THESIS

SOIL FACTORS AFFECTING PONDEROSA PINE GROWTH

Submitted by

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In partial fulfillment of the requirements

for the Degree of Master of Science

Colorado State University

Fort Collins, Colorado

July, 1965

COLORADO STATE UNIVERSITY

July 23 1965

WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR SUPERVISION BY Baban P. Kayastha

ENTITLED Soil factors affecting ponderosa pine growth

BE ACCEPTED AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE.

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ACKNOWLEDGMENTS

The writer wishes to extend his sincere thanks to Dr. Charles Terwilliger, Jr., Professor and Head of the Department of Range Management, for his encouragement, guidance and helpful suggestions throughout the course of study.

To Dr. A. C. Everson, Associate Professor of Range Management, the writer expresses appreciation for his advice and criticism.

The writer wishes to thank Dr. D. D. Johnson, Professor of Agronomy for his cooperation and constructive criticism throughout the study.

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CHAPTER I

INTRODUCTION

With increasing emphasis being placed on a multiple land-use policy in forestry, the problem of evaluating the suitability of a site for timber production becomes evident. To solve this problem, the complex of environmental factors including climate, topography and soils have been studied as to their effects on tree growth. Results of such studies, however, can be applied only to limited areas. Consequently, studies are necessary in additional areas to evaluate timber site potential.

Physical and chemical properties of a soil can be measured and related to the productivity of a site for a specific species. This information can then be used to predict the productivity of this species on a site in question. However, according to Coile (1952) physical properties of soil are more important than chemical properties in determining the rate of tree growth.

The Problem

Briegleb (1950) indicates that conventional height-age index of site does not always measure growth capacity of pine lands accurately. Myers and Van Deusen (1960) state that the conventional method of using height over age as a measure of site quality is inaccurate in young stands. Therefore, site index limitations and new criteria for site evaluation must be recognized.

Ponderosa pine (Pinus ponderosa Laws) 1/ is widely distributed in the Rocky Mountain region and is probably suitable for pulpwood. It is also used extensively in lumber production. In addition, this species, as well as this use, must compete for space with other possible uses. Therefore, more accurate site evaluations are necessary if ponderosa pine is to be properly managed.

The problem for this study is to determine the effect of soil depth, and texture on the growth of ponderosa pine and how they could be used in predicting the suitability of a site for the production of this species. Study of site-growth relationships in ponderosa pine forests may furnish a solution to this problem.

Objectives

The major objectives of this study were as follows:

1. To determine the growth index which can be used most successfully as a dependent variable.
2. To determine the best method of expressing soil depth and texture and their effect upon the growth of ponderosa pine.

1/ Scientific names of trees are after "Checklist of Trees of the United States, U. S. D. A. Handbook No. 41" by Elbert L. Little Jr. (1953). U. S. Govt. Printing Office, Washington 25, D. C.

3. To determine an equation for predicting the suitability of a site for ponderosa pine.

Problem Analysis

In order to fulfill the above objectives, answers to the following questions were determined:

1. What growth measurement is most closely correlated with site characteristics which determine growth of trees?
2. What methods of expressing soil depth are most closely correlated with growth of ponderosa pine?
3. What quantitative expression of soil texture should be used to express these characteristics?
4. Is the relationship between dependent and independent variables linear or curvilinear? If curvilinear, how should the data be transformed to fit the regression model?
5. What is the best prediction equation using soil depth and texture as independent variables?
6. What proportion of the variability in growth rate of ponderosa pine is accounted for by soil depth and texture?

Definition of Terms

1. Five-year growth index: - The height growth in inches for the previous five years (1959-1963).
2. Total height index: - The total growth of the tree at an index age of thirty years, e.g.

$$\frac{\text{Total height}}{\text{Total age}} \times 30$$

3. Percent sand: - The weighted mean percent of sand in the depth of the profile being considered, e.g.

$$\frac{(\text{Effective depth of A} \times \%\,\text{sand}) + (\text{Effective depth of B} \times \%\,\text{sand})}{\text{Total effective depth of A and B}}$$

4. Percent silt plus clay: - The weighted mean percent silt plus clay in the depth of the profile being considered, e.g.

$$\frac{(\text{Effective depth of A} \times \%\,\text{silt plus clay}) + (\text{Effective depth of B} \times \%\,\text{silt plus clay})}{\text{Total effective depth of A and B}}$$

5. Inches silt plus clay: - The amount of silt plus clay in the depth of the profile being considered expressed in corrected inches of depth, e.g.

(% silt plus clay in A x bulk density x effective depth of A) + (% silt plus clay in B x bulk density x effective depth of B)

6. Effective depth: - The depth corrected for rockiness of the profile being considered.

7. Log depth: - The logarithmic transformation of the data for depth of a profile.

8. Log effective depth: - The logarithmic transformation of the data for effective depth of a profile.

9. Montane Zone: - An elevation zone from about 5,500 ft. to 8,500 feet in northern Colorado characterized by the ponderosa pine - Douglas fir plant association.

CHAPTER II

REVIEW OF LITERATURE

Soil and site relationships of various forest species have been studied in many localities, but there is not much information available on soil and site relationships of ponderosa pine. A few studies indicate that the site quality for ponderosa pine is related to certain soil and site factors. The standard method of all such studies is to compile soil information and tree measurements and then subject the data to statistical analysis, mainly, to regression and correlation analysis.

Soil and Forest Growth

Site is defined by foresters as an area of land with a characteristic combination of climatic, topographic, biotic and edaphic factors. Site factors determine the rate of forest growth. Site quality refers to the productivity of an area for a tree species or a mixture of species.

According to Coile (1952) site quality based on conventional height-age relationships are unreliable or impossible to obtain under certain conditions. In areas devoid of forests or supporting very young or very old stands permanent features like soil and topographic characteristics must be used.

Measurement of Dependent Variables

Site index is commonly used as the dependent variable in soil and site studies. Site index refers to the total height growth of dominant and codominant trees at an index age. Sometimes, current growth measured over the last few years is the growth index used as a dependent variable.

Myers and Van Deusen (1960) used site index as a dependent variable in soil and site studies of ponderosa pine. Similarly, Einspahr and McComb (1951) used site index as dependent variable. However, Ferree, et al (1958) reported that five years of intercept index was a satisfactory method of evaluating growth in young red pine plantation.

Importance of Independent Variable

Climatic, physiographic and edaphic factors have been used as independent variable in all studies of tree growth. Climate includes factors like precipitation and temperature. Physiography includes aspect, slope, position on slope and elevation. Soil factors include both physical and chemical properties of soil. Physical properties of soil consist of texture, depth, drainage, moisture equivalent, stoniness, permeability, infiltration and aeration. Chemical properties of soil include available nitrogen, phosphorus, general nutrient level, reaction (pH), and alkalinity and salinity. These factors determine the rate of growth of a tree species in a given environment. All these factors are interrelated and have combined effect on the site quality. These are relatively stable factors of environment and are used to evaluate the site quality.

Soil and Site Studies in Conifers

Studies relating height growth to certain environmental factors have been made with various coniferous species. These are reviewed in the following paragraphs.

Ponderosa pine

Distribution and Ecology of Ponderosa Pine: - Ponderosa pine inhabits mountain slopes, dry valleys and high mesas, often forming forests of great extent. According to Sargent (1947) it is the most widely distributed tree of western North America and it can endure great variations in climate. It ranges from an approximate latitude of 51° north in the interior of British Columbia, southward through Washington and Oregon along the slopes of Sierra Nevada and the California coast ranges. It is a common tree in the forests of the Black Hills of South Dakota. It also occurs on several of the mountain ranges of Wyoming and of eastern Montana. In Colorado it occurs extensively in an elevation zone ranging from 4,500 to 9,000 feet.

Soil and Site Studies of Ponderosa Pine: - Various soil and topographic factors have been used to study the soil and site relationships of ponderosa pine.

Soil depth is an important factor related to the site index of ponderosa pine. Myers and Van Deusen (1960) working with ponderosa pine, related site index to soil depth. They used effective depth, depth to the top of C horizon and depths of A and C horizons. Effective depth was defined as the total soil depth reduced by the percentage of rock present. Only depth to the top of C horizon was found to be related to site index. The other methods of expressing depth were not significant. The relation between site index and depth to the top of C horizon was curvilinear and it accounted for 67 percent of total variability. Cox, et al (1960) found that the height growth of ponderosa pine in Montana was influenced by depth of soil mass where roots could freely penetrate.

Soil texture has also been correlated with the site index of ponderosa pine. Holtby (1947) reported a relationship between soil texture and site quality of ponderosa pine in southern Washington. Site index increased with increasing amount of fine materials measured at a depth of six inches.

Topographic factors like slope and aspect have been related to the site index of ponderosa pine. Myers and Van Deusen (1960) related slope position, slope percent and aspect to the site index of ponderosa pine in the Black Hills. Slope position, slope percent and aspect accounted for 7, 6 and 3 percent of total variability, respectively.

Other pines

Besides ponderosa pine, various other pines have been studied to establish relationship between soil properties and site index.

Many authors found significant correlation between depth of soil and the site index. Coile and Schumacher (1953) working with loblolly (*Pinus taeda* L.) and shortleaf pine (*Pinus echinata* Mill.) in North Carolina, correlated site index with the depth of surface soil. The relationship was curvilinear in both the species. Zahner (1957) reported correlation between depth of surface soil and site index of loblolly and shortleaf pine in southern Arkansas and northern Louisiana. Site index increased with increasing soil thickness to a maximum at about 18 inches. Deeper surface soil showed slightly decreased site quality. Linnartz (1963) found a relation between soil depth to least permeable layer and site index of loblolly. Longleaf (*Pinus palustris* Mill.) and slashpine (*Pinus elliottii* Englemn.) in Louisiana. The site index increased with increasing depth to the least permeable layer but it decreased when the least permeable layer was deep in profile in all three species of pine. Copeland (1958) correlated soil depth with the site index of western white pine (*Pinus Monticola* Dougl.). He used effective soil depth and depth to a zone of reduced permeability. Effective soil depth represented the depth in inches to a hardpan layer having a bulk density of 1.60 or more. The relationship was linear within the range of available data. Gaiser (1950) used depth to the least permeable horizon to relate soil depth with site index of loblolly pine in the coastal plain region of Virginia and Carolina. The relationship was curvilinear. Ralston (1951) used depth to a mottled layer to correlate soil depth with site index of longleaf pine in the Atlantic coastal plain. He found positive linear correlation of this factor with height growth.

Many soil and site studies indicate the effect of texture on site index. Zahner (1957) working with loblolly and shortleaf pine correlated surface soil texture and subsoil texture with the site index. Site index decreased with increasing amount of silt in the surface six to twelve inches of soil but it increased as the subsoil texture increased in fine material from sandy loam to clay loam. Linnartz (1963) working with longleaf, loblolly and slashpine, reported that site index decreased with increasing amount of sand in the subsoil. Earlier Haig (1929) related the site index of red pine (Pinus resinosa Ait.) with texture of A horizon. He used percent silt plus clay of A horizon and found that site index increased as the percentage of finer fractions increased in the A horizon. This differed from the study of Zahner (1957) which indicated that site index of loblolly and shortleaf pine decreased with increasing amount of silt in the surface horizon. Turner (1937) working with loblolly and shortleaf pine, found the best pine sites on silty or sandy loam soils with thick A horizons. Coile and Schumacher (1953) working with loblolly and shortleaf pine, and Gaiser (1950) working with loblolly, related imbititional water value of subsoil to site index. Imbibitional water value was defined as the difference between moisture equivalent and the xylene equivalent of soils. The former reported a negative linear relation where site index decreased with increasing imbibitional water value whereas the latter reported a positive linear relation where site index increased with increasing imbibitional water value.

Soil moisture is a dominant factor influencing the site index. Many soil and site studies used different methods of expressing soil moisture such as water holding capacity and moisture equivalent. Copeland (1958) correlated available water holding capacity with the site index of western white pine. Available water holding capacity was defined as the difference between moisture equivalent and the wilting percentage. He found a linear relation between this soil factor and the site index of white pine. Ralston (1951) working with longleaf pine, found that the growth capacity was directly proportional to the moisture equivalent percent of the subsoil. Moisture equivalent was defined as water loss in percentage of oven dry weight of soil after soil saturated with water was allowed to drain excess free water and centrifuged at a force of 1,000 times gravity for 40 minutes.

The effect of slope on site index of pine species was studied by Zahner (1957) and Linnartz (1963). Both studies reported that site index decreased as the slope percent increased with gentler slopes providing better sites.

Other Conifers

Soil and site studies have been reported in various other coniferous species besides pine species. Such studies include soil properties, precipitation, elevation and other topographic factors.

Among the physical properties of soil, soil depth is the most commonly used factor to show its relationship with site index. The relationship between the site index and soil depth have been reported to be linear or curvilinear. Carmean (1954) found a linear relationship between the site index of douglas-fir and soil depth to substratum (C horizon). The site index of this species increased with increase in depth to C horizon. Aird and Stone (1955) related the growth of Japanese and European larch to the depth of soil above a layer restricting root development.

Gessel and Lloyd (1950) correlated site index of Douglas-fir with texture. He found that site index increased with change in texture from coarse to light to medium.

Factors like precipitation, elevation, drainage and run-off have also been found to be significant in soil and site studies of coniferous species. Carmean (1954) reported that the site index of Douglas-fir increased as the total annual precipitation increased. He found the relationship to be linear. Gessel and Lloyd (1950) also related precipitation to the site index of Douglas-fir. He found that site index increased with increasing precipitation up to 40 inches. Above this amount the site index decreased. Carmean (1954) related elevation to the site index of Douglas-fir. He found that a marked decrease in site quality occurred as elevation increased. Earlier, Storie and Wieslander (1948) reported that drainage and run off along with other soil factors appeared to limit the growth of conifers in California.

Chemical Factors of Soil

Chemical measures are inherently more precise than physical ones but it is difficult to measure the chemical environment in which plants live. Storie and Wieslander (1948) related growth of coniferous timber to chemical inhibitors. He found that alkalinity, salinity and high lime content inhibited timber growth. Chemical characteristics involving nutrient supply are important in tree growth. According to Kozlowski (1955) deficiency of elements like magnesium and iron often affects the degree of chlorosis and thereby influences photosynthetic rates and tree growth. The pH value of soil is also an important factor. Linnartz (1963) reported that the site index of loblolly pine decreased with increase in pH.

Summary of Site-Productivity Relationship

Productive capacity of a site is affected by various soil factors. Lemmon (1955) reports that the productive capacity of a site for timber is related to factors which provide optimum amounts of available moisture. Physical properties of soil have been found to influence availability of soil moisture. Besides this, aspect, slope and elevation also play a role in the moisture regime. Many soil and site studies discussed above took these factors into consideration and their results are summarized in the following paragraphs.

In almost all soil and site studies soil depth and texture have been found to be the most effective factors. The relationship of growth to the depth of surface soil, depth to the least permeable layer or depth to a mottled layer is usually curvilinear. This means that the growth increases with increasing depth but each additional unit of depth was less effective than the last. Myers and Van Deusen (1960) found a curvilinear relationship between the site index of ponderosa pine and soil depth to the top of C horizon.

Texture influences water infiltration and storage which is important to tree growth. Its relationship has been established with both hardwoods and conifers. Very heavy or very sandy soils are not favorable for tree growth. Holtby (1947) reported that site index of ponderosa pine increased with increasing amount of fine materials measured to a depth of six inches in south Washington.

Various methods of expressing soil moisture have been used in many soil and site studies. Relation of moisture equivalent, inbibitional water value and water holding capacity to the site index is linear indicating that the site index is directly proportional to these factors.

Many soil and site studies have indicated the effect of climatic and topographic factors on the site. Site indexes of both hardwoods and conifers have been found to be associated with precipitation, elevation, slope and aspect. Site index increases with increase in precipitation. With increasing slope, site index decreases. Aspect may or may not be significant in site index.

Chemical factors of soil and their relation to the site index have been studied to a limited extent. Soil nutrient factors are important in forest growth, but it is difficult to relate these factors to tree growth in a meaningful manner.

CHAPTER III

METHODS AND MATERIALS

Description of the Study Area

Location

The study area is situated along the Cache la Poudre river and the south fork of the Cache la Poudre river in the montane zone of northern Colorado. It is located approximately 20 miles west of the town of Fort Collins, Colorado, in the following townships: T8N-R71W, T9N-R72W, T8N-R73W, 6th principal meridian.

Climate

The climate of the area is typified by long cold winters and cool summers. Elevation, local topography and relative position on slope play an important role in determining local temperature and effective moisture. There is no weather station available within the study area but climatic data from weather stations at the towns of Fort Collins, Estes Park and Red Feather Lakes are used to give an indication of precipitation, temperature, and length of growing season (see Table 1, 2 and 3). The general growing season in the study area is defined as the period between the last killing frost in the spring and the first killing frost in the fall. The length of this period varies from about 140 days at the lower elevations to about 90 days at the upper elevations. Highest temperatures are recorded during July and August when the average monthly maximum ranges from the lower 80's at the lower elevations to the lower 70's at the higher elevations.

Table 1. Seasonal Distribution of Precipitation Based on Long Term Means (1931-1960).

Station	Period		
	Precipitation during Growing Season 1/ (Inches)	Precipitation during Non-growing Season (Inches)	Annual (Inches)
Fort Collins	8.54 (60%) 3/	5.65 (40%)	14.19
Estes Park	11.41 (71%)	4.66 (29%)	16.07
Red Feather Lakes 2/	10.06 (59%)	6.94 (41%)	17.00

1/ Growing Season - From May through September
2/ Indicates precipitation data from 1950 to 1963.
3/ Indicates percentage of the annual precipitation.

Table 2. Distribution of Average Maximum and Average Minimum Temperature in °F Based on Long Term Means (1959-1963).

Station		Month				
		May	June	July	Aug.	Sept.
Fort Collins	Max.	68.6	80.7	86.4	84.6	74.3
	Min.	42.6	51.2	55.6	54.6	45.2
Estes Park	Max.	63.6	73.5	77.8	77.2	69.4
	Min.	35.2	41.1	44.2	44.9	38.6
Red Feather Lakes	Max.	60.9	71.6	77.4	76.7	66.5
	Min.	33.4	41.0	44.4	45.3	38.2

Table 3. Climatological Data

Weather Stations	Average Annual Temp. in °F.	Length of Record in Yrs.	Average Annual Precipt. in ins.	Length of Record	Length of Growing Season	Growing Season in Days	Length of Record in Yrs.
Fort Collins	48.1	29	14.19	29	May 7 to Sept. 29	145	40
Estes Park	43.0	29	16.07	29	June 9 to Sept. 15	98	23
Red Feather Lakes	39.0	29	14.92	29	---------	--	--

The average annual precipitation increases from about 14 inches at the lower elevations to about 17 inches at the upper elevations. The largest percentage of this moisture comes during the growing season but there is a shift toward an increase in moisture during the fall and winter months as elevation increases.

Topography

The landform of the region is mature with a relatively large portion of the land area composed of an old eroded surface deeply cut by the Cache la Poudre river and its main branches, the north and south forks. Lateral drainages are short and steep and form a moderately dense dendritic pattern. The elevation difference between the upland surface and the stream bottom varies between 800 and 1,000 feet.

Geology

The geology of the front range of which the study area is a small part, consists of precambrian metamorphic and igneous rocks. Granite, gneiss and schist make up most of the rocks exposed in this range. The central part of the range where the study area is located consists mainly of schist and gneiss derived from old sedimentary rocks low in ferromagnesium minerals.

Soils

Soils of the area have not been completely described but a preliminary soil survey in the montane zone of the Red Feather Lakes area indicates that members of the gray wooded, cold chestnut and cold brunizem soils occur in association with ponderosa pine--douglas fir vegetation in the general area.

Soils in this study area are not well developed. They appear to be azonal and can be classified as lithosols and regosols with soil profiles characterized by A - C horizons. A few soil profiles show some development of a B horizon and approach the characteristics of chestnut soils. However, they are not mature enough to definitely be included as members of a great soil group. The textures are coarse and vary from loam or sandy loam to loamy sand. The residual soils are derived from gneiss and schist composed mainly of light colored minerals while the transported soils are derived from alluvium and colluvium from the same parent rock.

Vegetation

The dominant vegetation of the study area consists mainly of chaparral and ponderosa pine. At the lower elevations the south slopes are covered with shrubs, mainly mountain mahogany (*Cercocarpus montanus* Rydb.), 2/ while the

2/ Scientific name of grasses and shrubs are after "Manual of the plants of Colorado" by H. D. Harrington (1954). Sage Books, Denver, Colo.

north slopes support ponderosa pine. On the other hand at the higher elevations a ponderosa pine savannah is found on the rolling uplands. On the south slopes where trees may be quite scattered, a shrub cover of bitterbrush (*Pershia tridentata* Pursh.) and mountain muhly (*Muhlenbergia montana* Nutt.) and griffiths wheatgrass (*Agropyron griffithsii* Scribn.) is usually present. On the north slopes douglas-fir (*Pseudotsuga menziesii* Mirb.) *Franko*) and lodgepole pine (*Pinus contorta* Douge.) become dominant. Deep soils developed on alluvial-colluvial fans throughout the study area support grasses such as: bluegrass (*Poa* spp.), western wheatgrass (*Agropyron smithii* Rydb.), needle-and-thread grass (*Stipa comata* Trin. and Rupr.) and junegrass (*Koeleria cristata* Pers.). On many of these deeper soils stands of ponderosa pine have been planted. The trees in these plantations were about 30 years of age at the time of this study.

FIELD PROCEDURE

Selection of Study Plots

In the summer of 1964 study plots were selected by going over the area and observing the characteristics of soil and vegetation. The main criteria of selection was uniform characteristics of soil and vegetation. These plots were located where at least three ponderosa pine trees of uniform growth were available. Study plots were also located in the ponderosa pine plantations.

Tree-measurement

Three trees in each study area were cut at the ground level. Age, total height, and growth during the last five years were measured. Age was determined by counting rings at the ground level. Total height was measured from ground level to the tip of the terminal bud. The terminal leader growth for the last five years was measured to indicate the last five years of growth.

All measurements were made in inches and hundredths of inches except total height which was measured in feet and hundredths of feet.

Soil description

A soil pit was dug on each study plot. A standard soil description was made according to methods given in the Soil Survey Manual (1951). In the soil description special attention was given to abundance of roots and degree of rockiness, in addition, bulk density and infiltration index were measured on each site.

Bulk density of each horizon in the profile was determined using the volume-meter (volumeasure) manufactured by Soiltest, Inc. Infiltration index was determined by using a tin can open on both ends. The can was first forced into the ground about 2 inches and then two quarts of water were poured into it. Time taken for this water to infiltrate into the soil was noted as the infiltration index. Type and degree of erosion on each plot were observed and noted. Slope, aspect and position on slope were determined. Slope was measured on each site with an Abney level and aspect was determined with a compass; position on slope was determined by ocular estimation.

LABORATORY AND OFFICE PROCEDURES

Soil Analysis

Soil samples were collected from each horizon in each soil profile. These samples were dried and then sieved through a 2 mm. round hole screen. Soil samples thus obtained, were used for mechanical analysis. Mechanical analysis for soil texture was accomplished by Bouyoucos hydrometer method as described by Bouyoucos (1936).

Office Procedure

The office procedure consisted of summarizing the field data, calculating the variables to be used, and arranging them in proper form for statistical analysis. It involved three steps.

The first step consisted of the calculation of values for the variables listed in Table 4. In addition, correlation coefficients were calculated between all of these variables using an IBM 1401 computer. A study of these correlation coefficients led to step two.

Table 4. List of Variables Calculated for Step One.

Variables	Symbol
Five-year growth index	Y_1
Total height index	Y_2
Depth of A	X_1
Effective depth of A	X_2
Depth to C	X_3
Effective depth to C	X_4
Inches silt plus clay to C	X_5

In step two the additional variables listed in Table 5 were calculated and correlation coefficients were again determined. A study of these new correlation coefficients and the original ones indicated the best method of expressing soil depth and textures.

Table 5. List of Variables Calculated for Step Two.

Variables	Symbol
Log depth of A	X_6
Log effective depth of A	X_7
Log depth to C	X_8
Log effective depth to C	X_9
Percent silt plus clay in A	X_{10}
Percent silt plus clay to C	X_{11}
Percent sand in A	X_{12}
Percent sand to C	X_{13}

Step three then consisted of calculating the multiple regression equation using the best method of expressing soil depth and texture as independent variables and the best expression of production as the dependent variable.

CHAPTER IV

PRESENTATION AND ANALYSIS OF DATA

There are three steps involved in analysis of data. Each step is presented by using graphs and tables in this chapter.

Step 1. Initial screening of variables

Five site variables (Table 6) were used in the first correlation study. Two of these variables correlated significantly with five year growth index as shown in Table 7. They were effective depth of A horizon and depth of A horizon. Their correlation coefficients, .501 and .467, respectively, were significant at the five percent level. Correlation coefficients of depth to C, effective depth to C, and inches silt plus clay to C were not significant at the 5 percent level. None of the site variables showed a significant correlation with total height index. This, then, indicated that five-year growth index reflects the variation in growth due to the site factors better than total height index. Therefore, the total height index was dropped from further analyses.

Table 6. Mean and Range of Variables Used.

Symbol	Unit	Variables	Mean	Range
Y_1	Inches	Five year growth index	33.5	11 - 47
Y_2	Feet	Total height index	11.7	7 - 23
X_1	Inches	Depth of A	11.2	4 - 31
X_2	Inches	Effective depth of A	9.3	4 - 27
X_3	Inches	Depth to C	15.1	6 - 31
X_4	Inches	Effect depth to C	12.9	8 - 27
X_5	Inches	Inches silt plus clay to C	6.9	3 - 15

Scatter diagrams (Appendix figures 2 and 3) were drawn to analyze the relationships between five-year growth index and the two site factors showing significant correlations, effective depth of A horizon and depth of A horizon. These depth factors showed apparent curvilinear relationships. Logarithmic transformation of depth data appeared to have a linear relationship (Appendix figure 4) with five-year growth index.

All measures of soil texture used in step one showed poor relationship with tree growth. These methods of expressing texture were discarded in favor of percent sand and percent silt plus clay.

Table 7. Simple Correlation Coefficients Among First Set of Variables.

Variable	Y_1	Y_2	X_2	X_1	X_4	X_3	Legend
Y_1							Y_1 - 5-year height index
Y_2	.654**						Y_2 - Total height index
X_2	.501*	.144					X_2 - Effective depth of A horizon
X_1	.467*	.049	.925**				X_1 - Depth of A horizon
X_4	.157	-.121	.759**	.781**			X_4 - Effective depth to C horizon
X_3	.142	-.165	.692**	.722**	.972**		X_3 - Depth to C horizon
X_5	-.107	-.376	.431	.463*	.810**	.882**	X_5 - Inches silt plus clay to C horizon

* Significant at the 5 percent level

** Significant at the 1 percent level

Step 2. Final screening of variables

Eight additional variables were used in step two. The mean and range of these variables is shown in Table 8. Correlation coefficients among five-year growth index, depth data expressed as logarithms and texture data expressed as percentages are given in Table 9. Six of these variables were significantly correlated with five-year growth index. They were: logarithm of depth of A, logarithm of effective depth of A, percent silt plus clay to C, percent sand in A, and percent sand to C. Their correlation coefficients, .493, .543, -.520+, -.548+, .448, and .476, respectively were significant at the 5 percent level. Factors having no significant correlations with five-year growth index were logarithm depth to C and logarithm effective depth to C. The ranking of these variables according to correlation coefficients appear in the first column of Table 9.

Table 8. Mean and Range of Variables Used.

Symbol	Unit	Variables	Mean	Range
X_1	Inches	Five-year growth index	33.5	11 - 47
X_6	Inches	Log. depth of A	0.94	0.60 - 1.49
X_7	Inches	Log. effective depth of A	0.90	0.60 - 1.43
X_8	Inches	Log. depth to C	1.14	0.95 - 1.49
X_9	Inches	Log. effective depth to C	1.08	0.78 - 1.43
X_{10}	Percent	Percent silt plus clay in A	0.32	16 - 43
X_{11}	Percent	Percent silt plus clay to C	0.33	16 - 48
X_{12}	Percent	Percent sand in A	0.67	57 - 78
X_{13}	Percent	Percent sand to C	.66	52 - 78

Scatter diagrams (Appendix figures 4, 5, 6, 7 and 8) were drawn to analyze the relationships between five-year growth index and each of the significant site factors. All of these factors independently expressed apparent linear relationship.

Logarithm of effective depth of A with correlation coefficient of .543 was the best method of expressing depth and percent silt plus clay with correlation coefficient of -.548+ was the best method of expressing texture.

Step 3. Computation of a prediction equation

Multiple regression analysis was used to compute a prediction equation using soil depth and soil texture.

Table 9. Simple Correlation Coefficients Among Second Set of Variables.

Variable	Y_1	X_{11}	X_7	X_{10}	X_6	X_{13}	X_{12}	X_8	Legend
Y_1									Y_1 -5-Yr. growth index
X_{11}	.548*								X_{11}-% silt + clay to C
X_7	.543*	.591**							X_7 - Log ef. depth of A
X_{10}	.520*	.936**	.556-**						X_{10}-% silt + clay in A
X_6	.493*	.522*	.981**	-.483+*					X_6 - Log depth of A
X_{13}	.476*	-.970+**	.621**	-.893+**	.561**				X_{13}-% sand to C
X_{12}	.448*	-.892+**	.589**	-.955+**	.524*	.915**			X_{12}-% sand in A
X_8	.035	.091	.473*	.103	.504*	-.036+	-.036+		X_8 - Log depth to C
X_9	.031	.040	.475*	.016	.476*	-.012+	.040	.975**	X_9 - Log ef. depth to C

* Significant at the 5 percent level

** Significant at the 1 percent level

Five-year growth index was selected as a dependent variable from step one. Log effective depth of A and percent silt plus clay to C were selected as independent variables from step two.

Log effective depth of A was designated as variable x, and percent silt plus clay was designated as variable x_2. Five year height index was designated as variable y. The multiple regression equation used was after Snedecor (1956). The equation is,

$$Y = \bar{y} + b_{y1.2}\,(x_1 - \bar{x}_1) + b_{y2.1}\,(x_2 - \bar{x}_2),$$

where $b_{y1.2}$ and $b_{y2.1}$ are partial regression coefficients.

Procedures used in solving the equation were after Snedecor (1956). The prediction equation after computation was,

$$Y = 31.9 + 12.1\,x_1 - 28\,x_2,$$

This equation was verified and tested for significance by analysis of variance. F test showed that the regression was significant at the five percent level as shown in Table 10.

Table 10. Analysis of Variance of Regression, for Five-Year Height Index on Two Soil Factors.

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F Value
Total	18	1177		
Regression	2	423.8	211.9	4.5*
Deviation	16	753.2	47.07	——

* Significant at the 5 percent level

This indicated that these two factors contributed significantly to the five-year height index. In order to isolate the effect of one factor while holding the other constant, a test of each factor was carried out using analysis of variance as shown in Table 11.

Table 11. Test of Each Factor After the Effect of Other Has Been Removed.

Source of Variation	Degree of Freedom	Sum of Squares	Mean Squares	F Value
x_1 and x_2	2	423.8		
x_1 alone	1	363.3		
x_2 after x_1	1	60.5	60.5	1.28
x_1 and x_2	2	423.8		
x_2 alone	1	340.0		
x_{2_1} after x_{1_2}	1	83.8	83.8	1.78
ERROR	16	753.2	47.07	

This test indicated that the effect of either factor alone was not significant at the 5 percent level.

The coefficient of multiple correlation (R) was calculated following the method after Snedecor (1956). The R value .60, was significant at the five percent level. By squaring this value coefficient of multiple determination (R^2) was obtained which indicated that 36 percent of the total variability in five year height index of ponderosa pine was accounted for by depth and texture acting together.

CHAPTER V

DISCUSSION

In the preceding chapter, identification and ranking of soil factors influencing height growth of ponderosa pine were appraised by statistical methods and results expressed in statistical form. In this chapter, these results will be interpreted and the underlying relationships examined, partly in the light of other studies.

Selection of dependent variables

Total height index when compared with five-year growth index proved to be a poor measure of potential growth index. In fact, it did not have any significant relationship with site factors. The probable reason seems to be the effect of establishment period on the height growth. During the early growth period when seedlings are becoming established, they have to face keen competition with other vegetation for space and food. Due to competing vegetation, therefore, the growth rate is retarded. Trees in this area probably had to compete with surrounding herbaceous vegetation in their early growth period which slowed their growth rate. This idea is supported by Ferree, et al (1958). They indicate that inclusion of years to reach $4\frac{1}{2}$ feet in height can give large errors in estimating site quality.

Many other studies have used height of dominant mature trees as site index because it was felt that this measure is fully able to express the effect of site factors. If this index is used, the effect of the establishment period becomes less important in its influence on the height-age relationship. Anderson (1959) working with lodgepole pine indicates that fifteen-year site index was more closely related to site factors than 3-year site index. Trees used in his study were much smaller than those used in this one.

Five-year growth index in this study proved to be a better measure of site index potential than the total height index. This was due to the fact that trees used in this study were young but had already passed the establishment period. Slow growth rate due to competing vegetation did not affect this growth index. In addition, better root development with increase in age also enhances the growth rate by utilizing site factors more efficiently and as a result, this index period showed better correlation with site factors of depth and texture. Ferree et al (1958) stated that five-year intercept method is a satisfactory means of evaluating growth in young red pine plantations.

Climate variations cause fluctuations in growth rate that are independent of soil quality. If more years growth are included in the index, effects due to climate will be smoothed out and effects of soil factors on growth will become more evident. Therefore, measuring more years growth, possibly, would have given better relationships with the soil factors studied.

Relation of site variables with selected dependent variable

Factors expressing soil depth and those expressing soil texture related to five-year growth index are discussed in the following paragraphs.

Soil depth

The importance of soil depth has been reported in many investigations of soil and site relationships. Coile (1948), Einspahr and McComb (1951), Coile and Schumacher (1953), Myers and Van Deusen (1960), Zahner (1957) and many others have reported positive and significant correlations with soil depth.

In this study all methods of expressing depth of the A horizon were significant whereas those expressing depth to C were non-significant. However, Myers and Van Deusen (1960) correlated the site index of ponderosa pine with the depth to the top of C horizon in the Black Hills. The possible reason for this seems to be the rooting habit of trees in this region. Roots were spreading laterally and were mostly confined to the A horizon. Possibly, this horizon supplied most of the nutrients and water required for tree growth. The sub-soil on the other hand was very rocky in most cases and seemed to be poor in nutrients.

Curvilinear relationship between soil depth and five-year growth index showed that deeper soils did not increase growth rate in proportion to depth probably because of a decrease in nutrients and reduction in available water as depth increased. Coile (1952) indicates that the relationship of tree growth to the depth factor is usually curvilinear.

Effective depth was a better method of expressing soil depth than the actual measured depth, probably because the rock free soil accounted for better availability of nutrients and moisture.

Soil texture

Negative correlation of percent silt plus clay and positive correlation of percent sand cause one to conclude that coarse textured soil is favorable to ponderosa pine growth in this region. This condition may be attributed to the interaction between soil texture and climate. In this region most of the moisture--approximately sixty percent--comes during the growing season when the evaporation rate is high because of relatively high temperature and high wind velocities. This moisture could be saved from evaporation if the soil had a high infiltration rate. Coarse textured soil is associated with high infiltration rates and, therefore, plays its role by making more water available for plant growth. Fine textured soil on the other hand, with a low infiltration rate, allows most of the moisture to be evaporated and only little of it to be available for plant growth.

Soil texture is directly associated with soil and water relationships. The finer the texture of a soil the greater is the storage of moisture. Therefore, in regions where trees depend on stored moisture during growing season, silt plus clay becomes an important factor. In this region, however, since most of the moisture comes during the growing season, these trees depend less on stored moisture for their growth.

Many studies of soil texture indicate that texture of the surface soil and subsoil differ with regards to their effects on site index. Zahner (1957) indicated that site index increased with increase in finer material in the subsoil but it decreased with increase in finer materials in surface soil. Haig (1929) indicated that site index increased as the percent of finer fractions increased in the surface horizon. The present study, however, showed that the growth rate decreased with increase in fine texture both in surface soil and subsoil. These differing results are probably due to different climatic conditions under which the studies were made.

Depth and texture combined

Depth and texture when tested individually did not show statistically significant effects but the author believes that these effects are none the less real. One reason for this belief is the fact that the multiple regression using these two variables is significant and accounts for about one-third of the total variability in growth of ponderosa pine. It appears that an increase in soil depth is more effective in the growth of this species if the texture becomes more sandy at the same time. This type of an interaction would be expected where infiltration of water is so important in determining the moisture regime of the site.

Suggestions for further study

Using the information of this study and adding more factors of environment a site quality classification can be made for this area.

The variables evaluated in this study resulted in these recommendations:

1. Enlarge the study area to cover greater variations of soils and topography.

2. Determine the influence of microclimatic conditions such as temperature, precipitation and humidity on the growth of ponderosa pine.

3. Determine the effects of aspect, slope, position on slope and elevation on the growth rate of ponderosa pine.

4. Measure moisture factors and determine their effect on growth rate of ponderosa pine.

5. Measure chemical properties such as available phosphorus, calcium, potassium, iron, magnesium and organic matter in each horizon in the soil profile and correlate them with the growth rate of ponderosa pine.

SUMMARY

Site quality determination for ponderosa pine using site factors has not been done in the Montane zone of northern Colorado. This study was designed as a pioneering one towards the ultimate goal of site quality classification of ponderosa pine in this zone.

This study had three objectives: 1) To determine the best growth index to be used as a dependent variable, 2) To determine the best method of expressing soil depth and texture and, 3) To compute an equation for predicting the suitability of a site for ponderosa pine.

In the summer of 1964 nineteen plots were selected in the study area. The field work consisted of tree measurement and soil profile description. On each plot three trees were cut and for each of them five year leader growth and total height were measured. Soil factors were measured and described for the soil profile exposed on each plot. Soil samples collected from each soil profile were analyzed for texture determination in the laboratory. Soil and tree data were then compiled for statistical analysis. The statistical analysis was completed in three steps: 1) Initial correlation analysis, 2) Final correlation analysis and, 3) Multiple linear regression analysis.

In the first correlation analysis dependent variables tested were total height index and five-year growth index. Independent variables tested in this step consisted of depth of A, depth to C, effective depth of A, effective depth to C, and inches silt plus clay to C. In the second correlation analysis five-year growth index was used as dependent variable against a new set of independent variables. These variables were: log. depth of A, effective depth of A, log. depth to C, log. effective depth to C, percent sand in A, percent sand to C, percent silt plus clay in A, and percent silt plus clay to C. The third step consisted of multiple linear regression analysis using five-year growth index as dependent variable, and log effective depth of A and percent silt plus clay to C as independent variables.

Results of first correlation analysis showed that five-year growth index was a better measure of potential growth index than total height index. Inches silt plus clay proved to be a poor method of expressing soil texture as it was not correlated significantly with either of dependent variables. Results of second correlation analysis showed that all methods of expressing depth of A and all methods of expressing texture as percentage were significant. Depth factors to C were nonsignificant. Percent silt plus clay was negatively correlated whereas percent sand was positively correlated with five-year growth index. Multiple regression analysis showed that effective depth of A horizon and percent silt plus clay to the C horizon accounted for 36 percent of the variability in the growth of ponderosa pine.

BIBLIOGRAPHY

Aird, P. L. and E. L. Stone. 1955. Soil characteristics and the growth of European and Japanese larch in New York. J. Forest. 53: 425-429.

Anderson, C. R. 1959. Relation of certain environmental factors to height and vigour of juvenile lodgepole pine. M. S. Thesis. Colorado State Univ., Fort Collins. 43 p.

Bouyoucos, G. J. 1936. Directions for making mechanical analysis of soils by the hydrometer method. Soil Sci. 42: 225-228.

Briegleb, P. A. 1950. Growth of ponderosa pine. J. Forest. 48: 349-352.

Carmean, W. H. 1954. Site quality for Douglas-fir in southwestern Washington and its relationship to precipitation, elevation, and physical soil properties. Soil Sci. Soc. Amer., Proc. 18: 330-334.

Coile, T. S. 1952. Soil and growth of forests. Advances in Agron. 4: 329-398.

__________ and F. X. Schumacher. 1953. Relation of soil properties to site index of loblolly and shortleaf pines in the Piedmont region of the Carolinas, Georgia, and Alabama. J. Forest. 51: 739-744.

Copeland, O. L., Jr. 1958. Soil-site index studies of western white pine in the northern Rocky Mountain region. Soil Sci. Soc. Amer., Proc. 22: 268-269.

Cox, G. S., R. C. McConnell, and L. M. Matthew. 1960. Ponderosa pine productivity in relation to soil and landform in western Montana. Soil Sci. Soc. Amer., Proc. 24: 139-142.

Einspahr, D. and A. L. McComb. 1951. Site index of oaks in relation to soil and topography in northeastern Iowa. J. Forest. 49: 719-723.

BIBLIOGRAPHY (Continued)

Ferree, M. J., T. D. Shearer and E. L. Stone, Jr. 1958. A method of evaluating site quality in young red pine plantation. J. Forest. 56: 328-332.

Gaiser, R. N. 1950. The relation between soil characteristics and site index of loblolly pine in the coastal plain region of Virginia and the Carolinas. J. Forest. 48: 271-275.

Gessel, S. P. and W. J. Lloyd. 1950. Effect of some physical soil properties on Douglas-fir site quality. J. Forest. 48: 405-410.

Haig, I. T. 1929. Colloidal content and related soil factors as indicators of site quality. Yale Univ. School Forest., Bull. 24: 33p.

Harper, H. J. 1940. Relation of climatic conditions, soil characteristics, and tree development in the southern great plains region. Soil Sci. Soc. Amer., Proc. 5: 327-335.

Holtby, B. E. 1947. Soil texture as a site indicator in the ponderosa pine stands of southeastern Washington. J. Forest. 45: 824-825.

Kozlowski, T. T. 1955. Tree growth, action and interaction of soil and other factors. J. Forest. 53: 508-512.

Lemmon, P. E. 1955. Factors affecting productivity of some lands in the Willamette basin of Oregon for Douglas-fir timber. J. Forest. 53: 323-330.

Linnartz, N. E. 1963. Relation of soil and topographic characteristics to site quality of southern pines in Florida parishes of Louisiana. J. Forest. 61: 434-438.

Lovering, T. S. and E. N. Goddard. 1950. Geology and ore deposits of Front Range, Colorado, p. 19-29. In U. S. Geol. Surv. Prof. Paper 223.

Myers, C. A. and J. L. Van Deusen. 1960. Site index of ponderosa pine in Black Hills from soil and topography. J. Forest. 58: 548-555.

Ralston, C. W. 1951. Some factors related to the growth of longleaf pine in the Atlantic coastal plain. J. Forest. 49: 408-412.

BIBLIOGRAPHY (Continued)

Sargent, C. S. 1947. Pinus ponderosa, p. 77-82, vol. 11. In C. S. Sargent, Silva of North America. Peter Smith, New York.

Snedecor, G. W. 1956. Multiple regression and coveriance, p. 413-446. In G. W. Snedecor, Statistical methods applied to experiments in agriculture and biology. 5 th ed. Iowa State College Press, Ames.

Stoeckeler, J. H. 1948. The growth of quaking aspen as affected by soil properties and fire. J. Forest. 46: 727-737.

Storie, R. E. and A. E. Wieslander. 1948. Rating soils for timber sites. Soil Sci. Soc. Amer., Proc. 13: 499-509.

Turner, L. M. 1937. Some soil characters influencing the distribution of forest types and rate of growth of trees in Arkansas. J. Forest. 35: 5-11.

U. S. Department of Agriculture. 1951. Agr. handbook 18: Soil survey manual. U. S. Government Printing Office, Washington. 503 p.

U. S. Department of Agriculture. 1941. Agr. yearbook, 1941: Climate and man. U. S. Government Printing Office, Washington. 1228 p.

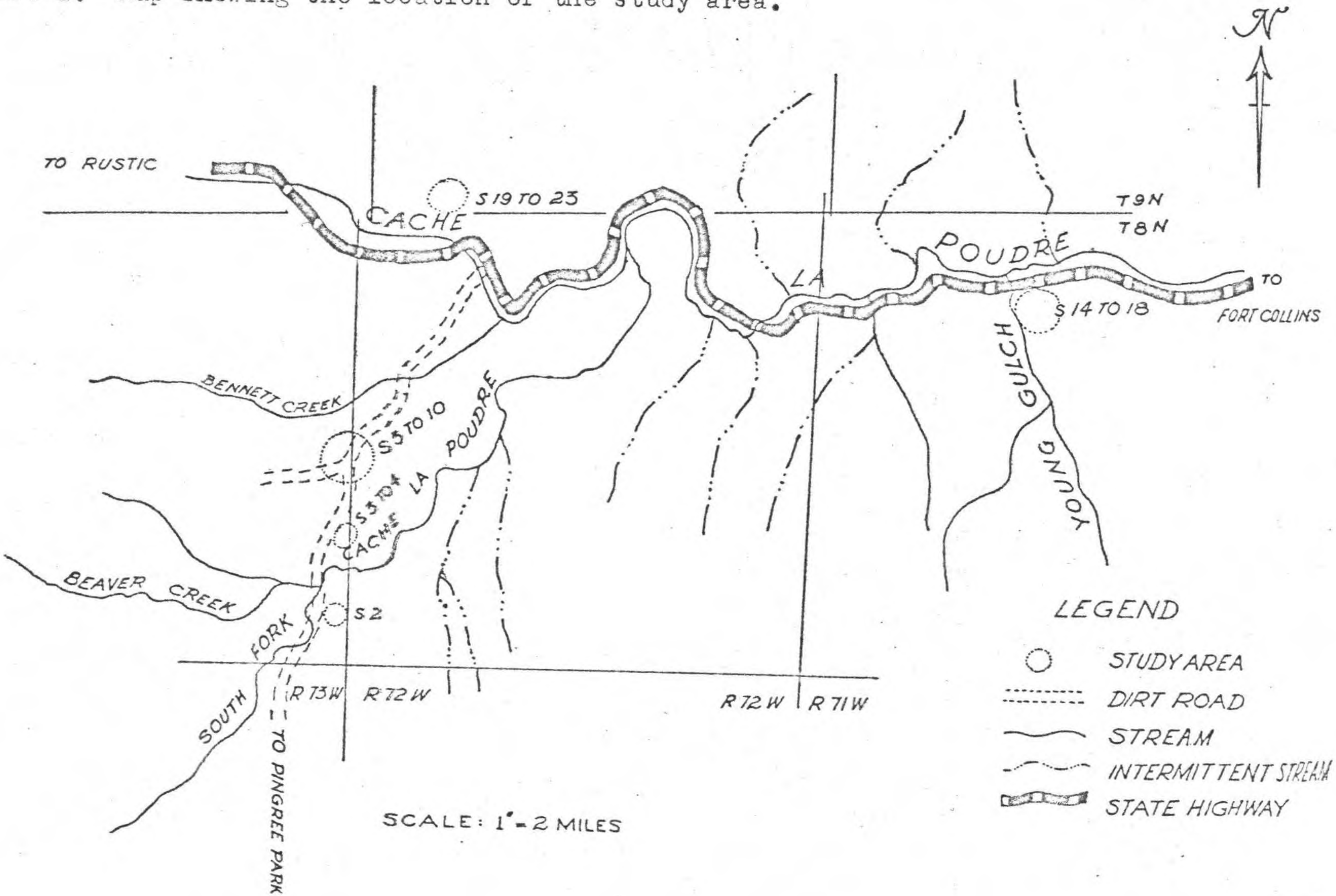
U. S. Weather Bureau. 1959-1964. Climatological data: Colorado. U. S. Government Printing Office, Washington. V. 64-69.

Weaver, H. 1959. Ecological changes in the ponderosa pine forest of the Warm Springs Indian reservation in Oregon. J. Forest. 57: 15-20.

Zahner, R. 1957. Mapping soils for pine site quality in south Arkansas and north Louisiana. J. Forest. 55: 430-433.

APPENDIX

Figure 1. Map showing the location of the study area.



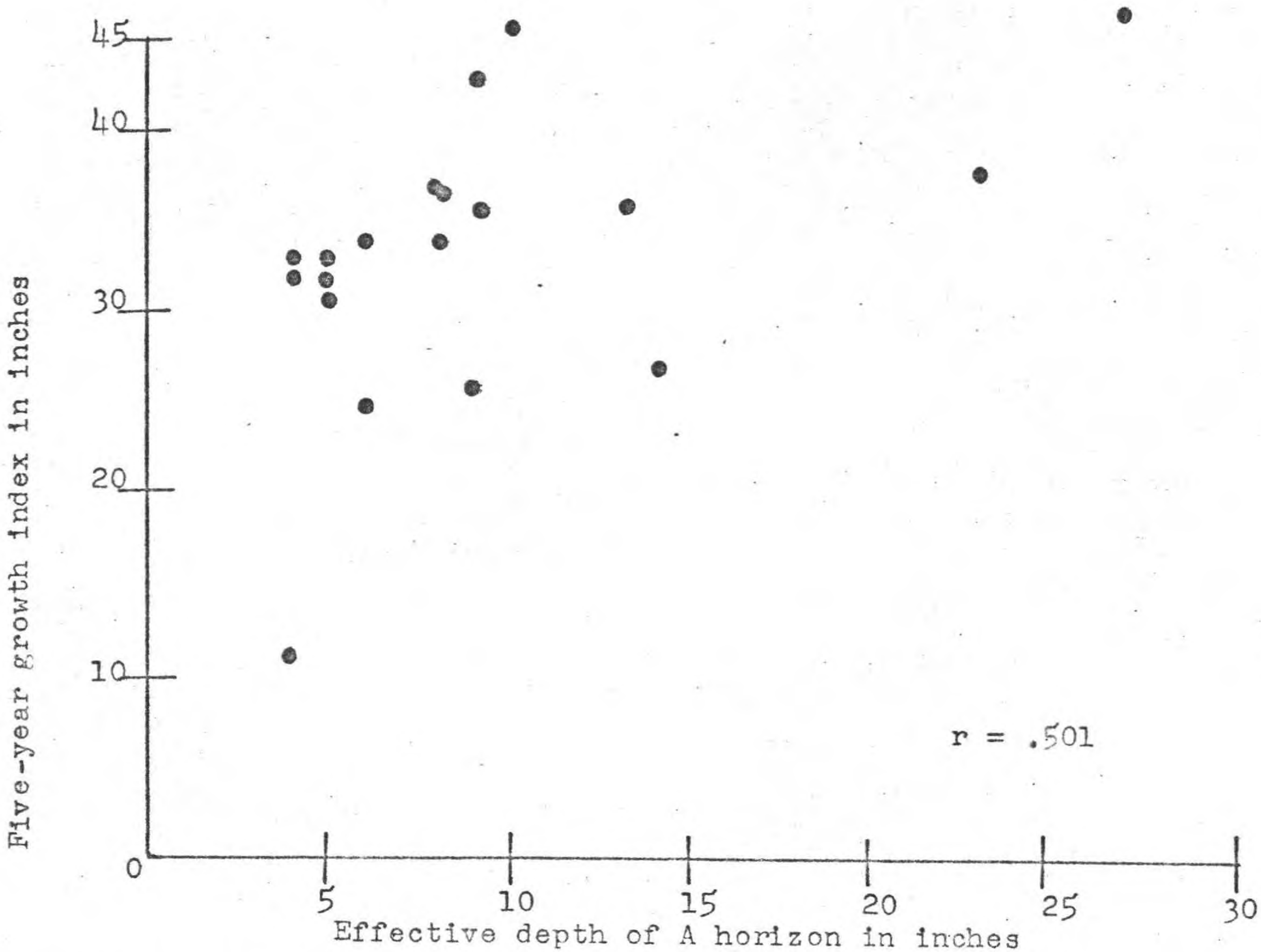


Figure 2. Scatter diagram showing curvilinear relationship between five-year growth index and effective depth of A horizon.

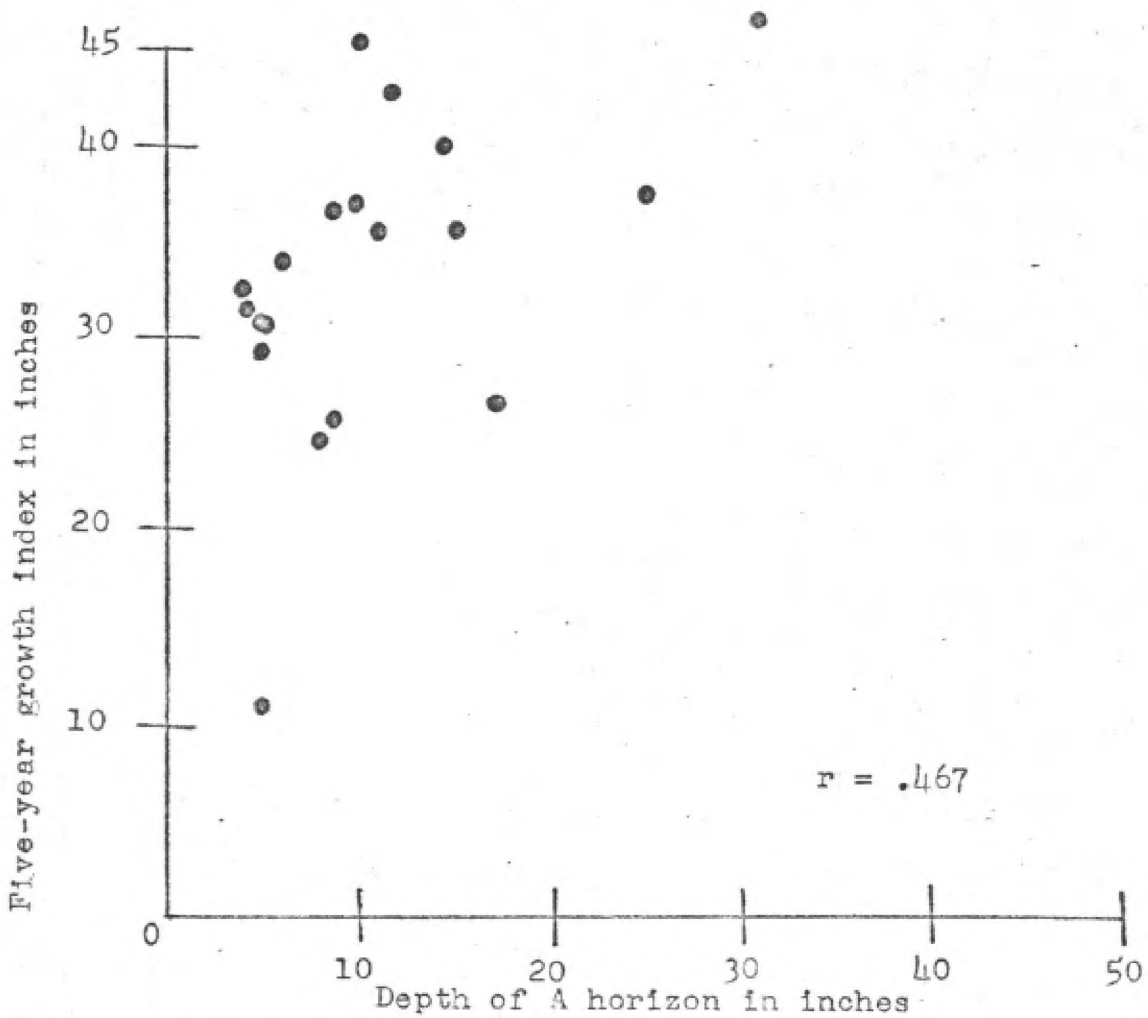


Figure 3. Scatter diagram showing curvilinear relationship between five-year growth index and depth of A horizon.

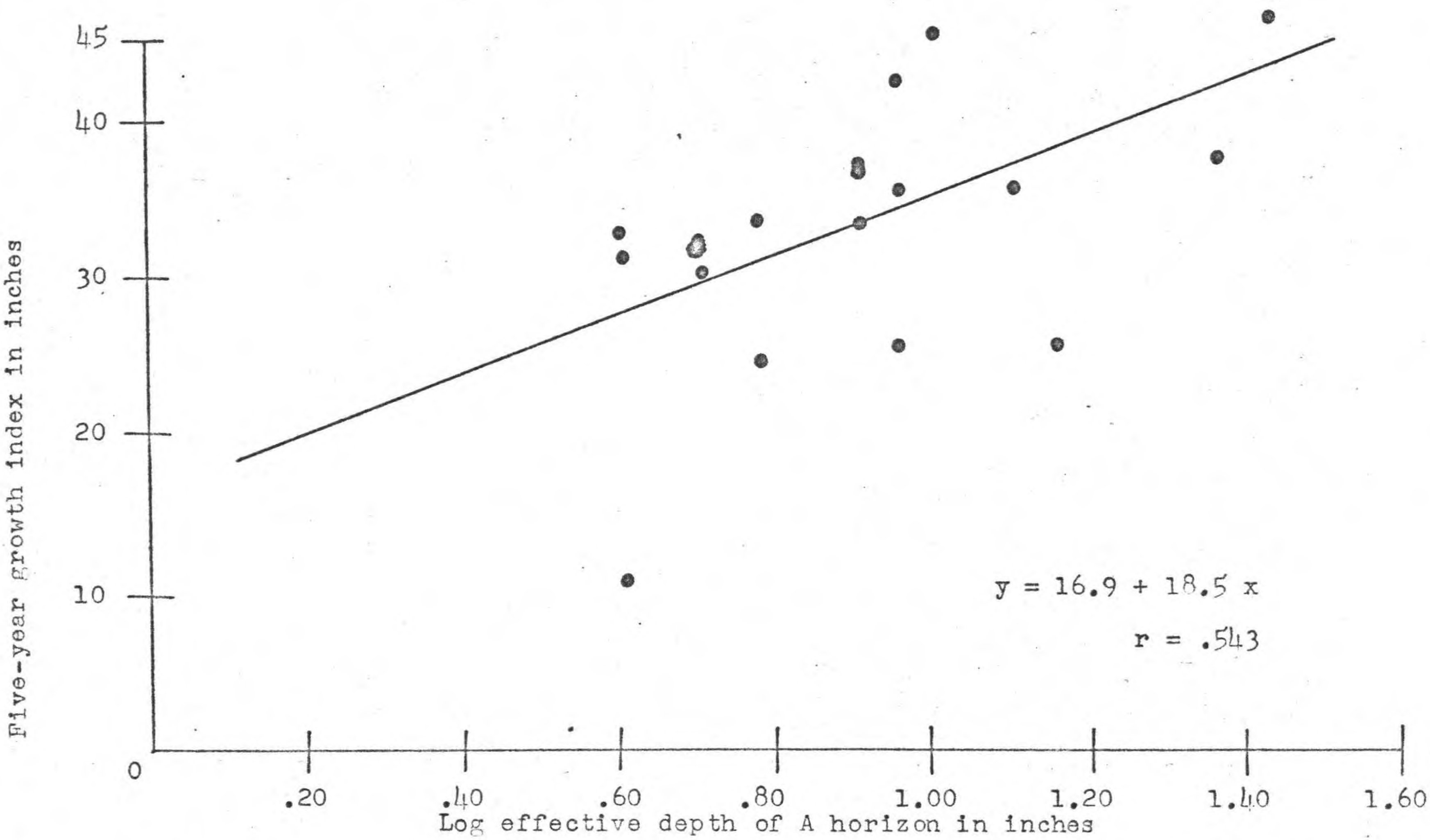


Figure 4. Scatter diagram and line of regression of five-year growth index on log effective depth of A horizon.

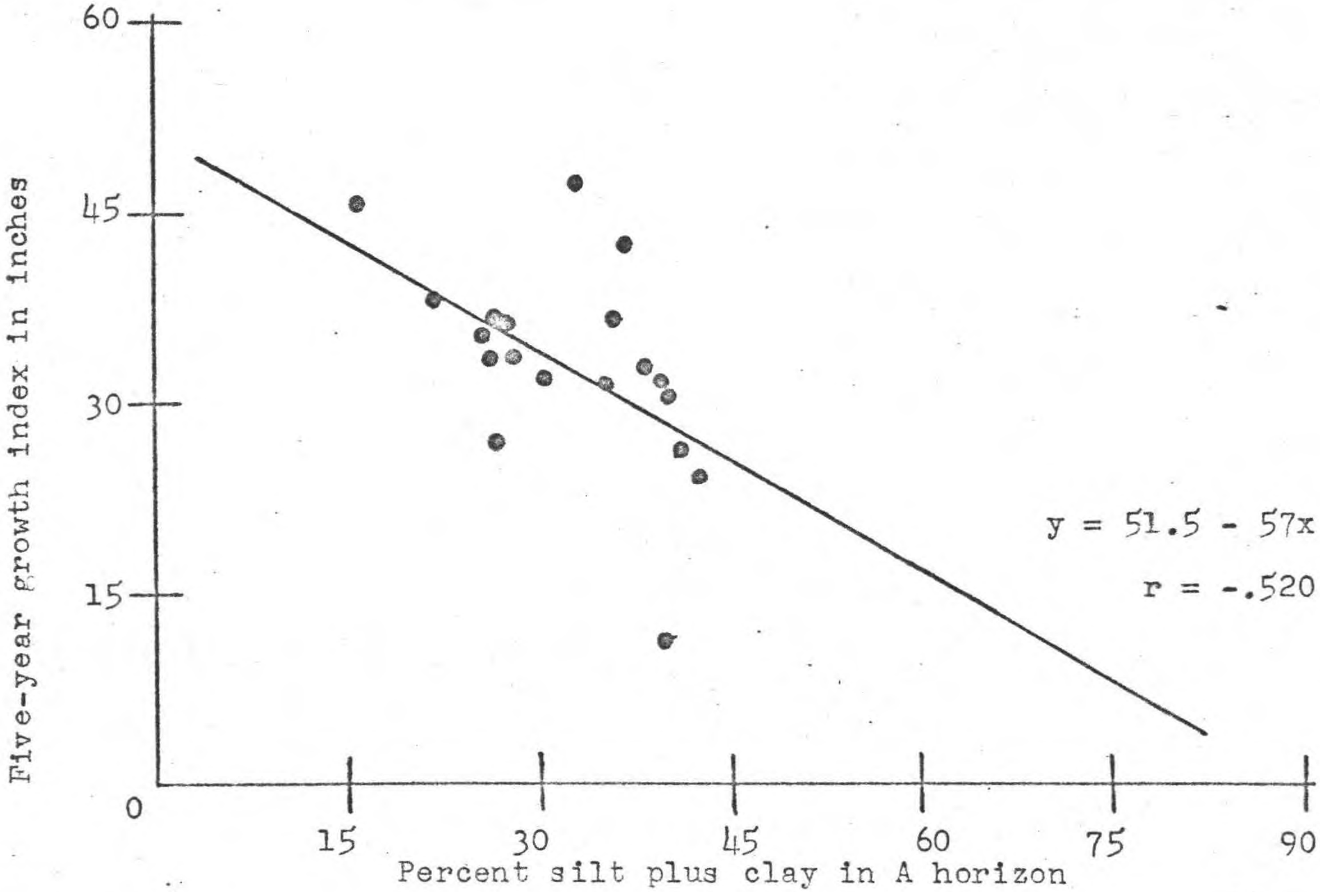


Figure 5. Scatter diagram and line of regression of five-year growth index on percent silt plus clay in A horizon.

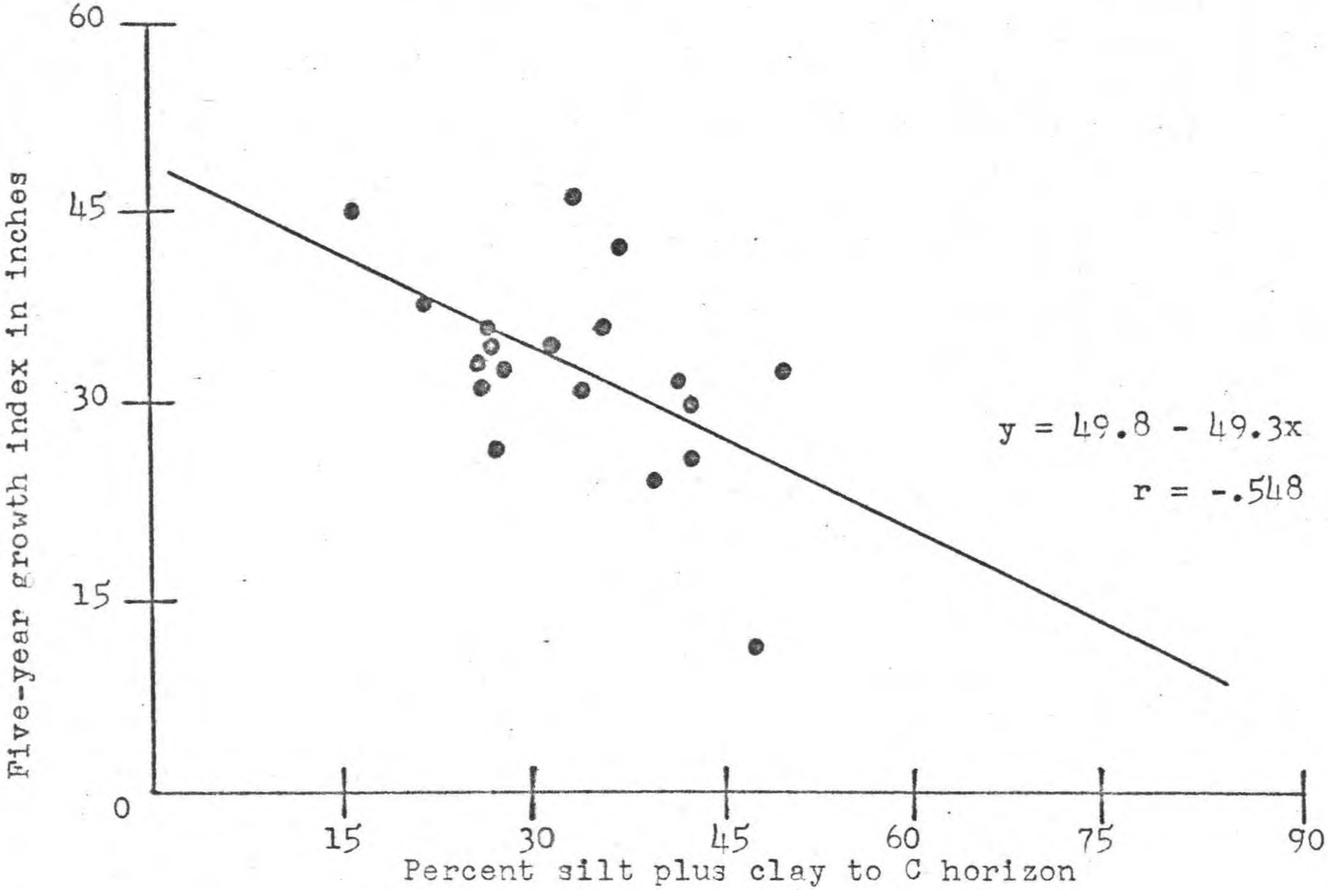


Figure 6. Scatter diagram and line of regression of five-year growth index on percent silt plus clay to C horizon.

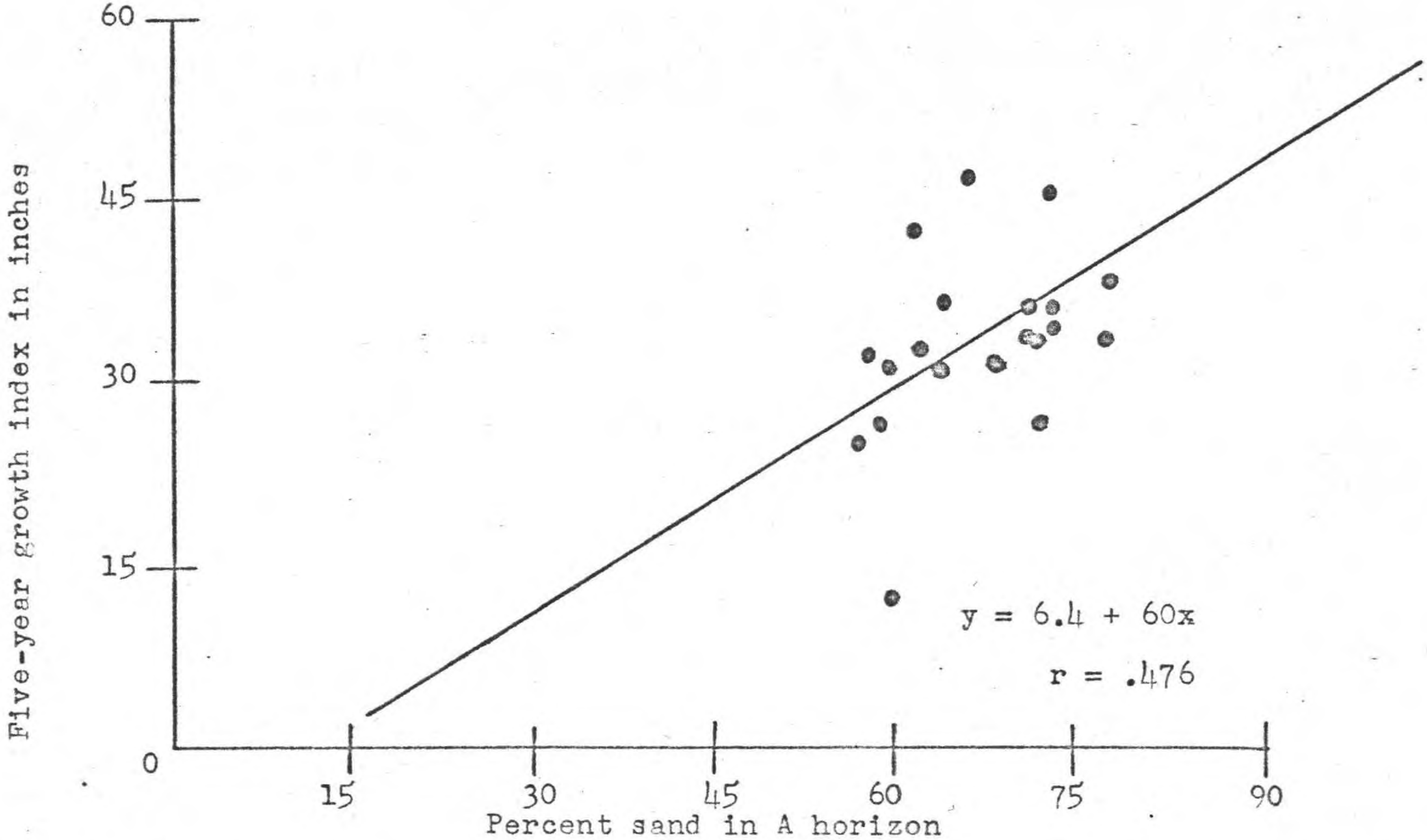


Figure 7. Scatter diagram and line of regression of five-year growth index on percent sand in A horizon.

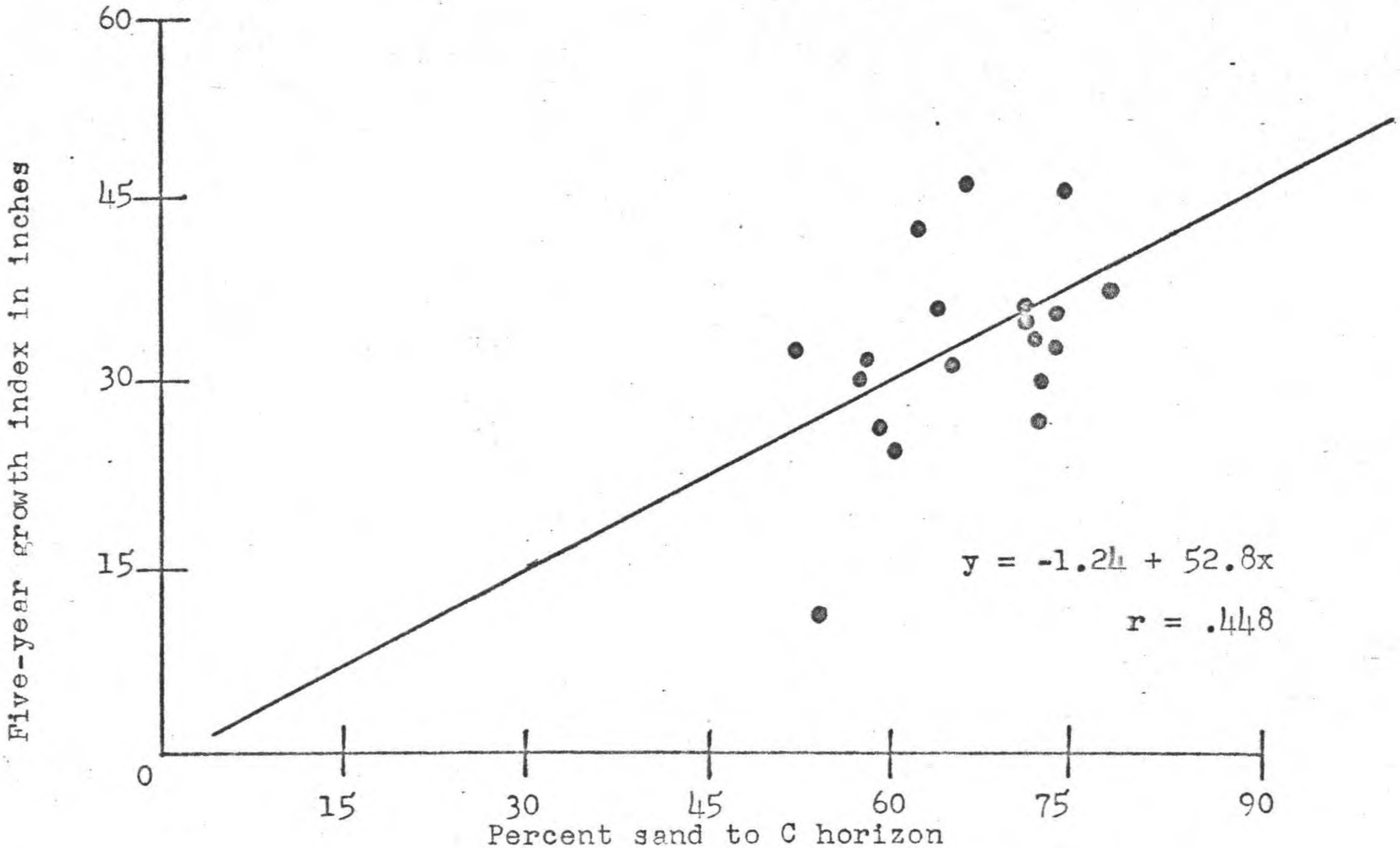


Figure 8. Scatter diagram and line of regression of five-year growth index on percent sand to C horizon.

ABSTRACT OF THESIS

SOME SOIL FACTORS AFFECTING THE GROWTH OF PONDEROSA PINE IN THE MONTANE ZONE OF NORTHERN COLORADO

Ponderosa pine, one of the most valuable species in the Montane zone of northern Colorado, needs to be studied as to its relationships with soil factors. This study, dealing with soil and growth relationships in ponderosa pine, is a basis for evolving methods which will eventually lead to site quality classification.

Nineteen plots were selected in the study area. Three pine trees were measured and soils were described on each plot. Soil samples collected from each horizon were analyzed for partical size distribution in the laboratory. Soil and tree data were analyzed statistically in three steps. In the first step a correlation analysis was made using two dependent and five independent variables. Dependent variables were five-year growth index and total height index and independent variables consisted of various methods of expressing depth and texture factors. In the second step the dependent variable used was five-year growth index and independent variables consisted of new methods of expressing depth and texture factors. In the third step a multiple regression analysis was made

using the best depth and the best texture factor selected from the first and second step and five-year growth index.

Five-year growth index was a better measure of potential growth index than total height index. All methods of expressing depth of A horizon were significant. Methods of expressing depth to C were not significant. All methods of expressing texture as percentage were significant. Effective depth of A horizon and percent silt plus clay to the C horizon accounted for 36 percent of total variability in growth of Ponderosa pine.

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