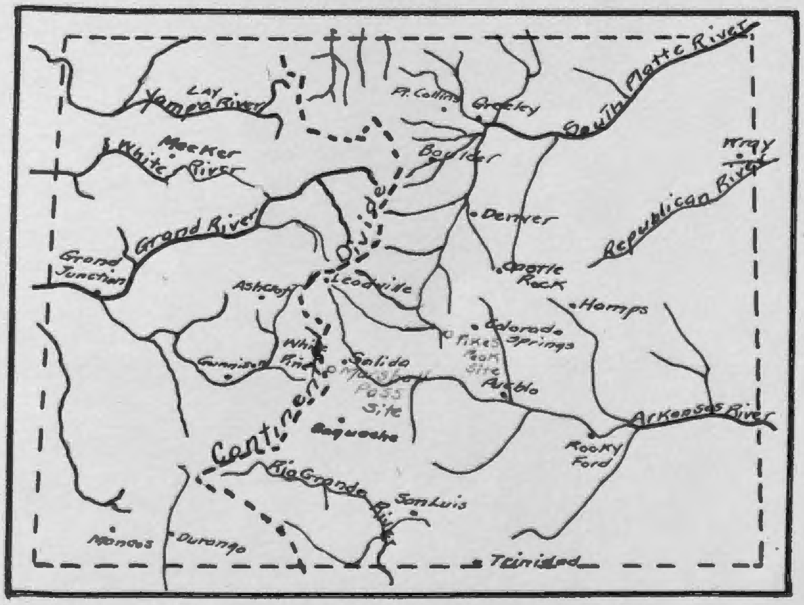
State of Colorado



Mass Elevation of Colorado

Fig. 16.

State of Colorado



General Topographic and Drainage Map.

Fig. 17.

103,480 square miles. The mass elevation of the state may be shown by Figure No. 16 and the following table:

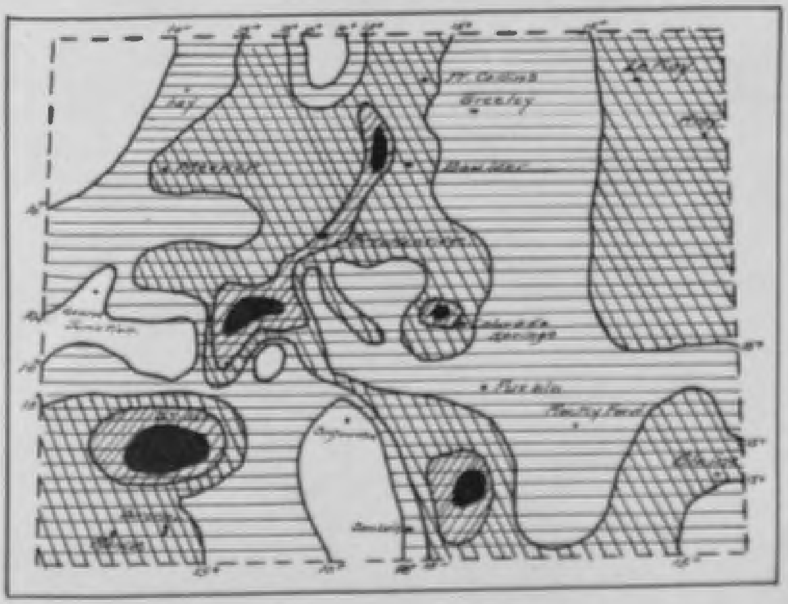
Elevation	Area in Square Miles	Percentage of Total Area
6,000 ft. and below	45,000	43
6,000 - 8,000 ft.	22,000	20
8,000 - 10,000 ft.	24,000	23
10,000 ft. and above	12,500	14

This table shows that the state is highly mountainous with about 37 per cent of it at elevations frequented by Engelmann spruce.

Drainage. The drainage of the state is divided into east and west portions by the northerly and southerly direction of the Continental Divide. This division is best shown by Figure No. 17

Precipitation. The meteorological stations are also well distributed in Colorado east and west of the Continental Divide, but few are located in the region of the zone of Engelmann spruce of from 9,000 to 12,000

State of Colorado



Mean Annual Precipitation

Fig. 18.

feet. However, the following table is instructive, for it gives the effects of the course of the high mountain ranges on the mean average precipitation for the east and west sides. The 74 per cent of the east side contrasted with the 52 per cent of the west side of the percentage of precipitation coming during the growing season is an important relation in the success of plants. The better distribution of precipitation, during the season when it is needed most, could mean the success and failure of two direct seeding areas at equal elevations on eastern and western slopes.
Figure No. 18 gives the map of mean annual precipitation.

Station	Act. Ft. Elev.	Mean for Growing Season	Mean for Year	Per Cent During Growing Season
		East of Continental Divide		
Blaine	3,935	12.36	16.08	77
Boulder	5,347	12.83	18.46	69
Castle Rock	6,220	12.73	17.65	72
Cheyenne	6,088	9.40	12.20	77
Colorado Springs	6,098	13.00	14.41	90
Denver	5,272	10.03	14.02	72
Fort Collins	4,985	11.06	14.91	73
Hamps	5,400	11.82	14.56	81
Holly	3,386	12.71	15.32	71
Idaho Springs	7,543	10.65	15.44	68
Lake Moraine	10,625	18.44	25.59	72
LeRoy	4,380	12.20	16.05	76
Pikes Peak	14,108	19.07	28.65	66
Pueblo	4,734	9,17	12.11	75
Saguache	7,745	5.45	7.21	75
Salida	7,035	7.62	11.47	67
Wray	3,512	14.57	18.11	80
Mean Average		11.84	15.90	(74)
		West of the Continental Divide		
Ashcroft	9,483	10.67-	19.38	55
Breckenridge	9,536	11.99	26.76	72
Collbran	6,000	7.33	14.59	50
Durango	6,534	8.25	16.62	50
Grand Junction	4,608	4.27	8.50	50
Lay	6,162	6.37	12.72	50
Mancos	6,960	9.29	17.29	53
Meeker	6,182	8.42	15.91	53
Mean Average		8.57	16.45	(52)

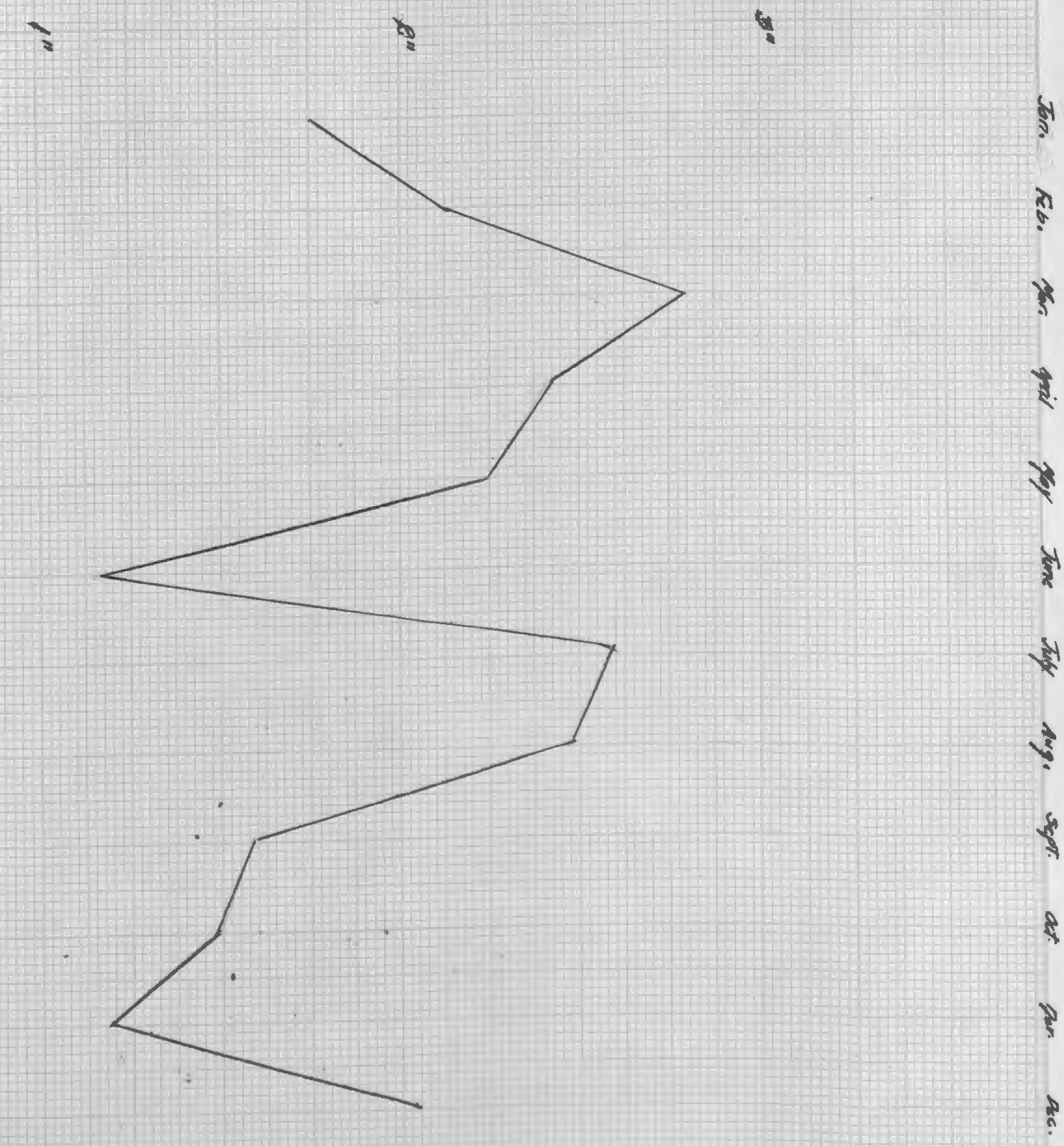


Fig. 19. Mean precipitation for twelve stations, 9,000 feet and up.

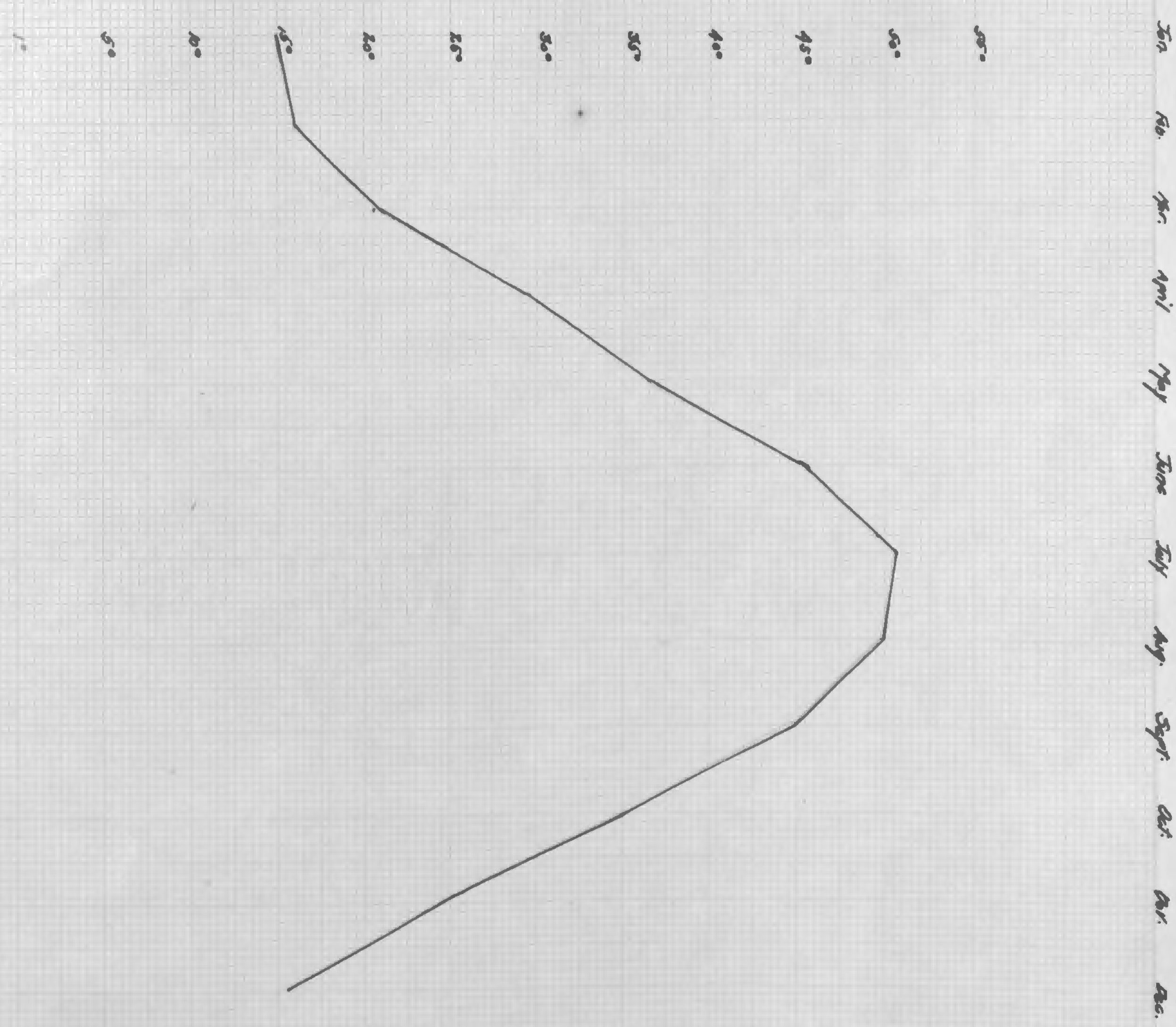
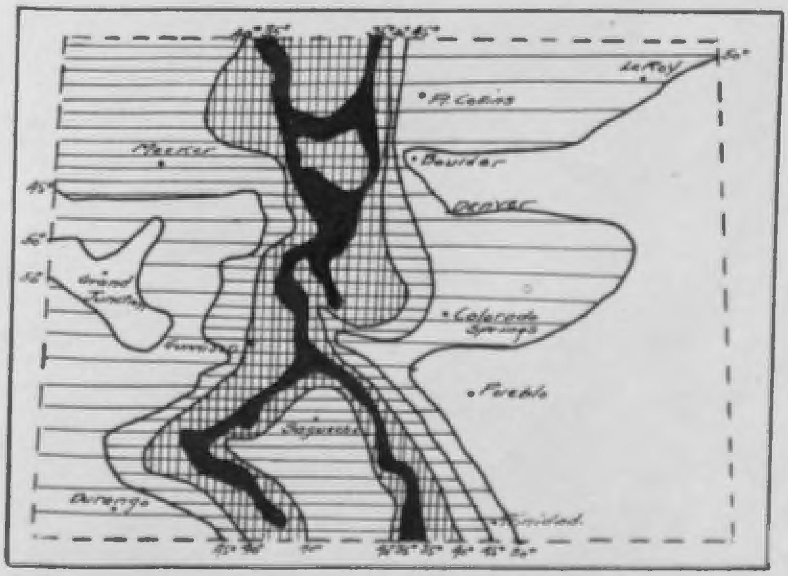


Fig. 20. Mean temperatures for twelve stations, 9,000 feet and up.

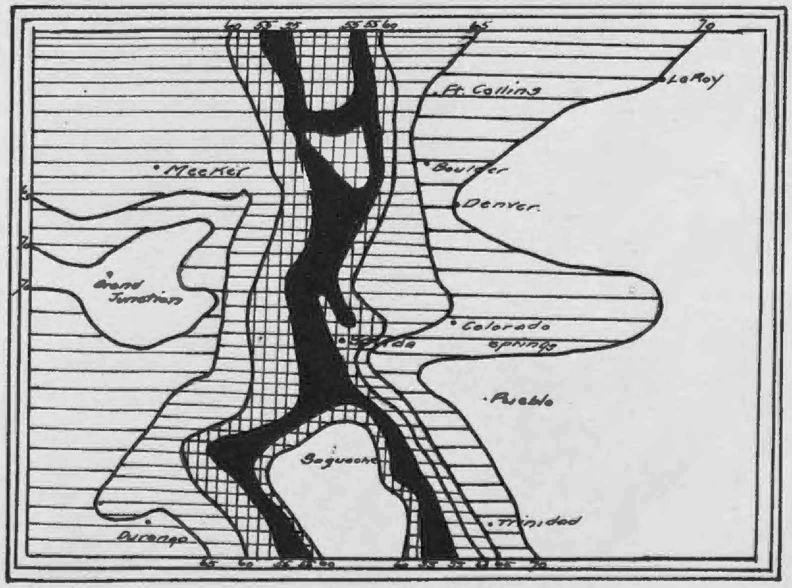
State of Colorado



Mean Annual Temperatures

Fig. 21.

State of Colorado



Mean Summer Temperature

Fig. 22.

Curves to show the distribution of mean monthly precipitation for stations 9,000 feet and above are to be found in Figure No. 19. March and July are the wettest months. June, September, October, and November constitute the dry months.

Temperature. Figure No. 20 gives the mean monthly temperature. As the curve represents the averages ofmean monthly temperatures for many years for twelve stations, and as these means are averaged again, a very even curve is the result. This evenness is of importance in showing that after the species gets fairly well started the average conditions are not so severe as might be expected. It is the diurnal range of temperature when the seedlings are very young which plays such an important part in the failure of the establishment of the species. Figure No. 21 gives the distribution of the mean annual temperature and Figure No. 22 the mean summer temperatures for the whole state of Colorado.

It is interesting to note the general correspondence of the above Figures No. 18, 21, 22 to the mass elevation map Figure No.16. A comparison will show that the higher the elevation the greater the mean annual precipitation and the lower the mean annual and mean summer temperatures.

The effect of altitude upon the average length of growing season and the average dates of the last killing frost is given below:

Altitude (feet)	Average date of last killing frost	Average length of growing season (Period without frost)
5,000 and below	April 28	5 mos 6 days
5,000 - 6,000	May 5	4 mos. 21 days
6,000 - 7,000	May 30	3 mos. 21 days
7,000 - 8,000	June 6	3 mos. 6 days
8,000 - 9,000	June 17	2 mos. 23 days
9,000 - 10,000	June 22	2 mos. 8 days
10,000 - 11,000	July 7	1 mo. 23 days
11,000 - 12,000	July 20	1 mo. 10 days

It may be assumed from the figures in the above frost data table that there is a diminution of growing season until nearing the higher limits of 12,000 feet, frosts may occur nearly every night and the season is shortened to a period of less than eight weeks. This shortness of the season for the growth and maturity of the spruce seedlings is of great importance when it is appreciated that in actual field conditions germination does not generally start until a period of ten days to a month has elapsed after the warmer temperatures of the month of June have come.

Sunshine. Colorado is a state of sunshine. On the average fifty per cent of the days are clear, thirty-three per cent partly cloudy, and seventeen per cent cloudy.

Humidity. The state of Colorado as a whole has low humidity, but relatively high humidity in the winter. For Pikes Peak at an elevation of 14,147 feet, Hann (l.c.289) gives the seasonal march of relative humidity as: Winter 79 per cent; spring 81 per cent; summer 75 per cent; autumn 77 per cent; year 78 per cent.

Wind. On the western slope of the Continental Divide, the average wind velocity is from five to six miles per hour; on the eastern slope, from seven to eight miles per hour; and on the northern to eastern borders, ten miles per hour. On exposed ridges and peaks on the mountains the wind has great velocities and blows almost steadily the year around. The winters are especially windy. The prevailing wind is from the west. Winds of the mountains and the valleys reverse in blowing up the mountains ravines during the day and toward the plains at night. This brings about great diurnal variations of humidity, cloudiness, and precipitation. The day direction of the winds also brings about the relatively frequent afternoon showers of high altitudes.

FAILURE OF NATURAL REPRODUCTION ON SODDED BURNS.

The discussion of the various factors of the continental climate which is prevalent in the zone of Engelmann spruce in Colorado shows clearly that the most favorable conditions for the normal germination and growth of the species are far from being advantageous.

But the mere occurrence of relatively good stands of the species on such severe continental areas, and the presence of an advanced reproduction underneath indicates that the species is able to withstand the great severity of the climate. This means at once that the conditions of its own habitat must be favorable enough for its existence and reproduction, although the species in nature may work very slowly. It is important, then, that a comparison of the physical and biotic factors of sodded burns be compared with the normal forest habitat as a standard. In this way it is possible to suggest differences of the quantity of the various factors which would prohibit the natural reproduction of Engelmann spruce.

	Sodded Burns
Light	Increased
Surface Temperature	Increased
Wind Velocity	Increased
Precipitation	Increased
Run-off	Increased
Humidity	Decreased
Humus	Decreased
Water Content	Decreased
Herbaceous Cover	Increased
Grazing Animals	Increased
Rodents	Increased
Birds	Increased

The table emphasizes at once that sodded burns are presenting distinctly the other extreme of condition from those which exist under a forest cover. Light, although increased, has little or no connection in the very early stages of seedling growth. High temperatures, unbroken high wind velocity, low humidity, and decreased water content, however, must have a great influence in preventing natural reproduction. This must be true, since the abundance of soil moisture and the greater humidity of the air both of which are demanded for the proper development of the species from the seed to the adult, are materially reduced. The competition with the ground cover and with the destructions caused by grazing animals, rodents, and birds bring out the other causes, which,although found in both habitats,are producing a greater detrimental effect on open grassy areas. It is also true that sod reduces the surface evaporation from that found on a bare open area and increases it at a six inch depth on account of the extraction of the soil moisture by the roots that frequent that depth. Sod might in this way help germination. It does prevent weathering, binds shifting soils, adds and slowly accumulates humus, partially exhausts the soil, and slightly modifies atmospheric factors. Nevertheless, the natural regeneration method of the species of broadcasting seed on unprepared ground is failing on account of the dryness of the air and soil; the subjection of the tender seedlings to the dessicating winds; the inability to maintain moist conditions by not having an overstory during the period of drouth to attain a fairly saturated atmosphere; the increasing frost action; and the increasing competition with ground cover, animals, birds, and rodents. Being placed, then, in such an unnatural habitat, and having only about 50 per cent of the natural quantity of seed which will have probably only a germination of 35 per cent to overcome these extra obstacles of the new habitat, the method of the species in nature is not proving adequate. It must be appreciated that in some localities small seedlings may be found, but the final survival of any such plants which are not established in the soil by a root system of from six to ten inches is doubtful, since annual heavy heaving of the soil during both the spring and the fall will throw the greater percentage of them out of the ground sooner or later. Even, assuming that after many years these sodded burns will be naturally reforested, the extremely slow rate at which it is being done could not be considered sufficient on account of the present and increasing value of these areas for protective forest sites. Consequently, the appeal is naturally next to artificial methods of which a discussion of various methods with variations in the operation and season is given in order to finally show what season and what method proves to be the best in solving the problem of regenerating Engelmann spruce on sodded burns.

ARTIFICIAL REFORESTATION

METHODS.

The writer has attacked the problem of reforesting sodded burns by three general methods of (1) broadcasting; (2) seed spotting; and (3) planting. These methods will be described and the results of the various methods at different seasons of the year will be given on two specifically described sites to show the success or failure of the present artificial methods.

Broadcasting methods have been divided into sowing on unprepared and prepared ground. The first means the scattering broadcast of seed at the rate of five good seeds to a square foot over an undisturbed soil. The second method differs only in the preparation of the ground. A suitable harrow, preferably of the spring tooth type, is dragged back and forth over the ground until the sod and the general herbaceous ground cover is torn, and the mineral soil disturbed to a depth of several inches below the surface.

Seed spot methods are divided into simple, regular, and cornplanter. The <u>simple seed spot</u> is prepared by one stroke of the mattock, which tears out a V-shaped hole into which about ten germinable seeds are placed. The seed is either covered with a thin layer of the soil and firmly pressed down with the toe of the shoe, or it may be simply pressed into the soil. The <u>regular seed spot</u> is prepared ten or twelve inches in diameter and three inches deep by means of a grub hoe. The seed is sown, then, at the rate of twenty-five good seed per spot. After the seed is scattered evenly over the spot, it is lightly covered with fine pulverized soil to a depth of one inch and then firmly pressed with the hand or the sole of the foot.

In the cornplanter method an "Eclipse" cornplanter is generally used, but any style which may be properly adjusted to drop the desired amount of seed at the proper depth may be used. On the "Eclipse" the cutting edges are easily cut down to a three-fourths inch limit. It was found, since the seed of the spruce is so small, that to properly adjust any type of cornplanter to liberate about four good seeds per spot, was an impossibility. Therefore, ten to fifteen seeds had to be dropped in each spot which was firmly pressed afterwards.

Planting operations may have so many variations that the feasibility of any one method may be based on the cost of a surviving transplant after two or three growing seasons. In the experimental work given hereafter, the cone method was used as a greater spread of root system was gained by it. It consists of building a cone of earth in the bottom of a hole four inches in diameter and ten inches deep, or larger if necessary to suit the conditions of various root systems. The root system is spread on all sides of the cone with one hand while the other holds the base of the stem of the transplant resting on the apex of the cone. In this position fine dirt, which is properly not mixed with a surface layer or duff, is sprinkled on and firmly pressed with the hand. Another one or two inch layer of the soil is added and firmed. This process is continued until the hole is filled. Finally, the soil around the transplant is very firmly pressed to prevent the loosening and subsequent drying out by the winds. This method is probably the most expensive of artificial planting, but, theoretically, it gives by its greatest spread of root system the greatest absorption area.

SEASONS:

Each method, with its variation, may be performed during the spring, summer, and fall, and in the case of

Fig. 23. Marshall Pass Experimental Site. Elevation 10,846 feet, southern exposure, one-eighth mile east of the top of the Continental Divide.

broadcasting methods during the winter on the snow. Spring consists of the months from March 1 to June 1; summer, June 1 to September 1; fall, September 1 to December 1; winter, December 1 to March 1.

MARSHALL PASS SITE:

LOCATION AND AREA. The above described methods at various seasons were tried out experimentally during the seasons of 1911 on an area of a total acreage of 3.82 acres comprising 16 plots 80 X 80 feet, and on the same number and size of plots on a contiguous area to the above, around which a barbed wire fence was built to protect the area from stock, during the seasons of 1912. This tract is about one-half mile east of the Marshall Pass Station on the Narrow Guage of the Denver & Rio Grande Railroad from Salida to Grand Junction, Colorado. (Figures No. 17 and 23).

The plots were located within an Engelmann spruce burn of about 35 years ago on an area at an elevation of 10,846 feet with a slope of from two to ten degrees and with a southern exposure. To protect from rodents, poisoned grain was distributed over the area at least three times a year. On this particular burned over area practically all of the timber which was not destroyed by fire has decomposed rapidly, leaving such conditions of herbaceous ground cover as are found on burned over tracts of high altitude. An incomplete list of species found in the ground cover is as follows:

Dry Sites	Wet Sites
Wheat grass	Red & white clover
Bromus	Marsh Marigold
Bunch grass	Buttercup
Cinquefoil	Elephant plant
Tansy	Wild geranium
Strawberry	Wild onion
Columbine	Red Indian paint brush
Indian paint brush	Potentilla
Wild pea	Cinquefoil
Bluebell	Grasses
Harebell	Mosses

SOIL AND CLIMATIC FACTORS. The moisture percentage, mechanical analysis and saturation percentage are of value in expressing concisely the physical soil conditions.

Moisture Percentage

Average of four samples at each depth

6 inch	12 inch	18 inch
12.697	15.327	17.097

Mechanical Analysis and Saturation Percentage

Depth	Saturation Percentage	Stones Grade 1	Gravel Grade 2	Coarse Sand Grade 3	Sand Grade 4	Fine Sand Grade 5
6"	44.50	22.89	16.08	21.36	10.48	29.10
12"	35.46	45.20	20.50	16.50	5.80	12.00
18"	29.00	37.47	25.33	15.65	7.28	13.27

The moisture percentages show a steady increase according to the increase in depth. The greater percentages of Grades 3, 4, and 5 at 6 inches, not only emphasize the saturation percentage of 44.50, but also probably indicate the clayishness of the soil which is shown in the fineness of soil particles. A reason for the heavy heaving of the soil of this area as well as on similar ones is probably to be found in this characteristic. The abundance of soil moisture present should have made good conditions for germination unless the temperature was necessarily reduced by the amount of soil water present.

The monthly and annual precipitation of the months and years through which the experiment ran as taken at the Weather Bureau Station on Marshall Pass, one-half mile west, are given in a table.

WEATHER OBSERVATIONS

Monthly and Annual Precipitation

	Precipitation				Snowfall		
Month	1911	1912	1913	1914	1911	1912	1913
January	1.05	4.08	1.91	0.	....	34"	23"
February	1.25	3.35	1.20	....	....	31"	14"
March	1.07	2.71	1.50	.85	....	30"	18"
April	0.59	1.33	1.63	1.42	....	16"	17"
May	T	0.54	0.47	1.05	....	8"	2"
June	2.42	3.32	2.06	0.98	....	8"	13"
July	5.98	2.39	1.75	....	....	Rain	Rain
August	2.46	0.90	1.26	....	....	"	"
September	1.70	1.34	1.23	....	....	7"	8"
October	0.70	1.58	0.31	....	12	19"	....
November	1.16	0.59	0.62	....	19	6"	....
December	0.32	1.51	2.10	....	8	15"	....
Total	18.70	23.64	16.04			174	

The above precipitation table indicates that the year 1912 presented more moisture for the first five months and for the year than did either the years

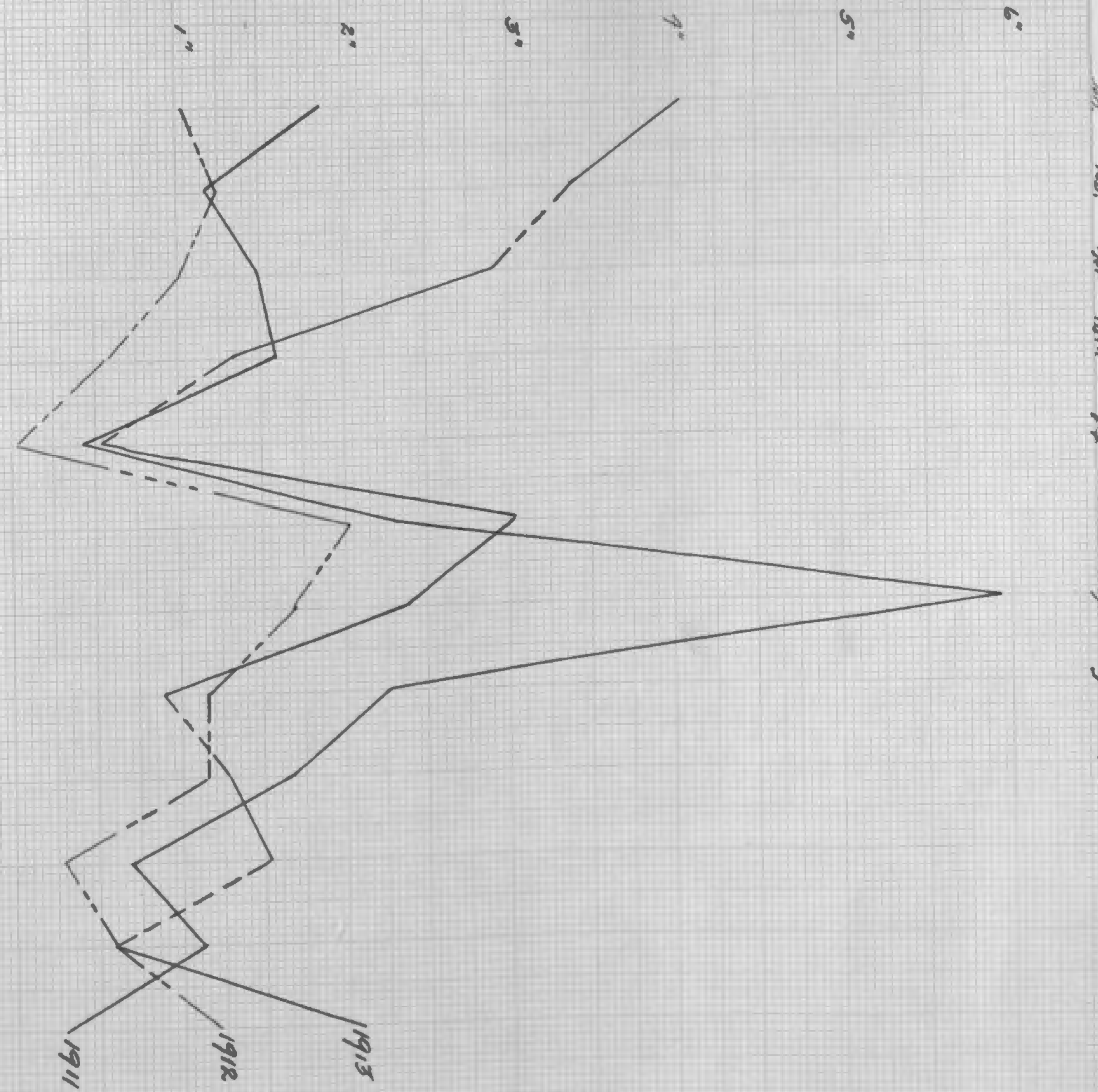


Fig. 24. Monthly precipitation for three years on Marshall Pass Site

1911 or 1913. Of the last two years the former is greater than the latter, which had about normal precipitation. From June to October, the year 1911 presents considerably more than the year 1912, and the latter more than the year 1913. In other words spring and fall precipitation for 1911 is below the normal and that of summer at the period of germination considerably above. The precipitation for the entire year 1912 was above normal, and for the year 1913, the spring and summer precipitation was below normal.

In comparing the curve (Figure No. 24) of the above monthly precipitational distribution with that of the curve in Figure No. 19 based on the average of the mean monthly precipitation of twelve stations located within the vertical range of Engelmann spruce of Colorado, a few differences are noted. In the first place the latter shows May as the driest month compared to June, except in the year 1911, and July as the wettest month in the year for the former. The drop of precipitation is not as early and less rapid in Figure No. 19 coming in September instead of August, but the amount of

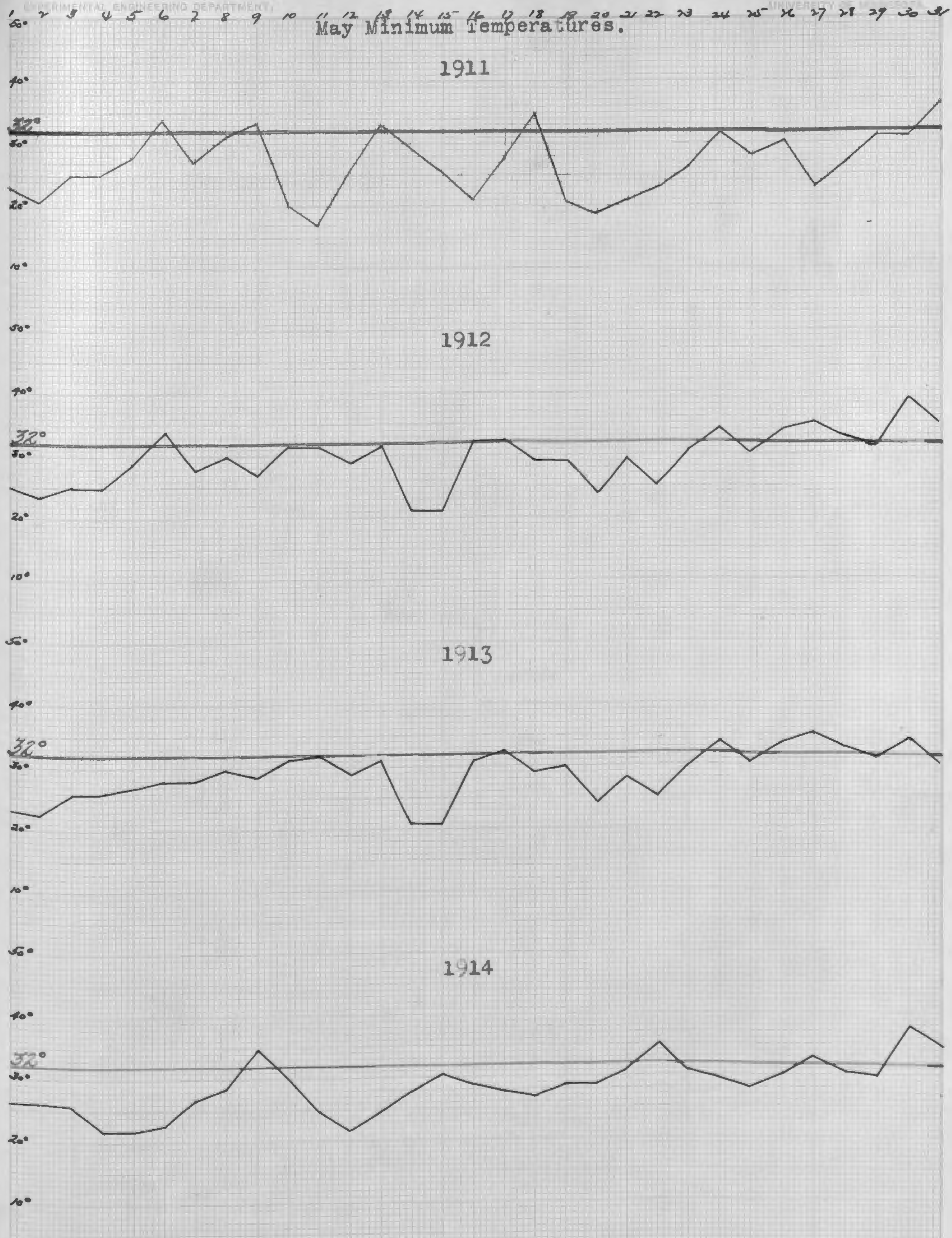


Fig. 25

June Minimum Temperatures

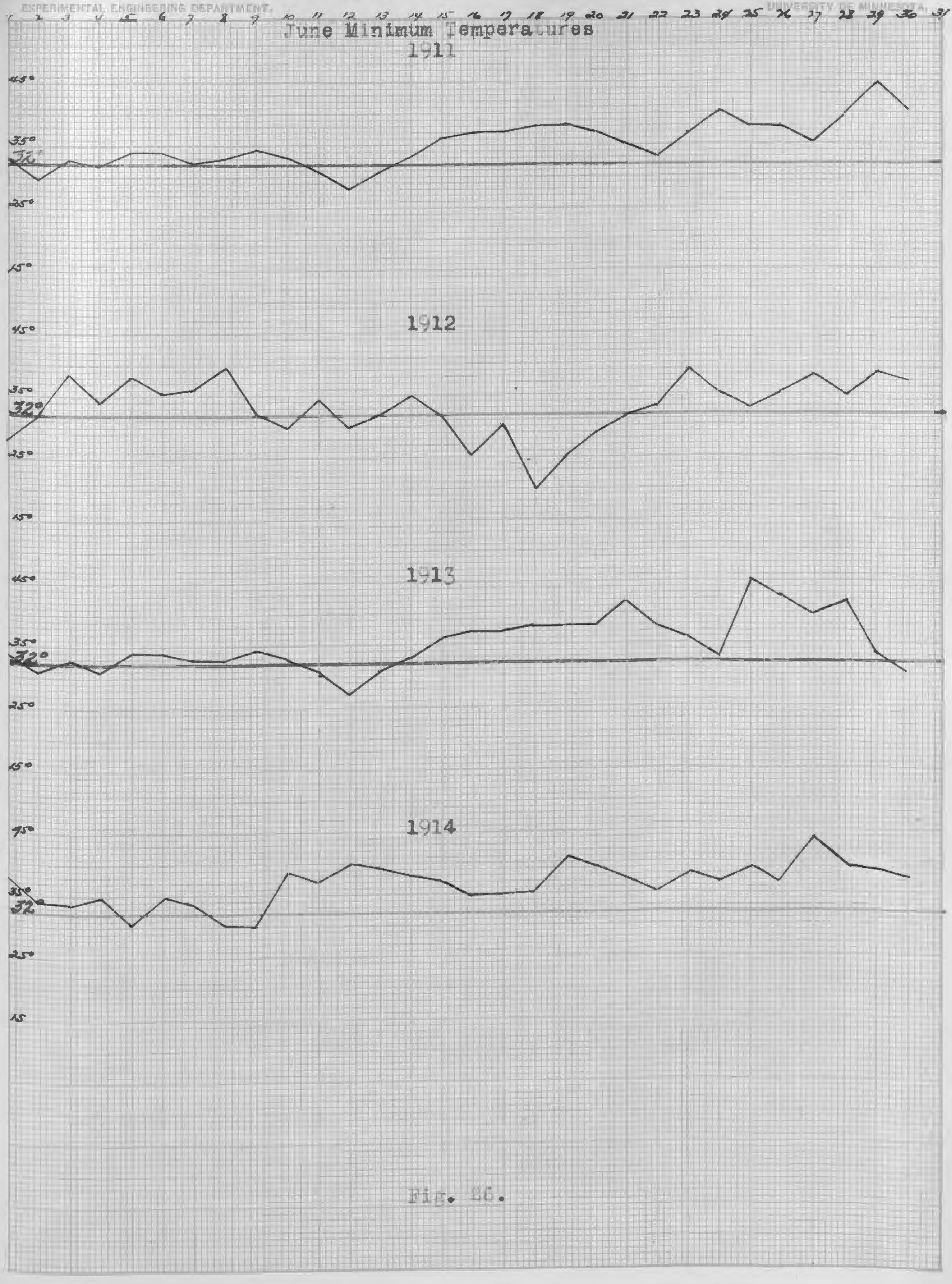


Fig. 26.

July Minimum Temperatures

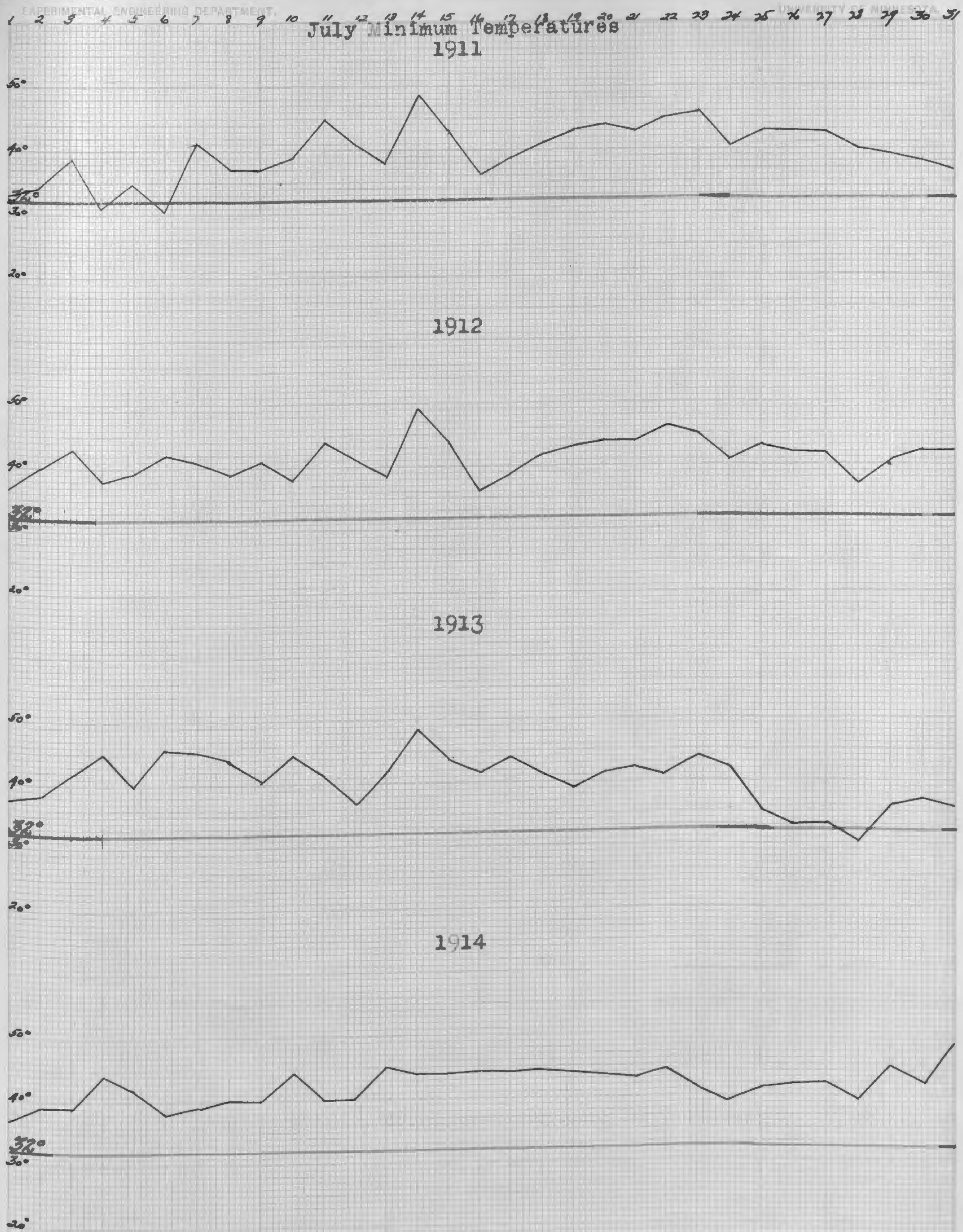


Fig. 27.

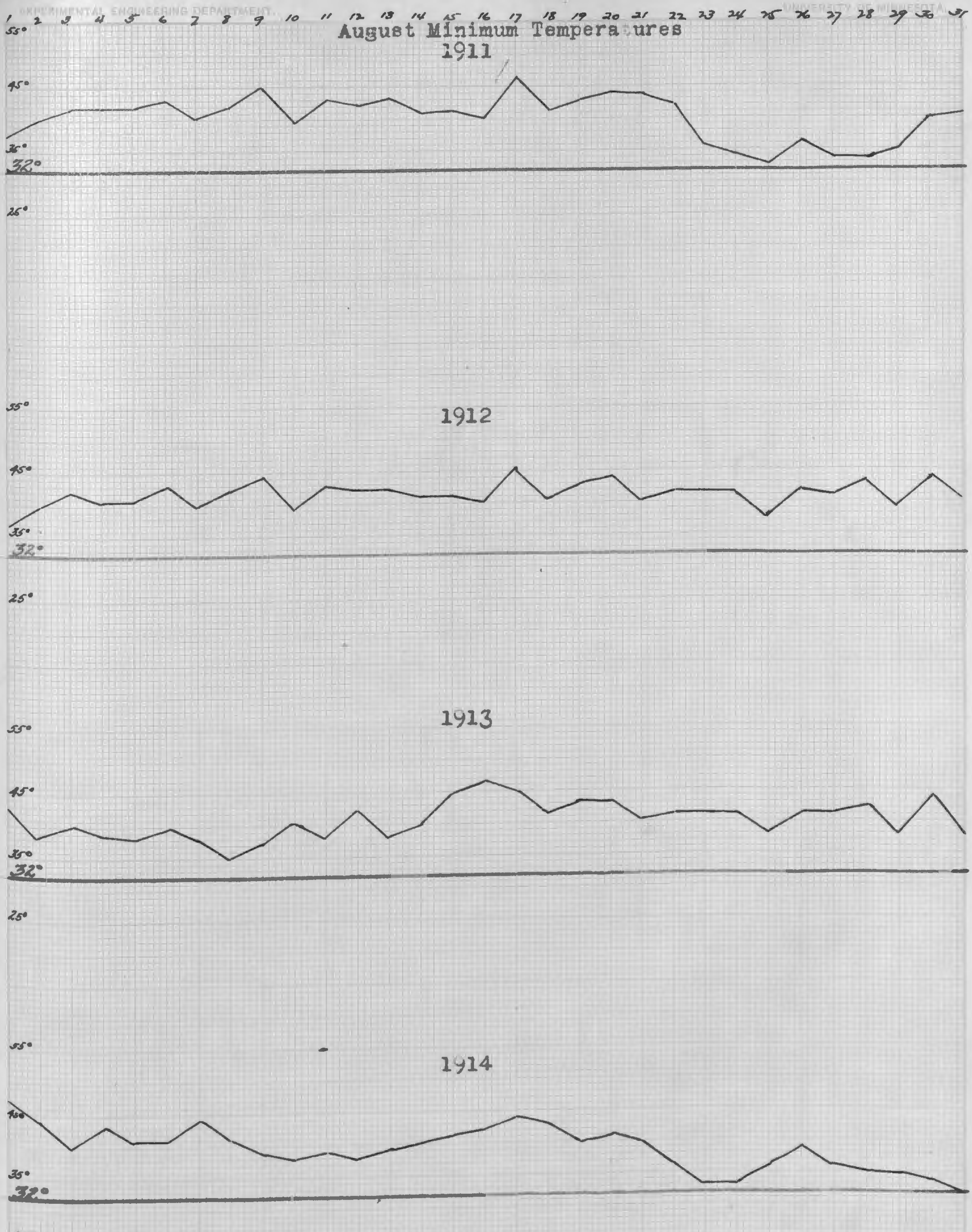

August Minimum Temperatures
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
1911
55°
45°
35°
32°
25°
1912
55°
45°
35°
32°
25°
1913
55°
45°
35°
32°
25°
1914
55°
45°
35°
32°
25°

Fig. 28.

September Minimum Temperatures.

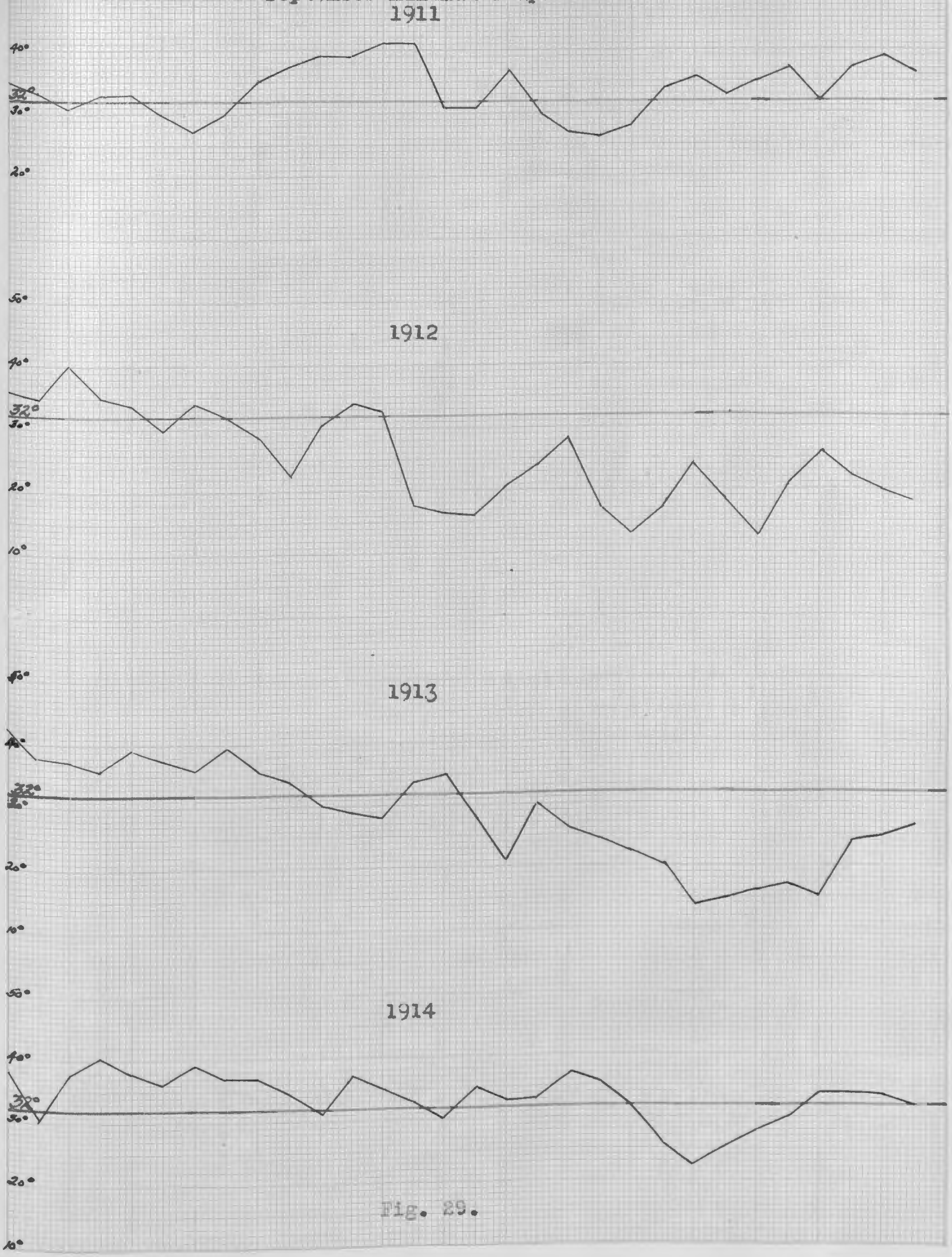


Fig. 29.

October Minimum Temperatures

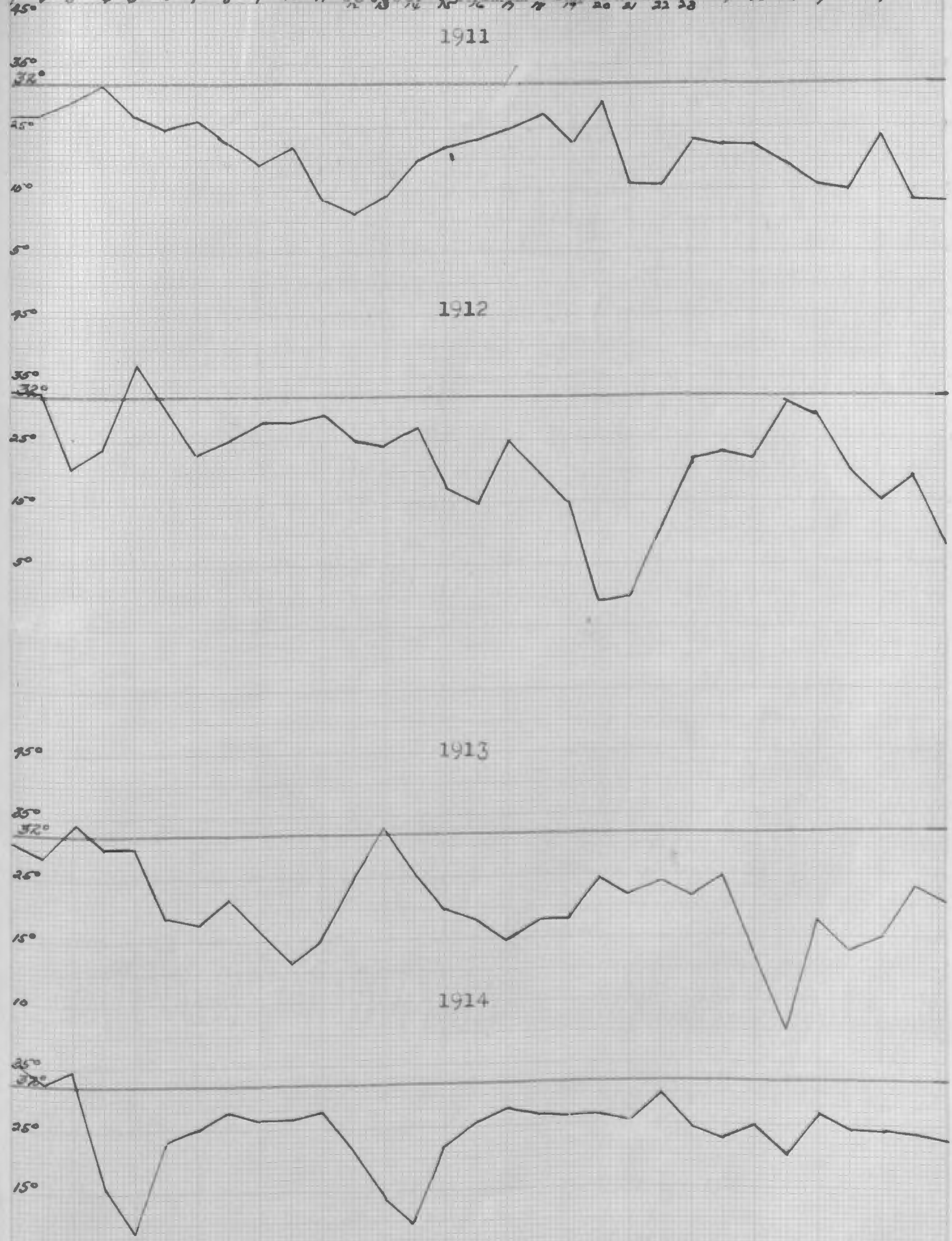


Fig. 30.

precipitation remains low in both cases from then on. As the snow lies on the ground until the last week of May, the usual dry springs as shown by both Figures Nos. 19 & 24 matters little. The importance of the precipitational distribution, however, from the month of June on to the first of October, when the ground is covered generally again with snow, cannot be overestimated. Climate extremes during this period predicts success or failure. For this reason, curves showing the daily variation in the minimum temperature of Leadville, Colorado at an average vertical range point of 10,248 feet for the Engelmann spruce zone, and for the growing months of the years 1911, 1912, 1913, and 1914 are drawn. See Figures Nos. 25 to 30.

These curves are of the paramount importance in emphasizing the real meaning of the variations of minimum temperatures in the heaving of the soil. The extremes of temperature shown by the curves mean the death of seedlings through freezing directly or by being tossed out of the ground by the contraction and expansion of the water of the soil.

In the month of May the last two or three days are the only ones during which freezing does not occur. The heaving of the soil due to such changeable conditions in temperature is sufficient to lift out of the ground a 1" X 2" X 6" stake which had been driven four inches into the soil leaving the top within two inches of the surface of the ground. The month of June has a less frequent drop to the freezing point, but it shows a few days for each year during which freezing weather would give seedlings, that might have started in the spring from seed, little chance of remaining rooted in the soil. In case the May heaving condition has not completely heaved out overwintered seedlings, but has simply lifted them enough to expose a portion of the root system, the continuation of the heaving during a few days in June either lays the seedling flat on the ground or exposes enough of the roots of the seedlings to cause a rapid drying out during the following periodic hot and dry summer periods.

The month of July for the years of 1911 and 1913 show points of freezing during the first and the last few days of the month respectively. The month as a whole for the several years in question is less unfavorable in minimum temperatures. The poor distribution of moisture and the prevalence of high drying summer temperatures associated with rather frequent and even daily wind velocity during the month of July and August, makes these months rather unfavorable in other ways than that of freezing and heaving.

The last days of August show freezing weather again. This is carried over into the month of September which gives the so called fall heaving, mentioned later in the results of artificial methods. The month of September is a severe one on the seedling growth of Engelmann spruce. Generally, the fall snows have not fallen to a sufficient depth to prevent the alternate freezing and thawing of the soil which takes place universally. By the last of September or the first of the month of October the depth of snow has increased and little danger to seedling growth is expected except in patches where strong winds have blown the ground bare again. From the middle to the last of the month a deep blanket of snow is present to serve as a protection from heaving and excessive surface evaporation.

FINAL RESULTS. The final results obtained of the actual germination, the death rate in number and percentage, and the number of thrifty surviving seedlings and plants in the fall of 1914 are found in the following table:

Operation	Year	No. Living 10/14	Act. Germ.	Death Rate Number	Death Rate Per Cent
Spring					
Broadcast prepared	1912	0	77	77	100.00
Regular seed spots	1912	1	576	575	99.83
Simple seed spots	1912	0	144	144	100.00
Cornplanter	1912	41	1159	1118	96.49
Planting	1912	235	....	165	41.25
Summer					
Broadcast unprepared	1911	0	39	39	100.00
Broadcast prepared	1911	0	98	98	100.00
Broadcast prepared	1912	6	17	11	64.71
Simple seed spots	1912	0	1	1	100.00
Regular seed spots	1911	0	157	157	100.00
Regular seed spots	1912	0	15	15	100.00
Cornplanter	1911	7	1065	1058	99.39
Cornplanter	1912	0	28	28	100.00
Planting	1911	159	...	241	60.25
Fall					
Broadcast unprepared	1911	2	27	25	92.59
Broadcast prepared	1911	0	146	146	100.00
Broadcast prepared	1912	8	26	18	69.23
Regular seed spots	1911	1	161	160	99.37
Regular seed spots	1912	1	4	3	75.00
Simple seed spots	1912	1	44	43	97.73
Cornplanter	1911	28	334	306	91.62
Cornplanter	1912	40	234	194	82.91
Planting	1911	254	...	146	36.50
Planting	1912	144	...	256	64.00
Winter					
Broadcast unprepared	11-12	0	1	1	100.00
Broadcast prepared	11-12	0	1	1	100.00

Correlation of Final Results with Precipitation.

By again referring to the curves of precipitation (Figure No. 24 and table page 57)the leading places,in the actual germination column of the spring,and summer operations of both 1911 and 1912, and the fall operations of 1911, are probably accounted for in part by the abundance of moisture during the summer of 1911 and the spring of 1912. The cornplanter operations lead in having for the spring of 1912, 1,159 seedlings, and for the summer of 1911, 1,065 seedlings. The greater number of seedlings here is probably due to the good precipitation which was present during the period of germination in the years 1911 and 1912. The greatest number next in this column is the 576 seedlings of the spring regular seed spots of 1912, which caught the June rains. Following this are the 334 seedlings of the cornplanter operations of the fall of 1911, and the 234 seedlings of the fall of 1912, both of which caught the June rains, since the seed remained dormant until early the next summer.

When more broadly considered, actual germination should also give the relation between more extensive preparation of the soil and the number of seeds which will germinate. The following table does not show a direct relation between the greater amount of extensive preparation of the soil and greater germination in the seed spot method and the simple cornplanter method, but does between the seed spot methods and the broadcast methods in which the ground was not disturbed.

Operation	Year	Season	Actual Germination
Cornplanter	1912	Spring	1,159
Cornplanter	1911	Summer	1,065
Regular seed spots	1912	Spring	576
Cornplanter	1911	Fall	334
Cornplanter	1912	Fall	234
Regular seed spots	1911	Fall	161
Regular seed spots	1911	Summer	157
Broadcast prepared	1911	Fall	146
Simple seed spots	1912	Spring	144
Broadcast prepared	1911	Summer	98
Broadcast prepared	1912	Spring	77
Simple seed spots	1912	Fall	44
Broadcast unprepared	1911	Summer	39
Cornplanter	1912	Summer	28
Broadcast unprepared	1911	Fall	27
Broadcast prepared	1912	Fall	26
Broadcast prepared	1912	Summer	17
Regular seed spots	1912	Summer	15
Regular seed spots	1912	Fall	4
Simple seed spots	1912	Summer	1

<u>Correlation of Final Results with Death Rate.</u> In the consideration of the death rate, the following table presents some important facts:

Operation	Year	Season	Death Rate Percentage 1914
Planting	1911	Fall	58.50
Planting	1912	Spring	41.25
Planting	1911	Summer	60.25
Planting	1912	Fall	64.00
Broadcast prepared	1912	Summer	64.71
Broadcast prepared	1912	Fall	69.23
Regular seed spots	1912	Fall	75.00
Cornplanter	1912	Fall	82.91
Cornplanter	1911	Fall	91.62
Broadcast unprepared	1911	Fall	92.59
Cornplanter	1912	Spring	96.49
Simple seed spots	1912	Fall	97.73
Regular seed spots	1911	Fall	99.37
Cornplanter	1911	Summer	99.39
Regular seed spots	1912	Spring	99.85
Broadcast prepared	1912	Spring	100.00
Simple seed spots	1912	Spring	100.00
Broadcast unprepared	1911	Summer	100.00
Broadcast prepared	1911	Summer	100.00
Simple seed spots	1912	Summer	100.00
Regular seed spots	1911	Summer	100.00
Regular seed spots	1912	Summer	100.00
Cornplanter	1912	Fall	100.00
Broadcast prepared	1911	Fall	100.00
Broadcast prepared	11-12	Winter	100.00
Broadcast unprepared	11-12	Winter	100.00

The foregoing table shows what a decided lead planting operations have over all direct seeding methods with an intimation of fall for the best season. The better prepared seed spots seems to have no advantage in resisting the physical and biotic factors of the habitat over the more cheaply prepared broadcast and cornplanter operations. Since the first rains by compacting the soil cause a great evaporation through the force of capillarity, the more thorough preparation of the soil was not found to preserve the soil moisture which is so essential for germination and growth. In fact in this way, the available moisture supply of the young seedlings was apparently greatly reduced. Another fact brought out in the table is the heavy death rate of the summer operations of both years.

Death and Cause
Percentage

Operation	Season	Heaved Out	Dried Out	All Other Agents
Cornplanter	Spring 1912	39.00	43.08	17.92
Cornplanter	Summer 1911	56.25	43.75	0.00
Cornplanter	Fall 1911	46.21	15.00	38.79
Planting	Summer 1911	46.16	5.13	48.71
Planting	Fall 1911	35.73	15.00	49.27
Regular seed spots	Fall 1911	19.23	55.33	25.44
Regular seed spots	Summer 1911	0.00	96.31	3.69
Regular seed spots	Spring 1912	5.81	91.61	2.58
Simple seed spots	Spring 1912	12.12	71.16	16.72
Broadcast prepared	Summer 1911	45.45	54.55	0.00
Broadcast prepared	Fall 1911	76.00	20.96	3.04
Broadcast prepared	Winter 11-12	100.00	0.00	0.00
Broadcast unprepared	Winter 11-12	100.00	0.00	0.00
Broadcast prepared	Fall 1911	60.00	20.00	20.00
Broadcast unprepared	Summer 1911	100.00	0.00	0.00
Broadcast prepared	Spring 1912	44.00	36.00	20.00
Broadcast prepared	Summer 1912	0.00	100.00	0.00
Regular seed spots	Summer 1912	12.50	6.25	81.25
Simple seed spots	Summer 1912	0.00	100.00	0.00
Cornplanter	Summer 1912	14.30	85.70	0.00
Planting	Spring 1912	4.20	0.00	95.80
Planting	Fall 1912	6.50	82.00	11.50
Cornplanter	Fall 1912	0.00	99.95	0.05
Regular seed spots	Fall 1912	100.00	0.00	0.00
Simple seed spots	Fall 1912	0.00	94.87	5.13
Broadcast prepared	Fall 1912	28.60	71.40	0.00

In the above table the heading "Heaved Out" comprises the percentages of seedlings which were completely lifted out of the ground by the expansion of the water in the soil. The percentages, although made up mostly of spring heaving, accounts for fall heaving. The caption "Dried Out" considers the loss of seedlings from drying out during their period of germination, or later during the hot and dry summer periods or during the winter. The summer drying constitutes the greater part of the percentages. "All Other Agents" column represents the combined percentages for erosion of the soil by spring freshets, and injury by ants, rabbits, grazing stock, and moles. The loss by damping off has also been accounted for here.

Transplants
Time and Number of Death
October 1914

Operations	Fall to Spring	Per Cent	Spring to Summer	Per Cent	Summer to Fall	Per Cent
Summer 1911	39	17.00	44	19.5	144	63.50
Fall 1911	60	55.05	34	31.19	15	13.76
Spring 1912	14	9.03	76	49.03	65	41.94
Fall 1912	36	18.00	120	60.00	44	22.00

The previous tables of the percentage of death and cause are the outcome of an effort to get some data on the time at which death occurs and the factors which bring about the loss of seedlings. Since examinations were made only once during each spring, summer, and fall of each year, the tables are to be considered more or less incomplete. Without more frequent observations it is impossible to account for the complete germination and death of all seedlings. However, each new seedling, which was yet on the ground when observations were made, was definitely located by a small white stake and its condition noted. The death, then, since the previous examination, when properly correlated with the data and Weather Bureau reports and with general weather observations on the site,gave facts from which a reasonable assumption could be made of the causes which brought about the loss.

A close examination of the death rate table brings out the important facts that the seedlings of the summer operations of 1911 suffered greatly from spring heavings, and from drying out during a few hot days with hot winds.

The last effect was marked in the case of the regular seed spots since here the seedlings were caught in their germinative period. In the summer planting operations of this year, five per cent of the transplants planted could be considered too small, undeveloped, and damaged to live at the time of planting. The fall operations for 1911 suffered also the most from the spring heaving of the soil in 1912 and from dry winds during the summer of the same year. Biotic factors, such as rodents and cattle injuries to the fall transplants of 1911, have brought about the death of over one-half of the dead in this operation. The two seedlings of the winter operations of 1911-12 stood well until they were finally completely heaved out in the spring of 1913.

The spring operations of 1912 favored by an abundance of moisture produced good germination, but periodic hot and dry windy weather conditions caught a considerable amount of the germination when coming out of the ground. The spring heaving of 1913 raised the death rate of this season's operations appreciably. The summer operations of 1912 never did well, due probably to a -.53 departure from the normal precipitation during the month of August, 1912, and to the early snows and cold weather in September, 1912. Natural drying during the summer of 1912 seems to be the main cause of death. Fall operations of 1912 never gave even a fair actual germination and the natural drying out process killed the seedlings that did start. In the case of the spring broadcast prepared methods of 1912 there is noticeable a percentage of 44 for the early fall heaving of the soil of 1912 which came at a time when rapid changes were being made from warm to freezing weather. The soil at this time was not covered with a snow blanket. This heaving condition is shown nicely on the sheet of minimum temperatures for the month of September 1912 (Figure No. 29).

In general, then, it seems that seedlings of all direct seeding methods are going to suffer sooner or later from spring or fall heaving, or be killed by the dry summer weather while in germination, unless the season's precipitation is so well distributed that rains will come every few days. To overcome these difficulties on this particular site at Marshall Pass, the planting of transplants presents the most feasible method, since transplants, which have big crowns and large root systems and which have been properly handled when planted, have withstood the climatic and organic conditions of this high continental area better for the money expended. A reference to the following tables of the surviving thrifty trees will lead to this assumption for the Marshall Pass site:

Operation	Season	Thrifty Trees 1914
Broadcast unprepared	Summer 1911	0
Broadcast prepared	Summer 1911	0
Regular seed spots	Summer 1911	0
Cornplanter	Summer 1911	7
Planting	Summer 1911	159
Broadcast unprepared	Fall 1911	2
Broadcast prepared	Fall 1911	0
Regular seed spots	Fall 1911	1
Cornplanter	Fall 1911	28
Planting	Fall 1911	254
Broadcast unprepared	Winter 1911	0
Broadcast prepared	Winter 1911	0
Broadcast unprepared	Spring 1912	0
Regular seed spots	Spring 1912	1
Simple seed spots	Spring 1912	0
Cornplanter	Spring 1912	41
Planting	Spring 1912	235
Broadcast prepared	Summer 1912	6
Regular seed spots	Summer 1912	0
Simple seed spots	Summer 1912	0
Cornplanter	Summer 1912	0
Broadcast prepared	Fall 1912	8
Regular seed spots	Fall 1912	1
Simple seed spots	Fall 1912	1
Cornplanter	Fall 1912	40
Planting	Fall 1912	144

By selecting from the foregoing table from each method, the season's operation which produced the best results and thus compare the most favorable season under each method, the following table arises:

Operation	Season	Thrifty Trees Fall 1914
Broadcast unprepared	Fall	2
Broadcast prepared	Summer	6
Regular seed spots	Fall	1
Simple seed spots	Fall	1
Cornplanter	Spring	41
Planting	Fall	254

Operation	Average Original Total Cost	Average Cost of Surviving Tree 1914
Broadcast unprepared	.85	.85
Broadcast prepared	1.15	1.15
Cornplanter	1.67	.23
Simple seed spots	2.46	2.46
Regular seed spots	3.27	3.27
Planting	7.80	.039

From the previous table the planting operations produced the cheapest cost of surviving tree at .039, although the original total cost of getting the transplants into the ground is from two and one-half to eight times greater than the other methods.

Method and Cost of Surviving Tree

Operation	Season	Cost of each tree 1914
Broadcast unprepared	Summer 1911	.....
Broadcast prepared	Summer 1911	.....
Regular seed spots	Summer 1911	.....
Cornplanter	Summer 1911	.284
Planting	Summer 1911	.060
Broadcast unprepared	Fall 1911	.394
Broadcast prepared	Fall 1911	.....
Regular seed spots	Fall 1911	2.697
Cornplanter	Fall 1911	.560
Planting	Fall 1911	.027
Broadcast unprepared	Winter 11-12	.....
Broadcast prepared	Winter 11-12	.....
Broadcast unprepared	Spring 1912	.....
Regular seed spots	Spring 1912	3.03
Simple seed spots	Spring 1912	.....
Cornplanter	Spring 1912	.040
Planting	Spring 1912	.031
Broadcast prepared	Summer 1912	.252
Regular seed spots	Summer 1912	.....
Simple seed spots	Summer 1912	.....
Cornplanter	Summer 1912	.....
Broadcast prepared	Fall 1912	.174
Regular seed spots	Fall 1912	2.73
Simple seed spots	Fall 1912	2.75
Cornplanter	Fall 1912	.041
Planting	Fall 1912	.049

From the method and cost of surviving tree table the following arrangement from lowest to highest in cost is possible:

Operation	Season		Cost of Surviving Tree
Planting	Fall	1911	.027
Planting	Spring	1912	.031
Cornplanter	Spring	1912	.040
Cornplanter	Fall	1912	.041
Planting	Fall	1912	.049
Planting	Summer	1911	.060
Broadcast prepared	Fall	1912	.174
Broadcast prepared	Summer	1912	.232
Cornplanter	Summer	1911	.284
Broadcast unprepared	Fall	1911	.394
Cornplanter	Fall	1911	.560
Regular seed spots	Fall	1911	2.697
Regular seed spots	Fall	1912	2.73
Simple seed spots	Fall	1912	2.73
Regular seed spots	Spring	1912	3.03

This above table presents two operations, planting and cornplanter, in the first six places of which the former holds the first two and the last two places with the latter at the middle in the third and fourth places. The seasons run fall, spring, spring, fall, fall, and summer.

PIKES PEAK SITE:

GENERAL DESCRIPTION. The parallel experiment which was conducted in the vicinity of Pikes Peak, Colorado, with which to check the results obtained at Marshall Pass, is described as follows:

The site comprises an Engelmann spruce and limber pine burn dating back to about the year 1880. It was again burned over in the year 1904. The area is on a steep, rocky, eastern to northeastern exposure at an elevation of 10,400 feet. The slope is from five to ten degrees. The soil is on an old glacial moraine and is very full of boulders of all sizes. It is strictly a coarse, sandy, granitic loam with scarcely any cover of humus and litter. Most of the surface is a bare mineral soil, but there is some scattered bunch grass. The site is covered by a rather thin stand of dry aspen and a scattered stand of aspen sprouts five to twelve feet high. The area in general is quite well exposed.

The description of the above site shows no indications of a heavy grass sod similar to that found on

Marshall Pass. For this reason the final results of the same methods on this site are given in order that a comparison may be made to the final results of the heavily sodded Marshall Pass site. Since the two areas are not more than approximately 100 miles apart, the general climatic conditions similar, and the methods and amounts of seed sowing in accordance with the same plan, the comparison of the final results may be made to show the hindering effects of heavy sod on old burns in preventing reforestation.

FINAL RESULTS

Operation	Season	Number living 1914	Actual Germination	Number of Death	Percent-of Death
Broadcast unprepared	F* 1911	43	70	27	38.58
Broadcast unprepared	W.11-12	25	32	7	22.88
Broadcast prepared	Sp.1912	41	498	457	91.79
Broadcast prepared	F. 1911	223	326	103	31.60
Broadcast prepared	F. 1912	35	124	89	71.77
Regular seed spots	F. 1911	45	102	57	55.88
Regular seed spots	Sp.1912	37	571	534	93.52
Regular seed spots	F. 1912	76	138	62	44.92
Simple seed spots	Sp.1912	2	38	36	94.77
Simple seed spots	F. 1912	5	20	15	75.00

* F.= Fall; W.= Winter; Sp.= Spring.

By selecting from each method from the foregoing table, the season's operations which produced the best results and thus compare the most favorable season under each method, the following table is formed:

Comparison of Best Season

Operation	Season	Thrifty Trees
Broadcast unprepared	Fall	43
Broadcast prepared	Fall	223
Regular seed spots	Fall	76
Simple seed spots	Fall	5

From the above table the importance of the fall season for doing direct seeding is very conspicuously emphasized.

COST TABLE

Operation	Season	Cost of Each Surviving Seedling
Broadcast unprepared	Fall 1911	.0023
Broadcast prepared	Fall 1911	.003
Regular seed spots	Fall 1911	.014
Broadcast prepared	Spring 1912	.023
Broadcast prepared	Fall 1912	.052
Regular seed spots	Fall 1912	.052
Regular seed spots	Spring 1912	.135

By bringing together all the results of similar methods of the two sites,a table of comparison is formed as follows:

Operation	Season	Marshall Pass Site		Pikes Peak Site	
		Thrifty Trees			
		No.	Cost	No.	Cost
Broadcast unprepared	Fall 1911	2	.39	43	.0023
Broadcast unprepared	Winter 11-12	0	....	25	....
Broadcast prepared	Spring 1912	0	....	41	.023
Broadcast prepared	Fall 1911	0	....	223	.003
Broadcast prepared	Fall 1912	8	.17	35	.052
Regular seed spots	Fall 1911	1	.27	45	.014
Regular seed spots	Spring 1912	1	3.30	37	.135
Regular seed spots	Fall 1912	1	2.73	76	.052
Simple seed spots	Spring 1912	0	....	2	....
Simple seed spots	Fall 1912	1	2.73	5	....

It is evident from the preceding table that under approximately similar conditions, heavy sod materially reduces the final stand of surviving seedlings. The heavy sod, in preventing the proper contact of the seed with the mineral soil probably reduces the original germination,and ultimately through this means and through the heavy heaving and drying out process, the number of surviving seedlings.

By selecting from each site each method, the season's operation which produced the best results and thus compare the best resùlts in the summary table, the following lists are made:

Operation	Season	Marshall Pass Site	Pikes Peak Site
		Thrifty Trees	
		No.	No.
Broadcast unprepared	Fall	2	43
Broadcast prepared	Summer	6	...
Broadcast prepared	Fall	...	223
Regular seed spots	Fall	1	76
Simple seed spots	Fall	1	5
Cornplanter	Spring	41	...
Planting	Fall	254	...

It is quite evident from the last table, that the best season and method for the heavily sodded Marshall Pass site is the fall planting of sturdy transplants. As planting methods were not tried out on the other site, no comparison of its possible success is advisable. However, since the general ground cover of grasses and herbaceous plants on the upper surface, and the sod beneath have not developed to the heavy matty stage of that found on the Marshall Pass site, more success would be expected on the Pikes Peak site for broadcasting methods. Consequently, fall broadcast on prepared ground is the best method and season that may be suggested at this time. The scattered aspen stand on the Pikes Peak site modifies the severity somewhat of the conditions of the unnatural habitat in shading and in producing the leaf mulch around the seedlings. As this cover would in part prohibit rapid changes of temperature, but not completely prevent it, heaving is going to occur year after year. Due to this fact, tender seedlings will probably be heaved after several years of growth and the percentage of seedlings on the ground from any direct seeding method after a ten-year period is liable to be very unsatisfactory. This loss from heaving would eventually raise the cost of surviving tree to a point where, economically as well as scientifically, the fall planting of sturdy transplants would probably prove the most satisfactory season and method of quickly and successfully reforesting sodded burns in the Rocky Mountains.

CONCLUSIONS

Engelmann spruce inhabits the zone of great soil moisture and relative humidity in the Rocky Mountains. It occurs at altitudes of 1,500 feet in the states of Washington and Idaho, and at 12,000 feet on the Continental Divide in the States of Colorado and New Mexico.

Engelmann spruce is an abundant seeder and reproduces itself naturally throughout its range, except on sodded burns within the type.

Sodded burns are found from the central Rocky Mountains southward through the state of Colorado into New Mexico and Arizona. Their greatest predominance and importance is found in the state of Colorado.

The habitat of the sodded burns in the state of Colorado is extremely unfavorable to tree growth in physical and climatic factors. Frequent freezing temperatures, high evaporation rates, periods of high dry winds and dry weather, and a very short growing season prevail on them.

The heavy grass sod on these burns prevents the proper germination of the seed from all natural and artificial direct seeding methods.
Of the seed that germinates, the heaving of the soil and the natural drying process kills the greater portion although a small percentage of death is caused by biotic factors.

All direct seeding methods of either a natural or artificial nature fail to present finally more than the unsatisfactory stand of less than one seedling on the average to every twenty-five square feet. The planting of sturdy transplants presents eventually one tree to every eight square feet.

For heavily sodded burns the fall planting of 2-1 transplants presents the best season and method of reforesting. For less heavily sodded burns the broadcasting on prepared ground is the best season and method at present of reforesting to obtain ultimately a fully stocked stand in the least time and at the least expense.

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