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A soil-site study of western larch (Larix occidentalis Nuttall) in Montana

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A SOIL-SITE STUDY OF WESTERN LARCH

(*LARIX OCCIDENTALIS*, NUTTALL)

IN MONTANA

by

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R.S.E.

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CHAPTER I

THE PROBLEM AND DEFINITIONS OF TERMS USED

One of the problems with which foresters are confronted is the determination of the growth potential of forest land that is not at present supporting adequate forest growth. The total area of such land is increasing due to improper management of the forests. The forest manager needs to know the productive potential of the land in terms of tree species to: (1) judge proper stocking for high production in the developing stand, (2) evaluate the potential of various species comprising the stand so as to guide him in regulating stand composition, and (3) provide guides for planting in the event of failure in natural restocking.

THE PROBLEM

Statement of the problem. The purpose of this study was to determine if there were any soil physical properties or physiographic features that might be used as an index to predict the growth of western larch (*Larix occidentalis*, *Nutt.*) in Montana.

Importance of the study. The direct measurement of forest growth has been the most widely used index of site quality on areas where even-aged, undisturbed stands of timber are growing. The height of the dominant stand in relation to its age is one measure that has been assumed to

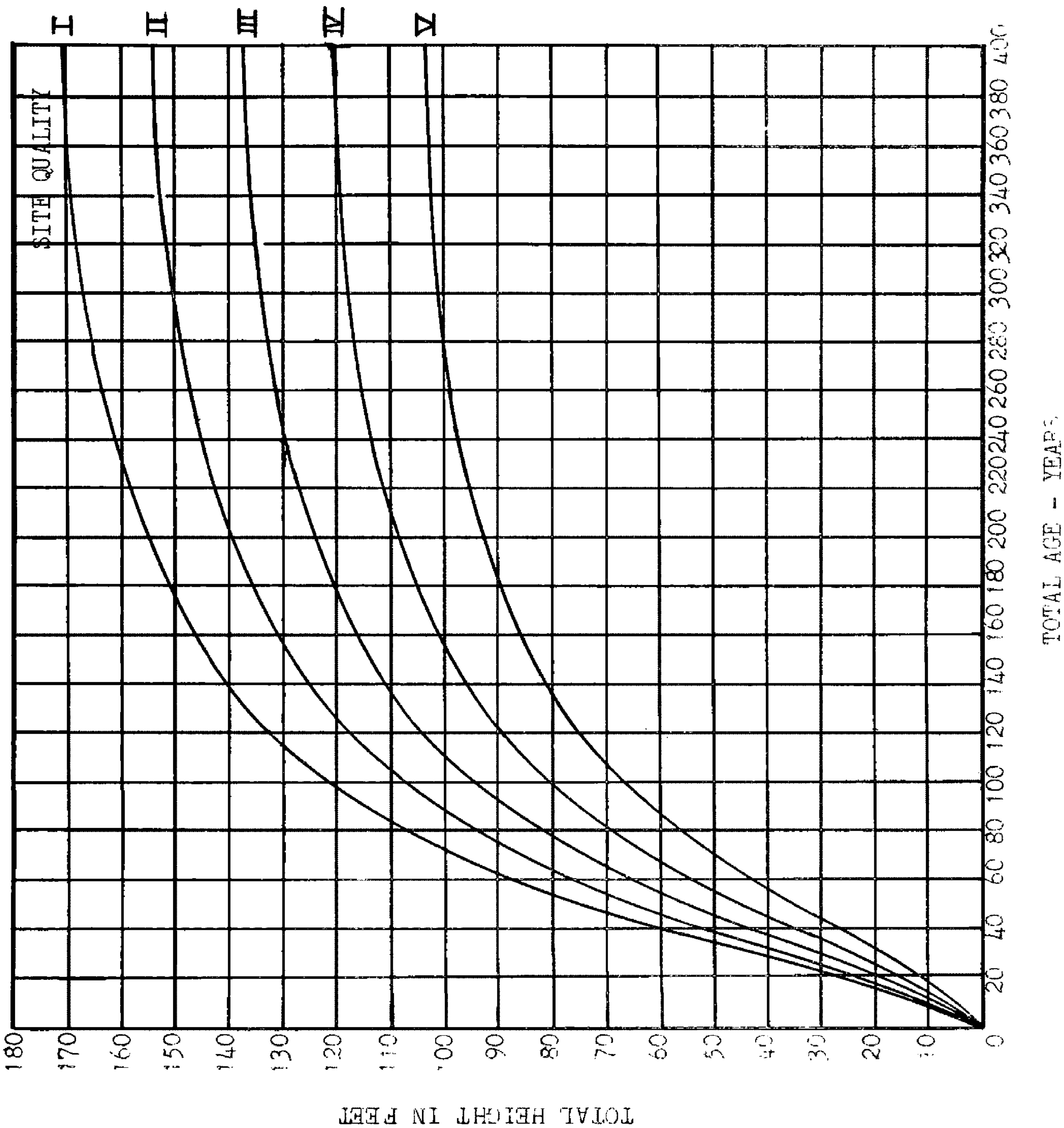

FIGURE 1
SITE CLASSIFICATION CURVES FOR WESTERN LARCH
(Based on average dominant and co-dominant trees)

(From Cummings, II)

be most independent of stand factors, primarily stand density. This height-age relationship is expressed as site index. From data obtained by this direct measurement of forest growth a family of site curves is constructed which shows dominant heights over a range of ages for each of several site indices. Such a family of curves may be found in Figure 1, page 2.

Site index is not, as most foresters realize, a true assessment of site quality. Many undetermined variables such as insect and disease depredations, genetical strain of the species, ground fires, stand density, and soil characteristics all introduce unknown error into the site quality determination. As an example of this inconsistency consider the following possible illustration: Suppose a 40-year old stand of timber was classed as Site II. The site is again determined when the stand reaches 100 years of age. At this later date Site III was recorded. If growth predictions had been made using the first site determination as a basis the predictions would have been in error. This type of error is one associated with inaccurate growth curves. If, however, it were possible to have growth curves for every soil type the growth inconsistencies due to soil factors would be eliminated or at least greatly reduced.

In an attempt to overcome the shortcomings of the site index approach to site evaluation, other methods have been proposed. The use of plant indicators is one such method. These indicator plants are ground species that have been found consistently associated with a particular quality of forest growth. The success of this approach depends upon the worker's knowledge of the ecology of plant associations. Due to variability and complexity of these associations only broad divisions of site quality such as "good", "medium", or "poor" are usually expressed (7).

The possibility of preparing growth curves by the various ecological types has been suggested, and, though this has not as yet been attempted, it appears that such an approach might be quite superior to our present information, particularly for larch.

Numerous investigations have been made in an attempt to establish a relationship between certain chemical, physical, and biological properties of the soil and forest growth. Coile (7), states that "the soil properties which influence the quality and quantity of growing space for the tree roots are most important in determining site quality." Since it is usually accepted that the combined influences of the many environmental conditions are reflected by the soil properties, it may be possible to determine growth potentials by the evaluation of certain of these soil properties. The success of such soil-site investigations has varied with location, species, and factors associated with site quality.

The soil and plant indicator approach to forest site appraisal are especially useful in areas that do not, at the time of measurement, support forest growth or which support uneven-aged, disturbed, or very young stands. Because much of the timberland in Montana falls into one or more of these categories, such a measure of site quality will be needed in order to help return these lands to their maximum productivity.

DEFINITIONS OF TERMS USED

Site. "In forestry a site may be defined as an area of land with a characteristic combination of soil, topographic, climatic, and biotic factors."(7)

Site quality. "A designation of the relative productive capaticy or quality of a site with reference to the species employed; the volume or the heights produced at a given age is used as a standard for classification."(20)

Site index. "An expression of forest site quality based on the height of the dominant stand at an arbitrarily chosen age."(20)

Forest type. "A descriptive term used to group stands of similar character as regards to composition and development due to certain ecological factors, by which they may be differentiated from other groups of stands. The term suggests repetition of the same character under similar conditions."(20)

Western larch type. "Forests in which 50 per cent or more of the stand is larch and less than 20 per cent is western white pine."(23)

CHAPTER II

REVIEW OF THE LITERATURE

SOIL-SITE STUDIES

There have been no soil-site studies in the western larch type. There have been, however, studies of this nature conducted in other forest types. In order to maintain some semblance of continuity, the investigations summarized here will be grouped according to the principal features studied.

SOIL PHYSICAL PROPERTIES

Depth correlations. Copeland (10) in his investigations of western white pine sites in the northern Rocky Mountains found that site index was correlated significantly with effective soil depth and depth to a zone of reduced permeability.

Depth to a hardpan seemed to be an important criterion for productivity ratings on five different forest cover types in Washington. According to Forristal and Gessel(15), high bulk densities impeded root growth and determined effective soil depth.

In a study of Douglas -fir in western Washington, Schlots, et al(26) noticed site quality decreased with decreasing soil depth over claypan, fragipan, and hardpan horizons.

Carmean(4) in his study of second-growth Douglas-fir in southwestern Washington found that site quality increased with an increase in depth to the C horizon.

Diebol(13) also found that depth, in conjunction with structure and consistency, of the subsoil was an important soil characteristic influencing site quality of deciduous trees in New York.

Depth of organic layer, depth of mineral soil, and depth of tree rooting were found by Godman and Gregory(18) to be fairly trustworthy indicators of site quality in undisturbed climax stands of southeast Alaska in areas of uniform parent-rock materials.

Gaiser(17) in a study of white oak sites in southeastern Ohio found that site index increased as depth of the A horizon increased.

In a study(8) of soil productivity for southern pines in the Piedmont and Coastal Plains region of the Southeast, it was noted that site index was affected by depth to mottling, which is an indication of poor drainage, and depth of the surface soil.

Depth of the A horizon was shown by Auten(1) to be positively related to site index of black locust and black walnut stands in the Central States area. It was also found by Auten(2) in a study of yellow poplar sites that depth to a "tight subsoil" was directly correlated with site index. Depth of the A_1 horizon was also positively related to site index in the yellow poplar stands of the south central states region, but this measurement was found to be insufficient without considering the depth to a "tight subsoil."

The growth of loblolly pine in the Coastal Plains region of Virginia and the Carolinas was shown to be affected by depth to an impermeable subsoil horizon(16).

Moisture relationships. Investigations by Copeland (10) show that the site index of western white pine was correlated with the available water-holding capacity of the top three feet of soil.

Site quality of second-growth Douglas-fir stands in Lewis County, Washington appeared to be determined by the moisture relations of the soil according to Hill, Arnst, and Bond(21).

Carmean(4) found that an increase in the site quality of Douglas-fir in southwestern Washington occurred as the product of moisture equivalent and percentage of gravel increased.

Studies made by Prochman(24) in the Englemann spruce-alpine fir type in British Columbia show that soil moisture appears to be the most important single differentiating factor within a climatic region.

A marked negative relationship was observed by Coile (6) between the water-holding capacity of the B_1 horizon and the site index of shortleaf pine. This relationship was not as pronounced in the higher site indices as in the lower indices because of the many other physical factors of the soil, which, singly or in combination, exert pronounced influence on height growth.

White oak site quality was found by Gaiser(17) to be influenced by the total available moisture in the A horizon. This total available moisture is, however, dependent upon the depth of the A horizon of the soil. Gaiser also found in his loblolly pine study(16) that site quality was affected by the imbibitional water value of the least permeable subsoil horizon.

Texture relationships. Holtby(22) noted that soil texture, six inches below the surface, is a fairly reliable indicator of site quality in the ponderosa pine region near Glenwood, Washington.

Carmean(4) observed that site quality decreases in second-growth Douglas-fir stands in southwestern Washington as the percentage of gravel in the soil profile increases.

In a study by Haig(19), colloidal content and silt plus clay content of the A horizon were found to be definitely correlated with site quality of red pine. The author notes, however, that his conclusions are applicable only to the brown, weakly podsolized forest soils of southern Connecticut and adjacent territory.

The "texture-depth index"(silt plus clay content of the B_1 divided by depth to the B_1) was taken to be a reliable measure of site quality for shortleaf pine on the soils studied by Coile(6). Coile(8) also observed that the nature of the subsoil with respect to its texture or consistence had an influence on the rate of growth of southern pines in the Piedmont and Coastal Plains region.

In Auten's(1) study of black locust and black walnut sites, it was found that the lighter textured surface soils, in general, predominated in the upper site index group while the heavier soils predominated in the lower site group.

Drainage relationships. A factor of importance in the southern pine Coastal Plains region is the surface drainage of the land. This property is, as Coile(8) states, independent of soil depth and texture.

Drainage or permeability of the soil was found by Auten(1) to be of primary importance in the growth of black locust and black walnut. Factors to which drainage can be related are: color, texture, compactness, and soil-horizon arrangement. These in turn are closely related to topography.

It was shown by Gaiser(16) that the mean site index of loblolly pine in the Coastal Plains region of Virginia and the Carolinas was higher on land of poor surface drainage than on land of better surface drainage.

SOIL CHEMICAL PROPERTIES

Soil reaction. Coile(5) noted that soil reaction under seven forest types in the Duke Forest did not differ greatly enough to be a limiting factor in the distribution of the forest types.

Auten(1,2) also failed to find any real relation between soil reaction and the growth of black locust, black walnut, and yellow poplar.

Nutrient relationships. In a study of soil fertility of the Douglas-fir region of the Pacific Northwest, Tarrant (30) found the nutrient content was, in general, too high to be a limiting factor in tree growth.

It was observed by Auten(1,2) that soil nutrients were seldom a limiting factor in the growth of black locust, black walnut, and yellow poplar.

Stones'(29) observations of magnesium deficiencies in eastern white, red, and jack pine of the Northeast show that gross reductions in shoot growth and needle length occurred only under extreme deficiency or when lack of magnesium was accompanied by a potassium deficiency. Fertilization of deficient tress with $MgSO_4$ resulted in increased height growth over a period of at least three years.

PHYSIOGRAPHIC FEATURES

"Topography through its three elements of aspect, slope, and position modifies soil-moisture content; hence it has an important effect on site quality."(2)

Gaiser(17) stated that site index for white oak was highest on the lower slopes and decreased rapidly in the vicinity of the ridge line. Superior sites were encountered on northeastern exposures and inferior sites on the southwest and west, The pitch or slope of the land did not appear to affect the site quality.

Carmean(4) noted a marked decrease in site quality as elevation increased.

According to Einspahr and McComb(14) the soil and topographic features which affect availability of moisture for growth appear to be correlated with the site index of oaks in northeastern Iowa. The north and east aspects produced the highest site indices and the south and west produced the lowest. Site index values were found to decrease as the percentage of slope increased. This relationship was found to be highly significant on south and west aspects but not significant on north and east aspects.

This review of past studies seems to establish the importance of the physical soil properties and physiographic features in soil-site work. Primarily for this reason, but also because such measurements are relatively easy to make, the scope of this study was limited to these two phases.

THE WESTERN LARCH TYPE

Western larch, the largest as well as the most important of all the larches or tamaracks, was first discovered on the upper Clearwater River in Idaho by the Lewis and Clark expedition in 1806. Its natural range, Figure 2, page 14, is resticted to the high mountain valleys and slopes of southeastern British Columbia and the upper Columbia River basin, bounded by the Rocky Mountains on the east and the Cascade Mountains on the west.(3,9,32)

Cool temperatures and an average annual precipitation of about 28 inches would seem to characterize the climatic zone in which western larch grows. The minimum annual precipitation tolerated is about 18 inches. Summer rainfall accounts for only an estimated 20-30 per cent of the total precipitation while December and January are usually the periods of maximum precipitation. Snowfall ranges from 40 inches to more than 80 inches a year. Mean air temperatures are above 43°F for 160-175 days a year with frost likely every month of the year. Temperature extremes range from -49°F to 107°F.(3,12)

The soils within the type were, as stated by Boe(3), originally classified as gray-brown podzolic. This great soil group was generally mapped as encompassing the entire Northern Rocky Mountain area in Montana, Idaho, and eastern Washington. Since this original classification several workers have put forth proposals suggesting that there is

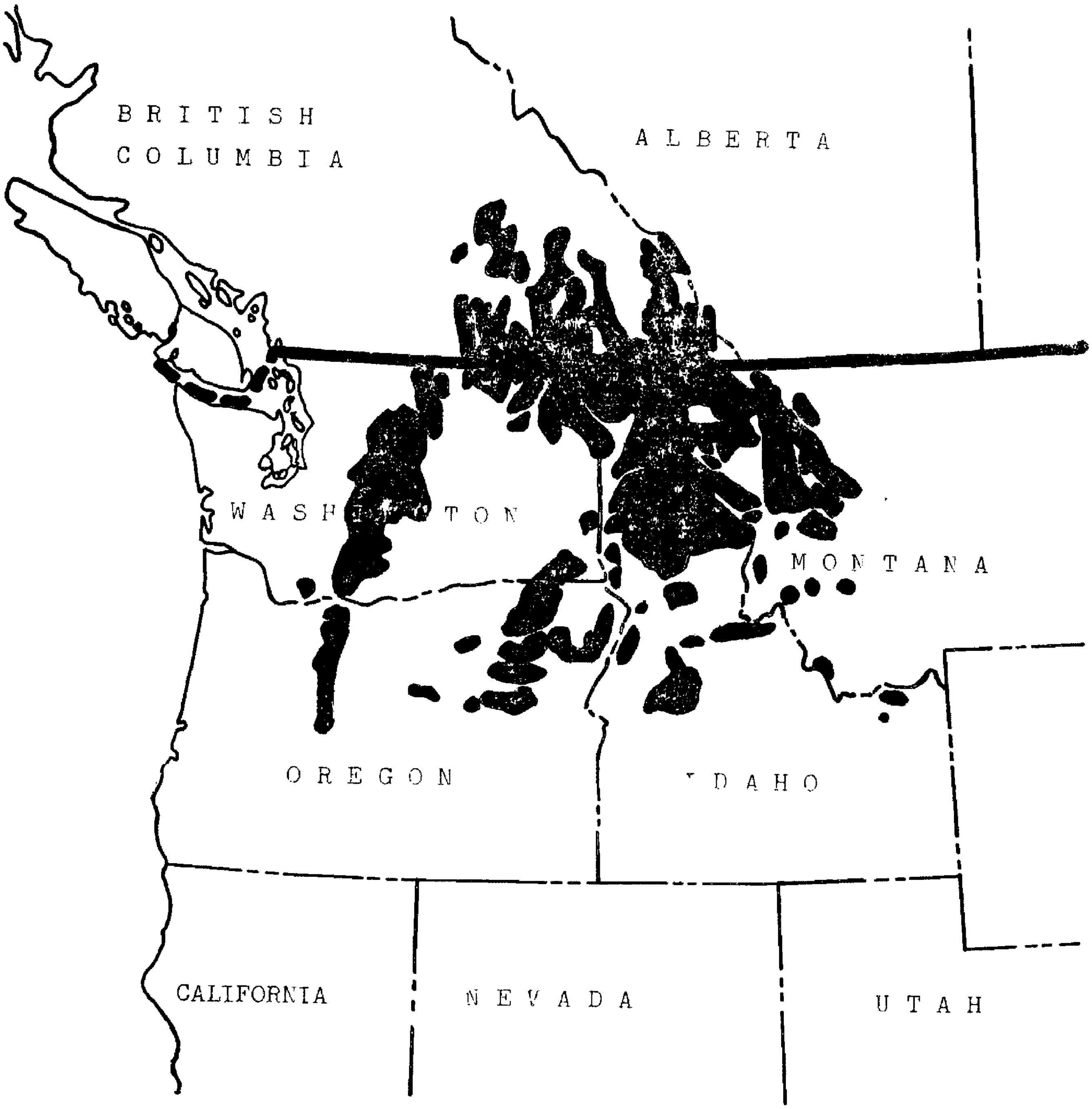

FIGURE 2
BOTANICAL RANGE OF WESTERN LARCH
(From Boe, 3)

represented in this large area, more than one great soil group. Some of the soil groups that are now recognized as occurring within this area are the brown-podzolic, the gray-wooded and the true podsol. The brown-podzolic soil group would probably be the most representative soil on which the larch type is found. A profile dexcription of this soil group may be found in the Appendix.

Northerly exposures, valley bottoms, benches, and rolling topography best characterize the sites on which this species attains its best growth. Southwest exposures are not favorable sites for larch. It occurs in the middle elevation zone at 2,000 to 5,500 feet in the north and up to 7,000 feet in the southern part of its range. Temperature seems to be the limiting factor in the upward extension of western larch.(3,12)

Though western larch sometimes occurs in pure, open forests it is generally associated with other species. The common associations in which larch is found are:

1. Western larch
   Douglas-fir(*Pseudotsuga menziesii*, *Britt*)

2. Western larch
   Douglas-fir
   Grand fir(*Abies grandis*, *Dougl*)

3. Western larch
   Douglas-fir
   Ponderosa pine(*P. ponderosa*, *Dougl*)

4. Western larch
   Western white pine(*P. monticola*, *Dougl*)

5. Western larch
   Lodgepole pine (*P. contorta*, *Dougl*)

WESTERN LARCH IN MONTANA

In Montana western larch is found west of the Continental Divide from the Canadian Boundary to about fifteen miles south of Missoula.(12) Forty-four per cent of all the western larch saw timber in the United States is in Montana-atotal of 11.8 billion board feet.(23) Commercial forest land in western Montana in 1949 amounted to almost 9 million acres. Twenty-nine per cent or 2.6 million acres of this land was classed as larch type. The total volume of live saw timber on Montana commercial forest lands was just under 39.7 billion board feet in 1949. Western larch accounted for approximately thirty per cent of this volume.(23)

Larch is one of the larger and more desirable trees in Montana, growing tall, straight, and clear. Diameters of five feet are not uncommon. The growth habits of larch are such that it will produce more clear wood than any other native tree. Seventy-two per cent of the volume in larch saw timber in 1949 was in trees twenty inches and larger.(23)

It is believed by some that larch may have more undeveloped potentialities than any other native species. At the present time it is used mainly for sawed lumber and transmission poles with some limited use for plywood, and in pulp as chips from mills cutting larch saw timber. Tests prove it to be a very good veneer wood. This species is also unusually rich in galactose sugar, an extractive that makes up from twelve to twenty per cent of the dry weight of the wood. The heaviest concentration of sugar is found at the butt of the tree but as yet no industrial use is made of this extractive.(23)

CHAPTER III

METHODS OF PROCEDURE

SOURCE OF DATA

Data for this study were gathered from temporary sample plots located in even-aged stands of western larch throughout northwestern Montana. Figure 3, page 19, shows the western larch type in Montana and the location of the sample plots. Each plot was carefully selected for its uniformity of site, age and density.

Plot sizes ranged from one-fortieth of an acre to one-tenth of an acre; the majority being one-tenth acre in size. The small plots were confined to dense, young stands. Plot shape was determined by the uniformity of the stand under investigation. The stands sampled ranged in age from 20 years to 130 years with all five site classes as described by Cummings(11) being represented.

During the field season of 1959, forty-five sample plots were measured. These plots form the basis for the present study. The data obtained from each plot were recorded on a field form designed for this study.

FIELD PROCEDURES

Mensurational data obtained and methods of determination were as follows:

1. For the five dominant trees on each plot:

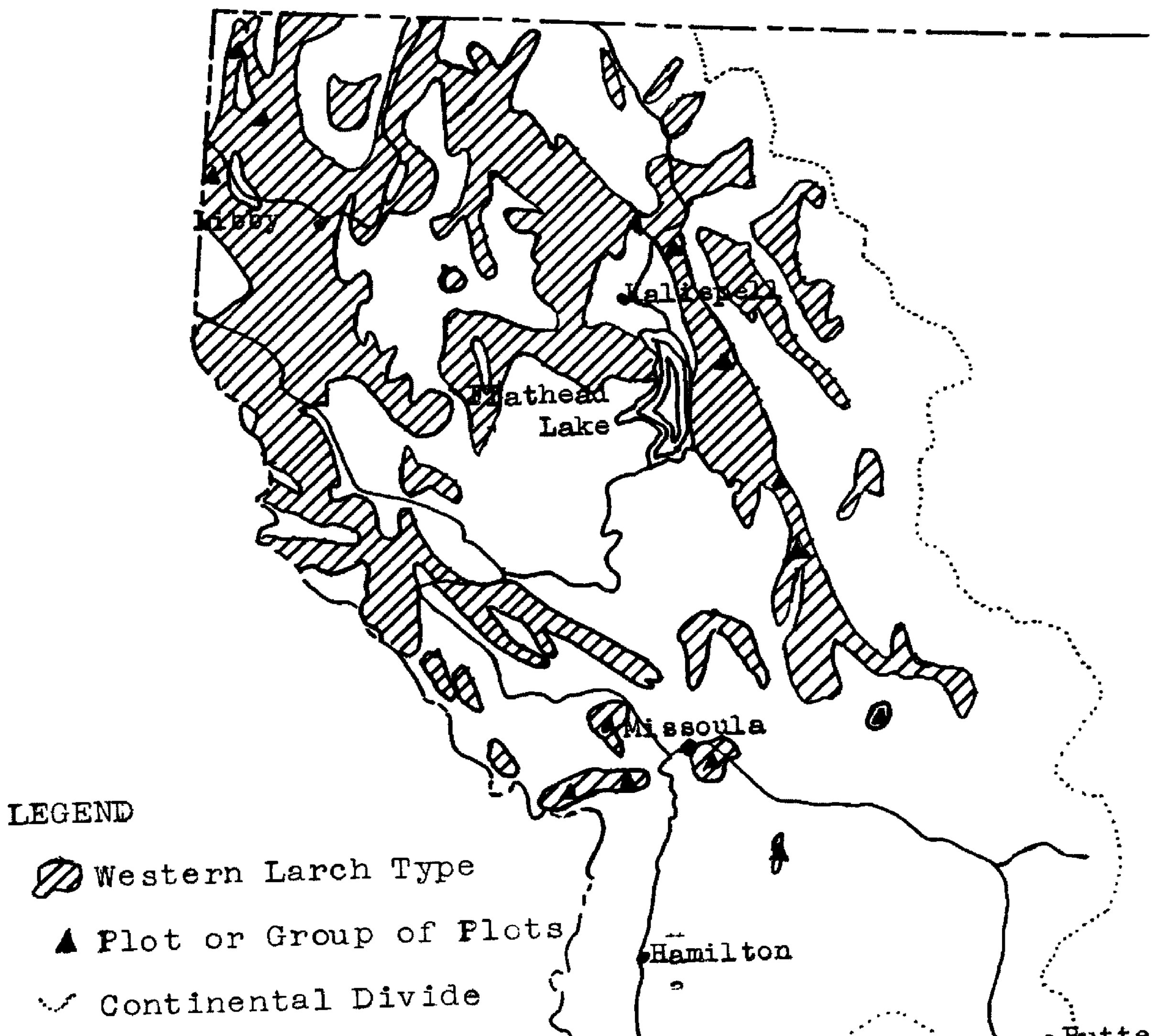

FIGURE 3
MAP OF WESTERN MONTANA SHOWING THE WESTERN LARCH TYPE AND THE LOCATION OF PLOTS OR GROUPS OF PLOTS MEASURED IN THIS STUDY. (23)

a. Total age-by increment borings
b. Total height-by Abney level
c. Diameter, breast high (dbh) to 0.1 inch-by diameter tape

2. Complete tally of all trees on the plot by one-inch diameter classes.

3. Plot size was recorded or if irregular plot the bearing and length of its exterior lines was noted.

Physiographic information and methods of determination were as follows:

1. per cent of slope-Abney level.
2. length of slope-0-10, 10-20, or 20+ chains.
3. exposure-bearing of direction slope faces by use of pocket compass.
4. position on slope-either lower, middle, or upper third of slope.
5. elevation-estimated from available contour maps.
6. drainage-soil drainage classes as described in the Soil Survey Manual(28), page 170.
7. relief-relief positions as described in the Soil Survey Manual(28), page 159.
8. landform-such as high terrace, till plain, etc.
9. surface stone-classification found on page 219, Soil Survey Manual(28).
10. plot location-by standard Public Land Survey System.

Soils information was obtained by opening one soil pit on each plot and making a complete description of the soil profile exposed. This pit was located in what appeared to be a representative area on the plot. The profile description consisted of the following information:

1. horizon designation
2. horizon depth
3. horizon boundary
4. soil color
5. soil consistency
6. soil structure
7. depth of rooting
8. parent material

9. percentage volume stone in the profile-the method for this determination may be found in the appendix.
10. bulk density-method may be found in the appendix.
11. special features and notes.
12. samples were collected from each horizon for laboratory analysis.

Note: Items 1-8 were described as suggested in the Soil Survey Manual(28).

Ground vegetation. The original study plan called for an analysis of the ground vegetation by estimating the percentage of the surface covered by each species present. This idea had to be abandoned due to the amount of time required to carry out such an analysis. However, a list of the commom species making up the ground cover observed on each plot was made and a composite list for all the plots may be found in the appendix.

LABORATORY PROCEDURES

Information obtained and methods used in the laboratory were as follows:

1. Textural analysis by the Bouyoucos method.

2. Organic matter content was determined colorimetrically. Description of method may be found in the appendix.

3. Soil reaction(pH) was obtained by the use of a Beckman glass electrode pH meter. A saturated soil paste was used in this determination.(25)

4. Moisture retention at one-third atmosphere was determined by the porous plate method.(25)

5. Moisture retention at fifteen atmospheres was determined by the pressure membrane method.(25)

Table I gives the maximum, minimum, and mean values for all information used in the analysis.

TABLE I

LABORATORY AND FIELD DATA RANGES

VARIABLE	MAXIMUM	MINIMUM	MEAN
Height- av. five dom. (ft)	118	21	58
Age- av. five dom. (years)	130	19	49
Stems per acre	4560	310	1313
Elevation (feet)	5600	2000	3882
Depth to C horizon (in.)	52	8	20
Effective profile depth (in.)	43	3	13
Depth of rooting (in.)	42	2	17
Silt + clay in the B (%)	75	26	51
Clay in the B (%)	33	3	10
Available H_2O (%)	33	5	18
Organic matter (%)	5.5	1.0	3.2
Slope (%)	63	0	27

CHAPTER IV

ANALYSIS OF DATA

Problems involving compound or multiple relationships are investigated by many researchers using standard laboratory methods. All the variables but one, or at the most three or four, are generally held essentially uniform. It is then possible to determine the effect of the factor, or factors, upon the dependent variable while the effects of differences in the other variables are largely eliminated.

It is easy to see that it would be virtually impossible to control, with any precision, the number of factors that vary simultaneously in a soil-site study such as presented here. In most cases not all the causes of variation are known, and the independent variables explain only a portion of the variation in the dependent variable, while the remainder of the variation must be assigned to unknown factors and to error.(31)

"Multiple regression analysis provides a convenient method for summing up all the evidence of a large number of observations into a single statement that expresses the extent to which differences in the dependent variable tend to be associated with differences in each of the other variables."(31)

METHOD

Average height growth of the dominant trees was used as the basic measure of site quality and the influence of soil characteristics, physiographic features, and stand factors on this variable was investigated by multiple regression analysis.

The fundamental growth curve as expressed by Schumacher(27) formed the basis of the regression analysis. This curve takes the following form:

$$Y = b_o + b_1x_1 + b_2x_2 + \ldots\ldots b_kx_k$$

In this equation Y is the logarithm of height of the dominant stand in feet, x_1 is the reciprocal of age, $x_2 \ldots$ x_k represent numberical equivalents of site factors to be tested, and $b_o, b_1, b_2 \ldots b_k$ are the regression coefficients.

The analysis of this study involved the testing of sixteen independent variables. In order to accomplish this rather complicated statistical procedure the raw data were sent to Montana State College at Bozeman and the regression was obtained by the use of an IBM 650 Electronic Data Processing Machine. The variables tested were as follows:

x_1 - Age. The reciprocal of the average total age in years of the dominant trees was introduced as the first independent variable.

x_2 - Density. To represent stand density the total stems per acre of all trees one-inch dbh and larger was entered.

x_3 - Elevation. This variable was entered as elevation in feet above mean sea level.

x_4 - Depth to C. This was the total depth to parent material in inches.

x_5 - Effective depth. Total depth to the C horizon corrected for the volume of stone.

x_6 - Depth of rooting. The depth of "abundant" rooting in inches. This was a comparative measurement.

x_7 - Silt + clay in the B. This measurement was obtained by weighting the percentage of silt + clay content for each B horizon by the depth of the horizon.

x_8 - Clay in the B. Obtained in the same manner as x_7 except that only the percentage of clay was used.

x_9 - Available H_2O in the effective depth. The average percentage available moisture weighted by the corrected rock-free depth of each horizon.

x_{10} - Organic matter in the B. The average organic matter percentage weighted by the depth of the various B horizons.

x_{11} - Interaction of $x_1 \cdot x_5$. Simple product of the reciprocal of age and the effective depth.

x_{12} - Interaction of $x_1 \cdot x_9$. Simple product of the reciprocal of age and percentage of available moisture in the effective depth.

x_{13} - Slope. The average slope percentage of the plot.

x_{14} - Aspect. The exposure of the plot but entered in regression as the Sin of the Azimuth + 1.

x_{15} - Interaction $x_{13} \cdot x_{14}$. Simple product of the Sin of the Azimuth + land the slope percentage.

x_{16} - Interaction $x_3 \cdot x_{14}$. Simple product of the Sin of the Azimuth + 1 and elevation.

The correlation coefficients resulting from this computation were tested for their significance by means of the "t test." Of the sixteen original variables only five were retained for use in a subsequent multiple regression computation. The significance of the other eleven varaibles did not warrant inclusion in the final equation. The five variables that were kept for the final solution were: x_1, x_2, x_3, x_{11}, and x_{12}.

TABLE II

ANALYSIS OF VARIANCE- SIXTEEN VARIABLE REGRESSION

SOURCE OF VARIATION	D/F	VARIANCE	SAMPLE "F"
R_{16}	16	8.19	14.12*
Residual (Error)	28	.58	
Total	44		

TABLE III

ANALYSIS OF VARIANCE- FIVE VARIABLE REGRESSION

SOURCE OF VARIATION	D/F	VARIANCE	SAMPLE"F"
$R_{1.2.3.11.12}$	5	24.57	42.36*
remaining 11 variables	11	.74	1.28
Residual (Error)	28	.58	
Total	44		

*Significant at the 1 per cent level.

Incorporation of the five variables into a single equation for estimating the height growth of forty-five western larch plots yeilded:

$$Y = 2.187 - 14.669x_1 - 0.0000522x_2 - 0.0000577x_3 + 0.17346x_{11} + 0.11293x_{12}$$

in which Y is the logarithm of height and x_1, x_2, x_3, x_{11}, and x_{12} are reciprocal of age, density in stems per acre, elevation in feet, product of effective depth and the reciprocal of age, and the product of available moisture and the reciprocal of age.

It would be possible to go one step further and drop out variable x_{12} because of its low significance. This step had to be omitted in this study as finances were not available for obtaining a new regression by use of the 650 IBM Computer and time did not permit the manual calculation of a four variable regression equation.

The following table gives the "t" values for each of the independent variables tested in the five variable regression equation.

TABLE IV

VALUES OF "t" FOR FIVE VARIABLE REGRESSION

VARIABLE	"t" VALUE
1	5.85*
2	3.91*
3	4.47*
11	3.12*
12	1.39

TABLE V

CORRELATION COEFFECIENTS OF THE INDEPENDENT VARIABLES WITH THE DEPENDENT VARIABLE

VARIABLE	CORRELATION COEFFICIENT
x_1 - reciprocal of age	-0.796
x_2 - stems per acre	-0.638
x_3 - elevation	-0.326
x_{11} - recip. age x effective depth	-0.288
x_{12} - recip. age x available H_2O	-0.668

CHAPTER V

DISCUSSION OF RESULTS

The percentage of total variation accounted for by each of the two regression equations was determined by calculation of the R^2 values. These values show that 89 per cent of the total variance is attributable to the sixteen variable regression and 84 per cent to the five variable regression. Thus it can be seen that the eleven variables that were eliminated in the final equation contributed very little to the total significance.

Of the five variables retained in the final regression equation only for are of particular importance: age, stand density, elevation, and the product of the reciprocal of age and the effective soil depth. The fact that the reciprocal of age is the most significant factor is to be expected. Age is usually considered to be the most important single variable influencing height growth. The product of the reciprocal of age and available moisture did not prove significant at the desired level and will not be considered as affecting the final equation to any great extent.

Stand density. Figure 4 illustrates the effect of stand density(x_2) on height growth with the other four variables held constant at their means. From this curve it can be seen that height growth, on the forty-five western larch plots sampled, is inversely related to density if all other factors are held constant.

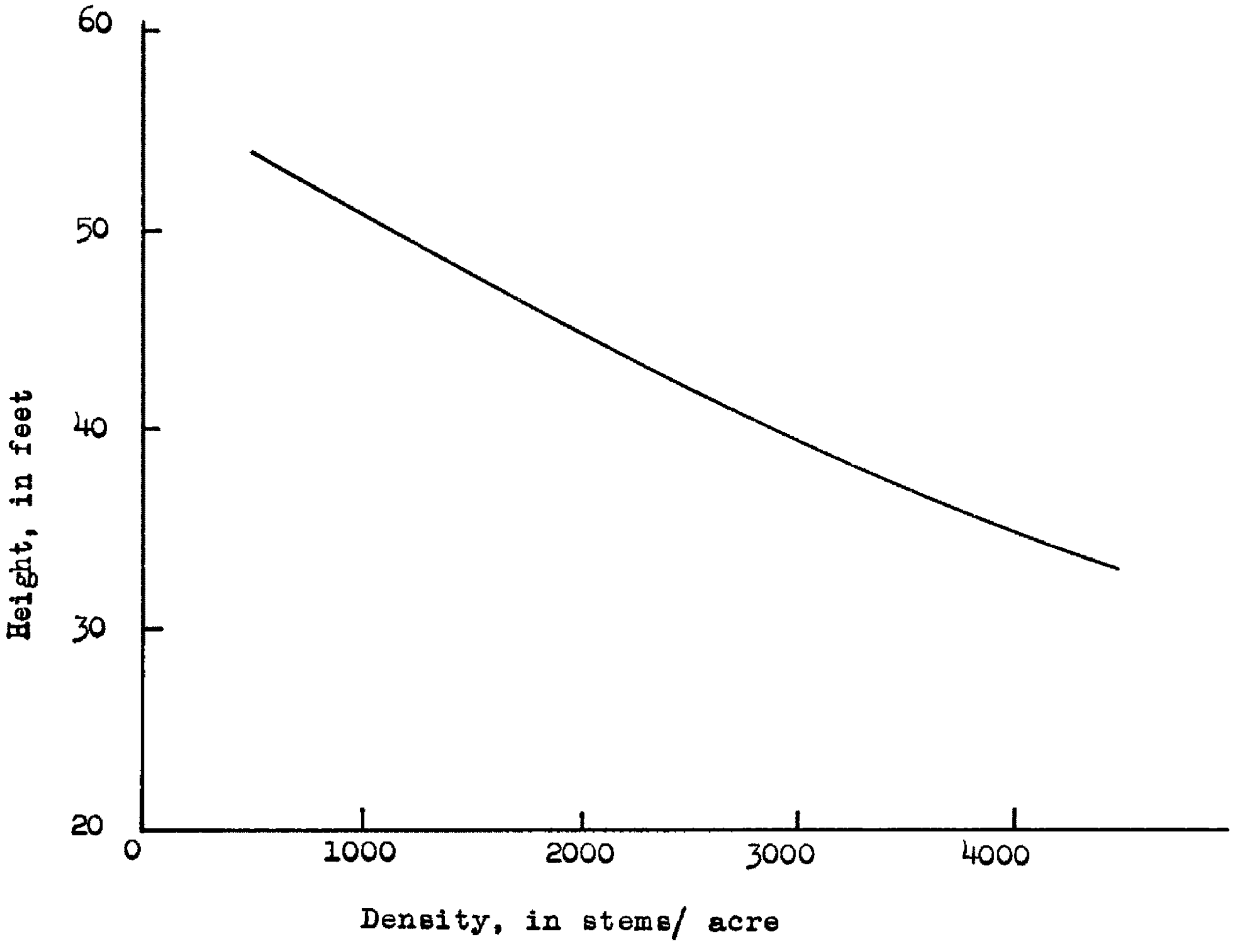

FIGURE 4
EFFECT OF DENSITY ON HEIGHT GROWTH
(all other factors constant)

This height-density relationship differs markedly from the one usually associated with these two factors. Height is more commonly thought to be independent of stand density.

A height-density relationship such as presented in Figure 4 might be expected from data confounded by site quality, ie., poor sites in high density stands and good sites in low density stands. This does not appear to be the situation in this study. From the information presented in this paper it seems that additional study of the height-density relationship of larch is needed.

Elevation. The effect of elevation(x_3) on height growth is shown in Figure 5. This curve was also obtained by holding the four remaining variables constant at their means. Height growth, on the sample plots, can be expected to decrease with increasing elevation if all other factors are held constant.

This elevation effect is in reality the effect of various climatic factors such as temperature, light, and moisture which are influenced by elevation. These climatic elements not only influence the tree directly but are reflected in the soil properties.

The reciprocal of age x effective depth. The effect of the product of the reciprocal of age and effective depth is shown by Figure 6. Since all factors are held constant at their means, including age, this curve actually shows the effect of effective depth and height growth. Within the

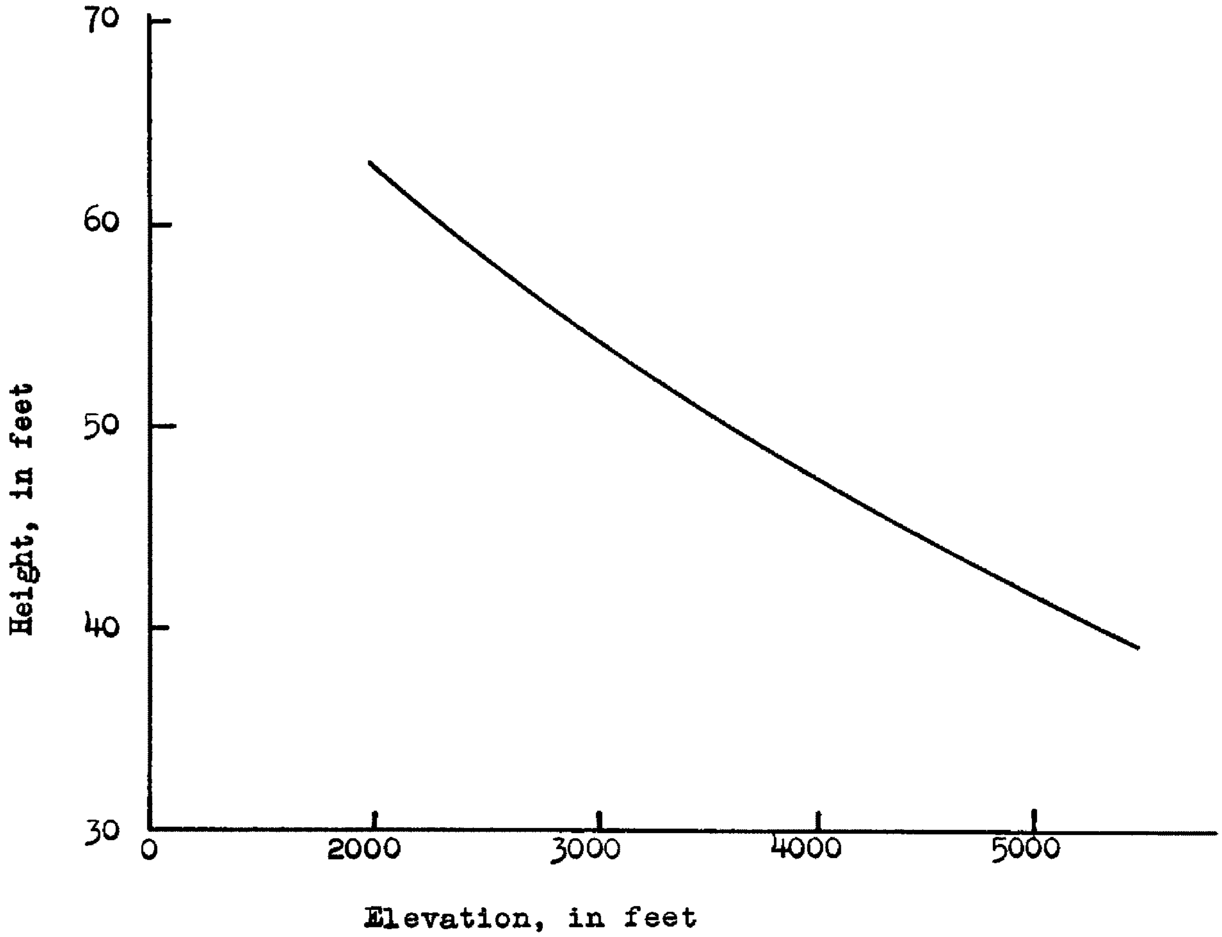

FIGURE 5
EFFECT OF ELEVATION ON HEIGHT GROWTH
(all other factors constant)

range of depths sampled there is a direct relationship between height growth and effective soil depth, when all other variables are held constant.

It will be noted that effective depth(x_5) was not significantly related to height growth until the age factor was considered with it. This is possibly due to the fact that in most cases the soil is sufficiently deep for adequate root development of the younger trees but becomes more of a limiting factor as the trees mature and the root system expands. If this supposition is true, then Coile's (7) statement concerning the importance of the quality and quanity of growing space available for root development is clearly applicapable to soil-site studies in western larch.

These illustrations of the independent effects of each of these three variables on the height growth of western larch is by no means an attempt to reduce the final regression to a single variable regression. It is only meant to show how each of these factors might be expected to influence height growth. The entire five variable final regression equation has to be considered before an accurate estimate of height growth may be obtained.

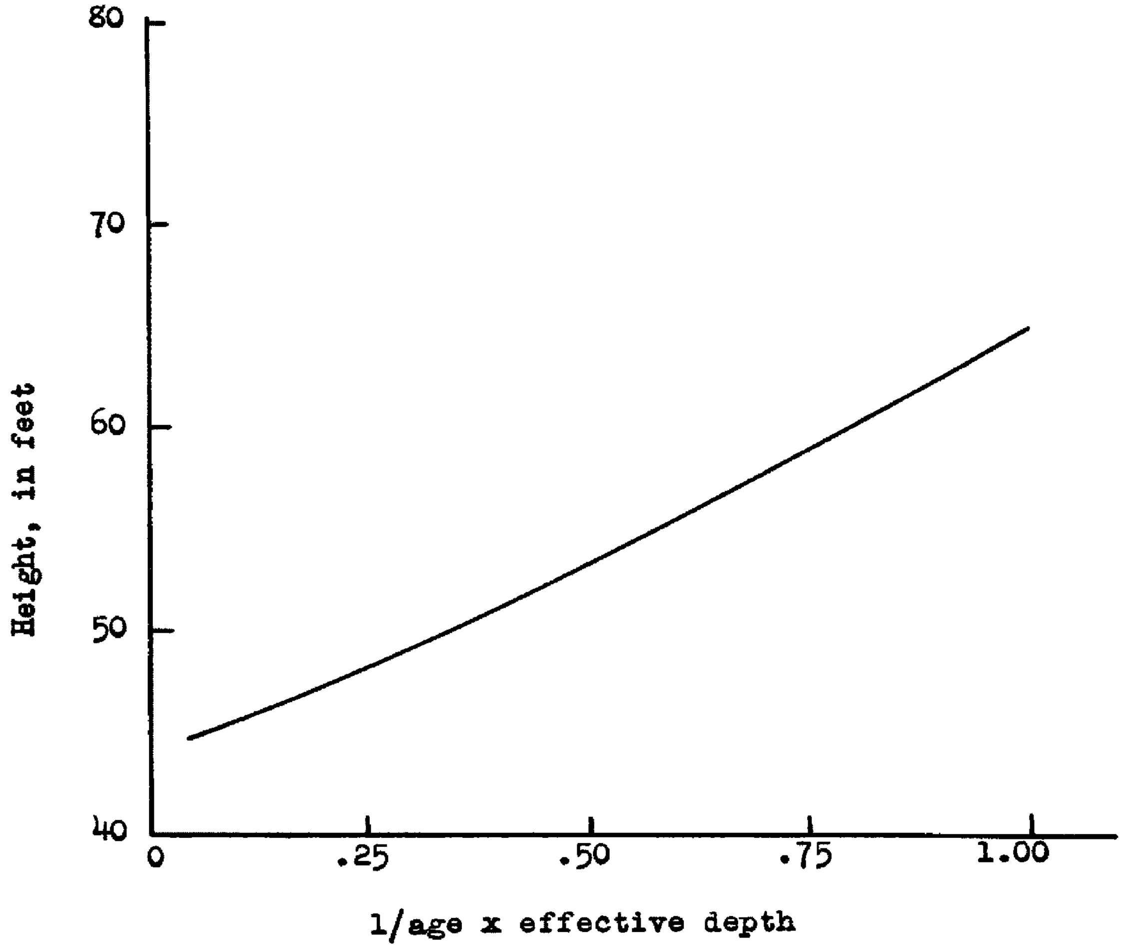

FIGURE 6
EFFECT OF THE PRODUCT OF THE RECIPROCAL
OF AGE AND EFFECTIVE DEPTH ON
HEIGHT GROWTH
(all other factors constant)

CHAPTER VI

SUMMARY AND CONCLUSIONS

<u>Summary</u>. Soil, mensurational, and physiographical information was obtained from forty-five temporary sample plots located in the western larch type of Montana. In order to apportion the gross effect of the more important factors usually associated with site quality determination, mensurational and physiographical information was included in this soil-site investigation.

The effect of sixteen independent variables on the height growth of western larch was tested by means of multiple regression analysis. Of the sixteen variables tested only five were retained in the final regression equation. Incorporation of these five variables into a single equation yielded:

$$Y = 2.187 - 14.699x_1 - 0.0000522x_2 - 0.0000577x_3 + 0.17346x_{11} + 0.11293x_{12}$$

in which Y is the logarithm of height and x_1, x_2, x_3, x_{11}, and x_{12} are the reciprocal of age, density in stems per acre, elevation in feet, the product of the reciprocal of age and effective depth, and the product of the reciprocal of age and available moisture.

Of these five variables, three-density, elevation, and the product of the reciprocal of age and effective depth-were investigated as to their effect on height growth. This was done by holding four of the variables constant at their means and obtaining a height growth value for several changes in the remaining variable. The following relationships were established from this investigation:

1. Height growth was found to vary inversly with stand density.

2. Height growth was found to vary inversly with elevation.

3. Height growth was found to vary directly with effective depth.

Conclusions. The significance shown by stand age, effective soil depth, stand density, and elevation in the assessment of western larch site quality indicates that future site investigations in this type might be more accurate if a soil-mensurational-physiographical approach were used.

This investigation is intended only as a pilot type study and does not imply that the results presented are in any way the complete solution to the prediction of growth potentials of western larch in Montana.

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APPENDIX

TYPICAL BROWN-PODZOLIC SOIL PROFILE DESCRIPTION

The following is a description of the characteristic features of a typical profile mapped during this investigation:

A_{00} Thickness: $\frac{1}{4}$ to $\frac{1}{2}$ inch. Loose non-decomposed coniferous litter accumulation.

A_0 Thickness: $\frac{1}{4}$ to 1 inch. Partially or fully decomposed organic material.

A_2 0 to $1\frac{1}{4}$ inches. Light gray-brown when dry. Silt loam. Consistence: dry, soft. Weak, very fine crumb structure. Clear, smooth boundary to the B_{21}. pH 6.0.

B_{21} $1\frac{1}{4}$ to 11 inches. Light gray when dry. Loam Consistence: dry, slightly hard. Weak, very fine crumb structure. Diffues, smooth boundary to the B_{22}. pH 6.0. Some iron concretions up to $\frac{1}{4}$ inch in diameter.

B_{22} 11 to 25 inches. Light gray when dry. Silt loam. Consistence: dry, slightly hard. Weak, fine crumb structure. Abrupt, wavy boundary to the C. pH 6.2. Some iron concretions up to $\frac{1}{4}$ inch in diameter.

C 25 to 34 inches plus. Light gray when dry. Silt loam. Consistence: dry, loose. Fine, structureless, massive structure. pH 6.5.

D Argillites and silts.

PERCENTAGE VOLUME OF STONE DETERMINATION

A metal can, graduated in terms of percentage of the total can volume, and a 2 mm soil screen were used for this measurement. The metal container was filled(to the 100 per cent mark) with material from the horizon being described. This volume was then passed through the 2 mm screen. The material less than 2 mm was then poured back into the container and its percentage determined. This percentage subtracted from 100 per cent gave the percentage volume of stone for the particular horizon under investigation.

ORGANIC MATTER DETERMINATION

Standard solutions were prepared using anhydrous dextrose, reagent grade, as described by Wilde(33). Using a Bausch and Lomb Spectronic 20 Colorimeter, the percentage of light transmittancy for each of the standards was obtained. A curve of organic matter over percentage transmittancy was thus obtained.

Wilde's(33) procedure for the rapid colorimetric determination of soil organic matter was followed except instead of comparing the samples with a Cenco-Wilde cellulose-acetate color chart the percentage light transmittancy was obtained from the colorimeter and the organic matter content was read from the standard curve.

A PROPOSED METHOD FOR OBTAINING BULK DENSITY SAMPLES IN ROCKY FOREST SOILS

Mervin S. Stevens[1]

The procuring of samples for the purpose of determining bulk density presents a special problem in the rocky forest soils of the Northern Rocky Mountains. As much of the sampling of these soils in the future will be done in the roadless back-country any sampling instrument developed should have the following characteristics:

1. be lightweight.
2. must be able to be used with a minimum of accessory equipment.
3. be accurate.
4. be durable.

In the literature various devices for measuring bulk density are mentioned. These devices are heavy cylinders requiring heavy accessory equipment. Due to their relatively large diameters they are unsuitable for sampling rocky soils.

The tool developed by the author for such sampling was constructed from a piece of seamless steel tubing, six inches long and one and one-half inches inside diameter. The required cylinder was cut from a longer piece of tubing by means of a pipe cutter which left a slightly inward curled lip. This lip aided in holding the sample in the tube while being removed from the soil. The end of the pipe

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[1]Graduate student, Montana State University, 1959.

to be the cutting portion was sharpened, tempered, and a scale etched on the outside of the cylinder with the O point being the cutting tip.

The core sampling process is simple. After the soil pit has been dug and the profile exposed, a relatively rock-free surface is selected in the horizon to be sampled. The cylinder is pushed or driven, if necessary, into the pit wall. The length of the core is determined by reading the scale at the point of contact with the pit wall. This eliminates any difference in length due to compaction of the core. The cylinder is then dug from the pit wall and the core placed in a sample container which can be sealed to prevent any moisture loss.

The core sample is brought into the laboratory where it is weighed and dried to a constant weight at 105°C. The volume of soil is obtained from a table giving the volume of cores of various lengths, one and one-half inches in diameter. The volume of water in the sample is subtracted from the core volume. The oven-dry weight divided by the corrected core volume gives the bulk density of the sample.

Advantages of this method are:

1. Equipment is lightweight, compact, and easily carried in a pack-sack.
2. Because of the small cylinder diameter the chances of finding a rock-free sampling surface are increased.
3. Equipment is inexpensive.

Disadvantages are:

1. Probably not as accurate as a larger cylinder.

2. More compaction as compared to the larger cylinder. If the sample is not to be coated with paraffin or moisture penetration tests are not to be made, this disadvantage would be negligible.

In using Steven's method in the western larch study it was found to be impossible to obtain satisfactory results due to the large amount of stone present and to the light, fluffy nature of some of the B horizons encountered.

GROUND VEGETATION LIST

SCIENTIFIC NAME		COMMON NAME	FREQUENCY*
1.	Calamagrostis rubescens	Pine grass	64
2.	Spireae lucida	Spirea	55
3.	Berberis repens	Oregon grape	49
4.	Rosa sp.	Wild rose	42
5.	Linnaea borealis	Twinflower	40
6.	Rubus parviflorus	Thimbleberry	40
7.	Vaccinium sp.	Vaccinium	40
8.	Arctostaphylos uva-ursi	Kinnikinnick	38
9.	Arnica sp.	Arnica	38
10.	Amelanchier alnifolia	Service berry	29
11.	Salix sp.	Willow	29
12.	Pseudotsuga menziesii	Douglas-fir	29
13.	Piceae engelmanni	Engelmann spruce	24
14.	Chimaphila umbellata	Pipsissewa	22
15.	Shepherdia canadensis	Buffala berry	22
16.	Thuja plicata	Giant redcedar	22
17.	Pachistima myrsinites	Pachistima	18
18.	Acer glabrum	Mountain maple	16
19.	Cornus canadensis	Bunchberry	16
20.	Physocarpus sp.	Ninebark	16
21.	Xerophyllum tenax	Beargrass	16
22.	Epilobium angustifloium	Fireweed	13
23.	Ménziesia glabella	Menziesia	13
24.	Ribes sp.	Ribes	13

Ground Vegetation (continued)

SCIENTIFIC NAME	COMMON NAME	FREQUENCY*
25. Clintonia uniflora	Queencup	11
26. Lonicera involucrata	Twinberry	11
27. Pteridium aquilinum	Braken fern	11
28. Fragaria vesca	Wild strawberry	9
29. Alnus crispa	Mountain alder	7
30. Betula paprifera	Paper birch	7
31. Tsuga heterophylla	Western Hemlock	7
32. Abies lasiocarpa	Alpine fir	4
33. Pinus contorta	Lodgepole pine	4
34. Pinus monticola	Western White pine	4
35. Abies grandis	White fir	2
36. Heuchera sp.	Alumroot	2
37. Juniperus communis	Dwarf juniper	2
38. Pinus ponderosa	Ponderosa pine	2
39. Symphoricarpos albus	Snowberry	2
40. Taxus brevifolia	Western yew	2
41. Trillium ovatum	Western trimmium	2

*Frequency denotes percentage of plots in which the species appeared out of a total of 45 plots.