

INFORMATION TO USERS

This manuscript has been reproduced from the microfilm master. UMI films the text directly from the original or copy submitted. Thus, some thesis and dissertation copies are in typewriter face, while others may be from any type of computer printer.

The quality of this reproduction is dependent upon the quality of the copy submitted. Broken or indistinct print, colored or poor quality illustrations and photographs, print bleedthrough, substandard margins, and improper alignment can adversely affect reproduction.

In the unlikely event that the author did not send UMI a complete manuscript and there are missing pages, these will be noted. Also, if unauthorized copyright material had to be removed, a note will indicate the deletion.

Oversize materials (e.g., maps, drawings, charts) are reproduced by sectioning the original, beginning at the upper left-hand corner and continuing from left to right in equal sections with small overlaps.

ProQuest Information and Learning
300 North Zeeb Road, Ann Arbor, MI 48106-1346 USA
800-521-0600

UMI[®]

NOTE TO USERS

This reproduction is the best copy available.

UMI

**SITE FACTOR VARIATIONS AND RESPONSES IN TEMPORARY
FOREST TYPES IN NORTHERN IDAHO**

By

Julius Ansgar Larsen

**A Thesis Submitted to the Graduate Faculty
for the Degree of**

DOCTOR OF PHILOSOPHY

Major Subject - Plant Ecology

Approved:

Signature was redacted for privacy.

In charge of Major work

Signature was redacted for privacy.

Head of Major Department

Signature was redacted for privacy.

Dean of Graduate College

**Iowa State College
1936**

UMI Number: DP12238



UMI Microform DP12238

Copyright 2005 by ProQuest Information and Learning Company.

All rights reserved. This microform edition is protected against
unauthorized copying under Title 17, United States Code.

ProQuest Information and Learning Company
300 North Zeeb Road
P.O. Box 1346
Ann Arbor, MI 48106-1346

TABLE OF CONTENTS

	Page
INTRODUCTION	3
Statement of the problem	3
Purpose and scope of the investigation	3
REVIEW OF LITERATURE	5
The effect of climatic factors	6
The effect of edaphic factors	14
EXPERIMENTAL	23
The location of the study	23
Selection of the stations	25
Methods of study	32
Determination of factors	32
Climatic factors	33
Light	33
Air temperature	34
Precipitation records	34
Relative humidity	35
Wind movement	36
Evaporation	36
Edaphic factors	37
Soil moisture	37
Soil temperature	38
Soil sampling and testing	39
Organization of seeding and planting tests	40
Series A	45
Series B	45
Series C	46
Series D	47
Results	48
Climatic factors	48
Light	48
Air temperature	49
Precipitation	56
Relative humidity	59
Wind movement	60
Evaporation	64
Edaphic factors	67
Soil types	67
Analysis of the soils	70
Soil temperature	76
Soil moisture in the field	83
Seeding tests	89
Planting tests	101
DISCUSSION	107
SUMMARY AND CONCLUSIONS	124
LITERATURE CITED	128
ACKNOWLEDGMENTS	133

INTRODUCTION

Statement of the Problem

At the time this study was first undertaken there existed practically no accurate information on the more suitable sites or the conditions favoring natural reproduction and growth of the different native trees in the Northern Rocky Mountain region. There was much uncertainty regarding the causes of distribution of the species in relation to temperature, rate of evaporation, soil moisture and nutrient requirements. Little was definitely known of the conditions which favored or retarded the development of pure or mixed stands, or the quality of the different forest soils. In short, more exact and dependable information was urgently needed in forest management, timber sale operations, reforestation and land utilization. These studies were begun as an approved part of the Forest Experiment Station program in an attempt to solve some of these problems which confronted the forester in the region.

Purpose and Scope of the Investigation

The object of the study was to analyze and evaluate the climatic and edaphic environmental factors which control the orderly progressional stages in the secondary forest succession

in northern Idaho.

For this purpose the climatic factors were studied by means of daily records of air temperature, humidity, wind movement and evaporation and the more important physical and chemical characteristics of the soil were determined. These were followed by tests of responses to the site conditions by seeding and growing native coniferous species, and by keeping records of germination, survival and growth of these over a period of five years and by planting native nursery-grown trees on the different sites, which later were observed over a period of 20 years.

This study had its beginning early in 1912 at the time of the establishment of the Priest River Forest Experiment Station of the United States Forest Service in northern Idaho. The climatic records, soil temperatures and soil moisture were obtained from 1912 to 1916, inclusive. The seeding experiments were conducted from 1913 to 1917, the planting installations were made during the period from 1912 to 1915 and their survival record continued until 1921 and the growth record until 1932. This investigation therefore spans a period of 20 years. In the course of two decades from its beginning the responsibility for most of the continuous records, a great share of the tabulations and the preparation of progress reports has rested upon the writer.

REVIEW OF LITERATURE

A review of the literature bearing on this and the related subjects reveals that most previously attempted study and analysis of the site factors or of correlations of these with germination, survival and growth are incomplete and usually confined to only one phase of the problem. Some which purport to be exhaustive deal only with the climatic or with the edaphic factors.

Many of the investigations are more or less duplications of the same factors measured in different locations. The magnitude of the task involved in a complete study of all factors for any one site is no doubt a reason for the limited number of such investigations. Nevertheless, there are many papers which have an important bearing on at least one phase of the problem.

It is obviously impossible to allot space to every one of these publications. It is, however, important to consider the papers which apply to conifers and particularly those referring to the conifers of the western United States. In this review, an effort has been made to group the papers under two heads: those dealing with the climatic and those dealing with the edaphic factors.

It has been pointed out by Maximov and others that the factors of site become controlling mainly as they reach the

maxima or minima tolerated by the species in question. In this way, any one of the factors, either atmospheric or edaphic, may of themselves become limiting.

Palmgren (46) has stated that there is much value also in paying due regard to the manner of reaction and to the interactions of the factors within their effective limits.

The Effect of Climatic Factors

Lundegårdh (39) maintains that every stage in the development of the plant seems to have its own optimum temperature and that the position of this cardinal point in temperature is influenced by light, nutrients and other factors. Moreover, the reaction within the plant to extreme conditions will depend upon the health or reserve of the plant itself. In other words, the lethal temperatures are raised or lowered by the influence of the other factors of life and growth. This author states further that exact evaluation of the factors is rendered difficult in that curves of the most important physiological processes do not increase regularly with increase in the factors.

For the territory of the Rocky Mountains we have the reports by Pearson (47), Bates (3), and Larsen (36) setting forth the ranges or requirements of most arborescent species in the matter of temperature and precipitation. These are voluminous reports dealing with regional and altitudinal distributions and zonations. A brief summary follows:

Type of vegeta- tion	:Northern Rockies:		Central Rockies:		Southern Rockies	
	: Mean	: Ann.	: Ann.	: Ann.	: Ann.	: Ann.
	: ann.	: precip.	: Temp.	: precip.	: Temp.	: precip.
	:Temp.OF.:	inches	: OF.	inches	: OF.	inches
Desert	-	-	-	-	68.0	10.4
Prairies	50.0	9.0	47.0	14.3	56.7	11.3
Pinon- Juniper	-	-	-	-	51.6	16.9
W. yellow pine	45.0	18.0	43.9	19.9	45.8	22.7
Douglas fir	42.4	27.8	38.5	26.2	42.7	34.2
W. white pine	40.0+	27.0+	-	-	-	-
Lodgepole pine	34.8	20.0+	33.7	15.5	-	-
Engelm. spruce	36.0+	26.0+	34.7	24.6	38.4	36.4

From the data given in these three reports, it is possible to prepare graphs and to estimate the maxima and minima of air temperature and the lengths of growing season for the various species involved. According to Larsen (36), this is from 235 to 254 days for prairies of northern Idaho; 201 to 241 days for western yellow pine; 165 to 201 days for western white pine; 110 to 145 for subalpine trees.

Robbins (52) also defined air temperature conditions for the various altitudinal zones in Colorado, giving the season of no killing frost as follows:

Elevation, feet	: Season of no killing frost	: Temperature ranges OF.
5,000 and lower	5 mos. 6 days	45-50.5
6,000	4 mos. 21 days	-
6,000-7,000	3 mos. 21 days	35-40
7,000-8,000	3 mos. 6 days	35-40
8,000-10,000	-	35-40
10,000-11,000	-	35

Pearson (49) minimizes the value of listing the length of the growing season. He states that it is impossible to fix any set limits on the growing season because, for the western yellow pine zone in Arizona, for example, there are some species which make their major growth in the late spring when the frost occurs almost nightly, and that most of the native trees and shrubs in this region cease vegetative growth long before the first freeze. Of course, there are many exceptions. The author of this thesis concurs in the conclusion that the length of the frostless season is a matter of greater concern for the introduced vegetable crops than for native forms.

Livingston (37) emphasizes the time element as well as the magnitude of the factors when he states that the various factors as the exponential indices, the ratio of the sum of the physiological indices to the sum of the exponential indices, the precipitation-evaporation ratios and the temperature-evaporation index, for any one species may be considered on the basis of the frostless season.

From the standpoint of injury to newly germinated evergreen seedlings resulting from over-heated soil surfaces, we have the reports of Baker (1), Li (38), Toumey and Neethling (57), and Korstian (35). Baker found that injury resulted to Douglas fir seedlings above 131°F., to western red cedar above 96°F., and to grand fir above 123°F. He concluded also that these species show no increased protoplasmic resistance with age.

Li (38) demonstrated that the surface soil temperatures in the open always reached higher points than under the forest. The figures given for extremes are 118°F. for the open; 88.6°F. for the grass, and 65°F. under the young forest. According to Toumey and Neethling (57), the older seedlings sustain less injury than the younger by virtue of a hardening of or increase in the epidermis, xylem and endodermis. This is in agreement with the conclusion reached by McLean (41) who states that if two plants are in different stages of development, the influence of the same factor will produce different results in the two plants.

Korstian (35) reports that Engelmann spruce seedlings were injured at temperatures between 108° and 129°F. Bates (6) believes that the resistance of evergreen seedlings to heat injury varies inversely as their resistance to transpiration. He lists the heat tolerance in order: lodgepole pine, western yellow pine, Engelmann spruce, Douglas fir.

Munch (43) shows that the heat of the surface soil varies with its dryness, looseness, and color. Other factors being equal, the drier, looser, and darker the soil the higher is its temperature. The highest temperature of moist top-soil recorded was 100.4°F. while the highest temperature of similar soil when thoroughly dry was 145.4°F. He attributes the lesions on seedlings as due directly to heat at the soil surface. In his study of surface soil temperatures where damage was taking place, he recorded temperatures of 140°F. and in some cases even

higher. Incubator temperatures killed the seedlings quickly by raising them from 125.6 to 129°F. or 131°F.

Pearson (47) and several other authors have observed an inversion of temperatures in that the lower-lying zone of western yellow pine has lower atmospheric minimum temperatures than the more elevated spruce or Douglas fir zones. They attribute this fact to the downward drainage of cold air at night and the corresponding upward rise of air at night from the flats or benches. These low minima at night are distinctly injurious to young Douglas fir and constitute an important factor in the elimination of the tree from such sites.

Direct or diffused sunlight may easily become a limiting factor in the establishment of evergreen seedlings not in the open or on northerly aspects, but under cover of other trees or brush or in the presence of dense herbaceous vegetation. The seedlings of many coniferous species will continue to exist with a total illumination as low as two percent, but this will weaken them to such an extent that competition causes their elimination. Toumey and Kienholz (59) show that the competition for soil moisture of underground roots of trees in the overstory was an important cause of decreased growth and even death of new seedlings. They state that this mortality has often erroneously been attributed to a low degree of shade tolerance.

Nevertheless, the author is quite certain that the trees used in this investigation possess ability to tolerate shade in

different degrees and that these characters express themselves in seedlings as well as in mature trees. In support of these statements, the investigations of Burns (12), Shirley (54) and many earlier workers are cited. The relative light requirements are often in themselves responsible for the mortality of naturally sown seedlings in various locations of the forest areas.

Bates (5) reports that six species tolerated minimum light quantities as follows: Engelmann spruce 1.1 percent; Douglas fir 1.5 percent; western yellow pine 1.8 percent; lodgepole pine 2.4 percent; limber pine 2.7 percent; and pinon pine 6.3 percent. He considers that these seedlings differed in their water requirements inversely as their photosynthetic activity under low light conditions. However, since only two percent or less of the total water transported upward in the plant is used in carbon assimilation, it is difficult to believe that this matter is significant.

Burns (12) exposed potted plants of a number of species to 750-watt nitrogen-filled electric bulbs and measured the minimum light intensity at assimilation-respiration equilibrium with a vacuum thermocouple and found the requirements in percentage of total sunlight in this order: western yellow pine 60.0, Mugho pine 7.5, Engelmann spruce 6.5, American hemlock 4.7.

Prinz (50) explains that air temperature and light are somewhat compensating in their effect on growth and distribution of evergreens particularly in relation to their northern

and southern geographic limits.

A study of rainfall is of importance chiefly as it affects available soil moisture. It is well known that even under abundant rainfall and suitable air temperatures periodic deficiency of soil moisture may be the cause of xerophytic vegetation. In most instances, however, with favorable temperatures, an increase in atmospheric moisture results in greater quantity of soil moisture and more hydrophytic vegetation. The different degrees of precipitation under which the Rocky Mountain trees grow have been set forth in papers by Pearson (47), Bates (3) and Larsen (36).

There are other relationships involved in regard to that portion of the precipitation which falls as snow. The depth and duration of the snow cover bear a direct relation to soil temperatures and the length of the active growing season. Depths of snow cover prevailing in Rocky Mountain forests are given by Larsen showing 17 to 50 inches for the prairies, 37 to 76 inches for western yellow pine, 66 to 207 for western white pine and associates and over 200 inches in the spruce-lodgepole pine forests at higher elevations. Delayed melting of the snow cover supplies water to the soil and this becomes available for the beginning and maintenance of growth in the spring months.

Hann (29) observes that the amount of evaporation expresses the need of the vegetation for water. Relative values only are of importance because the absolute depends so much upon the accidental circumstances and are not easy to obtain.

Atmospheric pressure varies with temperature, but the controlling pressure is exerted by the vapor present and not by the other gases with which it may mix. During the months of November to March the evaporation of snow in the forest was 46 percent of that in the open.

Dole (17) studied the effect of air temperature and relative humidity on the transpiration of white pine. At a temperature of 17.22°C. the atmometers recorded 9.39, 9.40 and 8.81 cc. while the plant showed 2.34, 2.44, and 2.50 cc. The transpiration of the plants increases with a rise in relative humidity and with increase in vapor pressure. The author explains that the apparent anomalies may be due to temperature as a factor. Nichols (45) places great reliance on the influence of summer evaporation and the precipitation-evaporation ratios, stating that in Connecticut this ratio is 61 percent for the eastern highland with northern hardwoods, 47 percent for the central lowlands hardwoods, and 42 percent for the eastern highland with sprout-oak hardwoods.

Weaver (60) has come closer to determining the evaporation characteristics of the northern Rocky Mountain evergreen species in giving for the hemlock-fir-white pine association a value 0.55 percent greater than the eastern hardwood of beech-maple according to Fuller (24). Evaporation in the larch-fir association is 20 percent greater than that in the

hemlock-fir-white pine association and in the prairie association it is 150 percent greater.

The Effect of Edaphic Factors

Reports of research dealing with the effects of edaphic factors are many but scattered, and few if any cover the subject completely for any one site or association. In the analysis of the amount of work done in this field it becomes necessary to consider the structure of the soil, its organic constituents, its bacterial and colloidal properties, the influence of these on temperature and moisture relations and the chemical elements present, particularly nitrogen, phosphorus and calcium as well as their effect on soil acidity and alkalinity.

Only very recently have the major soil groups of the world been proposed by Glinka (25). Under this classification the gray forest soils and podzols have received their position in the incomplete or endodynamorphic category. Ramann (51) suggests modification of Glinka's classification to variables of temperature and geologic origin. He believes that the changes in soil under raw humus are due to humic acids formed because of the lack of oxygen. The acids, he states, leach out the soluble material and cause a light colored soil layer.

Millar (42) and Burger (11) have investigated forest soils from the standpoint of porosity and water-holding capacity. The former in Michigan and the latter in Switzerland. Millar

observes that forest soils are far more porous than ordinary field soils, the difference being caused more by the organic materials present than by any other property. He also states that forest soils are more porous in the upper six inches than below and that this section absorbs water most rapidly. The ability of bare soil to absorb water is less on the surface than in the lower layers. Bur or reports the absorption of 63.6 percent of their weight for forest soils and only 3.8 percent for grassland soils. This naturally varies greatly according to the type of grass present. We are aware that bluegrass pasture soil in the United States ranks not very far below the forest soils in pore space.

Bokor (9) recommends that one should study carefully the microflora of forest soils as this presents a very complicated situation and one which is entirely distinct from that of agricultural soils. It is bound up with the amount of carbon dioxide, humus and lime content and with variations of pH. He states that the bacterial flora varies according to the light on the forest floor. He is certain that the bacterial life decreases with increase in acidity, and that the humus content is ordinarily a favorable medium for the development of soil bacteria.

Falconer (18) concludes that excess of moisture in the soil tends to favor anaerobic activity, optimum moisture the aerobic bacterial activity, and the turn in either direction may be decided by the fineness and coarseness of the soil. It is

stated that the litter of white pine decomposes more rapidly than the stems of common bracken ferns; that litter of red and white pine was found to decompose more rapidly than that of Jack pine; that twigs of white pine decomposed four times as rapidly as those of Jack pine; that litter increased in decomposition with increase in temperature and precipitation.

From Bouyoucos (13) we learn that a soil covered with a mulch or with dead vegetation has a higher temperature in the fall and winter and a slightly lower temperature in the spring than one not so covered. This means that a bare mineral soil responds more readily to external changes than a litter covered soil.

Bates (4) reports that a mean growing season soil temperature of 58° to 62°F. at the depth of one foot is favorable to the establishment of western yellow pine seedlings; at 55° or 56°F. the Douglas fir will appear with the pine; at 50°F. we may expect almost pure Douglas fir, and below 40°F. the Engelmann spruce will hold fairly complete sway.

Buckingham (10) states that the movement of moisture through the column of dry soil probably occurs as a result of diffusion and that the loss in this manner is proportional to the square of the porosity. Blackman (8) reports that, within limits, the rate of root absorption increases with the increase in soil moisture and as the moisture content of the soil becomes gradually reduced, the resistance to absorption increases. This

finally reaches the wilting point and what moisture is then left in the soil is not available to the plant.

Heinrich (31) in 1876 observed also what was later corroborated by Briggs and Shantz (15) that the ability of different plants to get water from the soil was under normal conditions about equal. He stated that not one of the 19 different cultivated plants used in his experiment were able to reduce the moisture of the soil to the equivalent of the hygroscopic coefficient. Briggs and Shantz (15) completed our concept of the situation by the discovery that soils vary in their ability to withhold water from the plants and that the sandy and gravelly soils show a lower water content at wilting than clay or loamy soils.

Craig (16) states that if aerial conditions permit transpiration and absorption to continue at approximately equal or moderate rates these two processes will go on until the water supply fails at its source and there will remain in the soil a quantity which is definitely related to the physical constant of the soil. That this physical constant is in a large measure dependent upon the colloidal properties is becoming more and more apparent. Haig (27) correlates the productivity of forest soils with the colloidal properties and Stiles (55) came to the conclusion that some of the finer soil particles would produce a colloidal solution with the film water or a coagulation product that is a gel; the film constituting the soil and the particles the suspended portion. This author makes the general

statement that the water content of the soil links its physical and chemical properties together, granted that the soil structure controls the water content. He recognizes also that any one soil may vary in its physical properties according to the shallow or deep layers. This led him to propose a humidity-coefficient for use in the classification of soils.

Pearson (48) on the other hand maintains that the tests of wilting of southwestern evergreens indicate no large difference in the pulling power upon the water of the soil. He thinks this pull depends somewhat upon the osmotic value and the ability of the seedling roots to reach moisture. Bates (5) lists the relative amounts of water the average tree will absorb per ounce of dry wood increment: limber pine 1000; western yellow pine 900; bristle-cone pine 800; lodgepole pine 725; pinon pine 680; Douglas fir 550 and Engelmann spruce 450.

Joffre (34) explains the formation of podzol in the following way: under conditions of sufficient or excess moisture the organic acid together with the carbonic, nitric and perhaps the sulphuric acid act on the mineral constituents and dissolve the bases. Finely divided organic substance in colloidal states are also active. Aerobic conditions usually exist and the iron probably moves as a sol protected by organic colloids. As a result of leaching of the bases the horizon of illuviation becomes enriched with electrolytes which cause precipitation of the iron and aluminum. These latter serve as a cementing material for incrustation. This process is responsible for the grayish white

horizon just below the layer of humus accumulation.

Falckenstein (19) concludes that site quality in the forest, which includes the relative height and rate of growth of the trees, with the resulting modification of site factors, is definitely related to nitrogen content. He gives for the best site quality 1,044 pounds of total nitrogen per acre and for the poorest site only 225 pounds per acre. The better sites show more properly decomposed humus and the poorer sites show less. The matter of nitrogen relation to height growth of forest trees has also been demonstrated by Hicock et al. (33). Waksman (59) reports that when large amounts of non-nitrogenous organic compounds such as sugars and hemicelluloses are present with the organic materials the microorganisms which decompose these rapidly combine any available nitrogen which may be present. Ammonia and nitrate-nitrogen that are present in the soil at any one time are dependent upon several other conditions such as temperature, moisture and aeration.

Fisher (21) states that the presence or absence of an abundant supply of combined nitrogen in the soil does not exercise an appreciable influence upon the nature of the organisms concerned in the decomposition of cellulose in the soil; that in the acid soils under aerobic conditions fungi are the only agents active in the decomposition of cellulose. He believes that in neutral or nearly neutral soils the moisture factor is most important in determining the nature of the organisms which

develop and that the activities of actinomycetes are limited to dry soils, as their slow growth does not enable them to compete with bacteria or fungi in wet or humid soil. His results show that in neutral or very nearly neutral soils the optimum moisture is 60 to 80 percent of saturation and that under these conditions the bacteria are probably as active as the fungi.

Fowers (22) reports that the amount of nitrification in forest soils is stimulated by burning and the resulting liberation of basic ash materials which increase the soluble mineral nutrients for some time after burning. However, since the burning destroys the top and surface organic matter, repeated and continuous burning is harmful. Hosselman (32) attributes the successful regeneration of spruce in Sweden to increased nitrification resulting from forest fires. In pure coniferous forests the heavy raw humus renders the electrolytes immobile and creates high acidity in the upper layers. This is unfavorable for bacterial activity and results in decreased nitrification. The release of these substances from the ash in the form of soluble salts after fire assists nitrification.

Barnette (2) concludes that there is a higher replaceable calcium content of soils on burned areas which may be attributed to the addition of ash following fires. It is probable, he continues, that the quantities of potassium, phosphorus, and other ash constituents are likewise somewhat increased by burning. A low pH concentration on burned areas is also believed to be caused by the addition of ash. He also states that burn-

ing seems to injure the colloidal properties as well as the physical properties and alters the chemical properties, but not below the four to six inch depths. Hackmann (26) discredits the value of nitrogen, lime and potassium fertilizers for forest soils and states that phosphorus fertilizers have greater value, basic slag being particularly effective. The phosphoric fertilizers, he maintains, give best results on soils with pH values from 4.5 to 6.5.

According to Fehér (20), the CO₂ production of the forest soil directly affects the forest air. The CO₂ production is attributable in large measure to the activity of microorganisms and is increased when aerobic forms of bacteria predominate. This presupposes suitable soil aeration.

By analysis of a great number of soil samples within the forests of the Schwarzwald, Frank (23) determined that the north exposures are more acid than south or west exposures and that ridge tops at higher elevations are more acid than adjoining low sites. Extreme alkalinity or acidity are both unfavorable for the germination of evergreen seeds. Soils with a pH of 3.7 to 4.5 are, according to Wilde (61), correlated with black spruce, tamarack, and hemlock and their associates. These trees may be termed acidophilous. In such locations the toxicity caused by the presence of the ferrous ion, manganese and aluminum is too great for most trees. The more highly alkaline soils support southern hardwoods. Alkalinity in this case is caused by the unfavorable effect of the OH ions or the excess

of calcium or manganese.

Stichting (56) claims that the bases are necessary in maintaining soil quality; and that to improve the impoverished soils under consideration the acid must be removed and the missing ingredients added. Schütze (53) demonstrated that in the German forests phosphorus, calcium, manganese, potassium and sodium all increase in quantity in the soils on the better sites.

EXPERIMENTAL

Location of the Study

The Priest River Experiment Station is situated in the panhandle of northern Idaho, in the north and south trending Priest River Valley within the Kaniksu National Forest. The general elevation of the valley floor at this point is 2300 feet above sea level. On the west side the hills are less than two miles distant and rise about 2000 feet above the valley; on the east side the divide rises to a total elevation of 6000 feet and is four to five miles distant. The region is uniformly covered with dense forests except for a few natural meadows on the eastern ridge and some scattered patches of cleared land on the main river and tributaries.

In this region the different forest types occur in altitudinal zones, beginning with a lower belt of western yellow pine, Pinus ponderosa Laws., which in places may reach an elevation of 4000 feet. This type, which may be considered a consociation, usually gives way at the upper border to the cedar-hemlock-grand fir association which always carries abundant western white pine. These trees in order from the yellow pine to those of the more mesic conditions are: (1) Pinus monticola D. Don., (2) Abies grandis Lindl., (3) Thuja plicata D. Don., and (4)

Tsuga heterophylla Sarg. According to local variations in the soil or aspect three other species are associates in the cedar-hemlock-grand fir association. These are western larch, Larix occidentalis Nutt., Douglas fir, Pseudotsuga taxifolia (Poir.) Britt., and Lodgepole pine, Pinus contorta var. murrayana Engelm.

At an elevation of 5000 to 6000 feet this characteristic association is superseded by the subalpine forest association consisting of Engelmann spruce, Picea Engelmannii Engelman Mountain hemlock, Tsuga mertensiana Sarg., alpine fir, Abies lasiocarpa Nutt., and white bark pine, Pinus albicaulis Engelm.

In composition the western yellow pine is comparatively pure, especially on the most severe sites. It may be associated with Douglas fir and lodgepole pine and even western larch on locations with more soil moisture. Within the intermediate belt the western hemlock and the cedar are the most shade enduring and permanent species, while Douglas fir, western larch, grand fir and western white pine are temporary. The white pine occurs chiefly on the northerly slopes, moist benches and flats and the larch on sandy bench land or on lower slopes. Douglas fir grows more often on steep slopes. The Engelmann spruce and alpine fir are sometimes met with along the cool creek bottoms or deep sheltered valleys.

From the standpoint of this report the investigation centers around the successional stages which take place within the central belt and the progression toward the final climax,

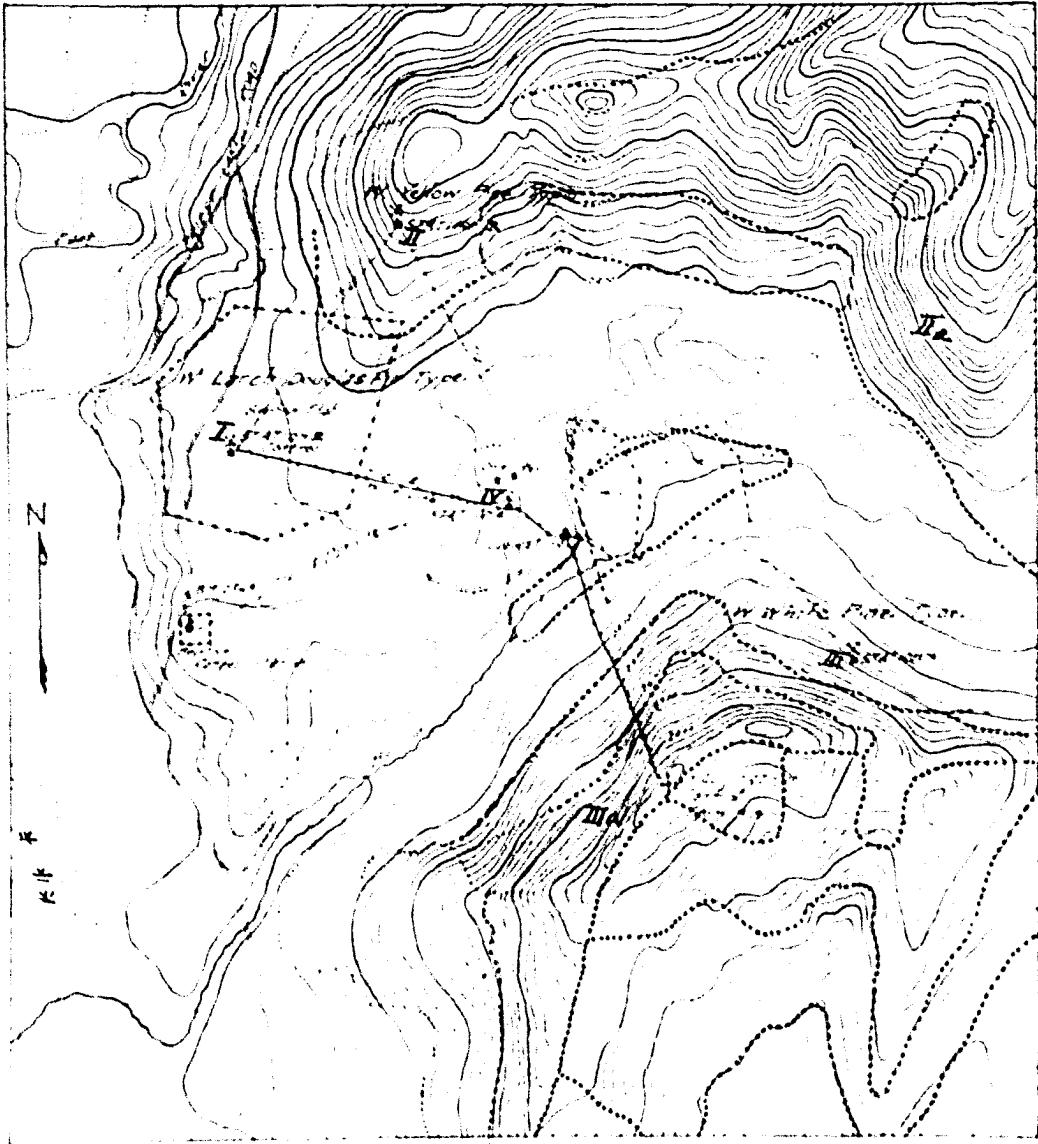
the cedar-hemlock association.

Selection of the Stations

Three main meteorological stations were used in this study: Station I, on the flat in the larch-fir type; Station II, on a southwest aspect in western yellow pine; and Station III, on a northeast slope in a forest composed principally of white pine. There were substations with shorter records: No. IV, on a low flat in the cedar-hemlock-white pine type; IIa, b and c, on steep phase exposed yellow pine sites; and IIIa on a steep northwest slope in Douglas fir. (Figs. 1, 2 and 3)

The station on the flat (Fig. 2a) which was used as a control for the others was placed within a clearing made partly by fire and by axe on a sandy bench approximately 100 feet above the main river. This plain has been formed by glacial lake deposits composed chiefly of granitic sand. The land was burned over twice about 70 and 40 years before the inauguration of the experiment and has since been slowly restocking with native trees, chiefly western larch. The earlier fire killed the mature timber and the later one cut big holes in the second growth. Much of the dead and down larger material had been removed for fire wood, and when the experiments were begun the remnant of debris was removed in order to have room for the station and the various planting tests. Some shrub vegetation had gained a foothold subsequent to the fires, the principal species being Mount-

Fig. 1. Station locations, topographic and forest type relations at Priest River Forest Experiment Stations, Kaniksu National Forest in northern Idaho.



Legend



Western white pine



Douglas fir



Western yellow pine



Natural meadow



Larch-Douglas fir



I-IV Weather stations



Fig. 2a. Priest River Valley and Benton flat; location of Station I, looking south from Station II, SW slope.

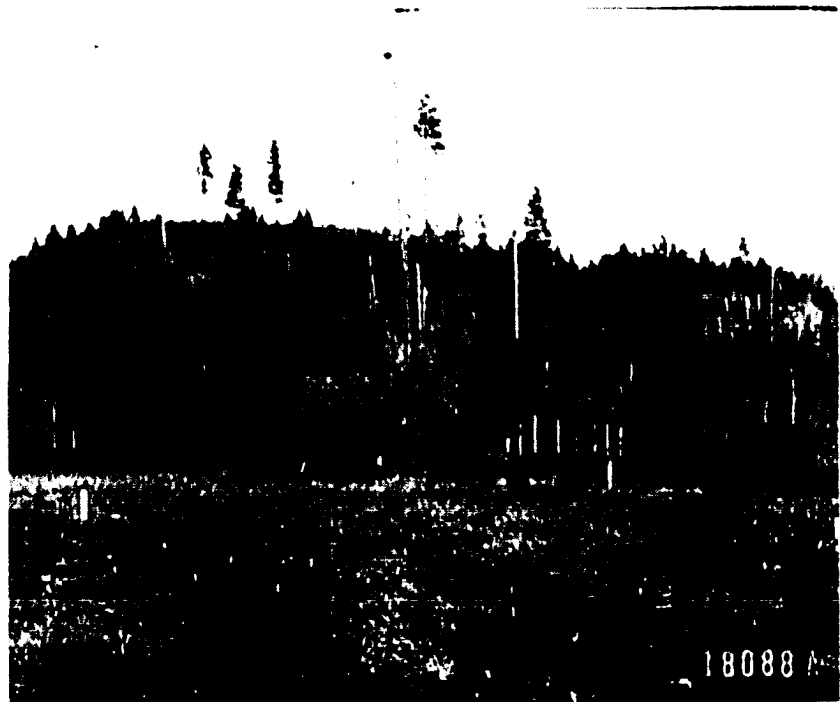


Fig. 2b. The southwest yellow pine aspect (Station II) in the background. The view is from Benton flat.



Fig. 3a. The location of Station III in a clearing, in the young timber on the northeast aspect.

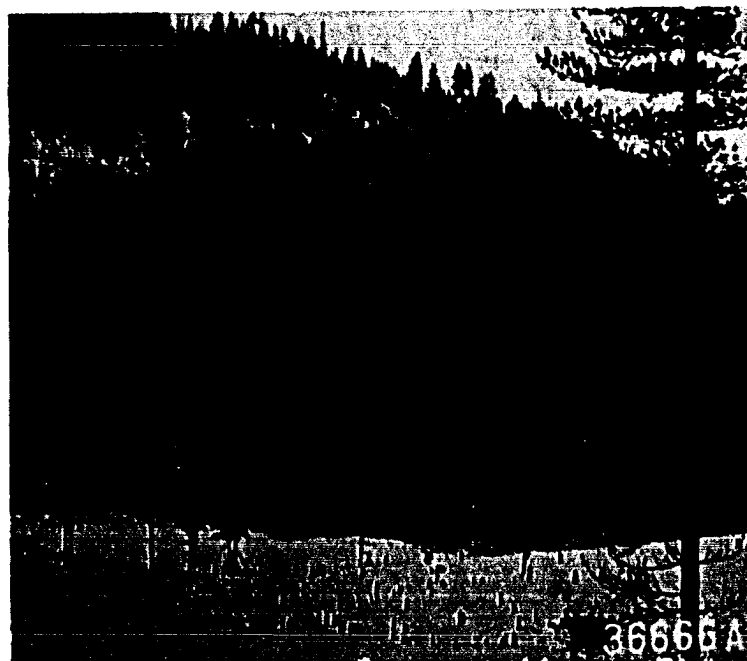


Fig. 3b. The location of Station IIIa. on the Douglas fir slope above the experiment station office.

ain balm, Ceanothus velutinus; Kinnikinnik, Arctostaphylos uva-ursi; ninebark, Physocarpus malveceus; June berry, Amelanchier alnifolia; Spiraea lucida, and Goat brush, Pachystima myrsinitis.

Station II is on a medium-steep southwest aspect directly north from the flat. (Fig. 2b) The forest consisted chiefly of mature, but very scattered, trees of western yellow pine and a younger understory of mixed yellow pine and Douglas fir, the fire history, destruction and later restocking, having developed along the same lines as on the flat. In addition there existed many clumps of shrubs, chiefly of willow, Salix scouleriana; ocean spray, Holodiscus dumosus; mountain balm, Ceanothus velutinus and C. sanguineus; mock orange, Philadelphus lewisi, and ninebark, Physocarpus malveceus.

The trees and shrubs combined would constitute a top-cover of about 50 percent, but of irregular occurrence. In the sub-dominant layer were pine grass, Calamagrostis suksdorfii; alum root, Hesperis bracteata; Oregon grape, Berberis aquifolium; Indian paint brush, Castilleja nictotata, and Lupine, Lupinus ornatus, etc.

The fires and the exposure to sun and wind typical of western slopes had reduced the humus layer and favored leaching of the soil. This had resulted in the appearance of shaly fragments near the surface and the absence of any appreciable amount of dark or loamy soil in the A horizon.

The slope reserved for Station III is on a 60 percent

northeast aspect across the valley of Bonton Creek to the east from Station II. (Fig. 3a) The crest of the secondary ridge is 600 feet above the main valley bottom. There was present on this slope a well developed 70 year old stand of western white pine, with some western larch, and other species. Toward the top of the ridge the stand was chiefly Douglas fir and from the middle slope downward there was an understory of cedar and hemlock. Evidently the second fire, which 40 years previous had caused destruction in the second growth on the flat and on the southwest slope, did no damage whatever on this site.

On this gradient the soil was 12 to 18 inches deep and loamy with a thick layer of humus and dead needles but with abundant angular shale fragments which no doubt have become mixed during periods of soil slipping. The reddish brown soil rested directly on a bedrock of shale.

Only under the trees where the light was much reduced were found various sub-dominant evergreens such as Twinflower, Linnaea americana (borealis), Cornus canadensis, Gold thread, Tiarolla trifoliata, Clintonia, Clintonia uniflora and Wintergreen, Pyrola bracteata. On this aspect there was no natural clearing and no shrubby association developed. A one-acre clearing in the young forest was therefore made. (Fig. 3a)

By means of these three locations representative sites were available for the installation of meteorological instruments, soil sampling and the seeding and planting tests.

The sub-station IV was on a bench having the same eleva-

tion as the flat referred to but nearer Benton Creek. For that reason the soil was silty and of a rather heavy texture and quite different from that at Station I. In contrast to the forest at Station I, western white pine predominated with the usual understory of cedar and hemlock. From the remaining dead trees and from the down timber it was concluded that the original stand previous to the early fire had been composed of mature white pine with considerable cedar and hemlock. The second fire had caused no damage. During the erection of the station buildings, 1911 and 1912, the second growth stand was removed exposing an area of about three acres.

In the course of this study observations were made during the growing season of 1915 at another point where the site appeared more extreme than on the southwest aspect, namely at IIA on a steep westerly slope. During 1915 records were also obtained at IIIa in pure Douglas fir second growth on a steep northwest aspect on the same secondary ridge but south from Station III. (Fig. 3b) When the final soil samples were collected in 1932 each one of these sites was represented and several additional locations chosen for sampling.

Methods of Study

Determination of factors.

The meteorological equipment used conforms to that employed

by the United States Weather Bureau. At each station there were placed maximum and minimum thermometers of the standard make, a Robinson cup-anemometer and one air thermograph. A standard sling psychrometer was used at all of the stations. The stationary instruments were housed in a shelter of the standard pattern four and one-half feet above the ground. Each station was also provided with soil thermometers of the maximum and minimum type at the surface, and soil thermometers for readings at six and twelve inches below the surface.

In addition to this equipment the station on the flat, which served as control station, was provided with instruments for the automatic recording of rainfall, sunshine and wind by means of a two-magnet meteorograph placed in the office. Records were also kept on cloudiness, amount of new snow each day and the depth of snow on the ground. The readings of all the factors were made according to mountain time at 5:15 p.m. on the northeast slope; 5:45 on the southwest, and at 6:00 on the flat.

Climatic factors.

Light. The duration of sunshine was obtained by means of an electric contact mercurial recorder at Station I. These records have been continued during the entire life of the Experiment Station, but since only one site is thus represented and because sunlight, or atmospheric illumination, whether direct or diffused can play only a minor role in the allocation of the

species in which we are interested, no great effort was made to press the matter of obtaining continuous records. The observations within the plant communities were confined merely to a few tests by the means of the Clements Photometer during the growing season of 1913.

Air temperature. Air temperature records were obtained at each of the three main stations during the entire five years and at station IV from 1914. At the other points, IIA and IIIA, they were obtained only during the growing season of 1915. The thermometers used were of the Weather Bureau pattern manufactured by Henry J. Green and the thermographs were the bi-metallic type of Julien P. Priez. The thermograph was checked and the record marked to indicate the time of reading. Corrections in the totals and averages were also made each month in accordance with the correction listed for the individual thermometers.

Although all of the hourly records for the entire five year period have been tabulated, the unavoidably voluminous data are largely omitted from this thesis.

Precipitation records. The measurements of precipitation embraced records of rainfall and snowfall and the depth of snow on the ground each day during the season of snowfall. Rainfall records were obtained by means of the standard United States Weather Bureau gauge located one at each station. At the time

of snowfall the melted portion was measured in the same manner as the rainfall and the unmelted portion was carried into the laboratory where it was melted and carefully measured. Now snow on the ground was measured with the rainfall scale on a canvas mat laid flat on the ground which was cleaned off after each record of new snow. The accumulated snow on the ground was read on the vertical United States Weather Bureau scale permanently located at each station.

At the control station on the flat a large Marvin shielded rain and snow gauge was in use, which was provided with a spring scale for weighing the amount of rain or snow for each day. By means of an electric tipping bucket connected with the meteorograph an excellent check was obtained on the duration and intensity of precipitation.

Relative humidity. All records of relative humidity were obtained by means of the United States Weather Bureau standard sling Psychrometer. The muslin on the wet bulb was renewed when soiled. Since the elevation of the control station was near 2300 feet above sea level, the pressure column for 27 inches was used in arriving at the relative humidity. No hygrographs employed at any time. Naturally the low humidity readings which are obtained in the afternoon and the evaporation records carry a much greater significance than readings for the morning hours when temperatures are low and humidity high.

Wind movement. Wind velocity data were obtained with the Robinson cup anemometer mounted nine feet above the ground at each station. At the control station an electrical connection was made to the office meteorograph, but the hourly tabulated records are omitted because there are no comparisons with the other two sites.

Evaporation. The evaporation records were not begun before 1914. During the season of 1915 and 1916 measurements were made of evaporation from free water surfaces. In 1915 these were set at all the six stations; but in later years only at the three principal points. In the middle of the summer of 1916, the Livingston porous cup atmometers arrived and were set up so that the subsequent data are mainly those obtained by this instrument. A comparison of the two methods was continued for some time during 1916.

The free water surface was that of an empty five-gallon gasoline can painted black and protected by one-inch poultry netting over the top. Each day the water levels were measured with the rain gauge stick and the water refilled to a line one inch below the edge of the can. The amount of rainfall naturally had to be considered in listing the total evaporation for the 24 hours.

Livingston porous cup atmometers were set in the ground to the neck of the jar and the cup itself was protected with

poultry netting. The round or black Livingston cups were not used at any time, as these had not been put on the market.

Edaphic factors.

Investigation on the character of the soil at the various stations includes analysis of the mechanical, physical, and chemical properties such as are ordinarily made in the course of soil laboratory tests at Iowa State College. In addition to these tests, measurements were made of soil temperature and soil moisture relations in the field during several growing seasons. In some cases, the temperature records of the soil were continued throughout the entire year.

The first tests of the soils at the different stations date back to 1915 and comprise the mechanical analysis. For this mechanical test the ordinary standard soil sieves were used. At this time physical tests were also made, but these have been discarded in favor of the more exact analysis in 1932.

Soil moisture. Percentages of soil moisture are all based on the dry weight of each sample obtained. The sampling was made by means of a geotome in the undisturbed soil during 1912, 1913 and 1914, and with the soil augers in the wells during 1916 and 1917. The depths represented are: surface inch; 1-6 inches; 6-12 inches. The cores of soil were removed from the geotomes and carried to the laboratory in screw-top one-half

pint aluminum cans. They were then dried in an oven to constant weight at temperatures not above 110°F. The samples were always taken in duplicate and at intervals of every seven days.

During 1915 and 1916 two soil wells were used at each of the three sites. These were 18 inches square and 18 inches deep. One of these was filled with sifted local soil, lightly tamped; the other with soil from the flat consisting of uniform sifted sandy loam. Each station had thus two soil wells; one of local soil and the other of common soil from the flat. The object in this was to obtain a closer comparison of the influence of the aspect as well as of the climatic factors on the loss of moisture from the soil. Soil removed from the wells for sampling was replaced with soil from the same source.

Soil temperature. The data on soil temperature were obtained by daily readings at the three main stations from the beginning of the growing season 1913 and continued until the end of 1916. Records were also taken at the sub-stations IIIa and IIa during the growing season of 1915. The points at which readings were made are: surface inch, 6 inches and 12 inches. Some records were also obtained during 1912 and 1913 at 24-inch depths.

Surface readings were obtained by means of the standard maximum mercurial and minimum alcoholic thermometers, the bulbs being set within the soil and the rest of the instrument covered with a cedar shingle.

For deeper readings, the mercurial thermometers were set in contact with the ground within 2x2 inch hollow wooden tubes in such a manner that the upper end was attached by a string to a wooden plug which closed the bore in the wood. For the 24-inch depth, permanently set soil thermometers were employed.

Some records for 6, 12 and 24 inch depths were obtained during the entire winter of 1915-16.

Soil sampling and testing. In 1932 soil samples obtained were sent to Ames where the writer made the tests according to standard usage.

At each point where soil samples were taken, a canvas was spread on the surface of the ground for mixing the soil. The upper layer of litter, duff and undecomposed organic material was removed and discarded. The spade was then thrust down to a depth of about eight inches, lifting the soil. This was then placed in a heap on the canvas. Here about 50 pounds of soil, taken from four separated pits, was thoroughly mixed with the spade. From this mixture a two-pound coffee can was filled, covered and expressed on the same day. Another smaller sample was obtained and put in the aluminum cans and tested for field moisture conditions.

The samples obtained are listed on the following page. In this list the first numbers refer to the site locations or meteorological stations, and the last set of numbers is a key to the soil type.

Location and description of soils tested in 1932.

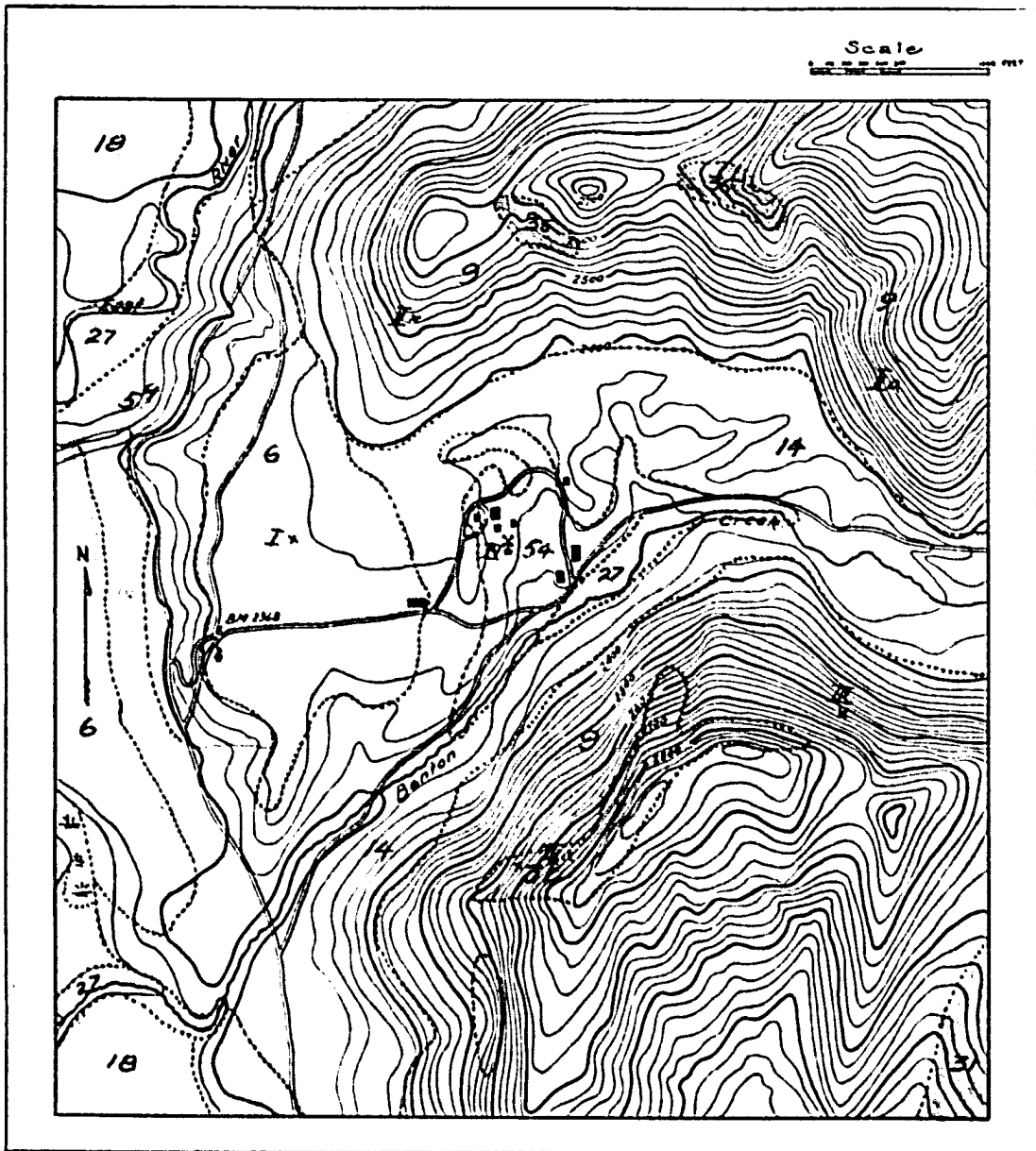
<u>Station: Map: :</u>				
<u>number</u>	<u>:no.:</u>	<u>Location :</u>	<u>Soil type :</u>	<u>Forest type</u>
I	6	Benton flat	Springdale sandy loam	Larch-fir
II	9	SW slope	Huckleberry fine sandy loam	Western yellow pine
IIa	9	SW slope	Huckleberry fine sandy loam (steep phase)	Western yellow pine
III	9	NE slope	Huckleberry fine sandy loam	Western white pine
IIIa	31	NW slope	" (stony phase)	Douglas fir
IV	54	Moist flat	Gray clay	Western white pine, cedar, hemlock
IVa	14	Low SW slope	Mission fine sandy loam	Larch-white pine
IVb	18	River bench	Loam	White pine, cedar, hemlock
V	-	Old River flat	"	" (loam)
VI	-	Rolling land	Sandy loam	Western yellow pine (old)
VII	"	Podzol	Mission fine loam	Western white pine

Organization of seeding and planting tests.

This part of the investigation was begun in 1913 by sowing seed of six different native evergreen species in duplicate series on the three main sites. At each of the three main stations there was one 4x12 seedbed with twelve sub-plots: bed A on the northeast aspect; bed C on the southwest; bed E on the flat. In each case the beds were placed in position to obtain the maximum possible light for that particular location.

Each unit experiment consisted of two sets of six plots which measured 2x2 feet or four square feet for each individual test or kind of seed. The six plots in one end of the beds

**Fig. 4. Soil types in the vicinity of the Priest River
Forest Experiment Station as related to topography
and points of sampling.**



Legend

- | | | | | | |
|----|--|--------------------------------|----|--|-------------------|
| 9 | | Huckleberry fine sandy loam. | 35 | | Loon sandy loam |
| 31 | | Huckleberry sandy loam, stony. | 27 | | No classification |
| 6 | | Springdale sandy loam. | 14 | | Mission fine loam |
| 54 | | Gray clay. | | | Swamp |
| 18 | | (No class.) River bench. | | | |

were located on natural undisturbed surface or without removing the grass or litter, while at the other end were six subplots where the vegetation was removed by burning. The burning was affected by piling and igniting brush and debris of local origin. It being well known that a great many seedlings begin their existence on newly burned surfaces in this region, and that some of the species seemingly succeed better on burned than on unburned ground.

Each subplot of 2x2 feet contained a definite number of seeds of the most recent and best quality available. Pre-germination treatment was given in order to insure as prompt germination as possible. The western white pine seed was soaked in the creek water for 72 hours and the seed of all other species for 48 hours. After this treatment all seed was immersed in tepid water for 48 hours.

When seeds were removed from the warm water, it was noticed that germination had begun in Douglas fir 33 percent, western yellow pine 10 percent, and western white pine 5 percent. There was no sprouting in case of any of the other species.

Once each week during the first summer after sowing, counts were made of germination and survival in each subplot. At this time the new seedlings were staked out with toothpicks having a special color for each month of germination. The seedlings which had died during the intervening days were removed

and the cause of death noted if determinable. Weekly soil moisture sampling was continued from the initiation of this experiment to the end of 1914, with other moisture determinations later.

Soil moisture samples at surface, 1-6 inches and 6-12 inches and soil temperature records were continued during the entire growing season of 1913 and of 1914 with biweekly observations on germination and survival of the plants. It will be noticed that the majority of the western larch and many of the western yellow pine and white pine seed germinated during the second growing season of 1914.

In the early spring of 1915 at which time and subsequently the adaptability of the seedlings to surfaces and sites would be expressed more by their survival and growth than by germination, each plot which showed survivors was thinned out to give the same number for all plots where possible and to provide equal spacing. This would for a time eliminate competition. From this time on spring, midsummer and fall counts and observations were made.

Planting tests were made on the three main sites during 1912, 1914, and 1915. These are described in Series A to D. All the planting was done by two-men crews, one man digging the hole with a mattock and the other setting and firming the plants carefully in the ground. Measurements and observations of the planted stock for survival and growth and causes of loss or damage were taken in the fall of the year in 1913, 1914, 1915, 1917, 1919,

and 1921. Twenty percent of the trees were measured for height growth.

Series A. Series A embraces four plots of 100 western yellow pine trees each set out in stations I and II during the spring of 1912. Four different age classes were used: 2-1; 1-1; 2-0, and 1-0. The stock was received from the Savanac nursery at Houghton, Montana, May 10, but as the site was not entirely ready for planting, it was heeled in until May 18 and 20.

Series B. Series B consisted of 1-2 western yellow pine stock graded into eight different size classes. These were planted in stations I and II in eight plots of 100 each during the spring of 1914. The trees were received from the Savanac nursery April 26 and were placed in the ice house until weather and soil were suitable for planting on May 20. When removed from the storage, growth had already begun.

Stock was raised from Bitterroot seed collected at 4000 feet elevation in 1911 and sowed at Savanac Nursery in the spring of 1912. Since the stock ran uniformly small in some bundles and large in others, it was necessary to select the grades from a run of bundles first and then fill those with the required number on each grade. These eight grades show the following proportions:

Grade	Percent of all	Select- ed from	Length of root	Total length	Diameter stem	New growth
		Percent	inches	inches		inches
1	5	0-5	7.76	11.3	2.1	0.6
2	5	5-10	8.6	12.8	2.6	0.9
3	5	10-15	8.1	12.5	2.6	1.0
4	5	15-20	8.2	12.9	2.6	1.0
5	5	20-25	8.4	13.9	3.2	1.1
6	25	25-50	8.3	13.8	3.5	1.0
7	25	50-75	8.8	15.4	4.0	1.2
8	25	75-100	9.6	17.0	4.9	1.3

Series 0. Eight grades of 2-0 and eight grades of 1-2 nursery-grown western white pine trees were planted in stations I and II planted in the spring of 1915. This made 1600 trees on each site. The spacing for all trees on both sites was strictly 2x2 feet. The 2-0 pines were from Kaniksu N. F. seed and therefore local, and the 1-2 trees were from Coeur D'Alene N. F. seed near Rose Lake, about 40 miles to the southeast. Grading was done on the basis of root length, total length and diameter of the stem. From each lot of stock a mechanical number, one in each five as they were counted, were saved for measurements and for photographing. In the table below are given only the smallest and the largest, as the other classes range in regular order in between.

Measurements in millimeters.

Class	2-0			1-0		
	Root length	Total length	Stem diameter	Root length	Total length	Stem diameter
Small	5.6	7.7	1.3	6.5	8.8	1.6
Large	8.6	12.4	3.3	10.8	14.9	3.7

Series D. This series embraces three plots of 3-0 and three plots 1-2 stock planted in station II, west slope; IIa, south slope; IIb and IIc, southeast slope, in the spring of 1915. Notes on the stock are as follows, (dated April 26, 1915): "The 3-0 western yellow pine (Bitterroot), sown fall 1911, Benton Flat. The seedlings were inclined to be tall and spindly. Heights varied from 8 to 16 inches, averaging 12 inches. Spring growth had just moderately started, the buds beginning to elongate. Length of new growth was 0.5 to 2.3 inches, averaging 1.4 inches. The 1-2 western yellow pine were from Bitterroot seed, sown on Benton Flat, fall 1911, transplanted to Meadow nursery, spring 1913; healthy vigorous stock with tops 4 to 10 inches, averaging $6\frac{1}{2}$ inches. The spring growth was moderately started; the average length of new shoots (0.5-3.5) was 1.5 inches. This stock was measured April 26 when taken up. It was stored in the ice house where little or no growth took place until date of planting, May 15, but underwent considerable breakage of the top terminals during the planting operation. The field plots were 100 x 50 feet at right angles to the slope, spaced 5x5 feet.

In September 1932 the author obtained final measurements on many of the plantations. Those on the three chief station sites were measured for each year's growth from 1932 to and including 1922. An effort was made to get at least 100 trees at each station, but since some of the trees in the planta-

tions were severely crowded, $2\frac{1}{2} \times 2\frac{1}{2}$ feet, only trees in dominant classes were included in the measurements. In some instances 100 representative dominant trees were not available as in case of Series A on the southwest aspect.

Results

The inclusion of the greater part of the accumulated data in the course of this study would produce an inordinately bulky volume. For this reason many of the tables originally prepared have been reduced. In this process the more essential or significant parts have been retained. It is the purpose to present the results as briefly and clearly as possible, taking up in order the climatic factors, the edaphic factors and the results of the seeding and planting tests.

The climatic factors.

Light. Since light was not considered one of the controlling factors in the allocation of the species by site or slopes very few light readings were obtained. Some observations made in the clearings with the Clements Photometer during the summer of 1913 are given below (Station I was used as the standard):

Date	Sta. I Flat	Sta. II SW	Sta. III NE
May 2	1.00	0.89	0.44
July 5	1.00	0.70	0.25
August 27	1.00	1.00	0.47
Standard	1.00	Aver. 0.86	0.38

These few records show that even in the clearing on the northeast aspect light is considerably reduced below that on the flat or southwest slope, averaging only 38 percent as much. Some readings were also obtained in the shade of shrubbery on the flat and southwest slope and under the young stands of trees on the northeast slope. These values referred to the same standard are in order 0.61; 0.61 and 0.03, with variations 0.30 to 0.80 on the flat; 0.70 to 1.00 on the southwest slope; and 0.02 to 0.05 on the northeast aspect.

It is expected that decreased light will reduce or retard growth of intolerant trees which happen to germinate and survive for a period on the northerly exposures, especially when mixed with more tolerant trees, and that seed production may be curtailed, under these conditions, even in case of the tolerant species.

Air temperature. The air temperature records have been summarized in Table I and are shown graphically in Figs. 5, 6 and 7. The data in Table I and Fig. 5 reveal that the maxima reach higher points on the southwest slope than at the other stations but that the flat is not far behind. The northeast slope takes the lower level in that there seems to be an absence of hot weather on this slope. Minimum temperatures show much less spread than the maxima and are appreciably lower on the flat than elsewhere. This has the effect that the greatest

temperature range occurs on the flat and least on the northeast slope. The absolute minima vary even more than the means of the minima; they are:-29.5 on the flat; -20.0 on the southwest; and -17.5 on the northeast. For these three stations in order the lowest monthly minima reached during the growth period were: 39.2, 43.4 and 44.2.

The thermograph records given in Fig. 6, plotted according to the two-hour periods in Table II, are of interest in showing the daily amplitude of oscillations for the three sites. They show also the time at which the highest and the lowest air temperatures occur. From December until February inclusive the high points of temperature for all the stations is about 4 p.m. but from this time onward the maximum on the northeast moves back to 2 p.m. and in August is highest at noon. The maxima at the other sites generally occur at 4 p.m. or from 4 to 6 p.m. This divergence in case of Station III is caused by the fact that the sun rises more and more to the north in summer and its rays meet the northeast aspect during the forenoons. At the other stations the extremes of temperature, wind and relative humidity coincide more closely.

Table I. Summaries of maximum and minimum air temperatures. 1912-1916.

Datum	:Period:	:Station I; Station II; Station III		
		: Flat	: SW slope	: NE slope
Averages of monthly maxima	Growth	73.5	74.5	70.0
	Rest	42.5	43.7	41.8
Averages of monthly minima	Growth	39.2	43.4	44.2
	Rest	22.0	25.5	25.9
Means	Growth	56.2	58.9	57.1
	Rest	32.1	34.9	32.9

Table I. Concluded.

Datum	Period	Station I	Station II	Station III
		Flat	SW slope	NE slope
Average annual range		26.2	23.6	18.9
Absolute maxima		97.0	99.0	95.0
Absolute minima		-29.5	-20.5	-17.5
Extreme range		126.5	119.5	112.5

Table II. Days having specific air temperature.

		Freezing: :32°F.	Cold :	Cool :	Moderate: :	Warm :	Hot :Above
		and less:32.1-40;40.1-50;50.1-59.0;59.1-72.0;72.0					
Rest Per-							
iod Oct. I	87.4	68.7	45.2	5.7	0.0	0.0	
to Apr. II	79.4	65.7	54.8	12.4	0.0	0.0	
incl. III	92.0	66.4	47.8	6.2	0.0	0.0	
Growth							
period I	0.0	1.2	30.6	59.6	59.8	1.8	
May to II	0.0	1.2	21.8	55.0	66.6	8.4	
Sept. III	0.0	2.0	32.4	61.0	56.4	1.2	
incl.							
Year							
I	84.4	69.9	75.8	65.3	59.8	1.8	
II	79.4	66.9	70.6	67.4	66.6	8.4	
III	92.0	68.4	80.2	67.2	56.4	1.2	

Typical seasonal amplitudes are shown in Fig. 7. There is naturally a greater diurnal fluctuation in summer than in winter, but these curves show that the oscillations are much more pronounced on the flat than elsewhere and that the drop in the minima from midnight until the low point is reached in the morning is practically identical and much less sudden for the two slopes than for the flat. During the colder months and particularly at time of cloudy weather the tendency of the temperature curves is to converge and coincide.

In order to learn how the air temperature differences

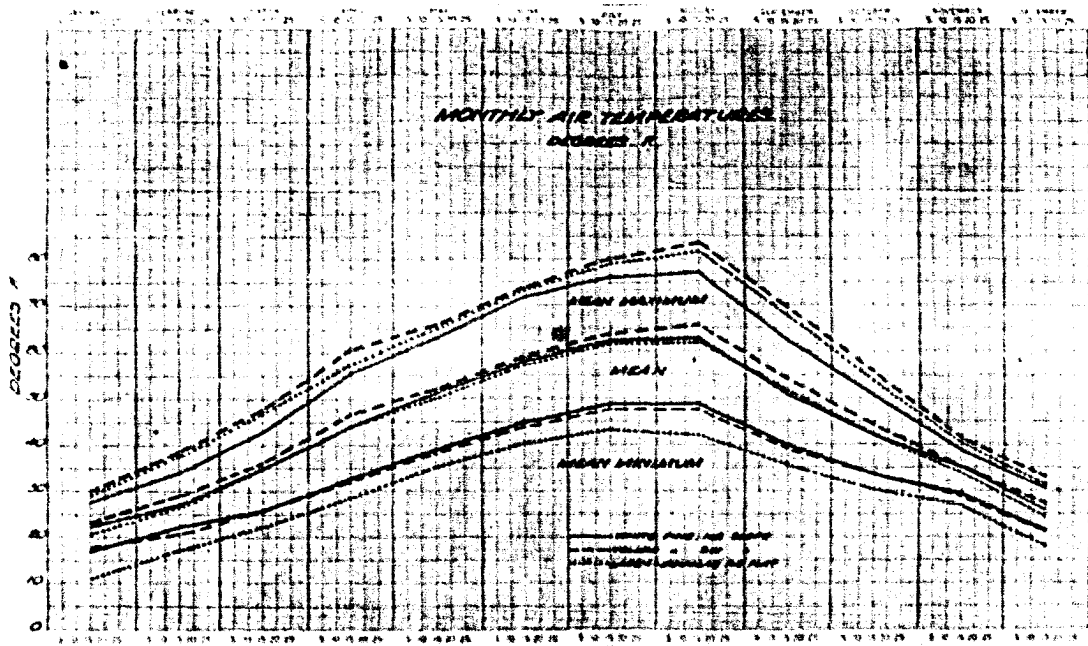


Fig. 5. Maximum and minimum air temperature in degrees Fahrenheit for the three stations, 1912-1916.

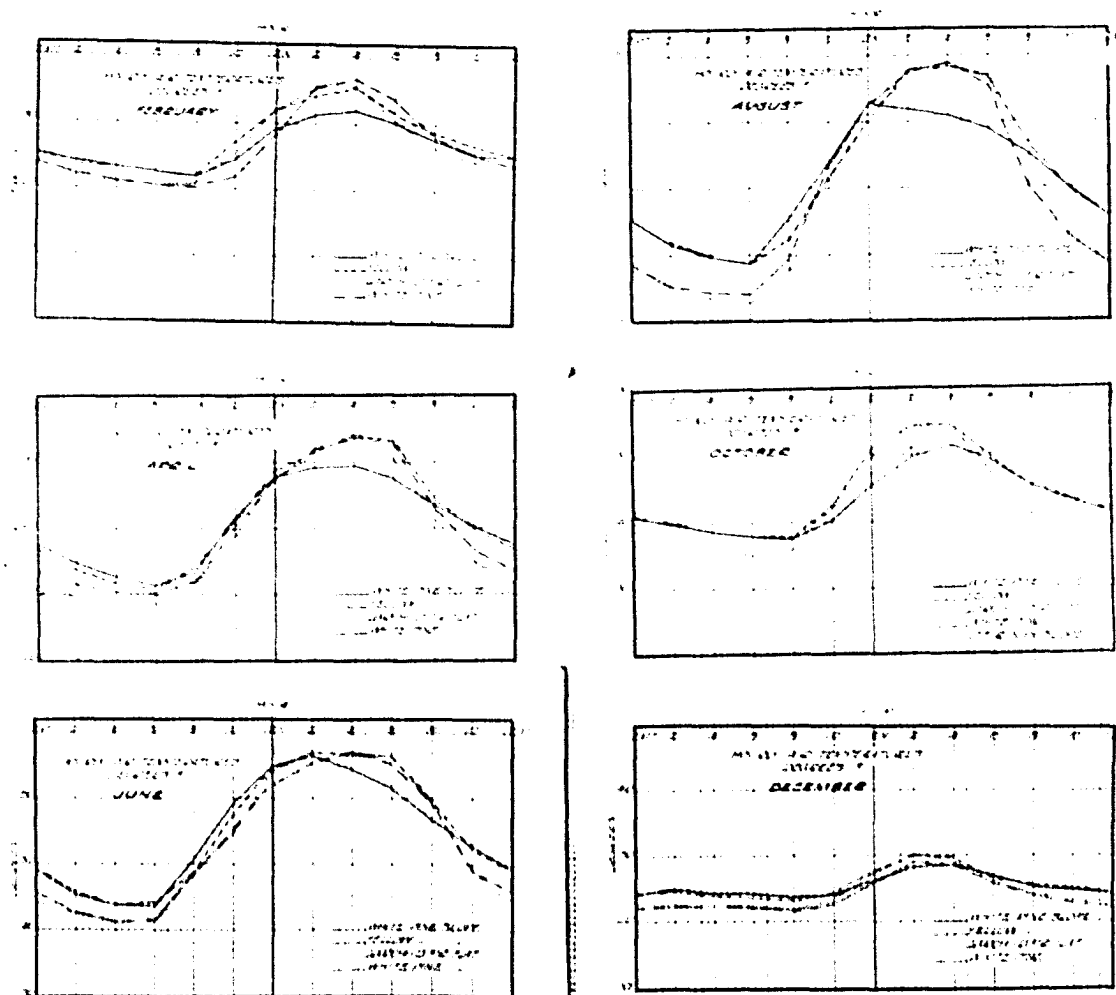


Fig. 6. Diurnal temperature oscillations plotted from thermograph records of the sites, 1912-1916.

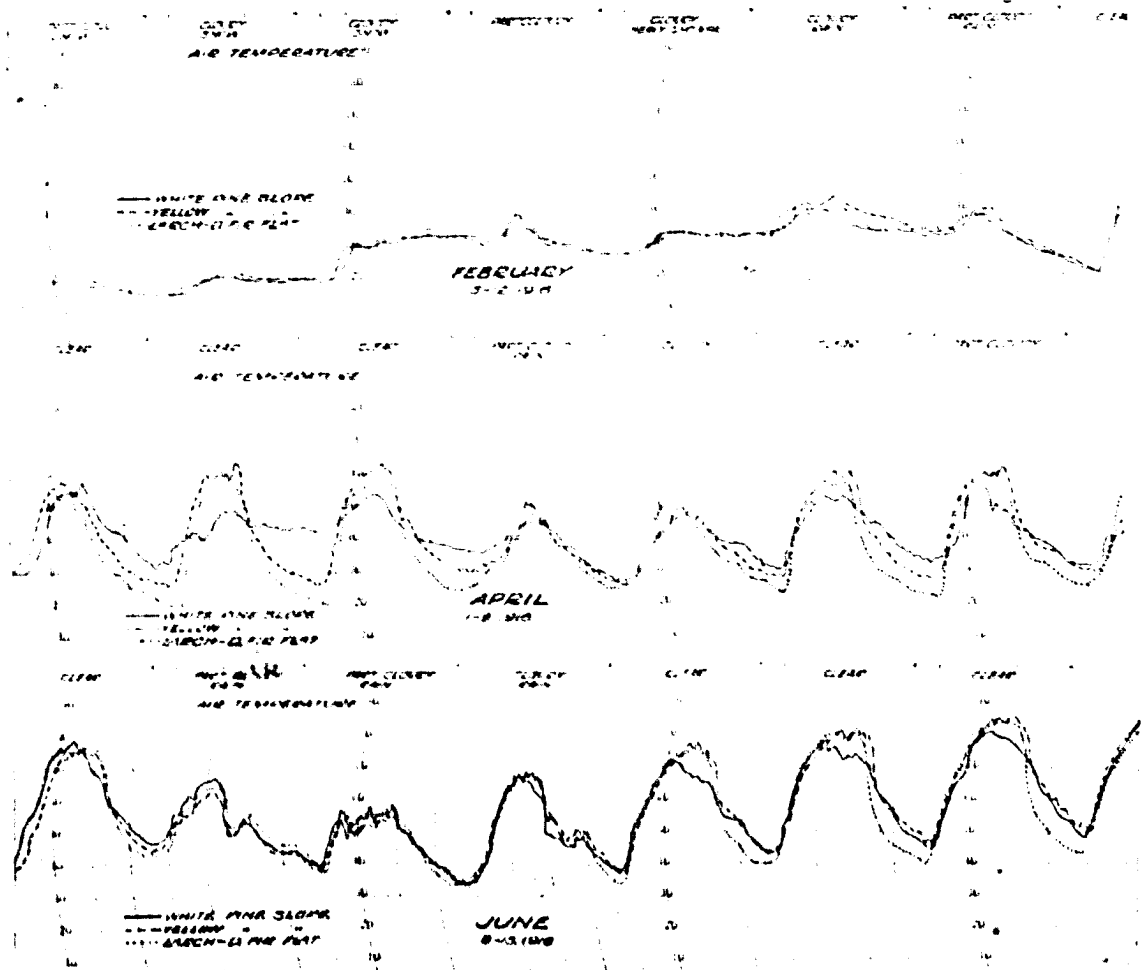


Fig. 7. Comparison of typical thermograph records from the three stations for representative periods.

affect the periods of warm, hot or cold days on the several sites each day having specific air temperatures of 32°F. and below, 32 to 40.0, 40.1 to 50.0, etc., was selected. (Table II) In this manner it was found that there were from six to seven more warm as well as hot days on the southwest slope than on the flat; no warm or hot days (above 59 and 72°F.) whatever on the northeast, and 13 more freezing days on the northeast than on the southwest slope. This comparison is based on the averages of the maxima and minima and therefore does not express the differences as accurately as it would if it were based on readings at two-hour intervals.

However, we find, from the thermograph records, tabulated in hours of temperature above 43°F., that the southwest slope actually has 70 more hours of effective temperature than the flat and 75 more than the northeast slope.

In this region, frosts have occurred during every month in the year, July and August not excepted. No frost damage to the native vegetation has been noted during the summer months and only the tender shoots of Douglas fir and western white pine have shown injury by freezing on the flat in the spring. It was found well nigh impossible to establish Douglas fir plantations on the unprotected flat, because of frost injury of the tender shoots. The effect is the formation of numerous stool shoots and no real advance in growth. The white pine plantations showed frost injury during the spring of 1918 only, an unusually dry and cold season.

Precipitation. The precipitation records are listed in Table III, and the depth of snow in Table IV. In Fig. 8 are given depth and period of snow cover for the different sites.

By reference to Table III we learn that there is very little difference in the total precipitation between the three sites. The average annual for the flat is 33.2 inches, for the southwestern slope 31.1 inches, and for the northeast slope 33.9 inches. There is less difference between the sites in the summer months than in the winter, and the greatest variations occur in November and March, during the windiest months, and at a time when much of the precipitation occurs as snow which is carried about by the wind, swept hurriedly past the most exposed places at a low angle to the rain gauge, and settled in eddies on the leeward slopes. The summer differences are chiefly caused by the wind and are possibly augmented by evaporation. Since these differences are very small, and since sufficient moisture falls on all three sites to maintain a good stand of western white pine, if other factors are favorable, it is evident that precipitation is not the controlling factor. It is, however, of great importance in indicating that we may expect to find even greater differences in the amount of precipitation in more mountainous country, where topographic features are on a large scale.

The five-year record in Table IV and Fig. 8 shows that

Table III. Average precipitation for a 12-month period, based on five years' data, 1912-1916.

	: Total precipitation (inches)		
	: Control	: flat	: SW slope : NE slope
WET PERIOD			
October	2.8	2.6	2.8
November	5.6	5.3	5.7
December	2.9	2.7	3.1
January	4.2	3.9	4.2
February	2.4	2.3	2.5
March	2.6	2.4	2.7
April	2.1	2.0	2.1
Average	22.6	21.2	23.1
GROWTH PERIOD			
May	2.7	2.5	2.7
June	2.6	2.5	2.7
July	2.1	1.9	2.1
August	1.0	0.9	1.1
September	2.2	2.1	2.2
Average	10.6	9.9	10.8
Year	33.2	31.1	33.9

Table IV. Average depth of snow at the three stations for the five year period, 1912-1916.

	: Depth of snow on the ground in inches		
	: Flat	: SW slope	: NE
	: Larch-Douglas fir	: Yellow pine	: Slope
October 15	0	0	0
October 31	0	0	0
November 15	1.5	1.5	2.2
November 30	8.4	5.5	8.8
December 15	9.3	5.5	9.4
December 31	18.1	9.2	19.1
January 15	25.1	18.5	27.0
January 31	27.3	16.9	27.8
February 15	26.8	16.5	30.1
February 28	24.2	6.1	24.8
March 15	18.2	0.3	21.3
March 31	7.2	0	12.7
April 15	0	0	1.0
April 30	0	0	0
Average	11.8	5.7-52 %	13.2-112%
Length of snow cover (days)			
Average	128	107	141
Maximum	147	133	154
Average date of disappearance of snow cover			
	March 24	March 8	April 6

Duration of Snow Cover

		Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	April	
1911-12	Flat							147 days	
	SW slope							133 "	
	NE slope							154 "	
1912-13	Flat							132 days	
	SW slope							106 "	
	NE slope							130 "	
1913-14	Flat							125 days	
	SW slope							109 "	
	NE slope							130 "	
1914-15	Flat							126 days	
	SW slope							91 "	
	NE slope							126 "	
Average	Flat							132 days	
	SW slope							110 "	
	NE slope							139 "	

Fig. 8. Duration of snow cover on the larch-fir flat, southwest yellow pine slope and northeast white pine slope, 1911-1915, inclusive.

there is very little difference in the time of appearance of the snow cover on the different sites. Often the first snow remains on the ground both on the northeast and the flat, but melts on the southwest slope. In the spring, however, there is a fairly constant time interval in the date of disappearance of the snow cover on the three sites. The average date for the southwest slope is March 8, for the flat; March 24, and for the northeast slope, April 6. The duration of the snow cover on the northeast slope is 141 days, on the flat 128 days, and on the southwest slope only 107 days. This difference in time of melting varies somewhat according to the depth, the time of the last snowfall, and the character of weather, whether sunny, cloudy, or rainy, but is in the main directly attributable to the difference in air temperature, wind movement, and degree of insolation received on the three sites.

From the data on depth of snow in Table IV we discover three successive periods: that of accumulation, that when evaporation and melting equals the precipitation, and that of melting. The first period ends January 15, and up to this time there are only slight differences in the depths of the three stations. The second period ends February 15. Following this date the difference in depth of snow on the northeast and the southwest slopes becomes greater.

Relative humidity. By reference to the graphs in Fig. 9 it is seen that the driest air is found on the southwest slope

and the most humid on the northeast. This holds true for averages and extremes, though differences in the minima registered on the southwest slope and the flat are very small. August marks the climax of the increasing dryness of the air with the progress of the summer. This month shows an average of 44.1 percent on the flat, 38.9 percent on the southwest slope, and 47.1 percent on the northeast slope. But the actual lowest monthly humidity, that is, the month of lowest average in any of the five years, indicates the relative site conditions more accurately than either the five-year averages or the absolute minima. These values are: larch-fir flat, 26.2 percent; southwest yellow pine slope, 23.6 percent, and northeast white pine slope, 33.0 percent.

It will be noted that the air on the flat is seemingly more humid in late fall and winter than on the other sites. This is not an actual condition, but is brought about by the later time of reading, at a time of the day when the relative humidity increases rapidly with a lowering of the temperature.

Wind. Wind velocities are given in Figs. 10 and 11. The results show, as would be expected, that the greatest air movement takes place on the southwest slope where the average per hour both winter and summer is 2.8 miles and the average maximum for any one day in winter is 5.3 miles and in summer 6.2 miles. This is approximately twice the movement on the flat

Relative Humidity

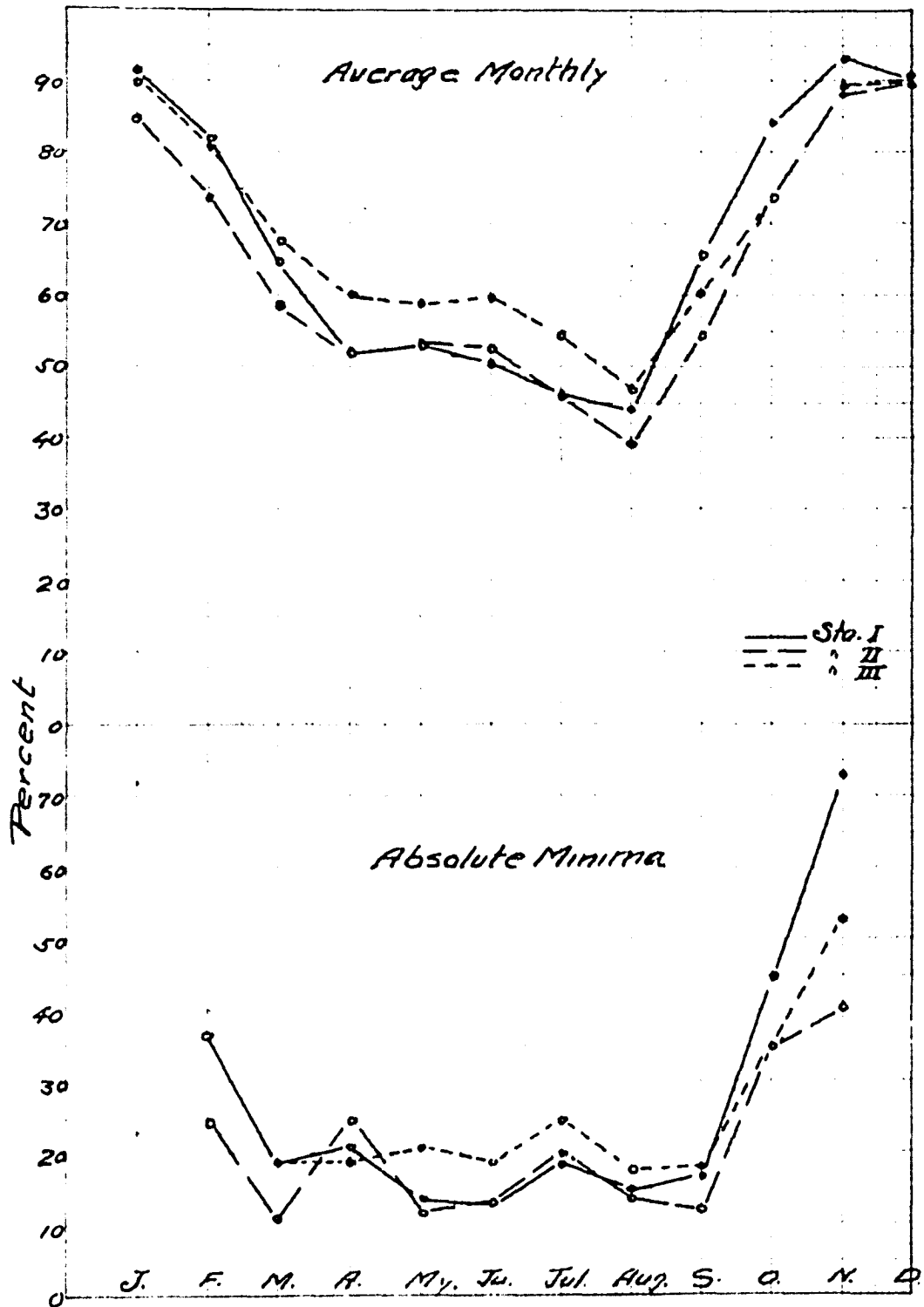


Fig. 9. Monthly average and absolute minima of relative humidities on the flat, southwest and northeast slopes, 1912-1915.

Wind Movement

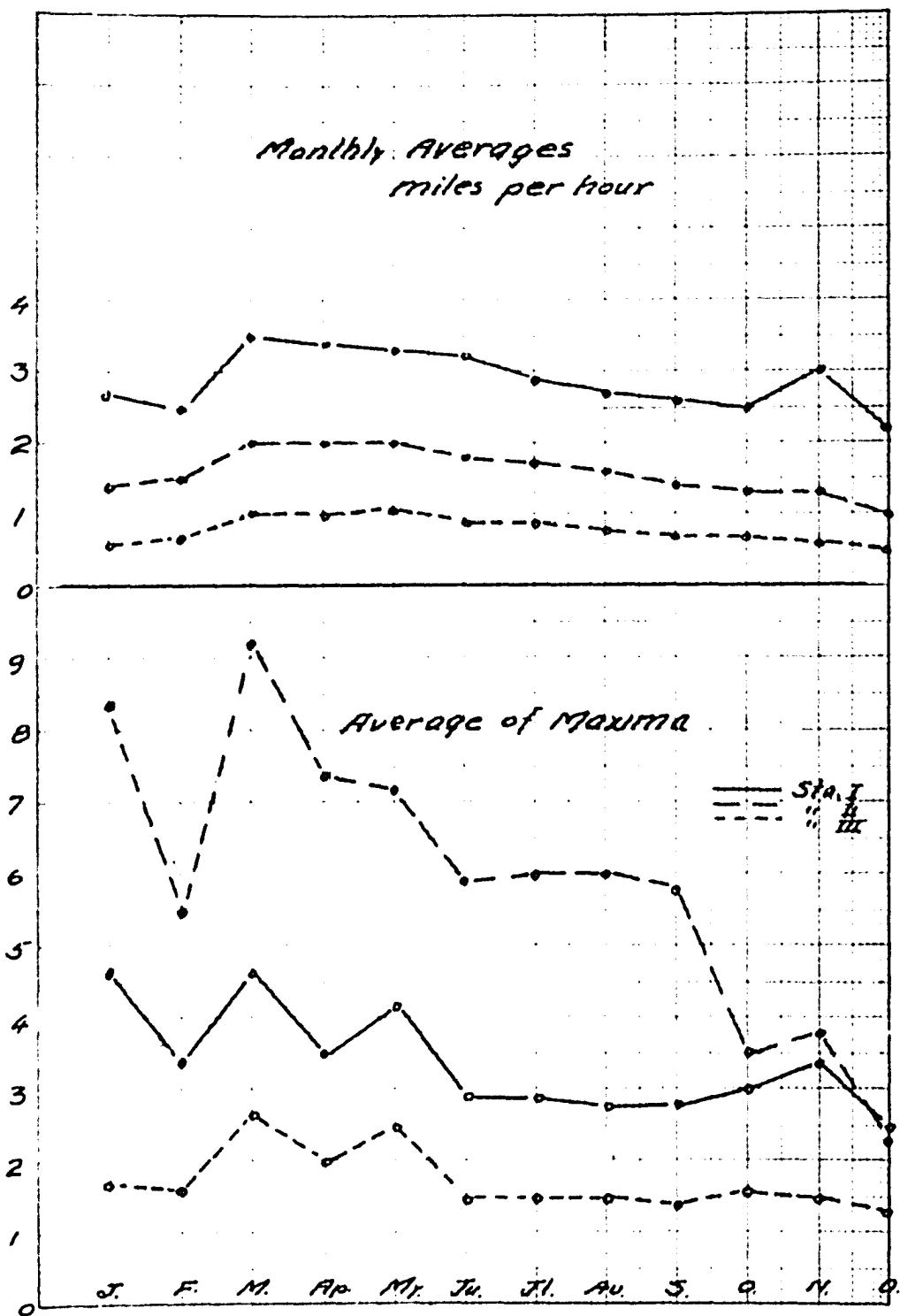


Fig. 10. Monthly average and maximum wind velocities for the flat, southwest, and northeast aspects, 1912-1913.

Average Wind Movement Curves 1912 to 1919 Inc.

Station on Flot



Fig. 11. Average wind velocities for two-hour periods during the growing season. Meteorograph record, 1912-1919.

and four times that on the northeast slope. The records show very little wind as compared with the other weather stations in the region; for the summer months Spokane shows 5.3; Kalispell 4.4; Helena 7.8; and Yellowstone Park 6.9 miles per hour.

Tabulated hourly wind records obtained on the flat and registered on the meteorograph are given in Fig. 11. These have no value for comparisons of the sites but illustrate the typical rhythmical rise of the wind during the day and drop at nightfall. The greatest velocities occur from 2 to 4 p.m., attaining average movement of 3.2 to 3.9 miles per hour at 2 p.m. and lowering to about one-half mile per hour at midnight or dawn. The sunshine, wind and moisture deficit of the air fluctuate in close harmony in this region, especially during the summer months.

Evaporation. The earliest evaporation records for these stations were obtained from free water surfaces and are, therefore, given in inches. In 1917 when the Livingston porous cup atmometers became available the records are in cubic centimeters.

Referring to the month of August 1916 Table V, we observe evaporation to the amount of 3.52 inches for the flat; 3.76 for the southwest slope and only 0.34 for the northeast aspect. The amount of water lost on the exposed slope is therefore 4.4 times that of the northeast. In terms of rainfall-evaporation

ratio we have 0.34 for the larch-fir flat, in August; 0.32 for the yellow pine slope; and 1.03 for the northeast white pine site.

Table V. Evaporation from a free water surface. 1916.

	: Total evaporation and rainfall in inches, by 15- : and 30-day periods		
	: Flat, I	: SW, II	: NE, III
June 3-30	3.19	3.94	1.71
Evaporation			
Rain	3.19	3.11	3.13
July 1-31			
Evaporation	4.03	4.48	1.78
Rain	1.66	1.49	1.83
August 1-31			
Evaporation	3.52	3.76	0.84
Rain	1.22	1.12	1.27
Sept. 1-30			
Evaporation	1.86	2.25	1.39
Rain	1.86	1.80	1.86

Evaporation from Livingston porous cup atmometer, cubic centimeters per day, 1917.

July 1-15	30.0		
July 16-31	29.3		
August 1-15	26.6	30.0	23.4
August 16-31	27.6	30.0	26.3
Sept. 1-15	12.0	13.1	10.7
Sept. 16-31	16.1	21.2	14.1

During 1917 also the greatest evaporation took place on the southwest yellow pine slope, and the least on the northeast white pine slope. (Table V) During August, the flat showed an average daily evaporation of 27.1 cubic centimeters, the southwest slope 31 cc., and the northeast slope 24.8 cc., which in terms of percentages are 32.5, 37.5, and 30.0. During September the decrease over August was about 60 percent, with the greatest reduction on the northeast slope, and the daily

Evaporation (Relative inches, cubic, Free water surface 1914)

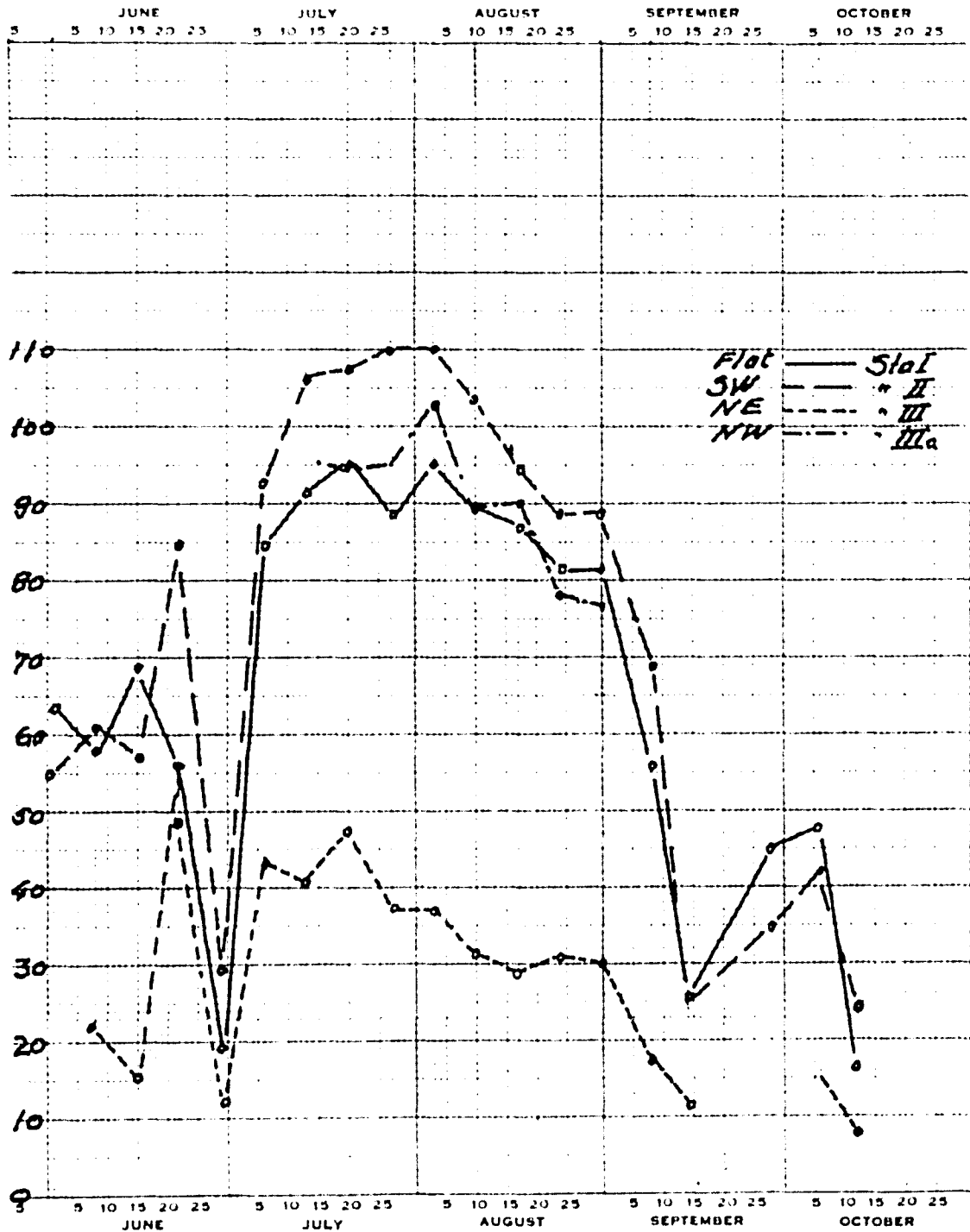


Fig. 12. Relative evaporation from free water surfaces at Stations I, II, III and IIIa, 1914. (Cubic inches per seven-day period).

rates were 14.1 for the flat, 17.1 on the southwest slope and 12.4 on the northeast slope. The amount of evaporation may be used to express solar intensities. Since it requires 1000 units of heat to vaporize one pound of water, we may express the relation between the three sites in calories according to the rate of evaporation. This will then be 123 calories per surface of the atmometer on the flat, 145 on the southwest slope, and 119 on the northeast slope. During September, this is reduced to 63, 77, and 54 calories.

Edaphic factors.

Soil types. The soil tests made in 1932 were correlated with the soil types distinguished and mapped in 1925 by H. H. Lapman and F. O. Young of the Bureau of Chemistry and Soils, United States Department of Agriculture, and the following is from their manuscript notes of 1925 in the Experiment Station files:

Along the Priest River, Benton Creek, East River and its south fork are low, poorly drained alluvial bottoms, comparatively narrow and of small extent. A little higher are terraces or flats of stream-laid or lake-laid origin. These are somewhat eroded and rolling in places, but are for the most part rather flat. (Figure 4)

The upper boundaries marking the edge of the old lake occur just above 2400 feet elevation in most places. Arms of the lake extension reach up along the various creeks which drain the area. ... The deposit is many feet in thickness; ... the soil has a smooth to lightly rolling surface. The drain-

age is generally good, as is the moisture-holding capacity.

The surface soils are remarkably similar in physical characters. ...Probably all of the soils contain considerable mica and they are also almost uniformly acid. The most important soil separations were those made on the basis of the character of the subsoil, the moisture-holding capacity and the drainage. The correlation of these soils is only tentative and the soil names used may not always be upheld by further studies. The names are merely for identification of the soil types described in this report.

It seems probable that the majority of the soils are somewhat modified by an admixture of loess or fine, floury, wind-borne material. The majority of the soils are remarkably free from horizontal development due to weathering; the subsoil being generally friable and free from marked compaction except in types 14 and 54.

The soil at Station I, Benton Flat, is a Springdale sandy loam (no. 6), supporting western larch and some Douglas fir on the edges of the flat. On this flat the sand and gravel are very deep and well sorted, leading to the supposition that lake water, possibly of glacial origin, was instrumental in its formation. Some pits were dug to depths of seven and eight feet without striking clay or bedrock.

At stations II and III, the soil (no. 9 on the map) is Huckleberry fine sandy loam supporting a mixed stand of western yellow pine and Douglas fir on the southwest aspect and mainly white pine on the northeast. This is one of the most important and by far the most extensive soil type in the area.

It occupies over three quarters of the area of the entire region tract. It is a residual soil from

Schists and Quartzites which occur in alternating layers overlying the granite which forms the backbone of the range to the east. The surface soil consists of 12 to 18 inches of light reddish brown fine sandy loam and usually contains a large percentage of gravel or rock. This soil mantle is of a good depth but small patches of rock outcrop are of frequent but irregular occurrence. The steeper phases are generally more shallow and stony.

This is particularly true of the steeper phases at IIa.

At Station IIIa the soil (no. 31) is also a steep, stony phase of no. 9, derived from the same parent material. At Station IIa there is also a mantle of Huckleberry fine sandy loam covering a steeper, more stony surface without humus, duff, or litter except under the scattered clumps of overgreen shrubs.

The soil at Station IV is gray clay (no. 54).

The soil consists of a light gray, rather compact, heavy clay loam or clay over a light gray compact clay subsoil. It is the same lake-laid material which forms the subsoil of the Mission fine sandy loam. The surface soil when exposed is apt to pack and bake into a rather impervious condition, and this may render it difficult for young trees to get a start. Once established, however, timber thrives, and a protective cover of duff prevents baking and helps to absorb moisture which might otherwise run off. The surface is generally somewhat rolling or sloping as the material is exposed along the terrace slopes. The surface drainage is somewhat excessive, though the sub-drainage is slow. In moisture-holding this soil rates very high.

It supports the more mesic of the forest associations: western red cedar, hemlock and white fir, as well as western white pine.

Soil type 14 (Station IVa) is a fine sandy loam, which is compact, friable, light brown or yellowish brown fine sandy loam and distinctly micaceous. The

subsoil of gray clay with rusty particles occurs at a depth from a few inches to two feet. This clay subsoil is apparently a part of an old lake deposit, the remnants of which are found in a number of places in the vicinity.

Analysis of soils. The mechanical analysis of the soils made at Priest River in 1915 are given in Table VI and all the essentials of the mechanical, physical and chemical study made at a later date have been entered in Table VII.

The mechanical analysis data given in Table VI reveal the stony nature of the southwest and the northeast sites, the first of which contains mostly western yellow pine and the second, pure Douglas fir. There is at these two locations very much less of the finer material present in the soil than where white pine thrives. In this series of tests 59 percent of the total weight of the sample from the northeast white pine site passed the one-half millimeter sieve and 67.6 percent from the white pine-cedar-hemlock flat at Station IV.

Table VI. Mechanical analysis of soils by sifting. (Tests made at Priest River Station, 1915)

	Soil: Percent passing mesh by weight							Total
	type	5 mm.	5 mm.	3 mm.	2 mm.	1 mm.	.5 mm.	used
Sta. I. Flat	6	9.2	5.1	5.9	12.9	27.6	39.3	272
Sta. II. SW slope	9	24.5	5.2	4.2	15.0	5.6	45.4	261
Sta. III. NE slope	9	26.5	3.4	3.0	3.4	4.3	59.0	233
Sta. IIIa. NW slope	31	38.5	6.8	4.4	9.2	9.7	30.7	293
Sta. IV. Flat	54	1.9	1.9	6.2	10.5	11.9	67.6	210

By the physical analysis of the soils (Table VII and Fig. 13) it is also well demonstrated that those which support western

white pine, with cedar and hemlock, contain a larger percentage of the clay fraction, and that where Douglas fir and western yellow pine grow the soils have a correspondingly higher sand fraction. The amount of silt is also greater for the more hydrophytic species and is present in the smaller degree under larch, Douglas fir and western yellow pine. (Fig. 13)

At Station II, on the southwest aspect the physical soil characters are also intermediate, and here we observe that occasional Douglas firs grow in mixture with the pine. At Station IIa the clay fraction is very low and all of the other physical characters are strikingly similar to those found under the old yellow pine forest represented by sample VI.

The soil of the Benton Creek flat (No. 54) surrounding Station IV and that of the virgin forest of white pine in Station V are very similar to the other mesophytic sites measured, both of these showing heavier portions of silt and clay. In comparing II, IIa and III, all of which are derived from the same parent rock, but now resting on different aspects we observe no appreciable variation in the sand and the silt portions but a much greater clay fraction in the mantle under the white pine forest on the northeast slope.

Analysis of the chemical properties, carbon, nitrogen, and phosphorus, are given in Table VII. These data indicate that where one of these elements is low, the others are also generally more limited, and vice versa; the only exception is

Table VII. Physical and chemical properties of the soils.

No.	Type	Location	Sand percent	Silt percent	Clay percent	Satura- tion
I	Larch-fir	Flat	62.43	19.54	18.03	50.4
II	Yellow pine	SW slope	50.99	33.61	15.40	70.1
IIa	Yellow pine	SW slope	36.18	47.93	15.89	50.7
III	White pine	NE slope	30.98	32.78	26.50	78.7
IIIa	Douglas fir	NW slope	39.14	36.18	24.68	65.5
IV	White pine	Flat	17.39	35.01	47.60	74.3
IVa	White pine	Low slope	32.03	39.09	28.88	79.1
IVb	White pine-cedar-hemlock	River bench	14.39	53.41	39.02	104.8
V	Virgin White pine	Flat	12.53	54.10	33.37	89.7
VI	Virgin yellow pine	Rolling	37.13	29.35	33.52	39.7
VII	Podzol	Flat	19.73	54.16	34.43	101.6

	Water:	Gravi-	Wilting:	Organic:	Total	Phos-				
Satura-	hold-	Capil-	ta-	Hygro-	coeffi-	Carbon	matter	N	phos-	pH
tion	ing	lary	tional	scopic	cient	percent	percent	percent	percent	
50.4	45.05	40.2	10.3	4.85	7.5	1.405	3.422	0.1114	0.1422	6.
70.1	62.02	58.4	11.6	3.62	6.9	2.142	3.693	0.0084	0.1070	6.
50.7	41.48	38.6	12.2	2.88	6.3	0.577	0.994	0.0825	0.0739	6.
78.7	69.13	62.7	15.9	6.43	10.2	1.430	2.465	0.1061	0.1455	6.
65.5	59.65	63.8	11.8	5.85	10.2	1.261	2.174	0.0803	0.1016	7.
74.3	59.85	53.8	20.2	6.05	11.3	1.049	1.809	0.0889	0.2069	6.
79.1	73.81	67.9	14.6	5.91	12.1	1.306	2.251	0.0754	0.1472	6.
104.8	96.27	89.8	14.7	6.47	6.7	2.315	3.990	0.1259	0.2872	6.
89.7	81.26	74.5	15.0	6.76	9.4	1.745	3.008	0.0972	0.1598	6.
39.7	35.06	29.4	10.3	5.66	5.1	1.259	2.176	0.0918	0.1254	6.
101.6	56.07	48.4	16.2	7.67	-	3.030	5.220	0.1550	0.0825	6.

Mechanical Analysis of Soil Samples 1932

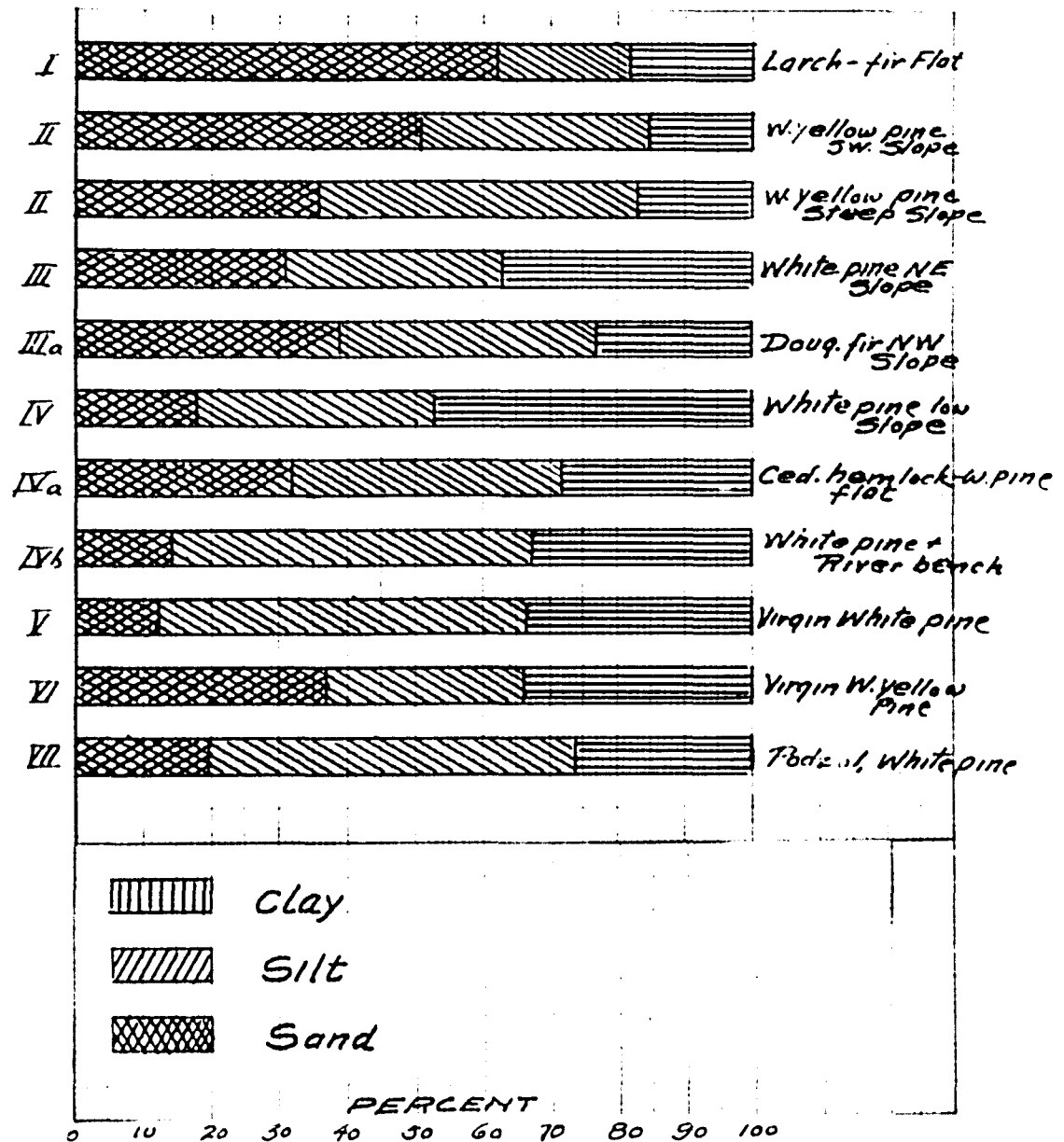


Fig. 13. The mechanical analysis of the soils.

in the amount of phosphorus in the podzol sample. This on the other hand, is not a true soil type. The steep phase yellow pine at IIa and the rather steep northeast slope, which are of the same type originally, reveal a rather sharp contrast; the former carries from one-third to one-half of the chemical elements which are present under the white pine. This indicates a tendency to increase toward the higher stages. (Fig. 13)

When we compare the soil of the virgin white pine forest with that of the old western yellow pine (Table VII), we discover that the differences in the clay and silt fractions are somewhat more outstanding than their variations in nitrogen. It appears, however, that the old-growth white pine sites contain more carbon and phosphorus than old-growth yellow pine.

In Figure 14 appear the quantities obtained and the relations expressed by the laboratory tests of the water relations of the various soils. The capillary water, the water-holding capacity, amount of water to saturate, gravitational and hygroscopic moisture, and the wilting coefficients; all vary in the same direction, showing greater magnitude for white pine, cedar, and hemlock sites at Station III and IV and sample IVb and V, and lowest for the virgin yellow pine. These characters are distinctly intermediate for Douglas fir and western larch. The knowledge gained of the different soils by the laboratory tests is corroborated by the field moisture studies given in the section on soil moisture.

Water Relations of Soils

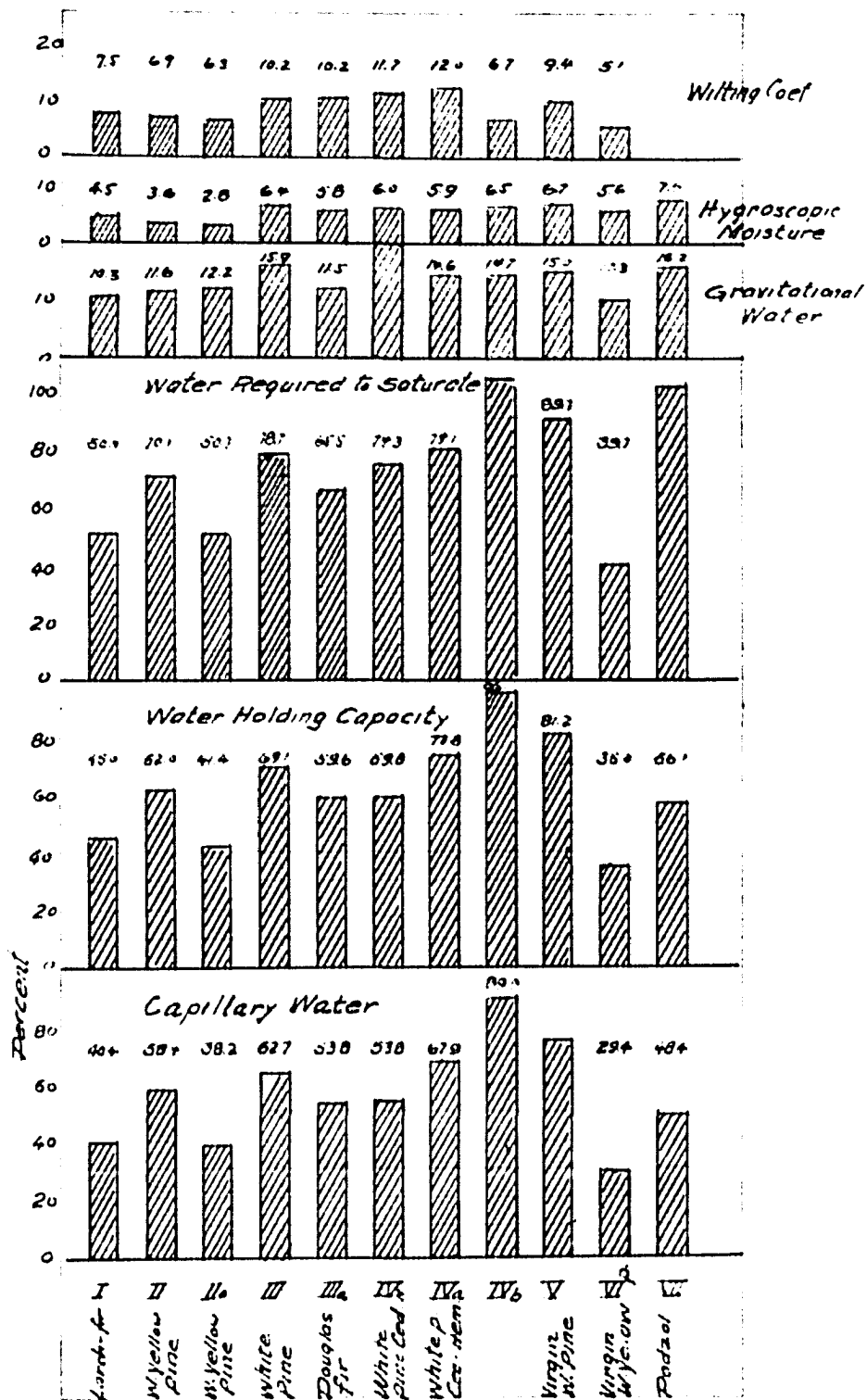


Fig. 14. The wilting coefficients, hygroscopic moisture, and other water relations of the soils, 1932.

The tests made for pH indicate that all of the soils tested except one are very slightly acid and that there is no consistent variation according to the species which grow on them. (Table VII) It has been stated that the newly burned surfaces are more alkaline in reaction than older soils or soils under old growth timber. If this were true the old virgin stand samples V and VI should show greater acidity than the newer soils or those under the younger timber, but our figures give only slight indications of a tendency in this direction. There are, moreover, other influences and complications of which we have no accurate knowledge from this study which would influence this relation.

Soil temperature. The records for soil temperatures obtained in 1913, 1914 and 1915 have been presented in Figures 15, 16, 17 and 18. These data are for surface, 6, 12 and 24 inch depths. Surface relations, 1913, are given in Fig. 16. The correlation graphs for the different depths are seen in Fig. 17; and the daily comparison graphs for the entire season of 1915 in Fig. 18. A summation of days having specific soil temperatures has also been prepared, Table IX.

The averages of the surface soil maxima (Fig. 15) show generally higher values on the southwest slope than elsewhere, although the stations on the flat show nearly as high an average maxima with occasional higher daily readings. The highest

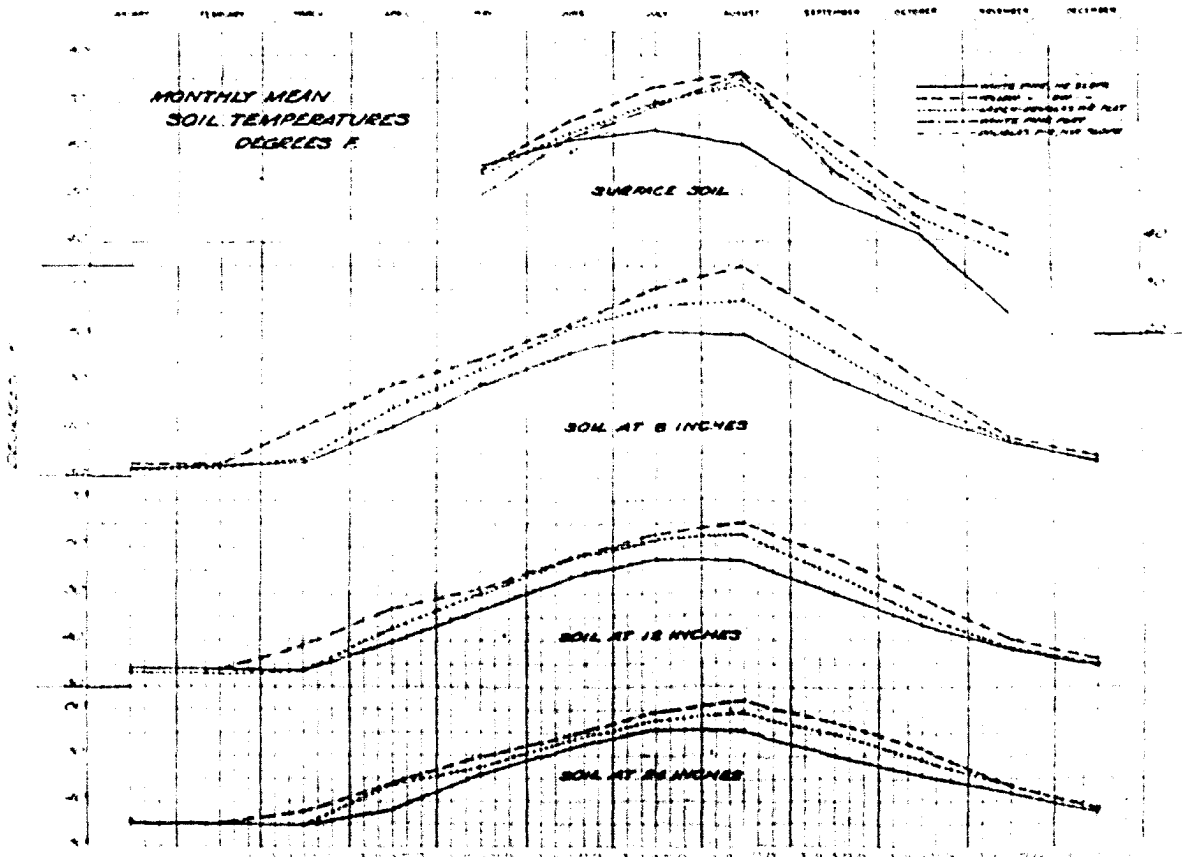


Fig. 15. The averages of temperature at surface, 6-inch, 12-inch and 24-inch depths for stations on flat, south-west and northeast slopes 1912, 1913, 1914, and 1915.* (*The 24-inch level is for the first two years).

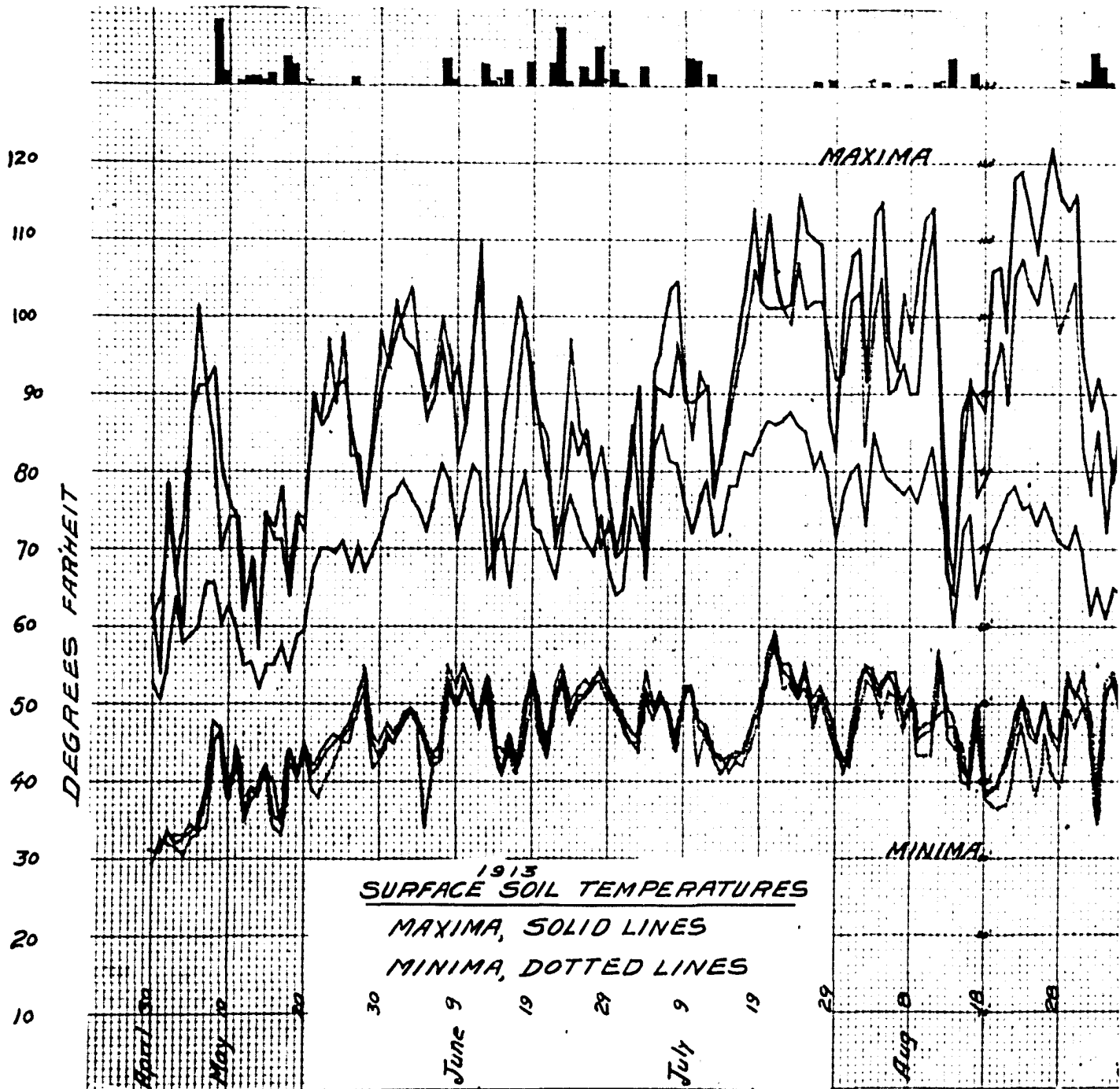
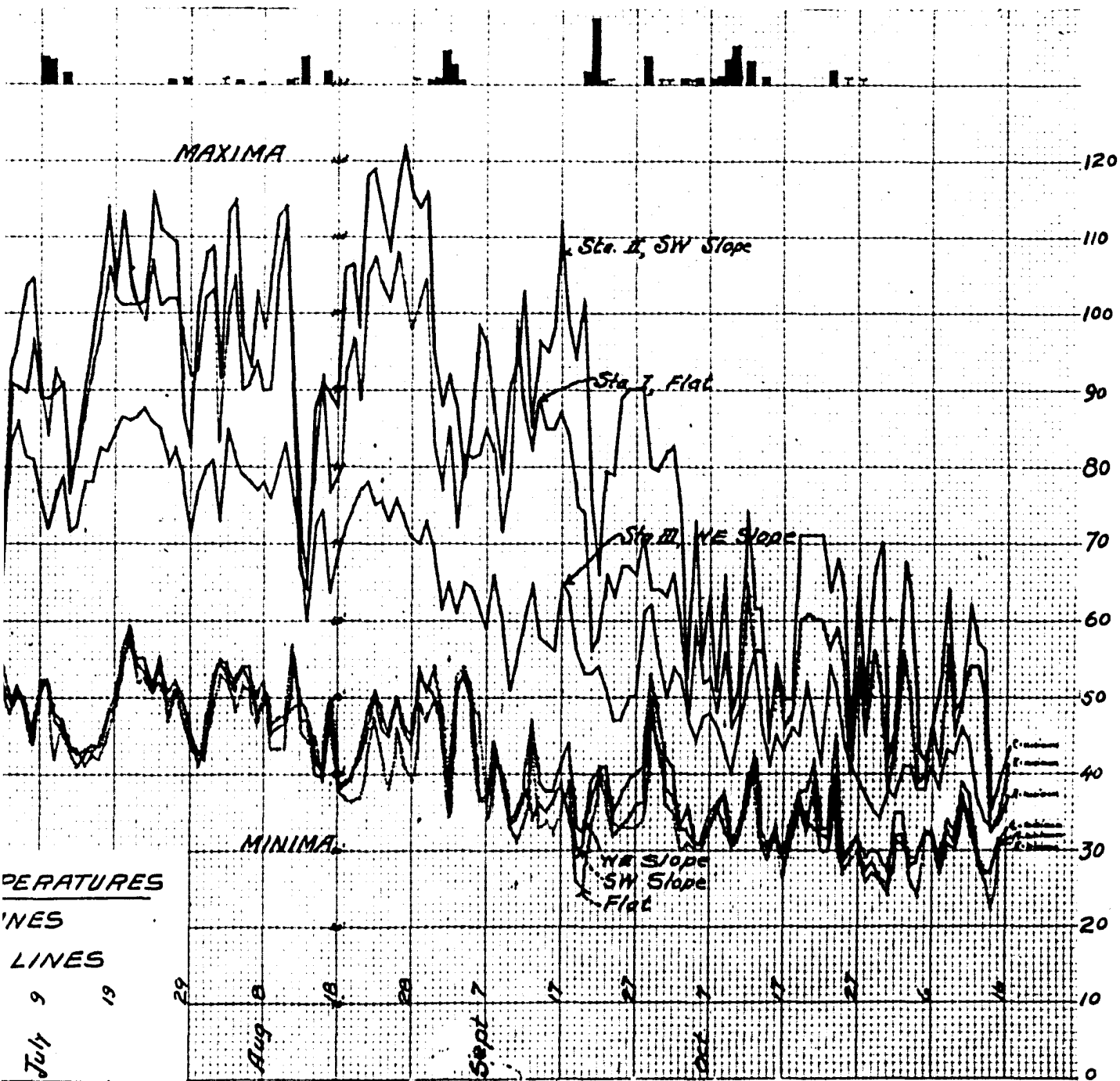


Fig. 16. The relations of maxima and minima on surface temperatures for the flat, southwest, and northeast slopes, 1913.



on surface tempera-
northeast slopes,

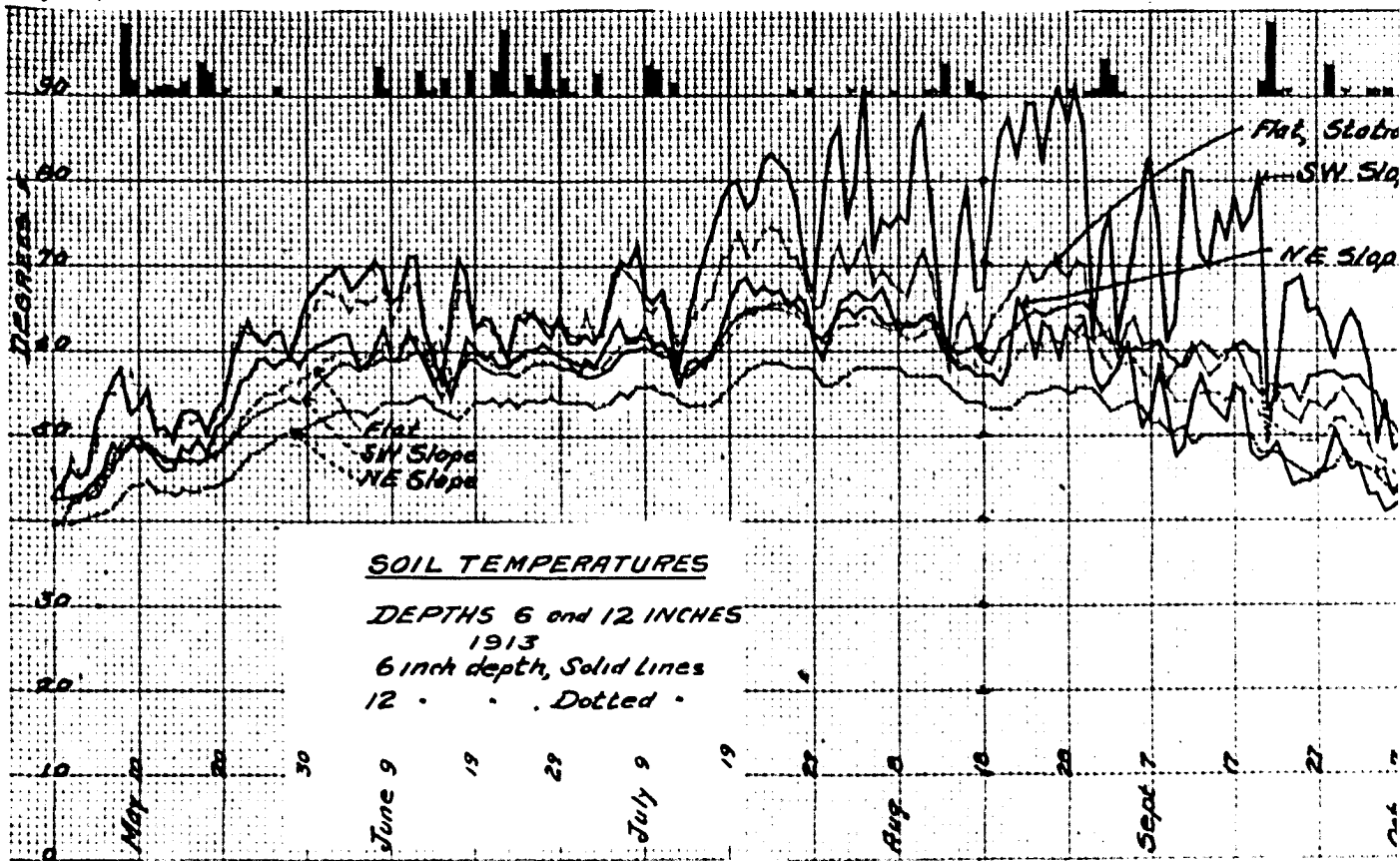
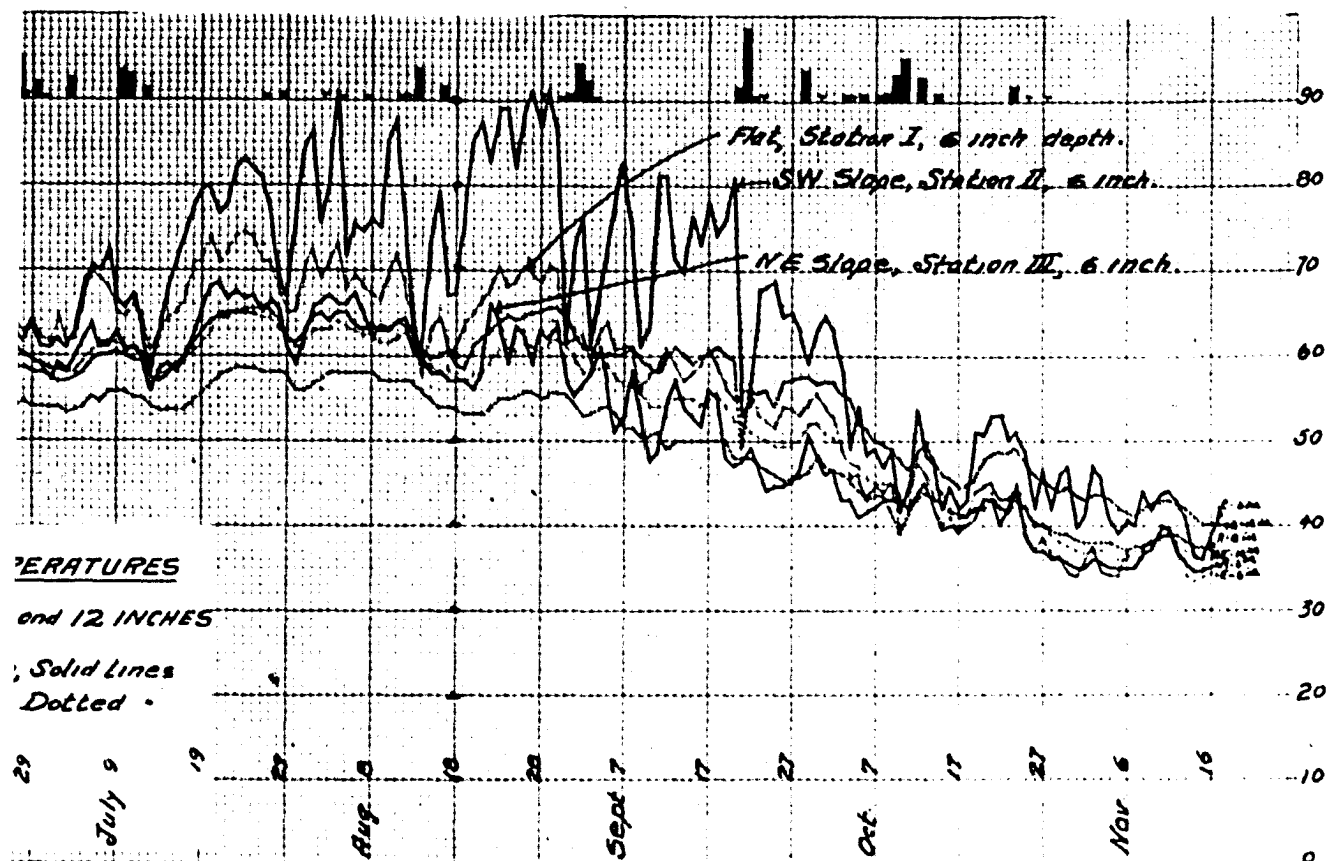


Fig. 17. Soil temperature relations at 6- and 12-inch depths for flat, southwest and northeast aspects, 1913.



ations at 6- and 12-inch
 southwest and northeast aspects,

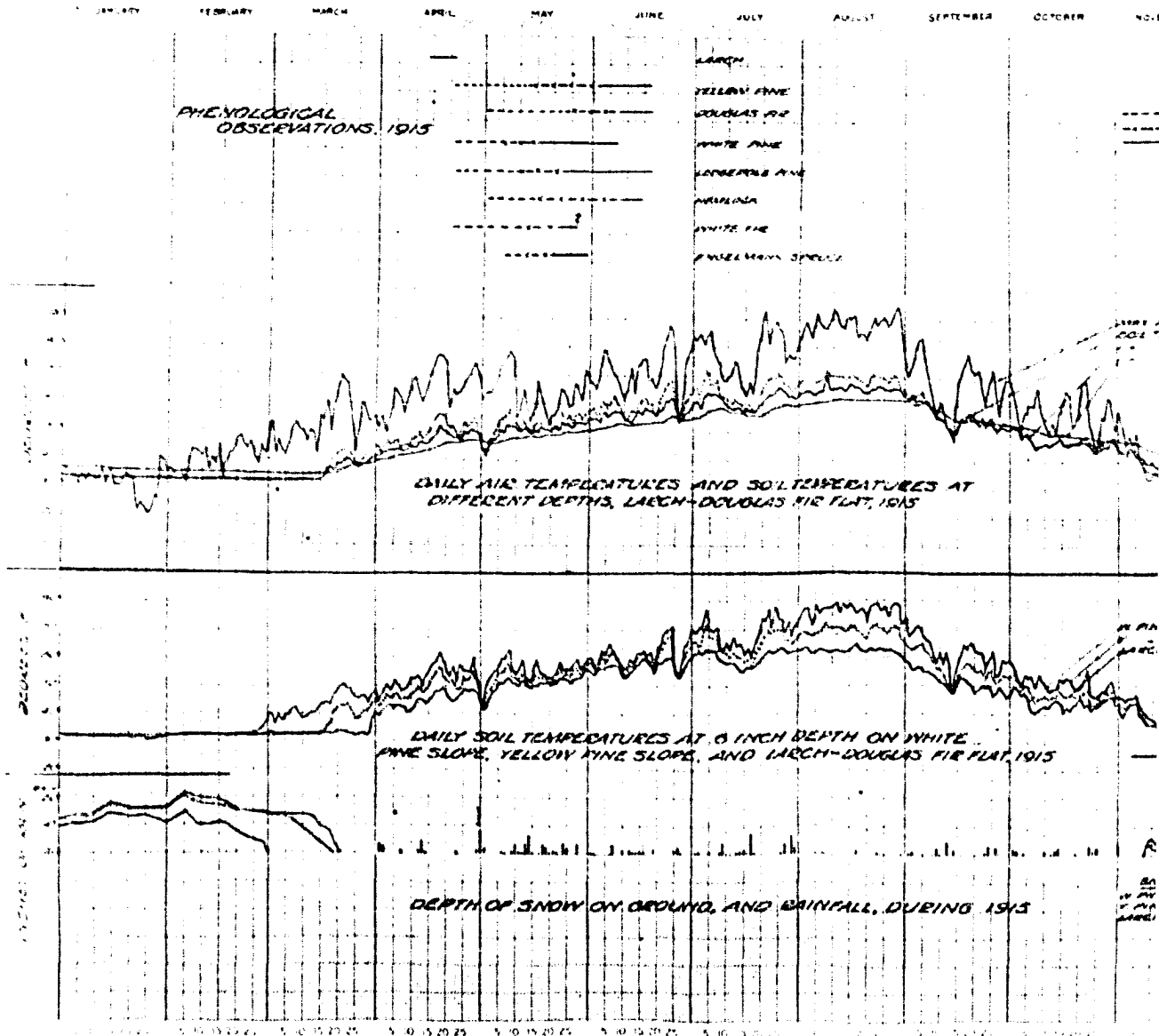
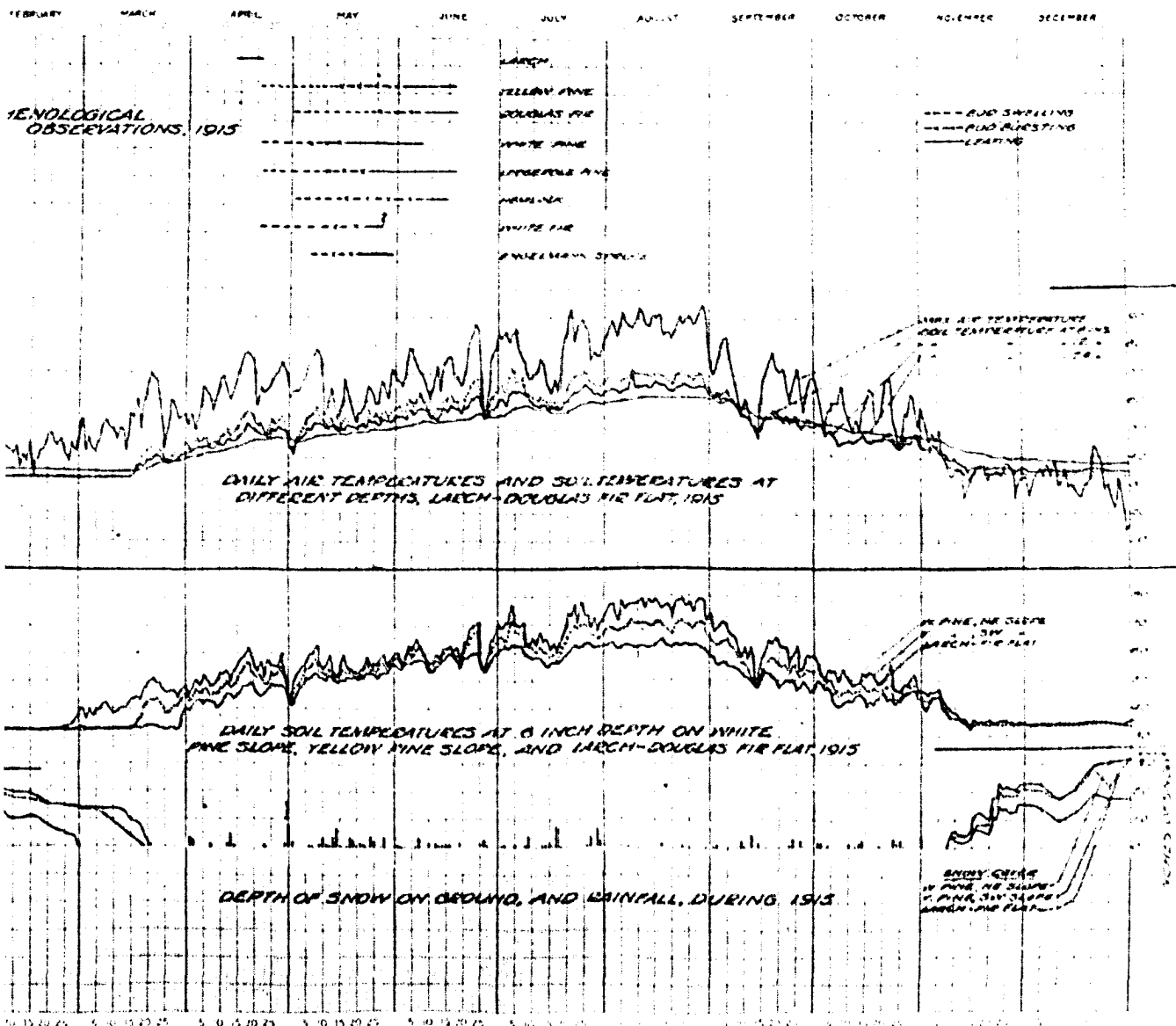


Fig. 18. Soil temperature throughout the year 1915 and its relation to beginning of growth, and the influence of snow cover on soil temperature.



temperature throughout the year 1915 and relation to beginning of growth, and the influence of snow cover on soil temperature.

surface soil temperature on record on the southwest slope was 125^oF.; the extreme temperatures on the flat and on the northeast slope are 118^o and 90^oF., respectively. The lowering of the curve for the northeast slope in the afternoon is due to the depression of the angle of inclination of the sun at that time.

At the six-inch depth and at the 12-inch depth, and deeper, the southwest slope is shown to be the warmest of the four sites and the northeast slope the coldest. There are more moderate temperatures for the lower depths and less diurnal fluctuations. (Figs. 17 and 18)

In Figure 16 an effort has been made to correlate the maxima and minima of temperatures in the upper inch of soil. The most noticeable feature here is the remarkable uniformity in the minima and the pronounced divergence in the maxima. The higher the maxima the greater will be the spread between the protected and the exposed aspects. At one point: August 27, 1913 this difference reached 45^oF. At the close of the season during late September and early October the maxima at the different sites became more uniform. The temperature relations, shown in Fig. 16, have a close relation to the germination and survival in the seeding tests discussed in a later section.

By reference to Figure 18 we may observe the relations existing between the air temperature and snow cover; the relation of air temperature to the beginning of growth in spring for the different species, and the influence of the daily air

temperatures on the heat imparted to the soil at different depths.

It is observed that no increase in soil temperature is possible previous to the complete disappearance of the snow cover, and that the soil temperature rises almost immediately after the snow mantle is removed. It also appears that beneath the snow the soil at a depth of six inches remains at about 32°F. throughout the winter, but is from two to three degrees warmer at a depth of 24 inches.

The lower soil depths ordinarily have less heat than the upper levels in summer and fluctuate in a more sluggish way with a definite lag of one day in 12 inches and two days at 24 inches. At times during the summer when a sudden drop in air temperature takes place, there is a complete reversal of the customary order in that the surface soil has a lower temperature than does the soil at greater depths.

The time of beginning of growth and its relation to air temperature are also given in Fig. 18. This shows the comparatively early start of larch and late beginning of spruce and the intermediate and simultaneous beginning of white pine, lodgepole pine, and grand fir, followed by Douglas fir and hemlock. These records refer to the forest surrounding the Experiment Station buildings and more particularly at the lower levels. They are therefore related to temperature data obtained on the flat.

By separating the days which show given soil temperatures at the 12 inch level (TableVIII), we find that there are 236 days with temperature above 40°F. on the southwest yellow pine slope; 220 days on the flat and at Station I and IV; and 210 days on the northeast slope. The larch-fir flat was 34 days with freezing records at this depth, which is 28 days more than occurs on the southwest and on the northeast sites.

TableVIII. Days having specific soil temperatures at 1-6 inch depth. 1912 to 1916.

		: Freezing : : Station; below 32°F. :	Cold : 32.1-40:	Cool : 40.1-50:	Warm : 50.1-60:	Hot above 60°F.
Rest period	I	34.0	111.5	62.5	5.0	0.0
	II	6.0	122.5	64.5	0.0	0.0
	III	6.0	148.5	57.5	5.0	0.0
	IV	-	146.0	62.0	19.0	0.0
Growth period	I	0.0	0.0	17.0	79.0	57.0
	II	0.0	0.0	11.0	106.0	65.0
	III	0.0	1.0	45.0	110.5	0.5
	IV	0.0	0.0	26.0	77.0	16.5
Year	I	34.0	111.5	79.5	84.0	57.0
	II	6.0	122.5	75.5	106.0	65.0
	III	6.0	149.5	103.0	115.5	0.5
	IV	-	146.0	88.0	96.0	16.5

Soil moisture in the field. The information on the amount of moisture in the soil is available largely through the field determinations from 1912 to 1915, inclusive. Field moisture determinations, expressed in percentage of dry weight of soil for the different stations are given in graphic forms in Figs. 19, 20, and 21, the first two for the 1913 season and the last for 1914 and 1915. In Figure 19 is given the three-station

SOIL MOISTURE

1913

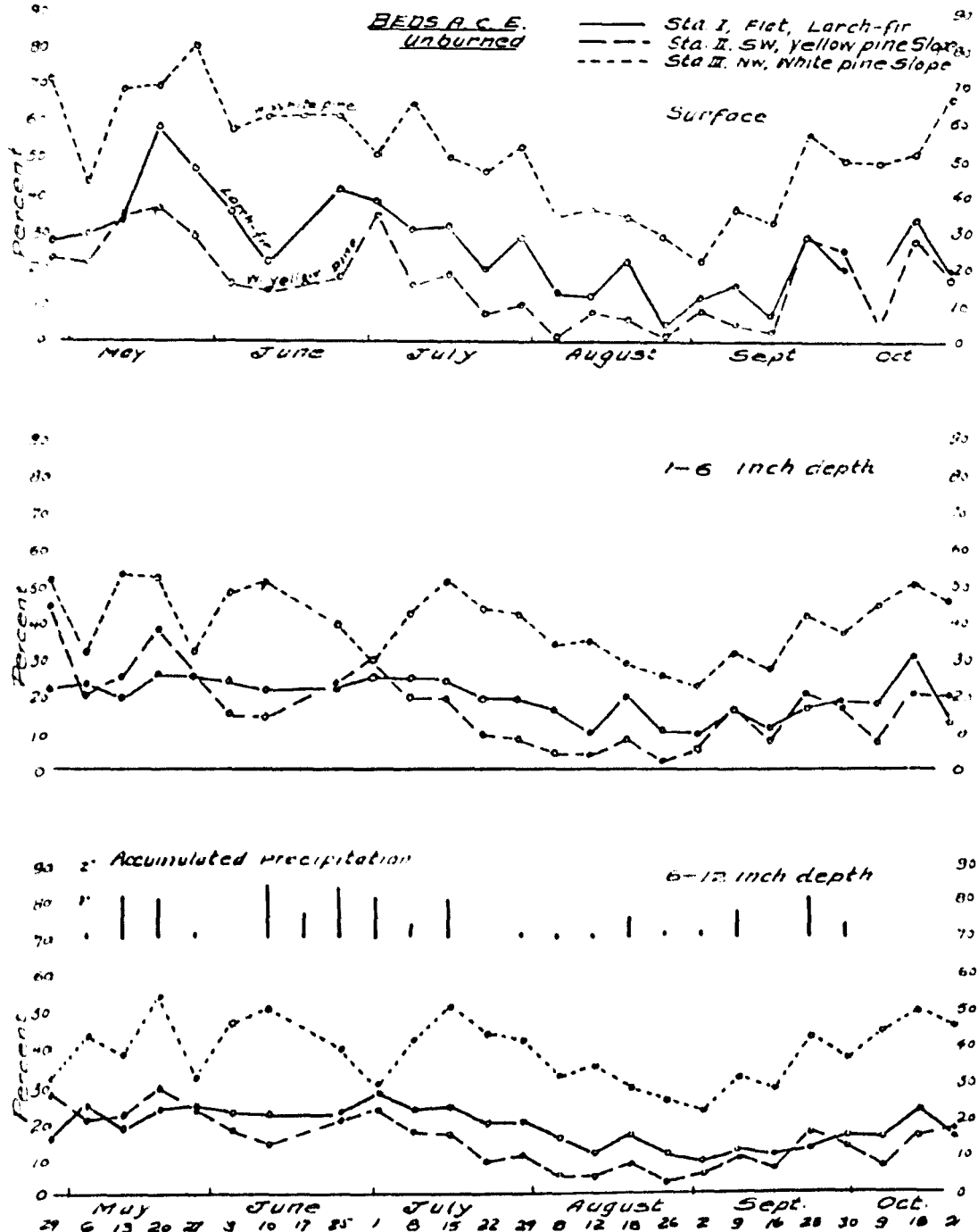


Fig. 19. Soil moisture relations for surface, 1-6 inch and 6-12 inch depths for unburned surfaces, 1913.

relations for surface, 1-6 inch and 6-12 inches in the unburned seeding plots. Referring to the graphs we learn that some variations occur from one year to the other, but that in the main the relations between the stations continue rather constant. The soil moisture on the northeast aspect and on the low flat with white pine and cedar-hemlock association is always in excess of that on the other sites. The surface minima are surprisingly low at most points during the middle of the summer, especially on the exposed yellow pine site and on the flat. This is naturally of much importance in seed germination and the first season's survival, but has little influence on the already established forest growth.

Referring to the graph in Fig. 21 it is readily observed that stations III and IV maintain high and safe levels and that these two remain closely associated; that the steep northwest aspect falls in the intermediate class and that the steep phase western yellow pine at IIa invariably falls below all the other sites.

The graphs furnish a good idea of the low points reached and the duration of the low moisture contents. This is naturally an important character of the factor and should receive due consideration. It was found that the moisture content at 6-12 inch depths for 1914, an average dry year, hovered around the minimum for a period of 42 days on the yellow pine slopes and for a period of 25 days on the flat; but did not reach below

SOIL MOISTURE

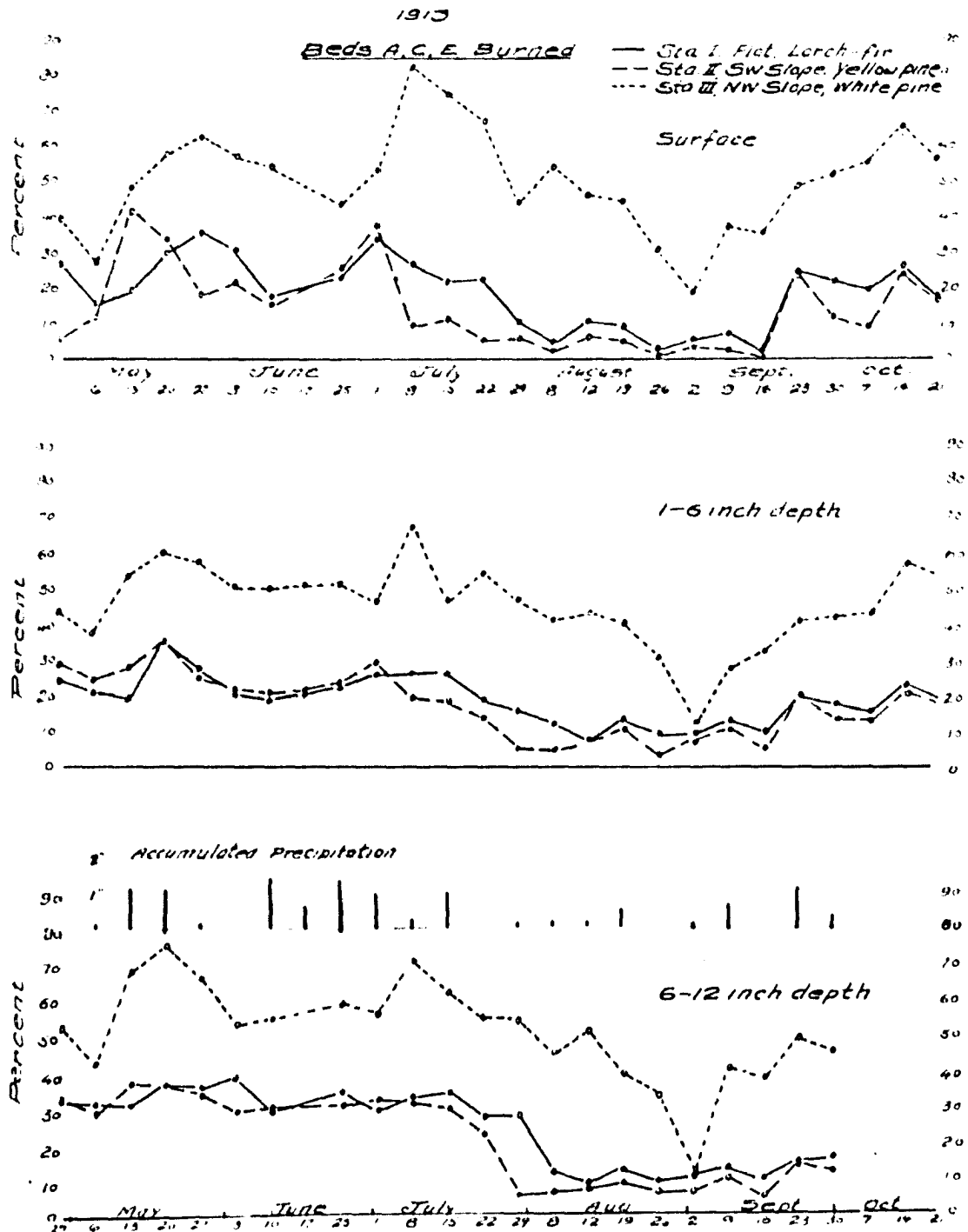


Fig. 20. Soil moisture relations at surface, 1-6 inch and 6-12 inch depths for burned plots, 1913.

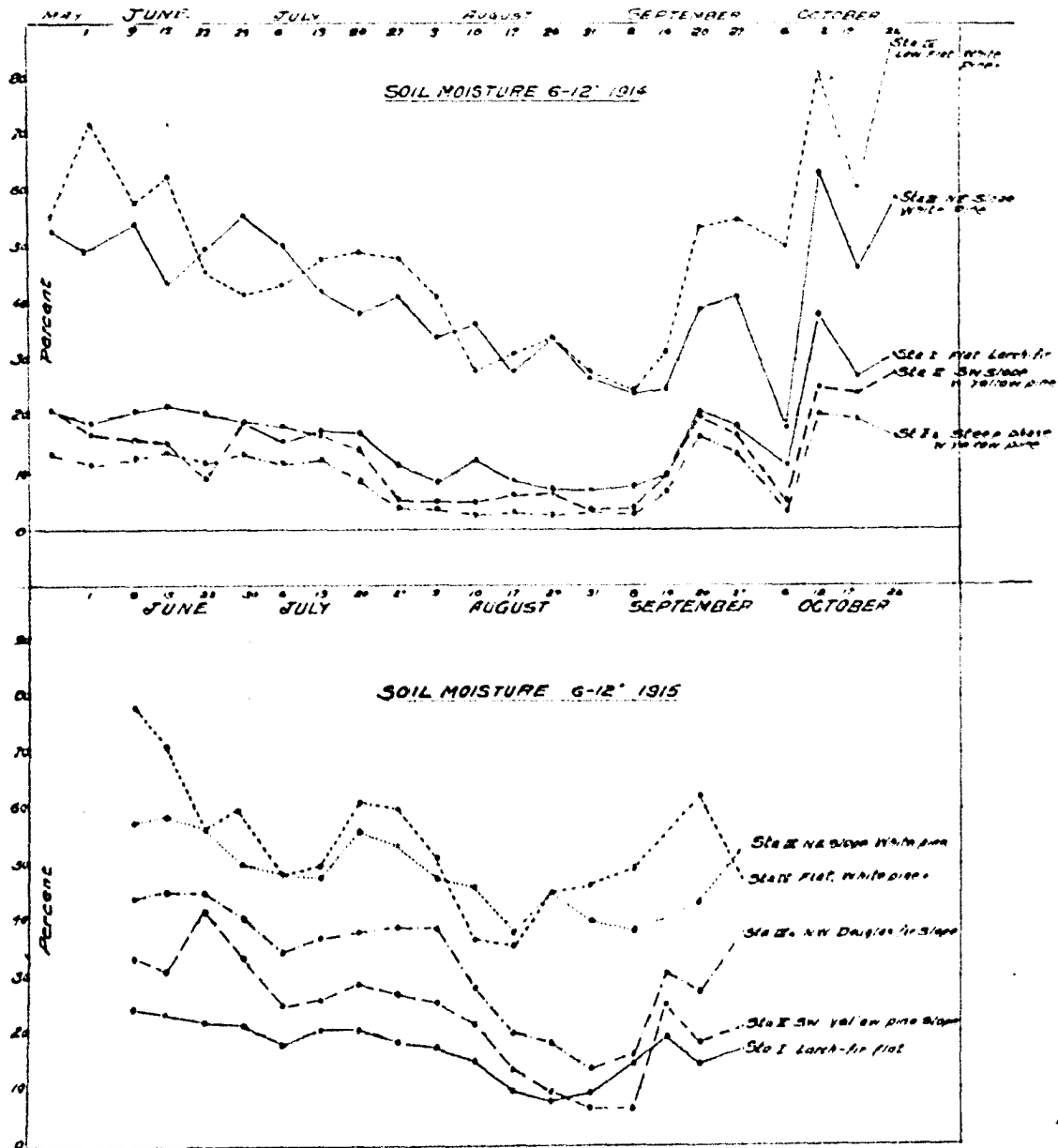


Fig. 21. Soil moisture relations at 6-12 inch depths for Stations I-IV, 1914 and 1915.

20 percent on the white pine northeast aspect. The soil moisture was below 10 percent for 57 days on the southwest slope; and for 37 days on the flat. (Fig. 21)

In Table IX are the soil moisture summations at 1-6 inch depths in the seedbeds during the 1913 season on natural vegetation surface and on burned ground. The natural surfaces averaged 19.7 on the flat, 16.5 percent on the southwest and 40.1 percent on the northeast. The minima are about ten points lower ordinarily than these values and the minima on the southwest frequently go below the wilting coefficient expressed for this soil. (Table VII)

Table IX. Soil moisture in seed beds at 1-6 inch depth. 1913.

Surface	Flat		SW slope		NE slope	
	Average	Minima	Average	Minima	Average	Minima
Vegetation	19.7	9.6	16.5	2.1	40.1	21.9
Burned	18.4	6.9	16.7	2.8	45.2	11.8

In Table X are recorded the mean and minima of soil moisture at different depths during August 1914. This proved an unusually dry season, and, since August values invariably coincide with the most critical part of the summer, the August data are listed. The average values are considerably below the 1913 figures but the minima appear safer. Again we observe that the white pine sites do not lose moisture below the given wilting coefficient. It is assumed that the mesic trees of white pine-grand fir communities would be unable to survive under

these extremes.

Table X. Mean and minima of soil moisture, percentage of dry weight. August, 1914.

Station	: I Flat :		: II SW :		: III NE :		: IV Flat :	
	:Mean:	:Min.:	:Mean:	:Min.:	:Mean:	:Min.:	:Mean:	:Min.:
Surface	7.0	2.1	7.7	0.5	43.6	0.7	19.1	0.4
1-6 inch	12.8	5.7	12.6	2.1	43.7	11.8	36.5	10.3
6-12 inch	13.4	5.0	13.2	2.6	43.9	11.9	39.3	10.6

An interesting comparison is afforded by the data on soil moisture in the local and the common soil obtained in 1915. (Table XI) This shows clearly that the soil from Station I, when placed on the other aspects has a lower water-holding capacity than any of the local soils and when in foreign locations its moisture content does not go below the wilting coefficient except on the southwest aspect.

Table XI. Soil moisture percentage August 1915 in local and common soils, 1-6 inch depth.

Soil type	: Flat :		: SW II :		: NE III :		: NW IIIa :		: Low flat IV :	
	:Ave.:	:Min.:	:Ave.:	:Min.:	:Ave.:	:Min.:	:Ave.:	:Min.:	:Ave.:	:Min.:
Local soil	10.1	7.3	12.1	4.6	33.7	-	37.3	14.9	21.8	16.7
Common soil	9.2	6.3	8.6	3.4	19.2	19.2	30.5	12.5	15.3	13.5

Seeding Tests.

The combined results of the seeding experiments are given in Table XII. The figures in this table embrace data on germination during the first and second season after sowing; the survival to the end of the third season and growth at the finish of

the fifth year, 1917. These data are discussed on the bases of species individually according to site and to natural and burned surfaces. Bed E was located on the flat; bed C on the southwest slope and bed A on the northeast gradient. (Table XII)

Referring to Table XII we find that western white pine germinated best on the northeast aspect in bed A; next best on the flat in bed E, and somewhat poorer on the southwest in bed C. There was generally better germination on the vegetation surfaces, especially during the first season. During the second season, however, many additional seedlings appeared, but more on the burned than on the unburned ground.

The fact that considerable seed germinated during the second season after sowing and that this took place more on the dry sites indicates that a portion of the seed remained viable, being better preserved on the exposed or dry surfaces than in moister surroundings. These second year's seedlings apparently possessed fully as much vigor as the earlier.

In the matter of survival the best results to the end of 1917 were obtained on the northeast slope and for the burned surface on the flat, with total failure on the southwest. The survival on the flat continued for a few years until competition eliminated most of the trees. As long as the stand remained there was a slightly better height growth on the flat than on the northeast slope. (See Fig. 25 for height and gen-

Table XII. Seeding tests. Germination, survival and growth of seedlings, 1913-1917.

Site:	Location:	nation	val to	Height:	Damping:	Ro-	Non-	Cut-	Un-		
Bed:	Surface:	1913:	Total:	1915	1917:	off	dents:	estab.:	worm:	known:	
WESTERN WHITE PINE											
Flat	E	Natural	7.0	10.5	7.2	6.5	66.6	-	-	11.1	22.3*
"	E	Burned	3.2	12.8	90.6	6.9	53.9	-	-	38.5	7.6
SW	C	Natural	1.2	9.1	0.0	-	50.0	13.6	-	22.6	13.6
"	C	Burned	0.7	6.9	0.0	-	72.7	-	-	-	27.3
NE	A	Natural	11.4	12.8	82.9	4.3	30.3	-	3.0	16.7	50.0
"	A	Burned	10.9	13.8	84.6	4.6	56.3	-	6.3	12.5	25.0
DOUGLAS FIR											
Flat	E	Natural	15.9	17.9	80.0	5.7	52.0	0.0	8.7	0.0	39.3
"	E	Burned	22.6	23.2	65.6	10.2	46.8	0.0	36.1	0.0	17.1
SW	C	Natural	3.7	7.3	2.7	-**	73.6	0.0	0.0	11.7	14.7
"	C	Burned	4.3	7.5	2.7	-	74.4	2.3	0.0	4.6	18.7
NE	A	Natural	0.5	5.1	25.9	6.0	77.5	0.0	6.5	6.5	9.5
"	A	Burned	15.0	15.6	79.5	5.5	40.5	0.0	9.5	0.0	50.0
WESTERN HEMLOCK											
Flat	E	Natural	1.0	1.0	0.0	-	26.1	0.0	0.0	0.0	73.9
"	E	Burned	4.0	4.0	1.7	-	74.6	0.0	0.0	0.0	21.1
SW	C	Natural	3.0	3.0	0.0	-	87.8	0.0	0.0	0.0	12.2
"	C	Burned	0.03	0.03	0.0	-	100.0	0.0	0.0	0.0	0.0
NE	A	Natural	3.4	3.4	27.9	6.7	46.0	0.0	0.0	0.0	54.0
"	A	Burned	2.9	3.1	32.0	2.2	43.0	0.0	21.5	0.0	35.5

*Percentages of total 1913 losses.
 **Losses subsequent to 1915.

wth of

1913. percent		: Germin-	: Percent:	:	Losses in 1913. percent						
Non-	Cut-	: nation	: survi-	:	Height:	Damping:	Ro-	Non-	Cut	Un-	
estab.	worm	known:	1913:	Total:	1917	1917	off	dents:	estab.	worm:	known
WESTERN YELLOW PINE											
-	11.1	22.3	17.6	21.6	87.5	8.8	35.6	0.0	10.8	10.8	42.8
-	38.5	7.6	45.6	49.0	84.5	10.6	50.0	0.0	21.2	0.0	28.8
-	22.6	13.6	18.4	21.9	34.2	7.6	66.6	4.2	4.2	4.2	20.8
-	-	27.3	15.3	20.1	77.6	8.5	56.5	0.0	0.0	17.4	26.1
3.0	16.7	50.0	23.4	23.7	54.8	7.0	79.0	0.0	2.5	0.0	19.5
6.3	12.5	25.0	41.6	41.7	71.7	9.4	57.6	0.0	11.6	7.1	23.5
WESTERN LARCH											
9.7	0.0	39.3	2.5	2.8	17.2	2.6	66.6	0.0	0.0	2.1	31.3
36.1	0.0	17.1	7.8	9.2	9.4	4.1	72.9	0.0	11.8	1.2	14.1
0.0	11.7	14.7	2.4	12.4	0.0	-	87.2	1.1	0.0	1.7	10.0
0.0	4.6	13.7	1.8	6.4	0.0	-	54.6	20.6	2.4	0.0	22.1
6.5	6.5	9.5	1.6	1.6	6.6	-	79.2	0.0	3.0	0.0	17.8
9.5	0.0	50.0	2.2	3.6	7.2	2.4	73.0	0.0	4.3	0.0	22.7
WESTERN RED CEDAR											
0.0	0.0	73.9	0.2	0.2	33.2	-	68.7	0.0	0.0	0.0	33.3
0.0	0.0	21.1	0.2	0.2	10.0	-	42.8	0.0	0.0	0.0	57.2
0.0	0.0	12.2	0.1	0.1	0.0	-	50.0	0.0	0.0	0.0	50.0
0.0	0.0	0.0	0.02	0.02	0.0	-	0.0	0.0	0.0	0.0	-
0.0	0.0	54.0	0.2	0.2	22.2	2.0	43.0	0.0	0.0	0.0	57.0
21.5	0.0	35.5	0.4	0.4	29.0	4.2	33.3	0.0	0.0	11.0	55.7

development of the seedlings on the two kinds of surfaces).

In case of western yellow pine the results listed in Table XII show a germination of 21.6 percent for the natural and 49.0 percent on the burned surface on the flat; 20.9 percent and 20.1 percent in the same order on the southwest slope and 23.7 percent on the natural and 41.7 percent on burned ground on the northeast aspect. From these results it is seen that, except for the exposed yellow pine slope, the germination about doubled on the burned ground. Survival was good on all sites but better in general on the burned surfaces than on the unburned, while height growth was better on the burned plots. (Fig. 25)

The second year's germination increased the stand by three to five percent on the southwest aspect and on the flat, but not on the northeast. Since the 1913 season was very moist generally the losses by damping-off were severe, especially on the northeast and in the presence of vegetation.

Douglas fir germinated on the whole best on the flat and poorest on the southwest slope, the burned surfaces holding the lead on all three sites. The second season's germination took place in all of the beds and added from 0.6 to 3.5 percent, being strongest in the presence of vegetation. Survival showed nothing on the southwest in 1917; medium on the northeast and good on the flat, while height growth was 10.7 inches on the burned surface and only 5.7 inches in vegetation on the flat. For the northeast slope the height growth gave 6.0 inches in vegetation

SEEDING TESTS BED 'E' ON F.

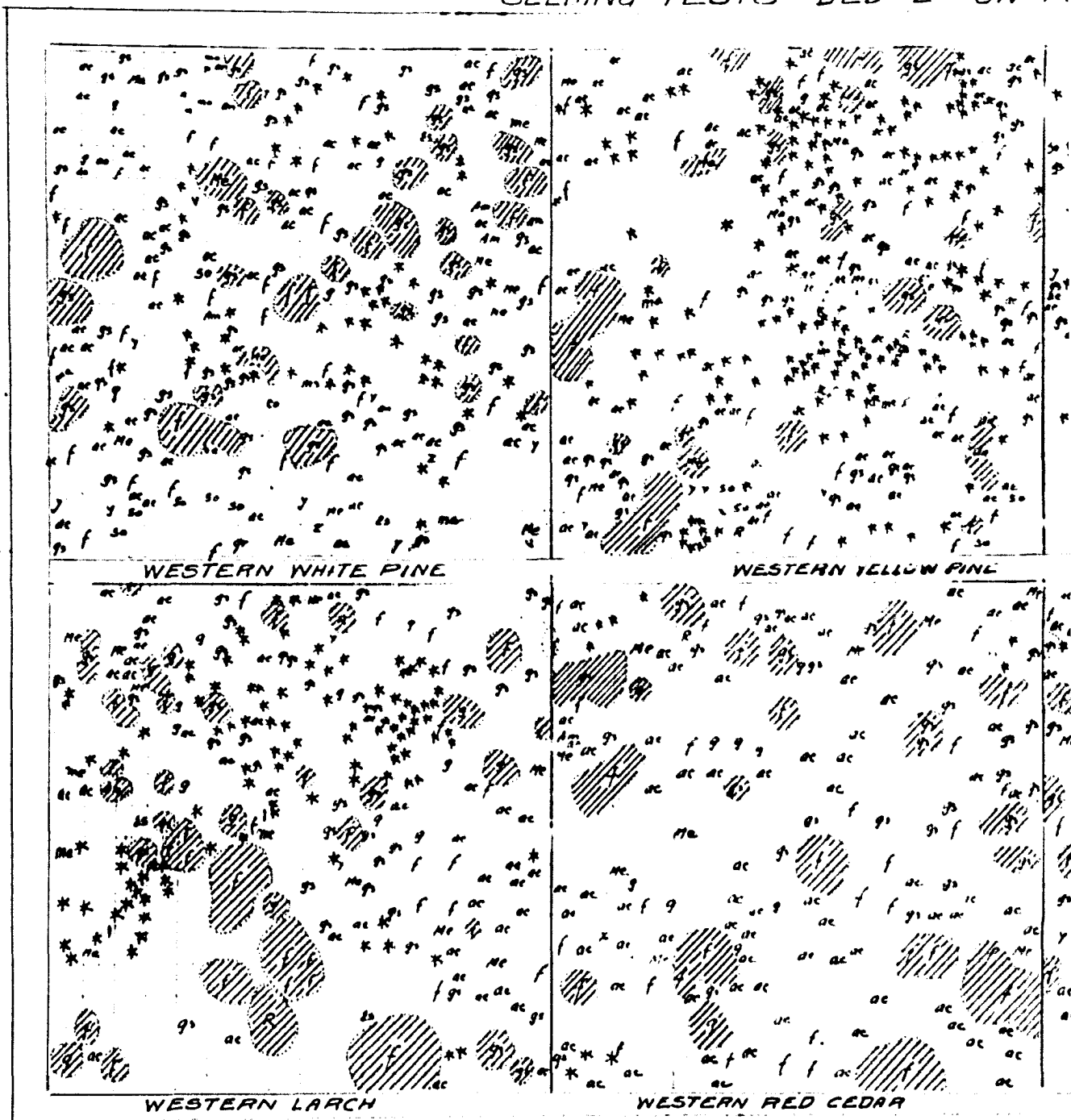


Fig. 22. Seeding quadrats for unburned surfaces on the flat.

WESTERN YELLOW PINE

DOUGLAS FIR

RED CEDAR

WESTERN HEMLOCK

SEEDING TESTS BED C SOUTHWEST

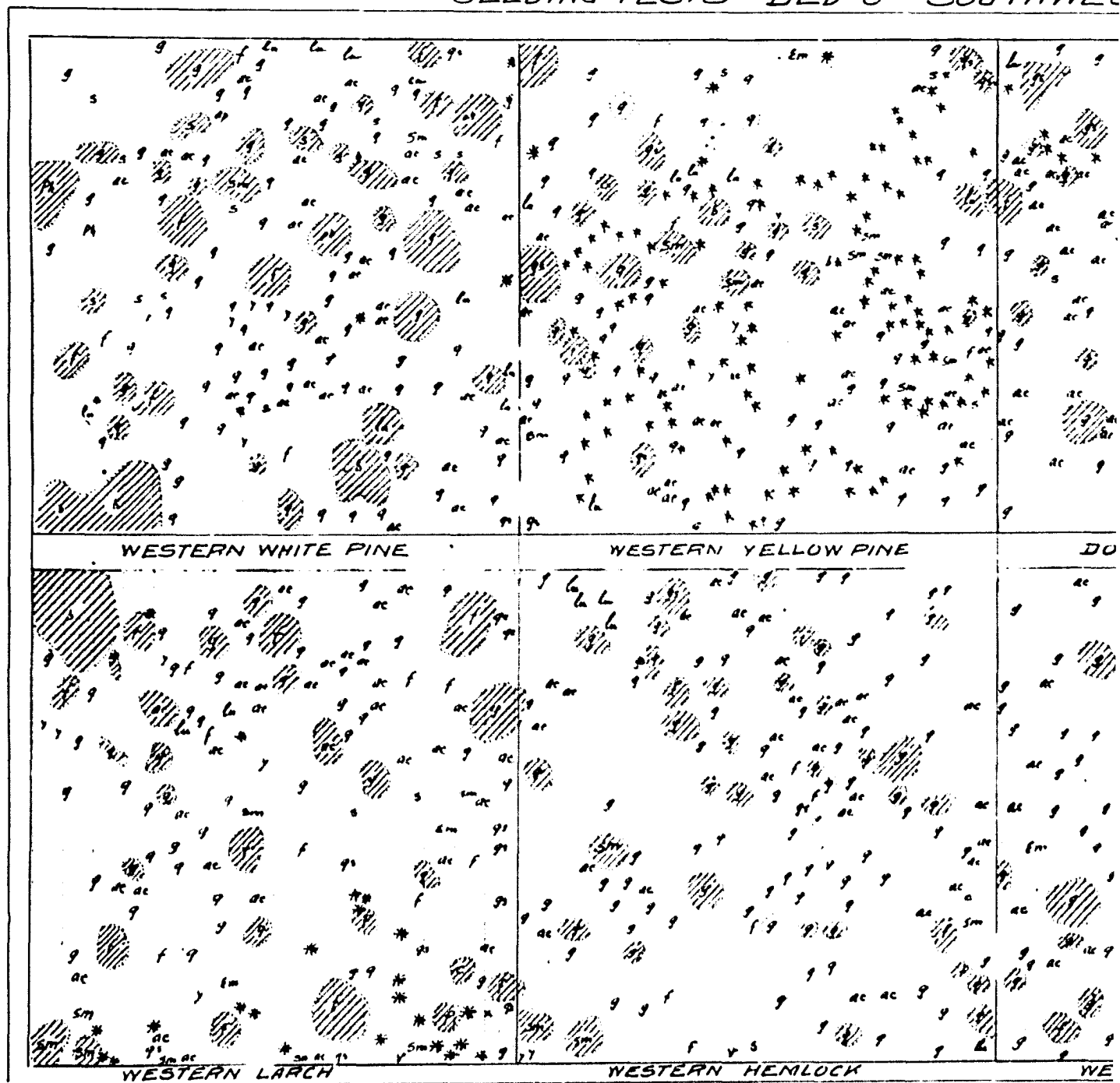
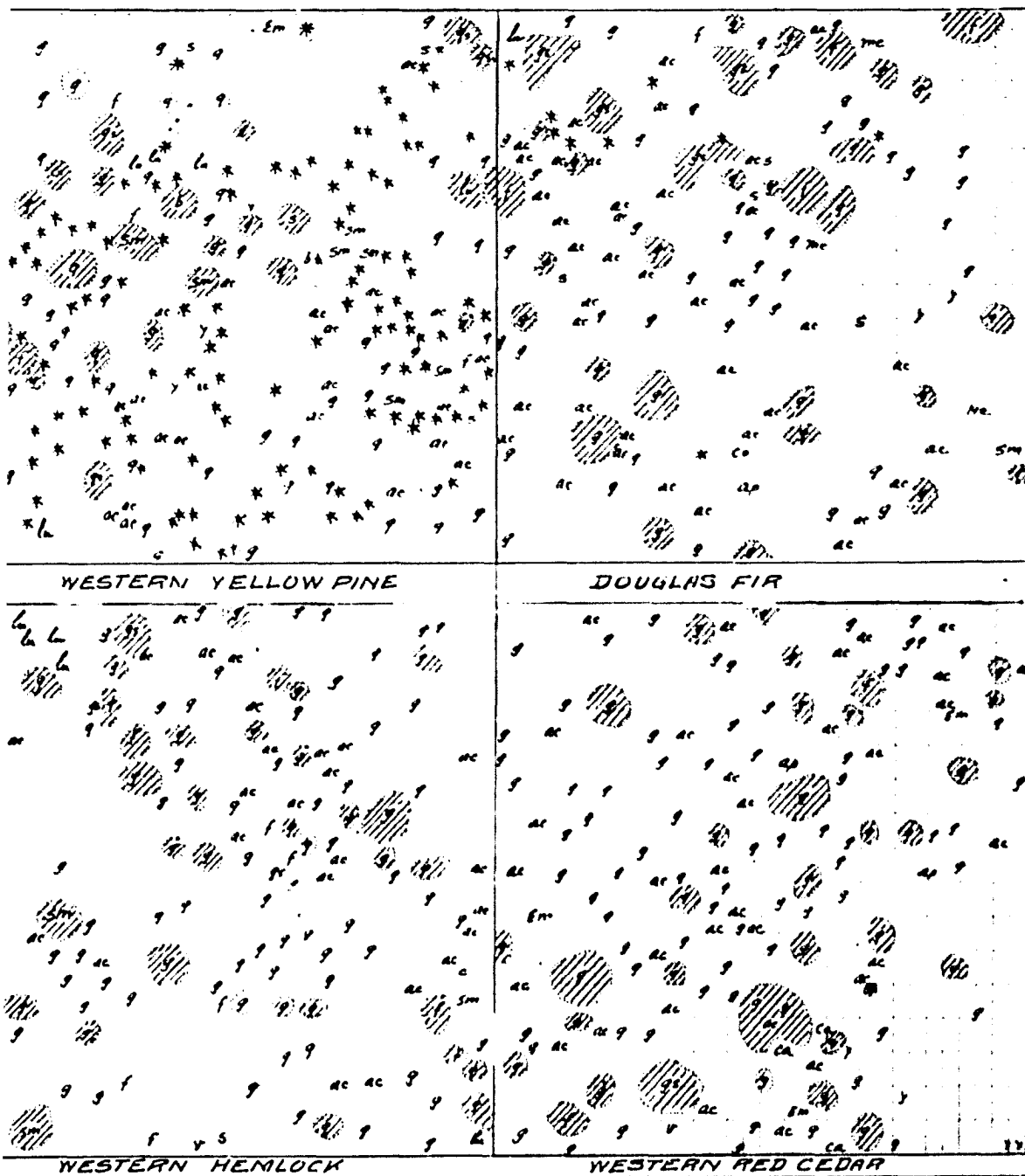


Fig. 23. Seeding quadrats for unburned surfaces on the southwest slope.

NG TESTS BED C' SOUTHWEST ASPECT



LEGEND

- g grass, bunch
- g* grass, less abundant
- lu Lupine
- sm Symphoricarpos
- ac Achillea millefolium
- f Fragaria
- co Collinsia
- b Berberis rep
- ho Apocynum
- ph Physocarpus
- s Sedum
- c Campanula
- em Epilobium minus
- y yucca
- ca Carex
- m Machysia
- x Mammillaria
- * Coniferous seedling
- hatched area Groups of vegetation

and surfaces on the southwest

2 feet

SEEDING TESTS BED A' NOR

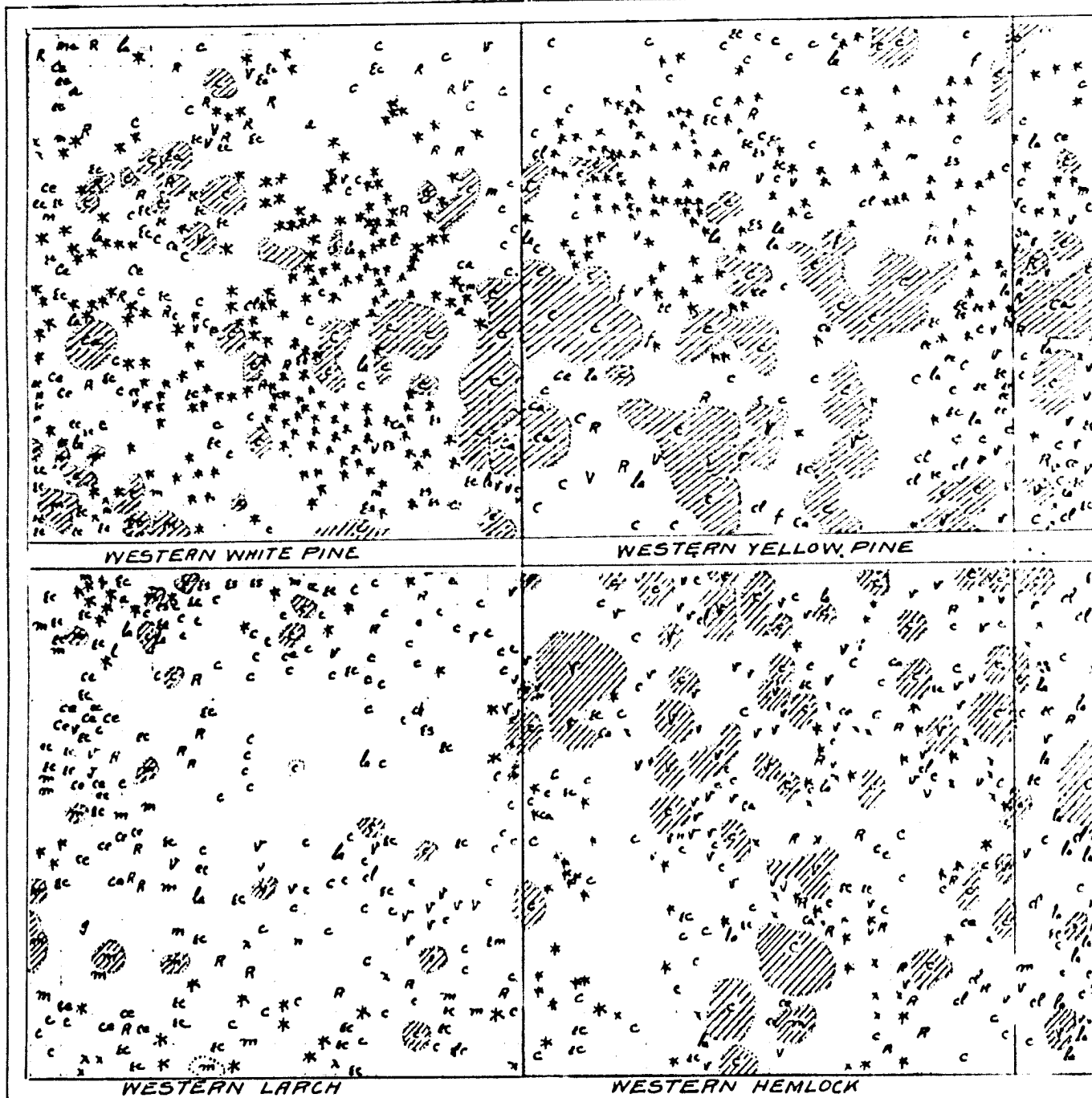
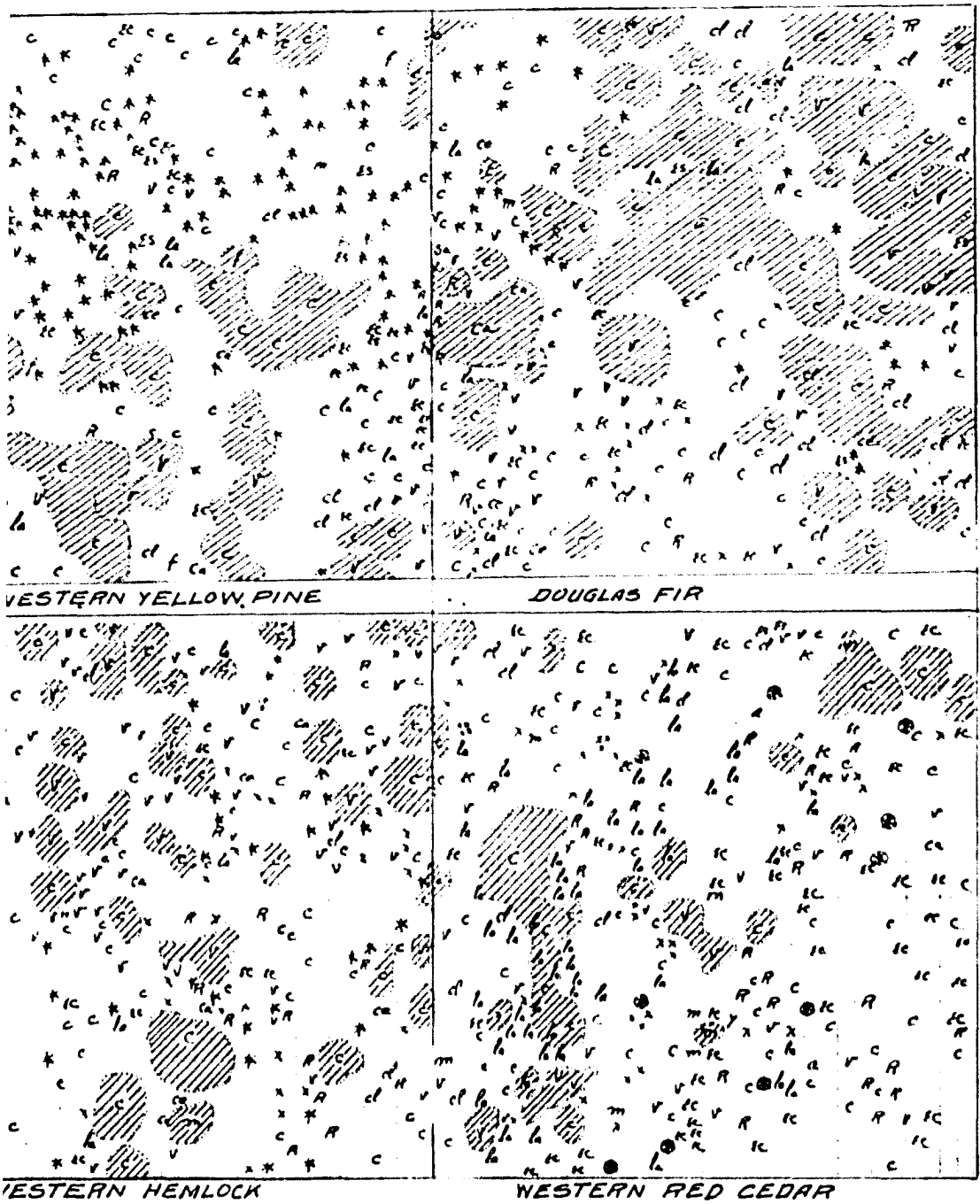


Fig. 24. Seeding quadrats for unburned surfaces on the northeast aspect.

DING TESTS BED A' NORTHEAST ASPECT



LEGEND

- V Viola
- C Capsis
- R Rous
- Co Carex
- EC Eriogonum cal
- Es Sarcocolla
- M Marchantia
- cl Chelonia
- A Antennaria
- la Lactuca
- ch Chenopodium
- Co Cereus
- Em Epilobium sp
- F Fragaria
- Da Galium
- So Solan
- R Ranunculus
- L Liriodendron
- Am Amelanchier al
- So Sorbus
- Me Melanthera
- My Myrica
- Seedlings
- Groups of Vegetation

ces on the northeast

2 feet

Fig. 25. Growth and development of seedlings on burned and unburned surfaces from 1913-1917, inclusive (from seed experiments).

and 5.5 on burned surface. (Table XII and Fig. 25) Losses by damping-off were uniformly severe on all sites.

Germination of western larch showed best results on the burned surfaces, more particularly on the flat and took the lead in the presence of vegetation during the second season with very good results on the southwest slope. Survival on the northeast and the flat continued good until the end of 1917, but was nil on the exposed southwest slope. None survived in the natural surface on the flat. Growth appeared more rapid on the burned surfaces. Losses from damping-off were very severe on all sites during the first season.

The seed of western hemlock germinated very much better on the northeast and poorly on the southwest aspect, where it gave the best results on the natural plot. In this respect, we have a reversal from what took place on the flat for in this location more seedlings appeared on the burned plot. Survival can only be credited on the northeast location where it was appreciably better on the natural than on the burned ground. It is interesting to observe that the seedlings in the presence of vegetation grew about three times more rapidly than those on the burned plot. The hemlock stand was greatly reduced by damping-off fungi and this loss proved heavier on burned than on unburned surfaces. In this respect, this species differs from all others used in this experiment.

It is quite certain that a greater number of western red cedar seedlings than were obtained in these tests would have

resulted from seed of better quality. Earlier germination tests for this sample were very low and for this reason much more seed was used. The germination on all sites was even, but lower than for the hemlock. The burned surface on the northeast gave the best stand. Similar to the hemlock, survival could only be found on the northeast exposure where the growth in height was far better on burned than on unburned ground.

The quadrats of Figures 23, 23, and 24 were made within the seed beds. These are for the surfaces on which the vegetation was left undisturbed. Those for the burned ground are not reproduced as there remained very little worth mapping, although considerable cover of moss, liverworts and lichens developed later.

The quadrats were made to show the position of the seedlings, which are marked with asterisks, the type of vegetation on the various plots, and its relation to the germination and survival. Hatched areas represent solid mats of vegetation, the individual plants being marked with a key letter explained in the right hand margin.

It is a safe assumption that the matted groups of vegetation, regardless of the sites and species, repel and prevent seedling establishment, for none occurred within these groups. A typical instance is seen in the white pine and Douglas fir plots. (Fig. 24) On the other hand, where no mats are present the seedlings are scattered among the individual plants, as in

the case of the Douglas fir quadrat in Fig. 22. In a sense, therefore, the density of the vegetative cover may become a factor affecting the restocking, and since this matter leads us into an unexplored field, further discussion of this phase must cease.

It is true that conditions may exist where individual plants would ameliorate climatic extremes and protect young trees. This seems to have been the case of larch and western red cedar. However, the keen competition for moisture and light which must be endured by the young trees growing in dense vegetative cover usually more than counteracts any advantage from protection afforded by that cover.

That the type of vegetation varies distinctly according to the site or exposure is sufficiently brought out by the lists of species given in the right hand margin of Figures 22 to 24. We have for the northeast slope a larger proportion of the succulent plants among which are Viola, Clintonia, Mertensia, and Rubus, and relatively few drought resisting varieties such as Houchoa, Lupine, Calamagrostis, Apocynum and Sedum, which occur in greater abundance on the southwest exposure. (Fig. 23) The vegetation on the flat bears a closer resemblance to that on the southwest slope than to that on the northeast aspect and supports a great many plants of the genera Achillea, Fragaria, Garex, Berberis and Pentstemon, etc.

This subdominant surface cover of miscellaneous species

possesses its own successional stages and cycles, which are little understood, and although this investigation did not include a quantitative study of the herbaceous cover, the writer recognizes its value and possibilities as indicators of site characters and quality.

A few definite statements may be made as to the germination and survival of the important species on the sites studied. Western white pine survived better on the northeast, grew better for a time on the flat, but failed completely on the southwest. Western yellow pine germinated best on burned ground, survived rather well on all sites and surfaces and grew best on the burned plot on the flat. It is considered that these tests were not carried on to the final and inevitable elimination of this species from what might prove an unsuitable environment for the yellow pine. Douglas fir germinated best on the northeast, second best on the flat; survived well also on these sites but failed on the southwest. Its growth was superior on the northeast. Western larch germinated on all sites but did not survive on the southwest exposure. Its growth was better on burned than unburned ground. Western hemlock and western red cedar germinated on all aspects but survived only on the protected northeast slope. The growth of the hemlock was best on the unburned and that of the cedar on a burned surface.

Planting tests.

Results obtained by the planting experiments are given in order for Series A, B, C, and D. These various tests have been described in the section on methods. The curves for survival and growth in Series A to C may be seen in Fig. 26.

In Series A (Fig. 26), the western yellow pine proved uniformly much superior in survival and growth on the flat than on the southwest slope. For 53.2 percent remained on the flat and 42.0 percent on the southwest slope. The height growth was 57 inches at the end of 1921 on the flat and only 15 inches on the slope. It is true that there has been greater grass and shrub competition on the slope, but even those trees which were planted and which grew without this interference on the exposed slope measured at the end of 1921 only one-half the height of similar trees growing on the flat. On both sites the transplant stock showed superiority over the seedlings.

In Series B (Fig. 26), the western yellow pine substantiated in a very clear manner the results obtained in the previous test in showing 56 percent survival and 29.5 inches on the flat compared with 44.0 percent survival and only 15.3 inches in height on the southwest. It is to be noted that there occurred a proportionately heavier mortality among the smaller classes on the southwest aspect than on the flat. This was in all probability caused by the lower moisture content in the soil in

the upper layers on the slope, in conjunction with greater air movement and more pronounced evaporation.

Since the flat is underlayed with porous material to considerable depth and that on the southwest slope by rock, the plants in Series A and B were subjected to somewhat unequal soil moisture conditions on the two sites.

Series C contained western white pine only and was installed for comparisons on the flat and on the northeast slope. Both in survival and growth this series (Fig. 26) points unmistakably to the more suitable site conditions for western white pine on the northeast aspect, which shows survival of 78 percent for 1-2 and 66 percent for the 2-0, and a very unfavorable environment on the flat, for very few trees remained until 1921. The 1-2 transplant stock survived better and showed superior growth on both sites. (Fig. 27a and 27b)

On the steep southerly sites in Series D (Table XIII), the 1-2 transplants show higher survival than the 3-0 stock. The survival of the 3-0 plants was 22 percent on the south and 12 percent on the southeast face of the hill. In case of the 1-2 planting stock it was 27 percent and 14 percent in the order given; the south face falling close to the west with 26 percent survival. The results are clear cut in that these critical sites, as indicated by the soil tests and field soil moisture tests previously discussed, were responsible for low survival and rather slow growth. In the matter of height growth no constant or significant relation is evident. It appears from

this series on the three exposures that the southeast is the most precarious or exacting. It is possible that the underlying rock may have an influence on the soil moisture relations in some way.

Table XIII. Series D planted stock of 3-0 and 1-2 western yellow pine on steep phase southerly aspects.

Site	Station	Class	Survival percentage		Height in inches	
			1915	1921	1915	1921
SW	IIa	3-0	35	22	9.1	21
S	IIb	"	45	24	10.0	23
SE	IIc	"	26	12	11.0	24
Average			26	19	10.2	23
SW	IIa	1-2	61	27	6.7	18
S	IIb	"	65	26	7.7	16
SE	IIc	"	49	14	8.6	21
Average			58	33	7.7	18

The measurements obtained during the fall of 1932 of Series A, B, C, and D, were made on 100 of the dominant trees regardless of original size classes. In many instances, however, this number of trees was not available for record. This explains why there is a limited number in the other series.

Records from the plantation measurements in the fall of 1932, which are summarized in Table XIV, repeat and confirm the earlier results with western yellow pine in showing better growth for Series A and B on the flat than on the southwest slope. On the flat plants of Series A averaged an annual height growth of 9.1 inches since the time of planting and those on the southwest only 4.0 inches, and for Series B are 6.3 and 4.9 inches. In Series C with western white pine those on the north-

east aspect show an average height growth of 5.0 inches and those on the flat 4.4 inches over a period of 18 years. Of the white pines set out on the flat only 12 have survived out of 100. In Series D planted on the steep phase, yellow pine site at IIa etc., the few surviving plants have averaged 4.3 inches in height growth from 1915 until the end of the growing season in 1932.

Summarizing the results from the planting tests, it appears, in conclusion, that the results obtained in the planting tests have confirmed, in a large measure, the natural selectivity of the species for given sites expressed earlier in the seeding tests: in that western white pine survives and grows better on soils with more nutrients and improved moisture-holding capacity, etc., and that western yellow pine takes the lead on warm, dry sites with porous and somewhat impoverished soils. These tests have gone farther than the seeding tests in that there has been shown a definite correlation of survival and growth of western yellow pine with soil quality and nutrients; a superior development under the most favorable edaphic conditions on the flat, intermediate on the southwest slope at Station II, and poorest on the steep phase situation at Station IIa.

Table XIV. Growth of dominant trees to end of 1932.

Series:	Location	Species	Average: height :inches	No. :trees:	Years:	Average growth :inches
A	Flat	Western yellow pine	182.4	51	20	9.1
A	SW slope	"	80.1	21	20	4.0
B	Flat	Western yellow pine	114.2	100	18	6.3
B	SW slope	"	88.2	36	18	4.9
C	Flat	Western white pine	75.5	12	17	4.4
C	NE slope	"	85.6	100	17	5.0
D	SW slope (steep	Western yellow pine	74.4	12*	17	4.3

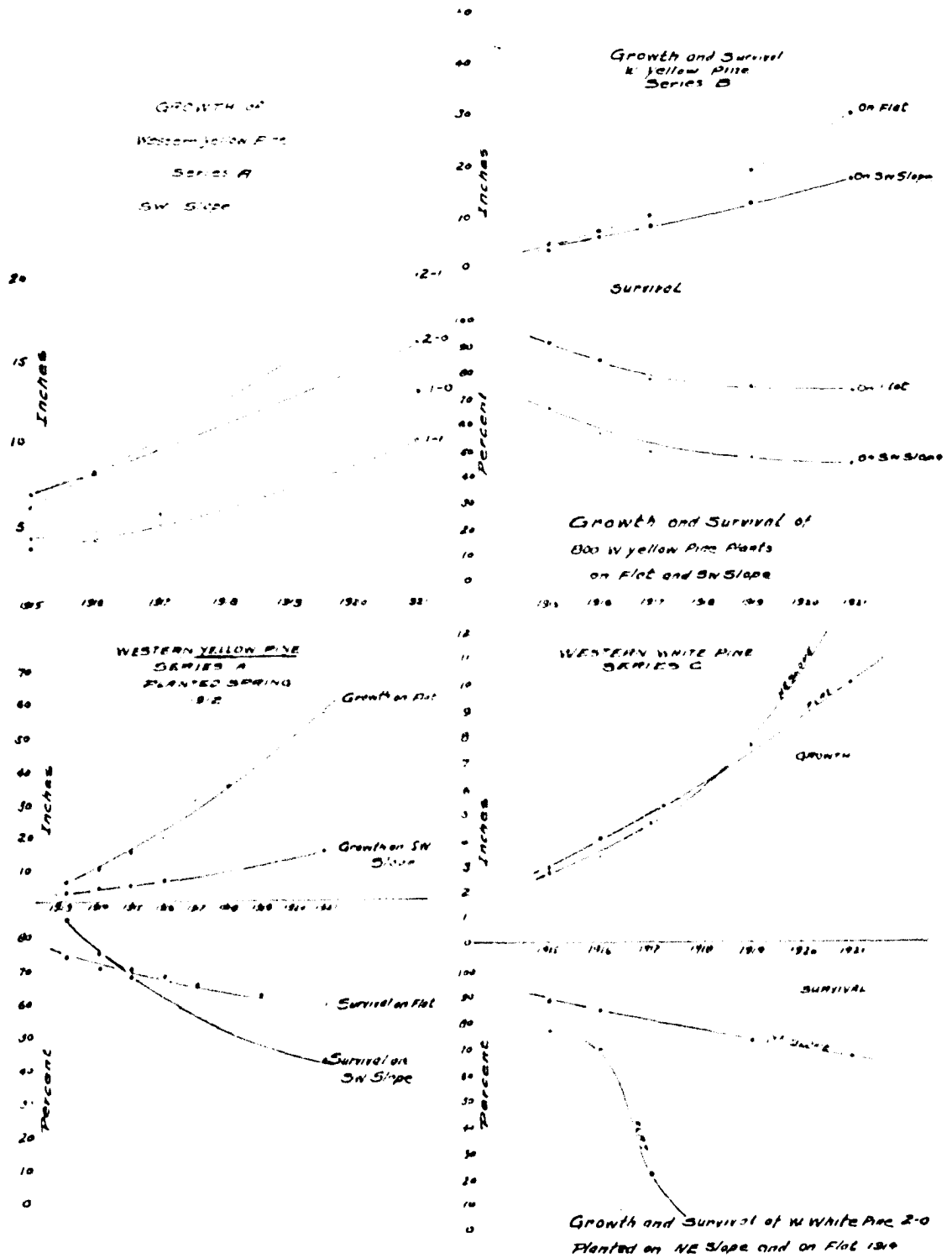


Fig. 26. Survival and growth of planted trees of western yellow pine and western white pine (Series A, B, and C) on various sites.



Fig. 27a; Western yellow pine, 1-2 stock used in Series C.



Fig. 27b; The 1-2 western yellow pine on the flat 1932.

DISCUSSION

It must be recognized that in studies of plant growth and development quantitative standards are yet in the making; the influence of variable intensities of the environmental factors is not fully understood and the relationship between any given factor and a definite response of the plant is difficult to establish. The investigator must therefore endeavor to learn what influences seem to be dominant or in what phase or period in the plant's development the individual external factor assumes a leading or limiting influence, and what combinations or summations of the environmental entities become significant, for single species and for groups or associations.

Light requirements and the tolerance of trees to shade are matters adjusted more or less to the local environment in that they vary according to moisture and temperature relations and fertility of the soil. For these reasons the records published by Bates and Burns and others have little significance in northern Idaho. The amount of direct sunlight is of importance in explaining the forest distribution and the life and growth of the trees, mainly through its influence on seed production. It is to be noted that all the native species generally bear seed at an earlier age and in greater quantity on sunny aspects than on the more shaded northerly slopes. The lesser amount of light

on the northeast aspect, moreover, becomes an important hindrance to growth of some species, especially the intolerant western yellow pine. All of the species in this region, except western red cedar and western hemlock will tolerate fully as much direct sunlight as the western yellow pine, for even the western white pine and the lowland white fir grow on western yellow pine slopes wherever there is sufficient ground moisture.

Seedlings and young trees of cedar and hemlock do not tolerate complete exposure to the sunlight in the summer, but the actual limits of light intensities, above or below which these and all the other native trees will not grow, is uncertain. From the seeding experiments it may be seen that the decreased light on the northeast aspect is not an important factor in germination but is necessary for later survival and growth.

In the work of tabulating and analyzing temperature data, and in dividing the days into active or inactive periods for plant growth the temperature at 43° F. is considered the average plant zero. The division of the year and months into periods of growth and rest is made according to the suggestion of Raphael Zon (62).

Mean air temperatures for the three sites--flat, southwest and northeast slope--are: for the summer months 56.3, 58.9 and 57.1° F. in the order given, and for the rest period 32.1, 34.6 and 32.9. The southwest slope station in yellow pine, therefore,

averages 2.6° higher than the flat. In August this difference is 3.8° .

Of interest in the temperature records are: the absence of hot weather on the northeast aspect in summer and the much lower points reached on the flat than at the other stations. While the extreme minima which occur in winter show considerable divergence, the low points occurring during the growing season are of greater importance, especially since seedlings which are tender and shallow rooted are protected by a mantle of snow during most of the rest period.

The much lower minimum temperature on the flat than at the slope stations may be attributed to the rise of warm air at night, especially during clear weather, and the inflow of cold air from higher levels. Since these depressed temperatures on the flat occur both winter and summer alike and whether there is a snow cover or not it is assumed that the vegetative cover plays no part or at least a minor role in the loss of heat which takes place at night.

In winter as well as in summer, and throughout every month of the year, the northeast slope shows the least temperature range and the flat the greatest. These relations are also brought out in the extreme range which is most pronounced for the flat and least on the northeast aspect. The tempering of the extremes, whether at high or low points, constitutes an element of safety to plants if very early photosynthetic

activity takes place, or in times of very early freezing in the autumn of late frosts in spring.

In the comparison of soil temperatures it is well to bear in mind that the composition of the soil particles themselves have considerable to do with the degree to which the soil absorbs heat under the sun's rays. A large amount of rock, gravel and sand favor rapid heat absorption because of the low specific heat of these materials. Furthermore, soils which contain much water heat up more slowly, by virtue of the high specific heat of water, than do dry soils. For these reasons the temperature of the clay soil on the flat is more similar to that of the soil on the northeast slope than on the other sites.

Soil temperatures reflect air temperatures; the lowest temperatures are reached by the upper soil layers on the flat and the highest temperatures on the yellow pine slope, the former reaching 115° and the latter 125° F. On the northwest aspect the high heat is increased by the low water content and scant humus. This is without doubt a factor contributing to the elimination of the more mesic and tender species, such as white pine, on exposed aspects. These extreme temperatures also, no doubt, retard or prevent bacterial activity.

Although an equal amount of atmospheric moisture is precipitated at all of the stations, all of this may not be available on the flat due to downward percolation in the porous soil.

An even lesser quantity may become available for plants on the southwest slope because of rapid run-off and high evaporation. These conditions have produced less complete vegetative cover and insufficient humus. While there is less loss of water from transpiration in this case than from sites with more profuse plant cover, it is nevertheless true that the meager organic matter results in a reduction of the water-holding capacity and the percentage of the available water in the soil.

The much shorter duration of the snow cover and its more shallow layer on the southwest aspect under western yellow pine than on the sites with larch, fir, or white pine, is an important factor in lengthening the growing season for the yellow pine and in giving greater protection to the soils and seedlings under white pine or larch-fir forests.

In this forested region where elevation is an important factor in tree distribution western yellow pine usually occupies a lower and warmer zone than white pine. Evidently the inclination of the slope makes up for the inverted position of the forest types. This materially shortens the growing season. However, from observations on the time of breaking of buds, leafing and flowering, it appears that growth activities on the northeast slope are more than 14 days behind those on the southwest aspect.

This shortening of the growing season occurs mainly in the spring, however, for in the autumn there is less temperature

variation between the sites. The melting of snow on the southwest slope is favored by the 4.3° high April maximum temperatures, the increase in radiant and reflected heat, due to the exposed and open character of the site and the greater angle of inclination to the sun's rays. Evaporation is hastened by the wind in March and April, which, owing to its greater velocity, causes the melting of more snow on the southwest than on the northeast slope, and carries away the air laden with moisture and supplies new air. The action of the moist air in this respect is very important, for the condensation brought about by the air at 32° F. in contact with the colder snow, may release enough heat (606.5 calories) to melt a layer of snow 7.6 cm. in thickness (28); and though this process operates to some extent on the other sites also, the atmospheric movement supplies new air more rapidly on the southwest slope than elsewhere. The greatest influence of the snow cover is, therefore, exerted during the period of melting and particularly in the spring.

Although the temperature is an important factor in melting the snow, the latter attracts much heat from the air, and it has been estimated that 25 cm. of melting snow cover may reduce the temperature of the air 1° C., through a layer of air 220 feet in thickness. Our records from March 1 to 20, 1915, during which time the snow remained on the northeast slope, and the southwest slope was bare, compared with March, 1912, when snow

covered both aspects, show 6.4° higher maxima on the southwest slope in 1915, and only 3.4° higher in 1912. The average difference in the five-year maxima is 3.8° F.

No hourly records of relative humidity are available for any of the stations. It is, of course, well recognized that through increase in temperature during the day the relative humidity is lowered, and that it is higher during the night. This partly explains the higher humidities on the northeast aspect and the lesser evaporation and loss of moisture from the soil. Reduction in wind movement on the northeast slope is also a cause toward this effect.

Later observations on relative humidity and air temperature at higher elevations than for these stations show that the air does not get so dry as it does on the flat and on the southwest slope. This is because the temperatures at higher points do not reach such great maxima. Lesser fluctuations in air temperature for high than low elevations result also in more equable humidity conditions at higher elevations.

Since the wind velocity is greatest in the afternoon during the hottest part of the day and at a time when the relative humidity reaches the lowest points, its effect in drying out the soil and hastening transpiration is a factor which must be given due consideration. Its influence on the southwest slopes is very much greater than on the other aspects or on the flat, for the prevailing direction is from the southwest. This situa-

tion brings about very critical conditions for the young seedlings, which ordinarily disappear in great numbers as soon as the dry weather sets in during July and August.

Soils on which the white pine, cedar and hemlock grow contain a larger percentage of clay and silt than those under Douglas fir and western yellow pine, and these soils possess a higher water holding capacity and more available water. The virgin white pine soil which also supports cedar and hemlock understory gave the highest clay fraction and the old growth yellow pine forest the lowest; larch and Douglas fir being intermediate.

The soils of lighter texture and with lower water holding capacity carry from one-third to one-half as much nitrogen, phosphorus and carbon as the heavier soils where more mesic trees grow. There appears to be no significant variation in the pH content between xeric and mesic locations. This fact may be considered as evidence that conditions in the mesic sites are suitable for complete disintegration of organic matter. There is no doubt that during some years subsequent to the destruction of the forest by fire the soil, especially in the upper layers, becomes alkaline, and that as the stages develop toward a climax an acid reaction is the order.

The surface soil temperature minima are perhaps most important in its relation to the heat absorbed and transmitted by contact and radiation to the new seedlings. In this re-

spect seedlings which get an early start may become somewhat resistant through increased differentiation of tissues.

Because the data on soil moisture were obtained on sites not occupied by the trees, they express more directly the conditions under which seedlings and young trees occur, and are of value in reforestation, not only in understanding the soil and moisture requirements of the species, but in determining sites for new plantations and the main causes of their success or failure, for the amount of moisture in the soil expresses better than any other measurable factor the quality of the site.

The minimum soil moistures attained at one to six inches and six to 12 inches has a more direct relation to seedling survival during the first season since it becomes a matter of roots in relation to soil, water and nutrients. In order to survive the critical period of dry soil during the peak of the summer the seedling roots must penetrate below 12 inches for even at the depth of six to 12 inches the minimum soil moistures recorded are 5.0, 2.6 and 11.0 percent.

For successful germination, growth, and survival of western white pine it is necessary to have at least 44 percent light, not less than 12 percent moisture in the first six inches of soil during the driest part of the season in the looser formations and slight protection either by other seedlings, vegetation, or standing timber. The character of the surface, whether of natural vegetation, burned, or denuded, has little influence

on germination and survival, provided the moisture conditions are right, but growth is reduced in competition with the natural vegetation. Increase in soil temperature through reduction of soil moisture and greater drying effect of the wind on larger clear cut flats and lower slopes may bring about conditions similar to those on the exposed slopes and render natural re-establishment precarious.

Within the zone occupied by the western white pine, cedar, and hemlock this pine is quick to reseed the terrain following single burns and destruction of the old forest. For this reason northern Idaho possesses many splendid stands of relatively pure western white pine. In a great many locations the cedar and hemlock will be seeded naturally along with the pine, but their much slower growth result in an understory which eventually becomes dominant when the pine decays and disappears. In very small openings caused by the fires and sheltered by larger trees the cedar and hemlock may restock the ground rapidly and successfully.

In case the western larch should seed in together with the pine, which frequently takes place, its rapid height growth enables it to keep in the lead of all other species. It therefore remains in the forest until the climax species succeed the white pine.

The western yellow pine germinated on all sites; survived best on the northeast slope and the flat for the first five

years and attained greatest height on the burned surfaced on the flat. Successful establishment and growth of seedlings requires a mean seasonal soil temperature between 60° and 70° F., from 50 to 100 percent of light and a mean soil moisture between 15 and 20 percent in the peak of the summer. It will tolerate lower soil moisture than any of the other species tried.

In view of the favorable showing of western yellow pine seedlings on the northeast aspect some may assume that this species will survive there, grow up and become a part of the forest. This is contrary to what actually takes place. Although individual trees of yellow pine will be found within the young stand on white pine sites their form and development is inferior and their growth slow as a result of competition with the white pine for moisture and light. They are eventually overtopped and suppressed, disappearing from the stand at a relatively early age.

The results with Douglas fir lead to the conclusion that natural regeneration of Douglas fir is comparatively easy of accomplishment on both natural and bared surfaces on north slopes and flats, but difficult on the exposed slopes. From the available data on this site it is difficult to prescribe what surface conditions here will bring best results. From general observations, however, it appears that the slight protection offered by shrubbery from the drying influence of

wind and sun in midsummer and the accumulation of leaf litter from these, which improves the moisture capacity of the soil, is very beneficial for establishment of Douglas fir on the drier, more exposed sites.

Douglas fir germination, like that of the white pine, may be expected on all sites provided the moisture conditions are favorable. The best results in germination were obtained on the burned surface of the northeast aspect and not at all on the southwest. These facts would indicate that this intermediate species will germinate and become established in yellow pine stands only with added protection and in white pine and cedar stands only where competition is greatly reduced.

Western larch gave generally better germination on the burned surfaces where it also showed superior survival. For successful establishment of western larch there must be assured sufficient soil moisture in the upper layers of soil one to six inches and six to 12 inches throughout the entire first growing season. This means not below 20 percent of moisture in the soil above 10 inches or so and fully 75 percent of sunlight. These conditions are found on cleared flats and open northerly slopes of low slopes and benches. From these results and from general observations, it is concluded that successful natural regeneration of larch can not be obtained anywhere except with full and unobstructed sunlight, and is generally

more easily obtained on a bared surface than in the presence of vegetation, except on the more critical sites.

Larch and western yellow pine seldom compete on the same terrain in northern Idaho. The larch grows under conditions of lower temperature and higher soil moisture than yellow pine and it belongs to a higher zone. In case they both happen to appear side by side the lack of soil moisture becomes the determining factor in favor of the pine, and if soil moisture is sufficient the larch will speedily outgrow the yellow pine. Both of these species rank about even in the amount of light required.

Competition between larch and Douglas fir is chiefly for soil moisture in that both of these species grow equally well under identical atmospheric conditions. The larch cannot survive where the soil moisture becomes low during the middle or latter part of the summer. This leaves the Douglas fir in possession of steep gradients similar to the northwest aspect where station IIIa was situated. On benches and lower northerly slopes, however, larch finds favorable conditions for rapid development and frequently becomes dominant.

The seed of Western hemlock germinated better in the shade than in the open and decidedly better on the northeast slope than elsewhere, chiefly because moisture conditions are more favorable; but survival was negligible except in the open site on the northeast aspect. Establishment of this species requires

soil moisture not below 20 percent and at least 20 percent of full sunlight. These conditions are met on better soil in the breaks in the virgin timber on flats and northerly slopes. Greater death by fungi occurred on bared surfaces and better growth occurred in the presence of vegetation than on the burned and denuded surfaces. In these respects it differs from all other species except grand fir, and it is possible that this is another evidence of its preference for organic material, which results in so much reproduction in decaying wood. That further tests with this and other species in different kinds of soil under uniform air and moisture conditions are needed is clearly indicated.

In case of western red cedar no survival resulted anywhere except on the northeast slope. Success of this species on the southwest or other exposed sites is absolutely out of the question and should not be looked for; but better results from those recorded here are sure to follow on more loamy and moist flats, for the site where Bed E was placed is essentially not for white pine and associated species, solely on account of the nature of the soil.

Cedar therefore requires constant soil moisture not below 12 percent in August, such as is found on the north aspects and loamy flats. It will not tolerate full sunlight. The failure of western red cedar and western hemlock on the southwest slope

is ascribed chiefly to the more exacting conditions arising from the greater wind movement, more sun, warmer soil and lesser and more irregular moisture conditions caused by the greater drying capacity of the air. It seems certain that the soil moisture in bed E on the flat was far too low for these species, and it is extremely questionable whether they would live even on a protected site under conditions of such limited soil moisture.

Other studies carried out by the author and other members of the Experiment Station staff point unmistakable to the fact that both hemlock and cedar seedlings survive and thrive on bare surfaces on low benches and flats provided the soil in which they grow are not exposed to direct insolation during the hot months of the year. The roots of the one-year old hemlock are very shallow and superficial, hence warm and dry weather accompanied by strong sunlight take heavy toll of the new seedlings.

Western red cedar has practically the same soil moisture and temperature requirements as the hemlock and successful reproduction can be depended on only on the flats with better soil and northerly aspects. Unlike hemlock it made noticeably better growth on the burned and denuded surfaces than among vegetation.

The tests of site characters by planted stock of native species embraced western yellow pine and western white pine on the three sites. These show that yellow pine survived best

and made better growth on the flat than on the southwest slope. Although the slope is distinctly a yellow pine and to some extent Douglas fir site, the stock fared better on the flat. This may be explained by the deeper and looser soil on the flat and the possibility of bringing by capillarity more continuous supply of moisture to their roots on the flat than is possible on the slope. It should be noted that in this valley, generally, the yellow pine is absent from the low flats and heavy soils, due no doubt to the more vigorous growth and more intense competition there of mesophytic white pine, hemlock and cedar. The planted stock of western white pine maintained excellent survival and growth on the northeast aspect and gave very discouraging results on the flat.

On the plots used on the lower part of the southwest aspect, local influences of shade and competition of shrubbery have upset the true relations which once existed in the stock, and have frustrated absolute comparisons. At the time of planting there was considerable shrubbery of willow, *Opulaster*, *Holodiscus* and *Geanothus*. These had a load on the planted stock and have offered serious and dissimilar competition for light and soil moisture. Later, dense mats of Kinnikinnick, goat brush, (*Pachystima myrsinites*) and sod have developed to a marked degree. Consequently there exists on each one of these plots very keen competition which has retarded growth and development of the plants.

In retrospect, it appears that the results obtained by the seeding tests and corroborated by the planting experiments have told the story better than any other set of data. Reduction in evaporation as affected by decreased air temperature and wind and by increased humidity resulted in higher soil moisture, denser vegetation, more abundant organic material and nutrients, which in turn favored establishment and development of mesic species, especially western white pine, on protected sites, and caused its elimination from exposed aspects. In a similar way we may trace the selection by other species of their proper habitat within the succession. This selection of the most suitable location is accomplished during the very first and second years in the life of the trees. However, on intermediate sites, the more mesic species may invade and remain suppressed for a long period of time and begin more active growth leading to dominance upon the elimination of more xeric species from the stand.

The order of secondary plant succession in northern Idaho, as determined by this field study of habitat requirements of the species, is from western yellow pine, through white pine to the red cedar-hemlock climax. The western larch has a place in the yellow pine stage under more favorable moisture conditions and grand fir occurs in the Douglas fir stage under the same conditions.

SUMMARY AND CONCLUSIONS

A study was initiated in 1912 at the Priest River Forest Experiment Station in northern Idaho, seeking to determine and evaluate site factors governing the reestablishment of temporary forest types of the secondary forest succession following forest fires, logging or other denudation.

Subsequent to the general forest fires, which occur periodically in this region and which are very destructive, the re-seeding and the natural return of the forest takes place by stages passing from the intolerant and xerophytic trees to the more permanent tolerant and moisture demanding species.

The investigation embraced a study of the climatic and edaphic factors as well as analysis of the soil with a view to evaluate the mechanical, physical and chemical properties. Responses of artificially sown native seedlings and planted trees formed a part of this study.

Well equipped weather stations were therefore located on a flat bench in larch-Douglas fir forest, on a southwest western yellow pine slope and on a northeast aspect within the western white pine type. Other secondary stations were chosen and the records for the main stations continued over a period of five years.

The results obtained from this study are briefly summarized

as follows: The air temperature relations show higher daily and seasonal maxima on the southwest aspect with a longer duration of temperatures favorable for growth than at the other points. This was followed closely by the station on the flat, but the northeast aspect shows the most moderate maxima. The minima of the air temperatures were lowest on the flat both winter and summer and highest on the northeast slope. From these relations it follows that the greater ranges and the danger from frost is more acute on the flat than at the other points.

Soil temperatures reflect and follow the trend of the air temperatures, but diverge far more at the surfaces and in the upper soil stratum than at the lower levels. The absolute maximum of surface readings were, on the southwest aspect, 125°, on the flat, 100°, and on the northeast 95°.

The southwest aspect which supports western yellow pine is characterized by a shallower snow cover which is of shorter duration than in the other types. This site is also favored above the others by higher maximum air temperature in summer and a longer period of growing temperatures. The soil moisture reaches more critical minima and remains at dangerously low points for extended periods in summer and the wind movement and evaporation are more pronounced than elsewhere. The opposite is true for the northeast aspect while the flat falls in between these two.

The soils on the northeast slope and others at sites where the mesic species grow contain a greater clay and silt fraction, higher capillary and other moisture retaining qualities than those occupied by the xerophytic yellow pine. These "mesic" soils show also a higher wilting coefficient and contain larger percentages of nitrogen, organic material, phosphorus and potassium than the soils of the exposed aspects. In all of these relations the larch-Douglas fir site appears to be intermediate.

Soils of the more sandy flats which become occupied with larch and Douglas fir are ordinarily not sufficiently improved in the physical properties to favor the growth of western white pine, cedar and hemlock. These areas will therefore remain in larch and Douglas fir indefinitely, while the more favorable soils are eventually claimed by species of greater tolerance and moisture requirements.

Seedlings which were raised from seed on the different sites expressed by their germination during the first two seasons, and by their survival and height growth to the end of the fifth year a conformity to the already existing forest trees which had seeded in after fires of 70 years ago, in that the white pine survived only on the northeast aspect and yellow pine flourished better than any other species on the southwest slope.

The five series of plantations consisting of western white pine and western yellow pine which were installed on the flat, the southwest and the northeast slopes from 1912 to 1915, and

measured at the end of 20 years, resulted in a better survival and growth for white pine on the northeast aspect and practically no survival on the flat.

These results demonstrate an early selectivity of the native species for their more suitable environmental conditions which is expressed through their survival and later development more than by their germination, for germination of white pine and yellow pine may take place on all of the aspects and on varying surfaces. The failure of mesic species to survive the peak of the hot and dry first summer on exposed sites, and the elimination of xerophytic species by fungus growth, lack of light and competition during the early part of their existence bring about the distribution which we have endeavored to explain.

It appears that the edaphic conditions to a large extent control and determine the order or stages in the progression of the temporary types especially through factors of soil temperature, soil moisture and water-holding capacity. But these characters are to a great extent the products of climatic factors, which vary for both the exposed and for the protected aspects. On the flats and benches, however, the type of forest which forms a part of the succession depends entirely upon the edaphic conditions, provided any one of the climatic factors does not become limiting.

LITERATURE CITED

1. Baker, F.S. The effect of excessively high temperature on coniferous reproduction. Jour. For. 27: 949-975, 1929.
2. Barnetto, R.M. and J.B. Hester. The effect of burning on the accumulation of organic matter in the forest soil. Soil Sci. 29: 281-284, 1930.
3. Bates, C.G. Forest types of the central Rocky Mountains as affected by climate and soil. U.S. Dept. Agr. Bul. 1233, 1924.
4. _____ Physiological requirements of Rocky Mountain trees. Jour. Agr. Res. 24: 97-164, 1923.
5. _____ How thirsty is a tree? Mimeoog. note 414, Lake States Forest Experiment Station, 1926.
6. _____ Relative resistance of tree seedlings to heat. U.S. Dept. Agr. Bul. 1263, 1924.
7. _____ Light intensities required for growth of coniferous seedlings. Am. Jour. Bot. 15: 185-194, 1928.
8. Blackman, V.H. The wilting coefficient of soil. Jour. of Ecol. 2: 43-50, 1914.
9. Bokor, R. Microflora of the forest soils. Proc. Intern. Soc. of Soil Sci. 4: 257-258, 1929.
10. Buckingham, Edgar. Studies on the movement of soil moisture. U.S. Dept. Agr. Bur. Soils, Bul. 38, 1907.
11. Burger, Hans. Physikalische Eigenschaften von Wald-und Freilandböden. III Mitt. der Schweizerischen Centralanstalt für das forstliche Versuchswesen, 51, Zurich 1929.
12. Burns, G.F. Studies in tolerance of New England forest trees. IV. Minimum light requirement referred to a definite standard. Vt. Agr. Exp. Sta. Bul. 235, 1923.
13. Bouyoucus, G.J. A new classification of soil moisture. Soil Sci. 2: 33-47, 1921.

14. _____ An investigation of soil temperature and some of the most important factors influencing it. Mich. Agr. Exp. Sta. Tech. Bul. 17, 1913.
15. Briggs, L.J. and G.L. Shantz. The wilting coefficient for different plants and its direct determination. U.S. Dept. Agr. Bur. Plant Ind. Bul. 230, 1912.
16. Craib, I.J. Some aspects of soil moisture in the forest. Yale Univ. School of Forestry Bul. 25, 1929.
17. Dole, J.E. Studies on the effect of air temperature and relative humidity on transpiration of Pinus strobus. Vt. Agr. Exp. Sta. Bul. 238, 1924.
18. Falconer, J.G., J. Wright and H.W. Beal. The decomposition of certain types of forest litter under field conditions. Am. Jour. Bot. 20: 196-203, 1933.
19. Falckenstein, von K. Vogel von. Untersuchungen von märkischen Dünen sandboden mit Kiefernbestand. Intern. Mitteil, f. Bodenkunde 1: 493-517, 1911.
20. Fehér, D. and G. Sommer. Untersuchungen über die Kohlenstoffe ernährung des Waldes. Biochem. Zeitschr. 199: 253-271, 1923.
21. Fisher, R.T. Soil changes and silviculture on the Harvard forest. Ecol. 9: 6-27, 1923.
22. Fowers, H.A. and R.E. Stephenson. Effects of burning on forest soil. Soil Sci. 38: 175-181, 1934.
23. Frank, E. Über Bodenazidität im Walde. H.M. Muth, Freiburg, 1927. Rev. in Jour. For. 30: 101-102, 1932. (Original not seen.)
24. Fuller, G.D. Evaporation and stratification of vegetation. Bot. Gaz. 54: 424-426, 1912.
25. Glinka, K. The great soil groups of the world and their development. Transl. by C.F. Marbut, Edwards Bros., Ann Arbor, Mich. 1927.
26. Hackmann, Geo. The fertilization of forests with special reference to phosphoric acid fertilizers. Phosphorsäure No. 6, 348-368, 1931. Abstracted in Chem. Abst. 26: 794, 1932. (Original not seen.)

27. Haig, I.T. Colloidal content and the related soil factors as indicators of site quality. Yale Univ. School of Forestry Bul. 24, 1929.
28. Hamberg, H.E. De L'influence des forets sur les climat de la' Suede. Stockholm, 1885-1896. (In files of Northern Rocky Mountain Forest and Range Experiment Station)
29. Hann, Julius. Textbook on Climatology. Macmillan & Co., London, 1903.
30. Harris, F.S. and J.S. Robinson. Factors affecting the evaporation of moisture from the soil. Jour. Agr. Res. 7: 439-461, 1916.
31. Heinrich, R. Absorptionsfähigkeit der Bodenarten für Wasserdampf und deren Bedeutung für Pflanzten. Landwirt. Ann. des Mecklenburgischen patriotischen Vereins 15: 1875, n.s. 15: 353-358, 1876.
32. Hesselman, Henrik. Om vara skogsforyngringsatgarders invirken pa saltpeterbildningen i marken och deras betydelse för barrskogens foryngning. (The effect of the regeneration measure on the formation of salt-petre in the soil and its importance in the regeneration of coniferous forest.) Skogvardföreläsningens Tidskrift. 16: 1-104, 1918.
33. Hicock, H.W., M.F. Morgan, H.J. Lutz, Henry Hull and H.A. Hunt. The relation of the forest composition and the rate of growth to certain soil characters. Conn. (New Haven) Agr. Exp. Sta. Bul. 330, Part II, 677-750, 1931.
34. Joffe, J.B. Soil profile studies. III. The process of podzolization. Soil Sci., 32: 303-323, 1931.
35. Korstian, C.F. and N.T. Fotherolf. Control of stem girdle of spruce transplants caused by excessive heat. Phytopath. 11: 486-490, 1921.
36. Larson, J.A. Forest types of the northern Rocky Mountains and their climatic controls. Ecological. 11: 631-672, 1930.
37. Livingston, B.E. and Forrest Shreve. Distribution of vegetation of the United States in relation to climatic conditions. Carnegie Inst. Pub. No. 284, 1921.
38. Li, Tsi Tung. Soil temperature as influenced by forest cover. Yale Univ. School of Forestry Bul. 18, 1926.

39. Lundegardh, H.G. Klima und Boden in ihrer Wirkung auf des Pflanzenleben. G. Fischer, Jena 1925.
 40. Marshall, Robert, and Clarence Averill. Soil alkalinity on recent burns. Ecol. 9: 533, 1923.
 41. McLean, F.T. A preliminary study of climatic conditions in Maryland as related to plant growth. Physiol. Researches 2: 129-208, 1917.
 42. Millar, C.E. Observations on the behavior of soils under reforestation. Mich. State Col. of Agr. Soil Sci. Bul. 2: 97-99, 1933.
 43. Münch, E. Beobachtungen über Erhitzung der Bodenoberfläche im Jahre 1914. Naturw. Zeitschr. f. Forst u. Landwesen. 13: 249-260, 1915.
 44. Nemeec, A. and K. Kvapil. Über den Einfluss verschiedener Waldbestände auf den Gehalt und die Bildung von Nitraten in Waldböden. Zeitschr. f. Forst u. Jagdw. 59: 321-352, 1927.
 45. Nichols, G.E. Summer evaporation intensity as a determining factor in the distribution of vegetation in Connecticut. Bot. Gaz. 56: 143-153, 1913.
 46. Palmgren, Alvar. Chance as an element in plant geography. Proc. Intern. Congress of Plant Sciences, Ithaca, N.Y. Vol. 1: 591-602, 1926.
 47. Pearson, G.A. Forest types in the Southwest as determined by climate and soil. U.S. Dept. of Agr. Tech. Bul. 247, 1931.
 48. _____ Light and moisture in forestry. Ecol. 11: 145-160, 1930.
 49. _____ Studies in transpiration of coniferous tree seedlings. Ecol. 5: 340-347, 1924.
 50. Prinz, Henrik. Granen og furuens utbredelse. Nyt Magazin for Naturvidenskaberne, 73: 167-219, Oslo, 1933.
 51. Ramann, E. Forstliche Bodenkunde. Julius Springer, Berlin, 1893.
 52. Robbins, W.W. Climatology and vegetation of Colorado. Bot. Gaz. 49: 256-280, 1910.
-

53. Schütze, W. Beziehungen zwischen chemischer Zusammensetzung und Ertragsfähigkeit des Waldbodens. Zeitschr. f. Forst u. Jagdw. 3: 367-390, 1871.
54. Shirley, H.L. The influence of light intensity and light quality upon the growth of plants. Am. Jour. Bot. 16: 354-390, 1929.
55. Stiles, Walter, and Ingvar Jørgensen. The nature and method of extraction of the soil solution. Jour. Ecol. 2: 245-250, 1914.
56. Süchting, H. Physikalische, chemische und biologische Eigenschaften verarmter und durch Humusbildung veränderter Waldböden sowie Mittel zur Besserung solcher Böden. Zeitschr. f. Forst. u. Jagdw. 59: 282-301, 1927.
57. Tourney, J.W. and Noethling. The effect of cover over coniferous seedbeds in southern New England. Yale Univ. School of Forestry Bul. 9, 1923.
58. Tourney, J.W. and Raymond Kienholz. Trenched plots under forest canopies. Yale Univ. School of Forestry Bul. 30, 1931.
59. Waksman, Selman, A., F.G. Tenney and K.R. Stevens. The role of microorganisms in the transformation of organic matter in the forest soils. Ecol. 9: 126-144, 1928.
60. Weaver, J.E. Evaporation and plant succession in southeastern Washington and adjacent Idaho. Plant World 17: 273-294, 1914.
61. Wilde, S.A. The relation of soils and forest vegetation in the Lake States region, Ecol. 14: 94-105, 1933.
62. Zon, Raphael. Meteorological observations in connection with botanical geography, agriculture and forestry. U.S. Monthly Weather Rev. 42: 217-223, 1914.

ACKNOWLEDGMENT

The writer is much indebted to Dr. Raphael Zon and Donald R. Brewster, whose inspiration and encouragement contributed materially toward the planning, initiation and early carrying on of this project; to the various Field Assistants in the Forest Service who helped with the daily records and first tabulations, particularly to T.S. Hanson and C.C. Delavan; and not least to Mr. Ernest C. Rogers, an early member of the station staff for the seedling records, moisture records and quadrats so faithfully and conscientiously prepared; and to Dr. J.M. Aikman for his kind help and criticism during the final stages of the investigation and in the preparation of the manuscript.