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Forest Research Branch

RELATIONSHIPS BETWEEN SITE FACTORS AND GROWTH OF LODGEPOLE PINE (*PINUS CONTORTA* DOUGL. VAR. *LATIFOLIA* ENGELM.) IN THE FOOTHILLS SECTION OF ALBERTA.

by

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ABSTRACT

A study was made of forest land productivity between the Red Deer and Brazeau Rivers in the Foothills Section of Alberta to facilitate prediction of yields for lodgepole pine. A preliminary site classification was developed on the finding that pine growth differs between parent materials. Pine growth in terms of dominant height, average height, basal area per acre, and total volume per acre is better on the Lobley Loam Heavy Loam soil series than on the two other important soils in the study area (Caroline Loam Silt Loam on lacustrine substrates and the Horburg Sandy Loam on coarse gravelly alluvium).

Correlations between site, stand factors, and pine growth were used to construct prediction equations for the site expressions—dominant height, average height, and basal area, total volume, and merchantable volume per acre. Height growth can be predicted with greater precision than basal area, total volume or merchantable volume per acre. Stocking level has an important influence upon pine growth and the effect varies from one soil type to another. Dominant height and average height at an index age are good site indices provided a correction is made for stocking level. New prediction equations for pine and other species on other soils could be calculated using the survey and techniques outlined.

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by

P. J. B. DUFFY[2]

INTRODUCTION

The classification of forest land according to wood yield potential is an important phase of forest management in many parts of North America. The classifications vary from broad to refined depending upon the use to which they are put and the strength of the relationships which are developed between site and growth. The approach to classification may differ with the locality and with the investigator. For instance, sites have been grouped according to vegetation criteria in British Columbia by V. J. Krajina and his students; according to physiographic criteria, mainly soil moisture status, in the Mixedwood Section of the Boreal Forest Region of Alberta, Saskatchewan, and Manitoba by Rowe and Duffy[3]; according to broad physiographic criteria, including climate, kind and depth of geologic material, soil moisture, and soil profile in Ontario by Hills and Pierpoint (1960); according to vegetation classes in the Boreal Forest Region of Quebec by Heimburger (1941); and according to physiography and vegetation in the Boreal Forest Region in New Brunswick by Loucks (1962).

In Alberta, a physiographic site classification approach is justified because most of the landscape was modified by glaciers and meltwaters during the Pleistocene epoch and different depositional processes resulted in parent materials which were of various physical properties and topography. The parent materials differ in their homogeneity; for instance, glacial till varies less in textural composition from place to place than alluvial or lacustrine materials.

Because the parent materials vary importantly in texture and moisture-holding capacity, and because the climate over most of Alberta is moisture deficient with respect to the needs of forest growth, one approach to physiographic site classification is by examining site factor—growth relationships on several parent materials each of which appears to have a different soil moisture status.

To be useful in the management of Alberta forests, a site classification should lend itself to aerial photographic interpretation. This is because extensive areas are being surveyed for timber yield and the acreages involved and the problem of access dictate that photo-interpretation be employed in site mapping and classification. Such physiographic characters as land type[4], landform, slope grade, slope position, and aspect can be mapped from aerial photographs.

[1] Department of Forestry, Canada, Forest Research Branch Contribution No. 607. This paper is based on a portion of a dissertation presented in partial fulfillment of the requirements for the degree of Doctor of Philosophy from the University of Minnesota.

[2] Research Officer, Department of Forestry, Forest Research Branch, Calgary, Alberta.

[3] ROWE, J. S. and P. J. B. DUFFY. 1961. White spruce sites in the Mixedwood Section. Department of Forestry, Canada, Forest Research Branch, Unpub. M.S.

[4] Terminology used in the text is defined in a glossary in Appendix I.

Duffy and Meyer (1962) suggested that in the construction of aerial photo volume tables for lodgepole pine (*Pinus contorta* Dougl. var. *latifolia* Engelm.), significant differences in volume prediction equations might be discovered if the forest lands under study were first stratified according to a land productivity classification. This possibility is being pursued in current research.

The purposes of this study are to:

1. show the differences in lodgepole pine growth which occur between soils on three parent materials, namely glacial tills, alluvium and lacustrine.
2. employ a multiple regression method and present growth prediction equations for pine growing on the Lobley Loam, Heavy Loam soil series in an area which is partly covered by the Rocky Mountain House and Brazeau Map Sheets of west-central Alberta.
3. discuss the advantages of the method and the approach together with their shortcomings.

For the purpose of this study, it is hypothesized that, in general, physiographic site factors and stand factors are correlated with growth of lodgepole pine in such a way that they can be employed in regression analyses for the purposes of growth prediction.

REVIEW OF SELECTED LITERATURE

Characteristics of lodgepole pine

Lodgepole pine occurs throughout the Foothills Section (B. 19a and B. 19c) (Figures 1 and 2) of Alberta in extensive pure and mixed stands in the wake of fire (Rowe 1959: 24-25). Because it is not exacting in its soil requirements, it grows on a wide variety of soils. The best development has been described as occurring on moist but well-drained sandy or gravelly loam, although trees reach commercial proportions on a variety of soil types, except those of limestone origin (Harlow and Harrar 1950: 113). In west-central Alberta, the tree occurs in even-aged stands on soils on glacial tills, coarse gravelly alluvium, and lacustrine deposits (Duffy 1962). For details the reader is referred to a review of the silvics of the species by Tackle (1959) and a comprehensive monograph on lodgepole pine in Alberta by Smithers (1962).

Site factor studies

The study of relationships between site factors and forest growth has been underway for decades. "In the past 30 years, sixty-five articles have been published concerning the soil-site relationships for various tree species throughout the United States. A number of techniques have been used for expressing study results, but within the last decade there has been an increasing use of regression analysis" (Della-Bianca and Olson 1961).

In Canada, some site classification research has a basis in the work of G. A. Hills of Ontario. His techniques permit the categorization of the environment in terms of moisture regime, nutrient regime, and local climate. These are divided into several classes in a given region and correlations may be made between the classes and forest growth. Recently Hills and Pierpoint (1960) have used a refined method in the classification of forest sites in Ontario with growth of white pine (*Pinus strobus* L.) as the measure of land potential.

FIGURE 1. Boreal Forest Region, Lower Foothills Section (B.19a). Pure stands of lodgepole pine are in the middle background. Trembling aspen and balsam poplar are in the foreground. Near Saunders, Alberta. Tp. 40, R. 11, W. 5th.

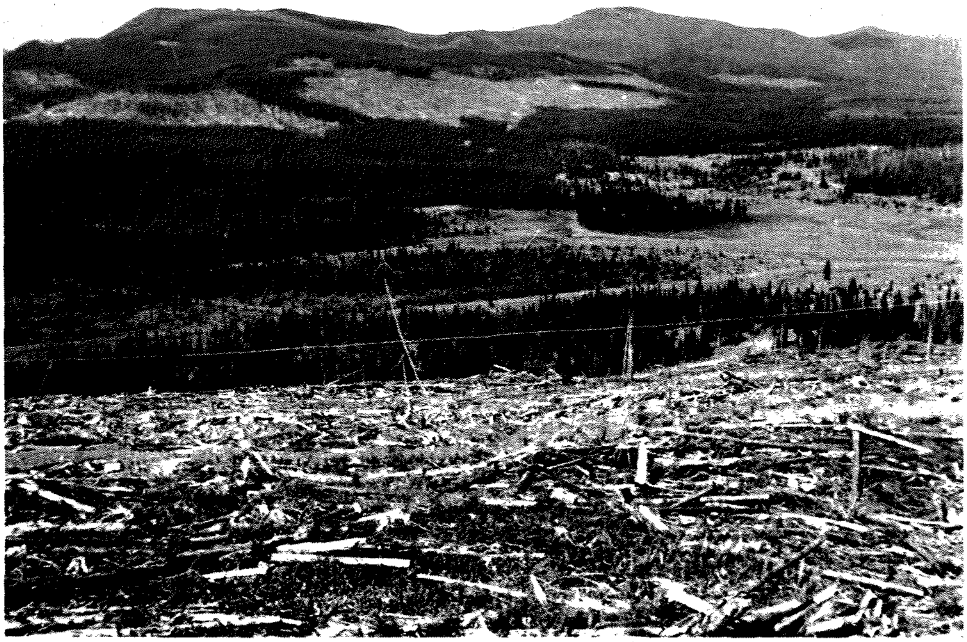

FIGURE 2. Boreal Forest Region, Upper Foothills Section (B.19c). Mixed spruce and pine stands near Entrance, Alberta. Tp. 53, R. 1, W. 6th.

There is a dearth of published research on the relationships between site factors and forest growth in Canada. In the U.S.A. however, there is much reference material available. Prior to about 1955, several such studies apparently involved the selection of only a few site factors which were correlated with tree growth. The size of the studies were limited, in part, by the analysis of the data. Examples are found in Auten's (1945) work with yellow poplar site index as related to soil depth, Coile's (1935) study of shortleaf pine site index and physical properties of soils, and (1948) study of loblolly and shortleaf pines in North Carolina, Gessel and Lloyd's (1950) study of soil and Douglas-fir site quality, and Hill, Arnst, and Bond's (1948) work with Douglas-fir. With the introduction of electronic computer facilities for analysis of forestry data, several comprehensive, multifactor studies of soil and tree growth have been undertaken. In the eastern and south-eastern U.S.A., several regression analysis studies have been instituted in hardwood species (Doolittle 1957), in the pines (Coile 1948), and in mixedwoods (Olsen and Della-Bianca 1959; Della-Bianca and Olsen 1961). Pioneer work by Coile (1948) in the application of regression analysis techniques to site-growth studies and research by Grosenbaugh (1958) at the Southern Forest Experiment Station at New Orleans, Louisiana, introduced techniques which permitted the simultaneous correlation of several soil-site (independent) factors and growth (dependent) factors. The number of variables to be correlated and introduced into multiple regression equations which summarized the relationships was far greater than those studies made previously. For instance, McGahan *et. al.* (1961) used the Southern Forest Experiment Station Program to obtain all possible regressions involving nine variables and a total of 511 regressions for each of six tree species in the State of Rhode Island. The work of Holmes and Tackle (1962) in lodgepole pine in Montana included an analysis of nineteen soil and stand factors.

In parts of the sub-humid to semi-arid mid-west and western U.S.A. where moisture deficits are common, soil-site factor studies have dealt with those characteristics which seem to control the supply of available soil moisture to the forest stand. Pawluk and Arneman (1961) concluded that growth of jack pine in a study area in Minnesota and Wisconsin is closely related to those characteristics of the soil which influence both fertility and available moisture holding capacity. Holmes and Tackle (1962) in Montana found that depth of the soil was related to height growth in lodgepole pine and the term was included in regression equations for the species. Stoeckeler (1960) found that physical properties of soils in northern Minnesota and northern Wisconsin gave higher correlations with site index (height of the average dominant and codominant trees at an index age) in quaking aspen than did chemical tests for total nitrogen, or available phosphorus, and other factors. It was inferred that good water relations are of vital importance to attain good growth of aspen (p. 41).

The multiple regression method

Multiple regression statistics have been employed frequently by Coile and his co-workers to summarize the relationships between soil-site factors and tree growth (Coile 1935; 1948; 1952). Coile (1948) reviewed several similar studies throughout the United States of America and applied multiple regression methods to site-growth data for loblolly pine and shortleaf pine in North Carolina. Since Coile's 1948 paper, and particularly since the introduction of electronic computing facilities, several similar studies have been conducted (Copeland 1958; Cox *et. al.* 1960; Forrestall and Gessel 1955; Gaiser 1950; Holmes and

Tackle 1962; Mader and Owen 1961; Zahner 1958). In general, different soil characteristics were related to the growth and yield of different species. Certain regional features of the environment were stated to be important in the choice of which factors to study. For instance, with reference to dry areas of the United States, Coile (1948) wrote, "it has been fairly well established that physical soil properties which allow for rapid infiltration and good water storage and low evaporation loss are associated with superior forest sites."

Hodgkins (1960) has discussed the suitability of multiple regression equation theory to application in forest site studies and has stated that one well-known requirement of the regression line is not met in most soil-site index studies, i.e. that the variable part of the dependent term not defined by the regression line should be normally distributed about the latter in a random manner. Further, he stated that the hazards of regression technique can only be avoided by working within small, rather uniform areas. Acton (1959) wrote that requirements of the classical regression model include that:

1. distributions (of the dependent and independent variables and of the variable part of the dependent variable) be normal;
2. their (theoretical) mean values lie exactly on the regression line;
3. variances about the mean be the same for all levels of the independent variable (i.e. homogeneous variance);
4. the observations be statistically independent.

Further, Acton wrote, "The assumption of normality underlies most of our useful statistical tests, but unfortunately most of the tests are not particularly sensitive to mild departures from normality. Such a test is said to be robust. No robust test for non-homoscedasticity (heterogeneous variance) is known" (p. 89-90). It would seem that more research is required to satisfy the assumptions underlying statistical theory and methods in the analysis of variance and regression in studies which relate environmental factors to growth and yield of forest species.

DESCRIPTION OF THE STUDY AREA

Geography and Topography

The study area is in the Foothills Section in west-central Alberta (Figures 3 and 4). It is bounded on the west by the front range of the Canadian Rocky Mountains, on the north by the Brazeau River, on the east by the Aspen Grove Forest Section of the Boreal Forest Region (B.17) and on the south by the Red Deer River. The town of Rocky Mountain House is located in the study area at approximately 52° 24′ north latitude and 114° 55′ west longitude.

In general, the regional topography is bed-rock controlled and the depth of the overlying mantle varies widely. The Foothills Section and the plains of Alberta are believed to be remnants of a Tertiary plain which sloped gently to the east. Erosion of the Rocky Mountains during Tertiary (Oligocene) times caused a deep layer of alluvial gravels to be deposited, remnants of which are found in parts of Alberta outside of the study area. The landscape in the study area is an eroded plateau with a west-east orientation.

Parent materials and soils

Both Cordilleran and Keewatin ice sheets traversed portions of the study area during the Pleistocene. The Cordilleran advance was the more important in that most of the glacial drift is of Rocky Mountains origin. At present there

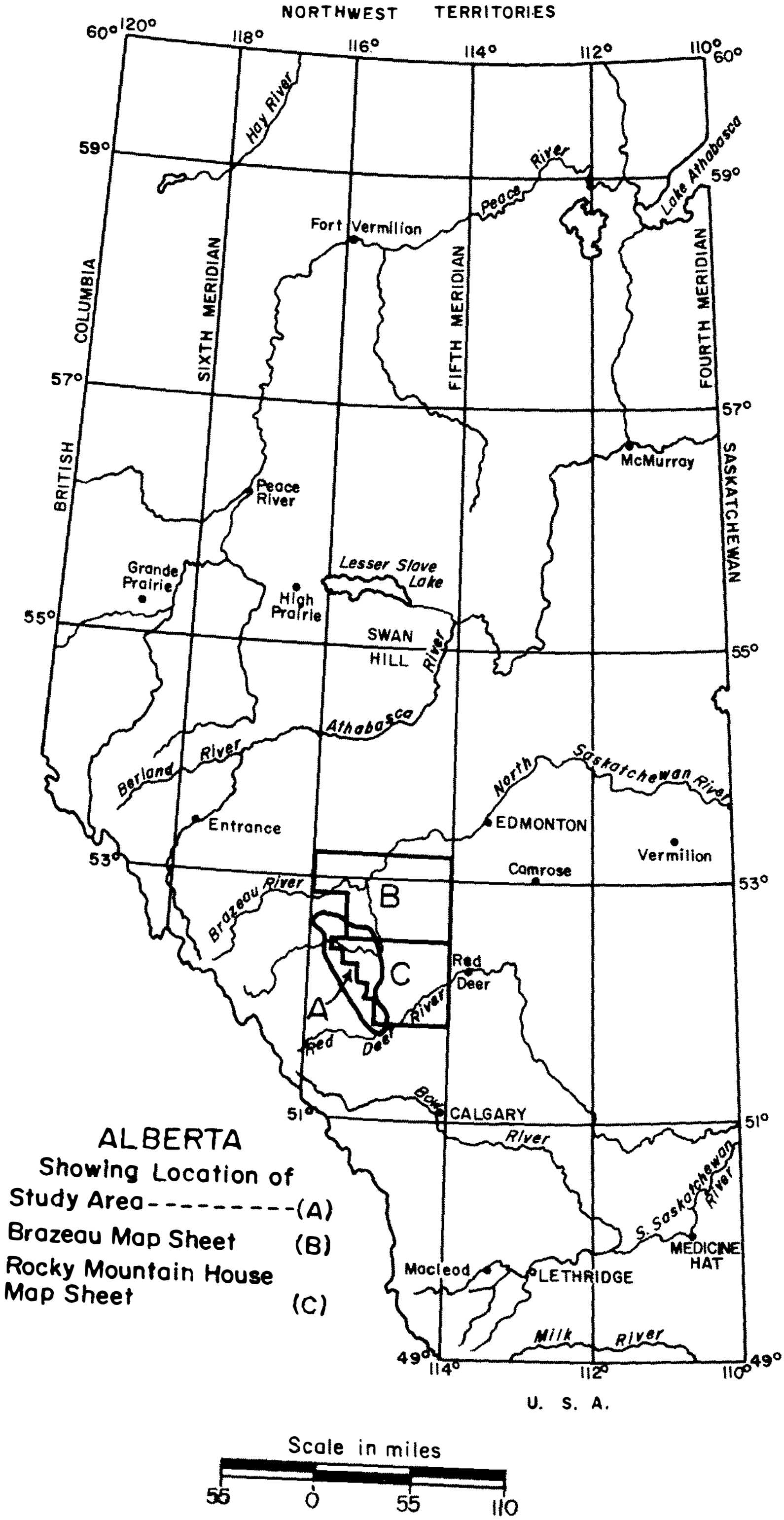

FIGURE 3. Sketch map of Alberta.

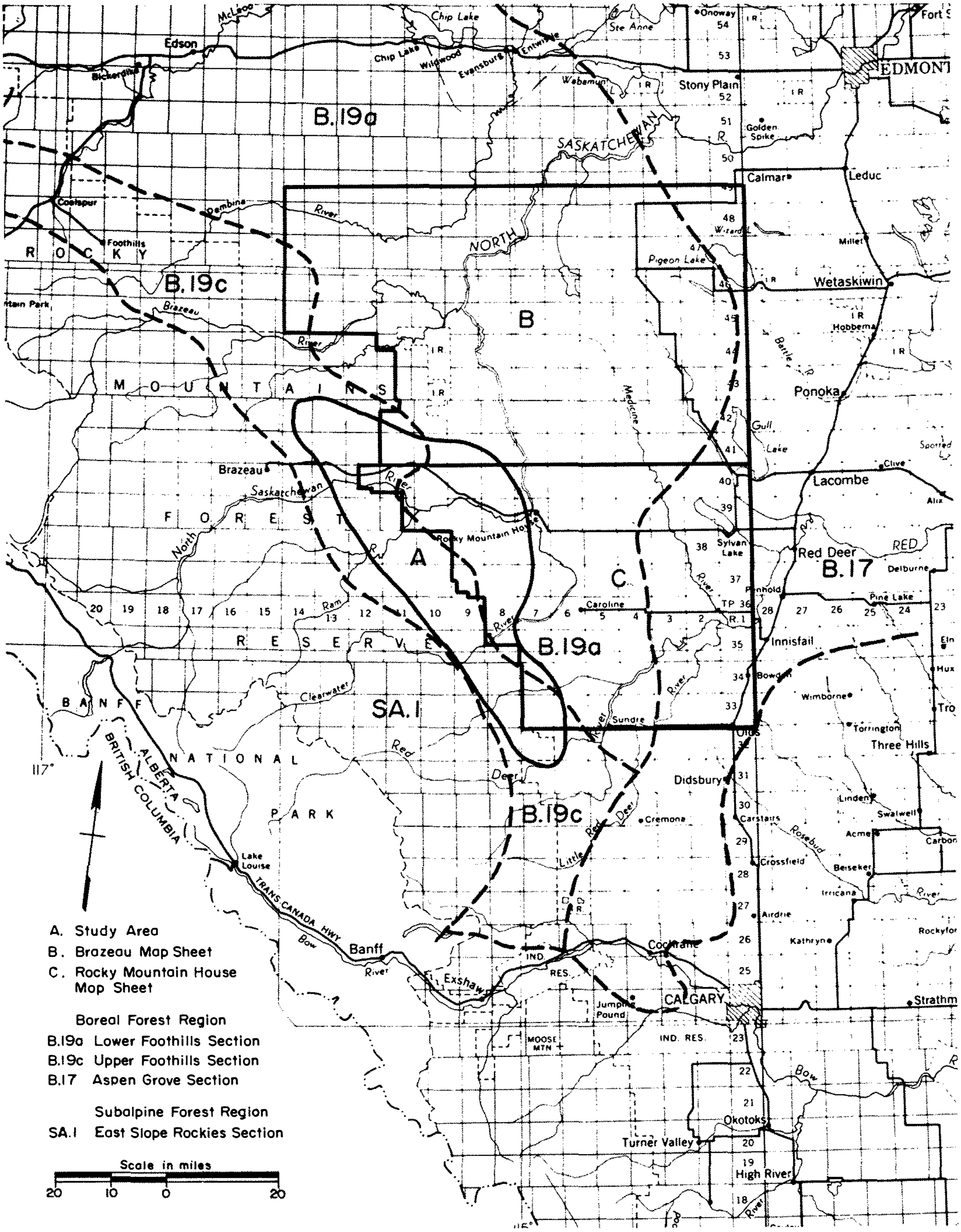

FIGURE 4. Map showing location of study area.

is evidence for only one glacial advance in the study area. Most of the area was covered by ice, probably to a considerable depth. As the ice retreated, melt waters flowed east and south-east along the ice margin of the retreating Keewatin ice mass and deep beds of coarse, gravelly alluvium were laid along the course of glacial melt water channels. Soils which have developed on this parent material are mapped as the Horburg Sandy Loam soil series (Figure 5). Deep lakes of glacial melt water formed in depressions in the east portion of the area and most of them drained. Lacustrine deposits are found on some of these locations now. In the main, soils which have developed on these parent materials have been classed and mapped as the Caroline Loam, Silt Loam soil series. Where the lakes drained, the dry lake beds were covered in deep beds of silt and sand. High winds in late-glacial and post-glacial times deposited silts and sands in aeolian dunes and plains. Soils on this condition have been classed and mapped as the Prentice Sandy Loam, Loamy Sand soil series. When the ice sheet wasted, glacial debris was left on the underlying bedrock. Most of the highlands between the river courses are covered by this glacial till mantle which varies in thickness from two to one hundred feet (Figure 6). The soil has been classed and mapped as the Lobley Loam, Heavy Loam soil series. The Horburg, Caroline, and Lobley soils have been classified under the Podzolic Order, Grey Wooded Great Group, Bisequa Grey Wooded Sub-group by the National Soil Survey Committee of Canada (1960). They have been described by Peters and Bowser (1960).

Each of the parent materials has a characteristic relief. The Lobley Loam, Heavy Loam on tills is generally hilly; the Prentice on aeolian materials is strongly rolling to rolling; the Caroline on lacustrine beds is mainly flat to gently rolling. The Horburg on coarse gravelly alluvium is also flat to gently rolling. Local sections of broken topography occur on all soils where water erosion has left steep-walled channels.

Climate

The climate of the study area is characterized by moderately warm summers and relatively cold winters. The mean summer temperature (May to September inclusive) at Rocky Mountain House is 50°F. The average daytime high for this period is about 65°F. January is the coldest month with a mean average of 10°F. The average annual precipitation at Olds is 18 inches; at Rocky Mountain House it is slightly under 20 inches. The yearly variation is usually not great, although the total has been as low as 10 inches and as high as 30 inches. Over 60 per cent of the precipitation falls during the growing season, April to October, and a large percentage of the precipitation that falls during winter months is lost in the spring run-off (Peters and Bowser, 1960).

Total precipitation does not vary importantly from year to year but moisture deficit (i.e. inches of precipitation minus inches of evaporation) does. The significance of year to year differences was not evaluated in this study. However, maps of moisture deficit for the Province of Alberta show that moisture deficit does not vary importantly in the study area in a given year (Laycock, 1960). Therefore it might be said that regional climate, particularly with respect to moisture availability, is homogeneous within the study area.

There is evidence to suggest that strong differences in local climate exist in the study area. For instance, exposed south and south-west facing slopes are often droughty because of strong insolation and drying winds. Evapo-transpiration is probably higher in these situations than on north and east facing slopes.

FIGURE 5. Horburg Sandy Loam soil on a coarse gravelly substrate. Near Saunders, Alberta. Tp. 39, R. 10, W. 5th.

FIGURE 6. Six to eight feet of glacial till overlying sandstone bedrock, on the study area near Saunders, Alberta. Tp. 40, R. 11, W. 5th.

Pure stands of lodgepole pine are rarely to be found on steep south facing slopes; trembling aspen (*Populus tremuloides* Michx.) is frequently an important component of stands on these sites.

Because the average elevation increases from approximately 3,000 feet on the east side of the study area to over 4,000 feet on the west side, there is a gradual shortening of the growing season towards the west. The average frost-free period at Olds is 100 days and at Rocky Mountain House it is 50 days. For more detailed meteorological data see Table 1, page 39 in a report by Peters and Bowser (1960).

Laycock (1960) has mapped average patterns of precipitation and evapotranspiration in the Canadian Prairies and after making small allowances for water surpluses, has made estimates of the regional differences in values. The study area lies within one of Laycock's cells of average potential evapo-transpiration, in which the average was between 18 and 20 inches for the period 1921 to 1950. The average deficit (i.e. precipitation minus potential evapotranspiration) is between 2 and 4 inches for the same period. Even though a study of Laycock's maps has shown that the study area lies within a relatively homogeneous climatic cell, there are differences in aspect, exposure, altitude and topography which cannot be quantitatively appraised with available climatological data for the area.

Vegetation

The study area lies in the Lower Foothills Section of the Boreal Forest Region and portions extend into the Upper Foothills Section. According to Rowe (1959: p. 24) the Lower Foothills Section lies between 3,000 feet and

4,000 feet elevation and the Upper Foothills Section lies between 4,000 feet and 5,000 feet elevation. Rowe's description of the important tree species applies to the study area without modification:

> "The distinctive tree species is the lodgepole pine (*Pinus contorta* var. *latifolia*) which, with aspen (*Populus tremuloides*) and balsam poplar (*Populus balsamifera*) has assumed a dominant position over much of the area in the wake of fire. In older stands the white spruce (*Picea glauca*) is an important constitutent and black spruce (*Picea mariana*) is frequently present too. White birch (*Betula papyrifera*) and tamarack (*Larix laricina*) have scattered representation with the above species on appropriate well-drained or poorly-drained sites, respectively. Both balsam fir (*Abies balsamea*) and alpine fir (*Abies lasiocarpa*) are common locally in the main body of the Section, although the over-all importance of these species in the forests is small."

With reference to the Upper Foothills Section, Rowe has written (1959: p. 25):

> "A distinctive feature in comparison with the lower-lying forests to the east is the relative scarcity of mixedwood stands, for the poplars (*Populus tremuloides*, *P. balsamifera*) and white birch (*Betula papyrifera*) are only sparsely represented. In addition to lodgepole pine (*Pinus contorta* var. *latifolia*), which is predominant, a major species is the typical white spruce (*Picea glauca*) rather than the Engelmann spruce—white spruce complex which occupies the same altitudinal zone in sub-alpine forests. Black spruce (*Picea mariana*) is a frequent constituent of the forests north of the Red Deer River, but its occurrence is sporadic to the south. Alpine fir (*Abies lasiocarpa*) is somewhat less prevalent than in the neighbouring mountains and tamarack (*Larix laricina*) has only a scattered distribution."

The understorey vegetation is variable. Certain plant species occur on almost all sites which support pure lodgepole pine stands. *Salix* spp.[1], *Ledum groenlandicum* Oeder, *Epilobium angustifolium* L., *Rosa acicularis* Lindl., *Cornus canadensis* L., *Arctostaphylos uva-ursi* (L.) Spreng., *Linnea borealis* L. var. *americana* (Forbes) Rehd., *Maianthemum canadense* Desf. var. *interius* Fern., and *Pleurozium schreberi* (Brid.) Mitt.[2] are examples. Other plants are restricted to certain soil types and may be employed tentatively as plant indicators. For instance, *Alnus crispa* (Ait.) Pursh, *Aralia nudicaulis* L., *Rubus pubescens* Raf., *Viola* spp., *Viburnum edule* (Michx.) Raf., and *Ribes americanum* Pursh are abundant on the Lobley Loam, Heavy Loam soil series and *Petasites palmatus* (Ait.) A. Gray is common on the Caroline Silt Loam soil series.

METHODS – 1960

1960 Sample

The purpose of the 1960 sample was to calculate correlations between soil-site factors and pine growth and to describe differences in productivity between three seemingly homogeneous parent materials in the study area. The specific objectives were:

1. to determine which site factors are related to important differences in pine growth over the range of sites which support merchantable stands of pine,
2. to identify the main sources of variation in pine growth, from a study of several site and stand factors,
3. to show, if practicable, which site index terms for pine are suitable for the prediction of pine growth.

[1] Names of vascular plants as in: MOSS, E. H. 1959. Flora of Alberta. University of Toronto Press, 546 pp.
[2] Names of mosses as in: WATSON, E. V. 1959. British mosses and liverworts. Cambridge University Press. 419 pp.

A stratified sample of growth conditions was conducted in pure, fully-stocked, 60-year old pine stands on three important parent materials, namely tills, alluvium, and lacustrine. In order to eliminate strong climatic effects pine stands were avoided which were on dry, south facing slopes or in closed topographic depressions which might have been subject to local frost occurrences. Four plots (repetitions) were located in each of the physiographic cells shown in Table 1. In all, 108 rectangular, one-fifth acre plots were established with compass and chain, and then sampled. The plots were distributed widely over the Rocky Mountain House map sheet and a portion of the adjacent Brazeau map sheet. Aerial photographs were used together with a soil survey map and report of the Rocky Mountain House sheet in locating suitable stands and parent materials (Peters and Bowser, 1960). Even though this did not ensure a random sample, it did lessen the possibility of creating large gaps in the sample and the chance of oversampling any one condition.

TABLE 1. PHYSIOGRAPHIC CELLS SAMPLED IN 1960. FOUR PLOTS PER CELL

	Parent material		
	Till (Lobley soil series)	Alluvium (Horburg soil series)	Lacustrine (Caroline soil series)
Slope—per cent	Slope position. Per cent of total slope length lying above plot centre		
0-5	0-33	0-33	0-33
	34-67	34-67	34-67
	68-100	68-100	68-100
6-15	0-33	0-33	0-33
	34-67	34-67	34-67
	68-100	68-100	68-100
16 plus	0-33	0-33	0-33
	34-67	34-67	34-67
	68-100	68-100	68-100

The following data were recorded:

Growth data:

1. Heights of ten dominant pine trees were measured in feet using a Spiegel relascope and a cloth tape.
2. Heights of five pine trees of average basal area.
3. A diameter tally was taken for all species. All trees over 0.6″ d.b.h. were measured using steel calipers.
4. Basal area per acre was estimated from the average of five plotless samples using a Spiegel relascope with a 5 factor. One sample was taken at the plot centre and one at one-half chain distances (i.e. 33 feet) along each of the cardinal directions from the plot centre. This permitted an estimate to be made of within-plot variation in basal area and merchantable volume in cords per acre.

Soil-site data

A soil profile description was made for an excavated soil pit (6 feet long and deep and 3 feet wide) and notes were made on the following items:

1. texture by feel,
2. total horizon thickness (soil plus stone) and effective horizon thickness (total minus stone content), in inches,
3. soil colour,
4. stone content (over 2.0 mm. in diameter), in per cent, by ocular estimate,
5. rooting characteristics and compact horizons,
6. depth to lime, using dilute hydrochloric acid.

Site data were recorded as follows:

1. identification of parent material,
2. slope grade in per cent,
3. slope position; percentage of the total slope above the plot centre,
4. length of slope, estimated,
5. aspect, to the nearest of 16 compass points,
6. moisture regime, porosity, and local climate using Hills' method of classification (1952),
7. list of ground vegetation with estimates of cover in per cent by species.

One-quart size soil samples for soil testing were taken from each important mineral horizon. A 100 cc. undisturbed sample for bulk density determinations was taken with an improvised sampler.

The following determinations were made on soil samples:

Bulk density (oven dry mass per unit volume) was measured during the field season using a constant volume core and a method described by Wilde and Voigt (1959: pp. 9-12).

At the Department of Soils, University of Minnesota at St. Paul, Minnesota, particle size analyses were run for sand, silt, and clay fractions (under 2.0 mm. in diameter) using sodium hexametaphosphate ("Calgon") as a dispersing agent and a modified Bouyoucos hydrometer method as described by Wilde and Voigt (1959).

Available moisture values were calculated from 15 atmosphere percentages using pressure membrane apparatus (Richards, 1947) and one-third atmosphere percentages using porous plate apparatus (Richards, 1949).

Total nitrogen values were calculated for the A_e ($A2_p$)[1] horizon soil samples only, using Kjeldahl apparatus and a method described by Wilde and Voigt (1959: 39-41) and expressed as per cent of oven dry weight of soil. Exchangeable potassium was measured using a flame photometer[2] and expressed in parts per two million. Extractable phosphorous was measured using Bray's sulfonic acid reduction method[2] and expressed in parts per two million. Total organic matter content was measured using a Cenco Photolometer[2] and expressed in per cent. Hydrogen ion concentration (pH) was measured using a soil-water paste and a Beckman pH potentiometer[2]. These tests were run on 458 soil samples.

[1] Horizon names as given in: BOWSER, W. E. 1960. Soil horizon designations. Proceedings of the Fourth Annual Meeting of the National Soil Survey Committee of Canada, February, 1960. Ontario Agricultural College, Guelph. pp. 3-7. Bracketed terms give horizon names as they appear in: Peters and Bowser, (1960).

[2] GRAVA, J. 1957. Soil analysis methods as used in the University of Minnesota Soil Testing Laboratory. Form 15-G (mimeograph). University of Minnesota, St. Paul.

ANALYSIS OF DATA—1960

Growth data

The growth data were compiled and summarized as follows:

1. dominant height of pine at 60 years,
2. average height of pine at 60 years, (i.e. mean of heights of five trees of average basal area),
3. basal area per acre in square feet at 60 years (from the plot tally of diameters) for all species,
4. total bole volume in cubic feet per acre at 60 years for all species (Blyth, 1955).

Soil—site data

The following soil-site data were compiled and summarized for the analysis:

1. slope grade
2. slope position
3. aspect, to the nearest of 16 compass points
4. cumulated thickness of the L, F, and H horizons, in inches
5. effective thickness of the A_e (A_{2p}) horizon
6. effective thickness of the B_f (B_p) horizon
7. effective thickness of the C/ (C_p) horizon
8. effective thickness of the B_t (B_2) horizon
9. total depth to the C horizon
10. effective depth to the C horizon
11. depth to a lime reaction
12. per cent clay in the A_e horizon
13. per cent silt plus clay in the A_e horizon
14. per cent silt plus clay in the A_e horizon multiplied by the thickness of the A_e horizon
15. per cent clay in the B_f horizon
16. per cent silt plus clay in the B_f horizon
17. per cent silt plus clay in the B_f horizon multiplied by the effective thickness of the B_f horizon
18. per cent clay in the C/ horizon
19. per cent silt plus clay in the C/ horizon
20. per cent silt plus clay in the C/ horizon times the effective thickness of the C/ horizon
21. per cent clay in the B_t horizon
22. per cent silt plus clay in the B_t horizon.
23. per cent silt plus clay in the B_t horizon times the effective thickness of the B_t horizon
24. per cent clay in the C horizon
25. per cent silt plus clay in the C horizon
26. available moisture in the surface 36 inches of the soil
27. pH of the A_e horizon
28. extractable phosphorus in the A_e horizon
29. exchangeable potassium in the A_e horizon
30. total nitrogen in the A_e horizon
31. per cent total organic matter in the A_e horizon
32. pH of the B_f horizon
33. extractable phosphorus in the B_f horizon

34. exchangeable potassium in the B_f horizon
35. per cent total organic matter in the B_f horizon
36. pH of the C/ horizon
37. extractable phosphorus in the C/ horizon
38. exchangeable potassium in the C/ horizon
39. per cent total organic matter in the C/ horizon
40. pH of the $\bar{B}_t$ horizon
41. extractable phosphorus in the B_t horizon
42. exchangeable potassium in the B_t horizon
43. per cent total organic matter in the B_t horizon
44. pH of the C horizon
45. extractable phosphorus in the C horizon
46. exchangeable potassium in the C horizon
47. per cent total organic matter in the C horizon
48. depth of abundant rooting, in inches.

Analyses of variance were run to determine whether or not there were significant differences in pine growth, soil moisture levels, and soil nutrient levels between parent materials, slope classes, and slope position classes; and further, to determine whether or not there were significant interactions.

The analysis of variance program (equal frequency case) at the Remington-Rand UNIVAC 1103 Scientific Computer of the University of Minnesota Numerical Analysis Centre (hereinafter referred to as "the computer") was used to complete the bulk of the calculations.

Correlation analyses were conducted in two parts. First, several combinations of site factors and growth terms were plotted on graph paper to discover if there were straight line relationships between the independent variables (site factors) and the dependent variables (growth terms). These plots also permitted the detection of obvious heterogeneous variances. The data from those combinations which showed linearity and homogeneous variance were entered on I.B.M. cards and run on the correlation matrix computer program. Higher order or interaction terms were not used on the basis of preliminary graphical examination of the data which showed that the scatter in the data was too great to justify other than straight-line analysis.

Second, three correlation matrices were calculated using the DevCor program on the computer. One matrix was run for the site-growth data from each parent material (i.e. tills, alluvium, and lacustrine conditions) because the analyses of variance had shown that important differences in pine growth and in soil moisture and soil nutrient levels did exist between parent materials.

RESULTS AND DISCUSSION—1960

The analyses of variance of pine growth on the main site factors key-out is given in Table 2; the analyses of variance of soil moisture properties on main site factors is given in Table 3; the analyses of variance of soil nutrient properties on main site factors is given in Table 4. All significant interactions were plotted out on graph paper in order to appraise their significance.

The starred F values in Table 2 show that there were significant differences in pine growth (in terms of all four growth expressions) between parent materials. There were also significant differences in growth (in terms of dominant height and average height) between slope classes within parent materials. This was indicated by the significant $M \times S$ interaction term. A plot of mean values of dominant height and of average height on slope grade showed that growth on tills improves as the slope increases. An explanation for this might be that ground water maintains a favourable soil moisture status on sloping sites during periods of drought. Growth on gravelly alluvium decreases as the slope increases; possibly because ground water is lost more swiftly on sloping sites than on flat sites. On lacustrine soils, growth was not related to slope class. The significant F value for position under average height in Table 2 was not meaningful when plotted out.

TABLE 2. ANALYSIS OF VARIANCE: PINE GROWTH ON MAIN SITE FACTORS*

Source of variation	Degrees of freedom (d.f.)	Dominant height (feet) mean square		Average height (feet)		B.a./ac., square feet		Total volume per acre, cubic feet		Table F.	
		(M.S.)	F	(M.S.)	F	(M.S.)	F	(M.S.) ,000	F		
Parent material (M) ...	2	664	35†	1052	48†	2452	5.6†	5500	7.3†	3.11	(.05;2,81)
Slope class (S).........	2	8	0.4	0.7	0.3	396	0.9	498	0.6	3.11	
Position class (P)......	2	15	0.8	67	3.1	476	1.1	1200	1.1	3.11	
M × S................	4	104	5.4†	105	4.8†	212	0.5	395	0.5	2.48	(.05;4,81)
M × P................	4	13	0.6	34	1.6	200	0.5	465	0.6	2.48	
S × P................	4	15	0.8	24	1.1	441	1.0	1046	1.4	2.48	
M × S × P...........	8	20	1.0	17	0.8	509	1.2	446	0.6	2.05	(.05;8,81)
Within cells (error).....	81	19		22		430		757			
Total..................	107										

*For 60-year old pine stands. 108 plots. Rocky Mountain House and Brazeau Map Sheets, Alberta.
†Significant at .05 level.

The Duncan Multiple Range Test (Snedecor 1956: 251-253) was used to discover all significant differences in growth (in terms of basal area per acre and total volume per acre) between parent materials. Significant differences were shown to exist for both growth expressions between till and lacustrine and between till and alluvium but not between lacustrine and alluvium. Mean site index values for slope classes by parent materials are given in Table 5.

It can be said that parent material and slope class can be related to pine growth, though slope class does not show a significant relationship on lacustrine materials.

It was found that there are significant differences in pine growth, soil moisture levels, and soil nutrient levels between parent materials. The differences are indicated by the mean values in Table 5; the soil moisture and soil nutrients data are in Appendix II. Because of these differences, it was decided that further analyses should be done on data from each parent material separately. Three correlation matrices were calculated to aid in selection of independent, additive terms which would be suitable for the construction of prediction equations using the multiple regression method. High "r" values were sought which were independent of other site factors and significantly correlated with pine growth.

75195—5

TABLE 3. ANALYSIS OF VARIANCE: SOIL MOISTURE PROPERTIES ON MAIN SITE FACTORS*

S.V.**	d.f.	Available moisture, surface 36 inches		Effective depth to C horizon		Per cent si+c in B_t horizon		Per cent si+c in B_t × effective thickness B_t		Per cent organic matter in profile		Effective thickness, B_t horizon		Table F
		M.S.	F	M.S.	F	M.S.	F	M.S.	F	M.S.	F	M.S.	F	
M	2	5132	47†	2032	34†	3894	33†	41720	37†	320	14†	742	24†	3.11 (.05;2,81)
S	2	44	0.4	58	1	283	2	3246	3	63	3	71	2	3.11
P	2	20	0.2	37	0.6	98	0.8	283	0.2	30	1	4	0.1	3.11
M × S	4	64	0.6	148	2.5†	373	3.2†	1729	1.5	23	1	25	0.8	2.48 (.05;4,81)
M × P	4	142	1.3	111	1.9	257	2.2	3163	2.8†	12	1	80	2.5†	2.48
S × P	4	141	1.3	66	1.1	188	1.6	1249	1.1	44	2	39	1.2	2.48
M × S × P	8	148	1.4	60	1.0	143	1.2	1093	0.9	16	1	32	1.0	2.05 (.05;8,81)
Error	81	108.6		60		117		1141		22		31		
Total	107													

*For 60-year old pine stands. 108 plots. Rocky Mountain House and Brazeau Map Sheets, Alberta.
**See Table 2 for full table headings.
†Significant at .05 level.

TABLE 4. ANALYSIS OF VARIANCE: SOIL NUTRIENT PROPERTIES ON MAIN SITE FACTORS*

S.V.**	d.f.	pH of B_t horizon		Total extractable phosphorus in B_t horizon		Total exchangeable potassium in B_t horizon		Table F	
		M.S.	F	M.S.	F	M.S. ,000.	F		
M	2	3.57	12.73†	10,048	15.89†	1,274	36.04†	3.11	(.05;2,81)
S	2	0.15	0.54	2,167	3.43†	121	3.42†	3.11	
P	2	0.19	0.68	715	1.13	15	0.43	3.11	
M × S	4	0.19	0.68	730	1.15	45	1.27	2.48	(.05;4,81)
M × P	4	0.13	0.50	803	1.27	39	1.10	2.48	
S × P	4	0.46	1.63	520	0.82	64	1.82	2.48	
M × S × P	8	0.30	1.06	554	0.88	34	0.96	2.05	(.05;8,81)
Error	81	0.28		632.3		35			
Total	107								

*For 60-year old pine stands. 108 plots. Rocky Mountain House and Brazeau Map Sheets, Alberta.
**See Table 2 for full table headings.
†Significant at .05 level.

TABLE 5. SITE INDEX VALUES FOR PARENT MATERIAL CLASSES AND SLOPE CLASSES*

Parent material	Slope Class (per cent)	Dominant height (feet)	Average height (feet)	Basal area per acre (square feet)	Total volume per acre (cubic feet)
Till (Lobley soil series)	0–5 6–15 16+	56.6 59.8 60.2	51.6 55.8 56.1	136.9	3540.9
Alluvium (Horburg soil series)	0–5 6–15 16+	54.6 48.2 48.2	47.1 41.7 41.9	118.7	2808.8
Lacustrine (Caroline soil series)	0–5 6–15 16+	54.9 55.3 56.2	48.8 49.6 49.8	120.8	2937.3

*For 60-year old pine stands. 108 plots. Rocky Mountain House and Brazeau Map Sheets.

Correlation-matrix results for tills (Lobley soil series), alluvium (Horburg soil series), and lacustrine (Caroline soil series) parent materials are given in Appendix II C. In order to check the importance of the "r" values, graphical plots were made of the combinations shown in these tables.

In general, correlations between nutrient levels and pine growth were too weak for purposes of prediction, with one exception. On the Lobley soil series, total volume per acre is negatively and weakly correlated with pH of the B_t horizon. The best volumes are associated with low pH values (Figure 7).

There were no significant nutrient level-growth correlations in the Caroline soil series data.

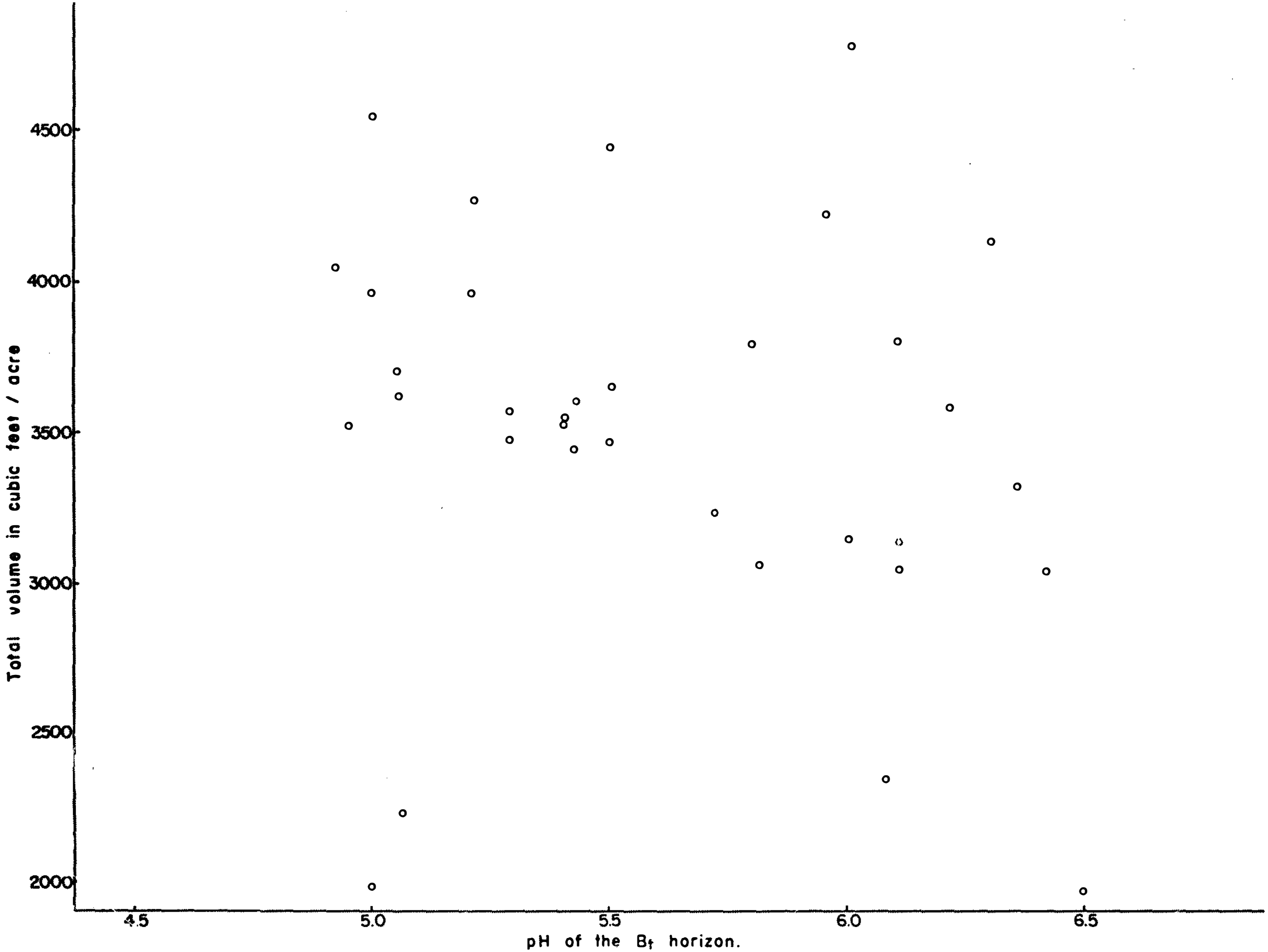

FIGURE 7. Total volume per acre, in cubic feet, on pH of the B_t horizon. 36 plots on Lobley Loam, Heavy Loam soil series. $r = -.351$

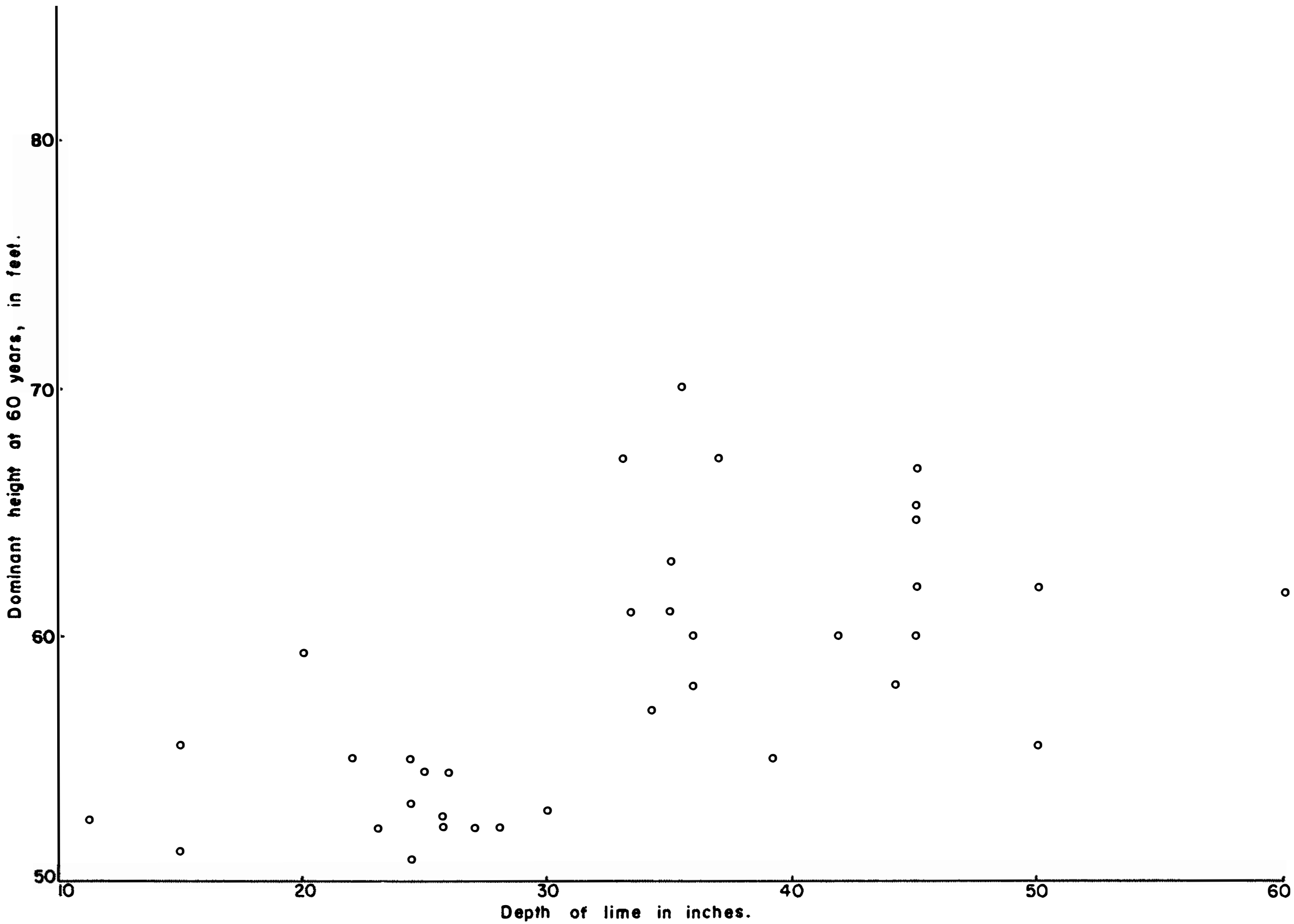

FIGURE 8. Dominant height at age 60 years on depth to lime. Lobley Loam, Heavy Loam soil series. r = .519

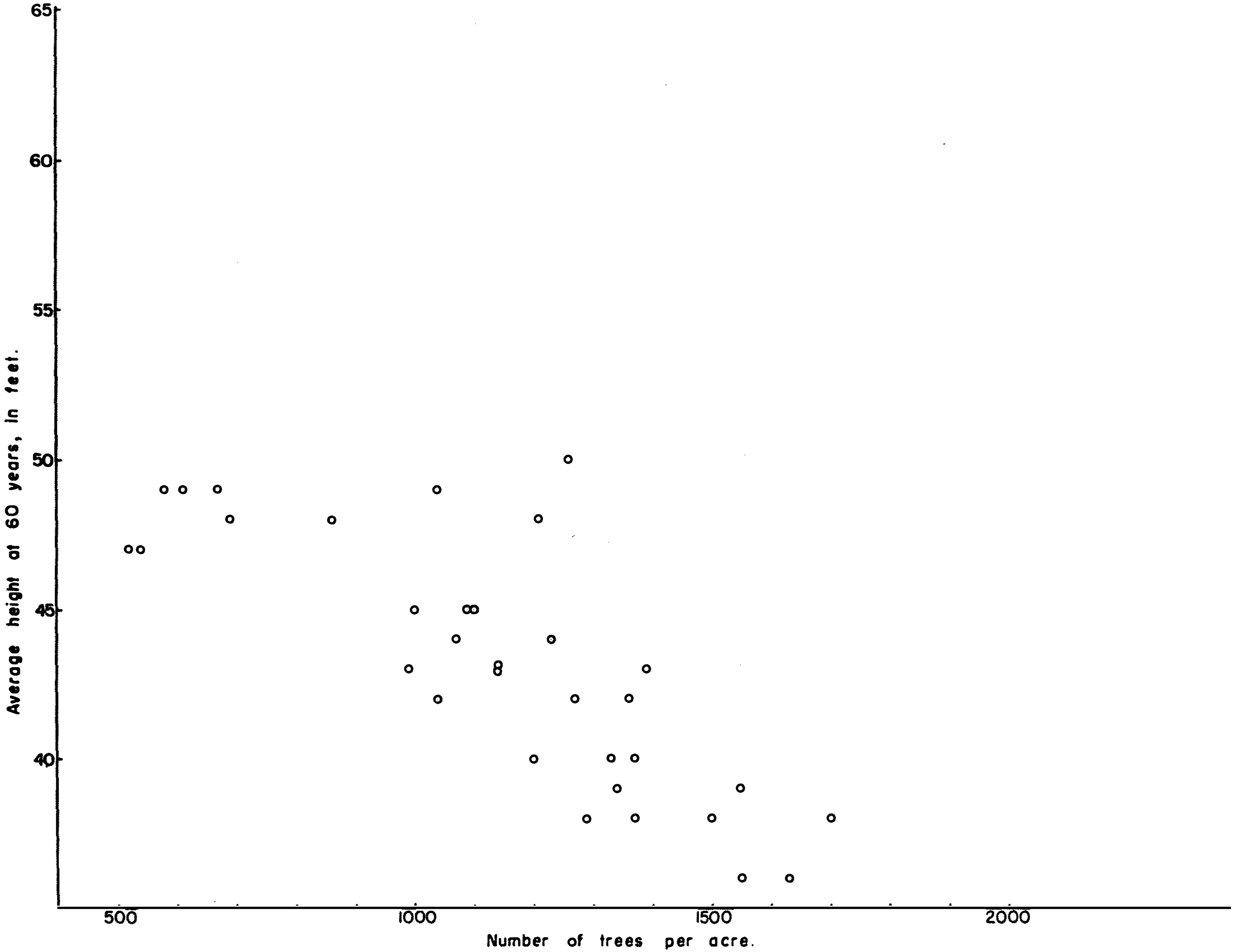

FIGURE 9. Average height at age 60 years on number of trees per acre. 36 plots. Horburg Sandy Loam soil series. r = −.762

Several soil moisture factors were sufficiently well correlated with pine growth to be potentially useful in growth prediction. On the Lobley soil series, depth to lime in inches was correlated with average height ($r = .550$) and dominant height (Figure 8); slope position was correlated with average height (–.465) and with total volume per acre (–.373).

On the Horburg soil series, depth to lime was correlated with dominant height (.377); slope grade was negatively correlated with dominant height and average height (Table 5); stocking level, a stand factor, was negatively correlated with dominant height (–.647), average height (Figure 9), and total volume per acre (–.370).

On the Caroline soil series, stocking level, a stand factor, was positively correlated with basal area per acre (.737) and total volume per acre (.587).

More site factors were correlated with pine growth on glacial tills than on the other parent materials. Considering data from all parent materials, there is no specific indication of strong correlation between soil nutrient levels and pine growth. It was decided, therefore, that further study should be concentrated on soil moisture factors as they are related to pine growth on the glacial tills of the study area.

It was not feasible to make a decision from the 1960 results as to which of the site indices (dominant height, average height, basal area per acre, and total volume per acre) was suitable for the prediction of pine growth. This question was kept under review for the duration of the study.

THE 1961 SAMPLE OF SITE AND GROWTH CONDITIONS

In the 1961 field season, 158 pine stands were measured in the course of a permanent sample plot re-measurement program. Plots had been located during 1951-1953 on several parent materials including glacial tills, lacustrine and alluvial deposits, aeolian sands, and stony colluvium. At that time, the soil types were not identified. Therefore, in 1961 it was necessary to collect growth and yield data and to describe the soil and site conditions by parent material and in terms of those factors which had been shown to be related to pine growth in the 1960 study.

The purpose of the 1961 sample was to appraise the relationship between site factors and pine growth over a wide range of age classes and stocking conditions on the Lobley soil series. The data were to be used in the computation of multiple regression equations to summarize the relationships.

During the 1961 field season it was found that the soils on glacial tills south of the Brazeau River were generally limy. North of the Brazeau River, the occurrence of calcareous tills was rare, being restricted to some sites near the Rocky Mountain front (Figure 10). It was decided that further study should be restricted to 70 plots on calcareous Cordilleran tills which are mapped in the study area as the Lobley Loam, Heavy Loam soil series.

In the vicinity of Mackay and Carrot Creek and in the Whitecourt and Swan Hills localities, the till soils are deeply weathered, heavy textured and non-calcareous (Figure 11). This suggested that the tills may be of different origin and age than the tills in the study area. The site and growth relationships which were developed in the study area in 1960 would not hold in these districts north of the Brazeau River. Hence the study was restricted to the Lobley soil series.

FIGURE 10. Podzolized Grey Wooded soil on non-calcareous till with weathered sandstone in the profile. Near Entrance, Alberta. Tp. 50, R. 21. W. 5th.

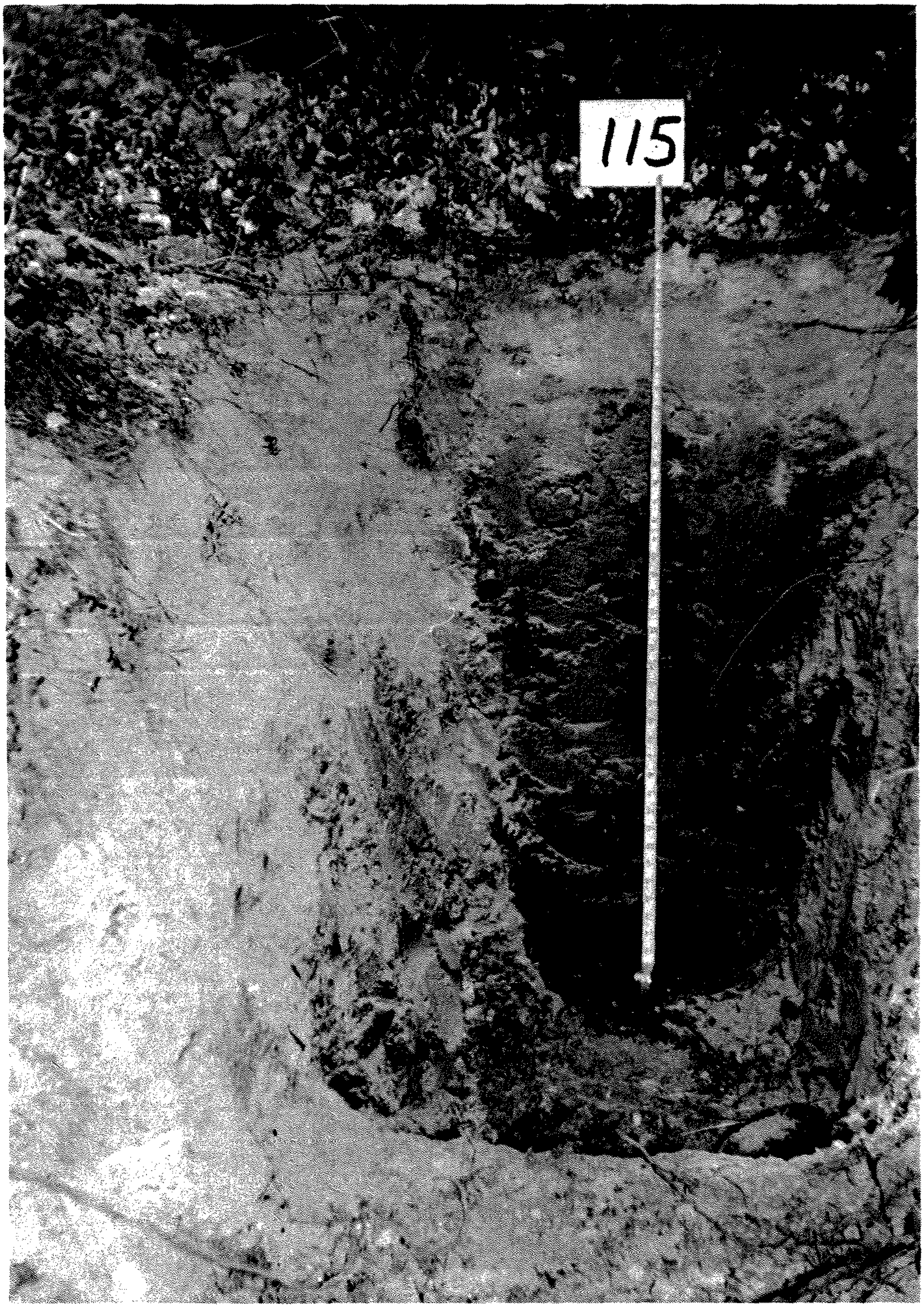

FIGURE 11. Podzolized Grey Wooded soil on heavy glacial till, Carrot Creek, Alberta Tp. 51, R. 12, W. 5th.

FIELD METHODS—1961

Thirty-seven plots, which ranged in size from one-tenth to one-half acre in size, were relocated and the following site and growth data were taken:

1. A soil-site description was made. Those site factors which were shown to be related to pine growth in the 1960 study were included, i.e. depth to lime in inches, slope position, slope grade, thickness of the Grey Wooded A_e horizon, per cent silt plus clay in the B_t horizon, effective thickness of the B_t horizon, pH of the B_t horizon. The last factor was measured with the Hellige-Truog Soil Reaction Tester, Model No. 694.
2. A plot tally was taken of diameter at breast height by species for all trees over 0.6 inches d.b.h.
3. Heights of three trees in each diameter class were measured, together with heights of ten dominant trees.
4. A plotless sample of basal area per acre was taken using a Spiegel relascope. The mean of five samples, one taken at the plot centre and one at each of the cardinal directions one chain from the plot centre was used as the plot value.
5. Age was measured at stump height on three dominant trees.

ANALYSIS OF THE 1961 DATA

The growth data was prepared as follows:

1. Plot tallies were compiled for estimates of number of trees per acre and basal area per acre.
2. Mean heights were calculated by diameter classes and entered on a height-diameter curve for each plot.
3. Mean dominant heights were calculated.
4. Basal area per acre was calculated from plotless samples and multiplied by the mean dominant height value and the factor .005 to arrive at an estimate of merchantable volume in cords per acre. This is a method which is used by the North Western Pulp and Power Limited (Hinton, Alberta) to calculate merchantable volume.
5. The mean age from three dominant trees was calculated.
6. Total volume per acre was compiled using the same method as with the 1960 data except that the height of the tree of average diameter was taken from the height-diameter curve for each plot.

Growth and soil-site data in coded form were transferred from field sheets to I.B.M. punch cards. The original data were coded by multiplying the reciprocal of age by 10^4, number of trees per acre by 10^{-1}, pH of the B_t horizon by 10^{-1}, and silt plus clay in the B_t horizon $\times$ effective depth of the B_t by 10^{-1}, and total volume per acre by 10^{-1}.

Using 1960 and 1961 data from 70 plots on the glacial till parent materials (Lobley soil series) a correlation matrix was calculated using the DevCor program on the computer to discover the straight-line relationships between the site factor levels and pine growth. As with the 1960 data, only straight-line relationships were sought and developed because the scatter of the data in graphical plots was too great to justify other than straight-line analyses. Those site factors which were shown to be correlated with pine growth in the correlation matrix were selected as independent variables for the calculation of multiple regression equations and the Multiple Regression Program at the computer was used in the computation of the following expressions:

1. R^2,
2. N (number of plots),
3. degrees of freedom for deviations from regression,
4. standardized regression coefficients,
5. standard errors of standardized regression coefficients,
6. t ratios,

Multiple regression equations were calculated for pine growth in terms of the following dependent variables:

1. dominant height, in feet,
2. average height, in feet,
3. basal area per acre, in square feet,
4. total volume per acre, in cubic feet,
5. merchantable volume per acre, in cords.

A similar set of equations were calculated for 60-year old pine stands, using the 1960 data from 36 plots on the Lobley soil series.

RESULTS—1961

Multiple regression equations were written from the computer output data using the form

$$Y = a + b_1 X_1 + b_2 X_2 + \ldots + b_n X_n$$

Where Y is the predicted value of the dependent variable, $b_1, b_2, \ldots b_n$ are the partial regression coefficients and $X_1, X_2, \ldots X_n$ are the observed values of the independent variables. Each standardized partial regression coefficient was tested for significance and analyses of variance were used to partition the variation in the dependent variable which was attributable to deviations from regression. The standardized partial regression coefficients were then transformed to ordinary partial regression coefficients for use in prediction equations. (Identical t test results are obtained using either standardized or ordinary partial regression coefficients). A multiple regression analysis was then re-run using only significant independent variables and the significance tests were repeated.

The equations which are listed in Table 6 apply to the combined 1960 and 1961 data from 70 plots. Of these, equations 2, 4, 6, 8, and 10 may be used most conveniently for prediction of pine growth. Several age classes are represented in the data and therefore one of the independent variables (X_1) is an expression of age. R^2 (the proportion of the variation in the dependent variable which is accounted for by regression) is given together with the F value from an analysis of variance. The equations which are listed in Table 7 apply to the 1960 data from 36 plots in 60-year old pine stands on the study area. Age is not included as an independent variable. The equations give the dependent variable as a function of significant and non-significant independent variables. For this reason they are not as useful in growth prediction as the equations in Table 6. However, they serve to illustrate that some site factors may have potential in growth prediction for even-aged stands, i.e. depth to lime and slope position are correlated with pine growth. It is important to note that none of the independent variables in equation 14 (Table 7) are significant. Even though the regression is significant, it is only a weak predictor.

TABLE 6. MULTIPLE REGRESSION EQUATIONS CALCULATED FROM DATA REPRESENTING SEVERAL AGE CLASSES*
LOBLEY SOIL SERIES

Equation number	a	X_1 $\frac{1}{\text{age}} \times 10^4$	X_2 $\frac{\text{number of trees per acre}}{10}$	X_3 depth to lime	X_4 slope position	X_5 slope grade	X_6 thickness of Grey Wooded A_e	X_7 pH, B_t	X_8 $\frac{\text{per cent silt+clay } B_t \times \text{effective thickness } B_t}{10}$	R^2	F
1. Y = (dominant height)	84.17	−.101527X_1†	−.085363X_2†	+.106931X_3	−.000932X_4	−.146767X_5†	+.096609X_6	−.078198X_7	−.001212X_8	.77	25.04†
2. Y = (dominant height)	82.90	−.090903X_1†	−.089754X_2†	—	—	−.152198X_5†	—	—	—	.75	64.83†
3. Y = (average height)	79.65	−.072349X_1†	−.108737X_2†	+.112543X_3	−.010265X_4	−.155699X_5†	+.059018X_6	−.119858X_7	−.001543X_8	.77	23.33†
4. Y = (average height)	75.07	−.057544X_1†	−.114809X_2†	—	—	−.166224X_5†	—	—	—	.75	65.47†
5. Y = (basal area per acre)	185.96	−.277443X_1†	+.067012X_2	+.086113X_3	−.020506X_4	−.813085X_5†	−.436997X_6	+.006148X_7	+.008320X_8	.29	3.07†
6. Y = (basal area per acre)	182.51	−.218494X_1†	—	—	—	−.850272X_5†	—	—	—	.26	11.50†
7. Y = (total volume per acre/10)	762.95	−1.167438X_1†	−.536790X_2†	+1.490611X_3	−.344425X_4	−3.654947X_5†	−1.531112X_6	−2.138650X_7	−.406698X_8	.54	8.82†
8. Y = (total volume per acre/10)	632.23	−1.088697X_1†	−.539767X_2†	—	—	−3.921639X_5†	—	—	—	.48	20.31†
9. Y = (merchantable volume per acre)	75.07	−.157270X_1†	−.031672X_2†	+.131383X_3	−.005114X_4	−.359242X_5†	−.028026X_6	−.106627X_7	−.018030X_8	.53	8.58†
10. Y = (merchantable volume per acre)	70.73	−.146761X_1†	−.035143X_2†	—	—	−.367327X_5†	—	—	—	.51	22.88†

*For lodgepole pine on the Rocky Mountain House and Brazeau Map Sheets, Alberta. 70 plots.
†Significant at the .05 level.

TABLE 7. MULTIPLE REGRESSION EQUATIONS CALCULATED FROM DATA REPRESENTING ONE AGE CLASS*
LOBLEY SOIL SERIES

Equation number	a	X_1 number of trees per acre / 10	X_2 depth to lime	X_3 slope grade	X_4 slope position	X_5 available moisture, surface 36" of soil	R^2	F
11. Y = (dominant height)	65.0	$-.083617X_1$†	$+.152137X_2$†	$-.022063X_3$	$-.033427X_4$	$-.044078X_5$	.58	8.18†
12. Y = (average height)	64.66	$-.103915X_1$†	$+.160980X_2$†	$+.008508X_3$	$-.086816X_4$†	$-.063156X_5$	.68	12.81†
13. Y = (basal area per acre)	97.17	$+.458788X_1$†	$+.695795X_2$†	$-.267993X_3$	$-.144976X_4$	$-.148335X_5$	.56	7.63†
14. Y = (total volume per acre) / 10	432.43	$+.246798X_1$	$+2.033748X_2$	$-1.301197X_3$	$-1.068506X_4$	$-1.625888X_5$	.37	3.47†

*For 60-year old lodgepole pine on the Rocky Mountain House and Brazeau Map Sheets, Alberta. 36 plots.
†Significant at the .05 level.

The range of data for the regression equations in Tables 6 and 7 is given in Appendices III A and III B respectively. An analysis of variance table for each equation is given in Appendix IV and the standardized partial regression coefficients with standard errors and t ratios are given in Appendix V. The correlation matrix for the combined 1960 and 1961 data is in Appendix II.

The prediction equations in Tables 6 and 7 which have minus signs before each of the regression coefficients cannot be used to predict growth above the value of "a" in the equation. For instance, average heights above 75.07 feet will not be predicted using equation 4 in Table 6. When the equations are put to use, the range of the basic data and the "a" value should be considered.

Data which are pertinent to equations 1 to 10 (Table 6; Appendix V) show that dominant height and average height may be predicted with higher precision than basal area, total volume, or merchantable volume per acre. Higher R^2 and F values are associated with equations 1 to 4. Also the standard errors of the regression coefficients are uniformly lower in these equations than in the others. Total volume and merchantable volume per acre are estimated with less precision; this is probably due, in part, to the relatively large measurement and compiling errors which are characteristic of these site indices. The basal area equations are the weakest predictors. This may be a result of the within-stand variation of basal area levels in natural pine stands.

The relative importance of each of the independent variables can be appraised by comparing the magnitude of the standardized partial regression coefficients and t values in Appendix V. Age and number of trees per acre are the main variables in most cases.

DISCUSSION

Parent materials and their associated soil series vary importantly in their internal and external drainage characteristics. Differences have been described in terms of slope grade, effective depth of the soil, available moisture, and soil texture (Appendix II A). Since each parent material has a moisture status which is more or less characteristic, the study area was partitioned or stratified by parent material for the sample. This permitted a preliminary grouping of pine sites. Other site factor-growth studies which have been conducted recently might have been more fruitful if, at first, an area reconnaissance was run and a preliminary stratification by parent material or soil series was employed. In a site-growth relationship study in Rhode Island, McGahan *et. al.* (1961) established 75 plots to study the site index of six different tree species. After working with ten soil-site, stand, and history factors, prediction equations were written for the mixed oaks, for white pine and for red maple. The equations were considered to be inadequate for accurate prediction purposes because of the influence of variables not included in the study and because of methods of measuring the variables which may not have been accurate enough to indicate the true relationships. It is reasonable to expect that a parent material stratification used in conjunction with the Rhode Island survey would have permitted a preliminary grouping of sites. Prediction equations might then have been written for each group. The same point can be made with reference to the work of Holmes and Tackle (1962) in lodgepole pine in Montana where a multiple regression equation was constructed showing the relationship of dominant height of pine to several stand and site variables. The main site factor to be correlated with pine height was effective depth of the soil profile (total depth to the C horizon minus stone content). This would suggest that a preliminary partition of pine sites by parent material might give a useful breakdown with the poorest growth on coarse, gravelly alluvium, and better growth on well drained glacial tills and colluvium sites. In Montana the correlation of effective depth of the profile and pine height may not apply to lacustrine sites where, in spite of a deep profile, the soils may have impeded drainage and aeration and therefore support only fair pine growth.

Where soil-site relationships with pine growth are sought, age and stocking level should be held constant, as much as it is practicable. Age is the main factor affecting growth, and stocking level has a somewhat smaller influence. Soil and site factors have an important influence on growth, but these effects are smaller than those of age and stocking and may be masked by them. This can be illustrated in a comparison of the 1960 and 1961 studies. Several site factors were shown to be related to pine growth from the 1960 sample of even-aged, fully stocked stands. Many of these factors could not be so correlated in the 1961 sample of several age classes and stocking levels. On the other hand, where a practical consideration of site relationships with growth is sought, variations in growth which are attributable to site factors should be viewed in conjunction with variations attributable to age and stocking levels. This was done in the 1961 study.

Forty-eight soil and site factors were investigated in the glacial till (Lobley soil series) portion of the 1960 study. Seven of those were picked for further study in 1961. This is not to say that these were the only soil-site factors which were related to pine growth. For example, no correlations were found between aspect and pine growth, probably because there was not an even sample of aspects, more north aspects were sampled than south aspects. Also the aspect-growth relationship would probably be dependent upon parent material, slope grade, and slope position. Further research on aspect is necessary.

Sources of error

A site factor may not be correlated with pine growth for one or more reasons:

1. The factor may be truly unrelated to tree growth. There is, however, the possibility of chance correlation. This can be checked in an analysis of new data.
2. The correlation may be a non-linear one. In this study, most of the significant site factors are related to pine growth in a linear manner. If present, curvilinearity may be so small that a straight line affords the best fit of the data. On the other hand, relationships which are strongly curvilinear will not show up in linear regression solutions. For example, when available moisture levels in Appendix II are compared with pine growth on different parent materials (Table 5), it is seen that pine growth increases with an increase in available moisture up to a certain point (about 5 to 6 inches of moisture in the surface 36 inches of the profile), then growth stops increasing with increased available moisture. Further study may develop useful curvilinear regressions, but such relationships will not be dealt with in this report.

   Slope grade was found to be positively correlated with pine height growth on tills in the 1960 study (Table 5), yet in the prediction equations based on the 1960 and 1961 data the slope grade expression was a negative one (Table 6). Further study is required on the slope grade-pine growth relationship by parent materials.

3. The method of measurement of a given independent variable (site factor) may not be sufficiently refined to show a correlation. For instance, in the 1960 study of even-aged, fully stocked stands, pH of the B_t horizon was shown to be negatively correlated with total volume per acre. The relationship was not confirmed in the 1961 study of several age classes and stocking levels because pH accounted for a smaller portion of the variation in growth and because it was measured in the field using a less accurate method than the 1960 method.

   In the 1960 sample, slope position was shown to be related to basal area per acre and total volume per acre. This relationship was not found in 1961. Apparently the effect of position is dependent on slope grade. Further study will be necessary in order to clarify this relationship.
4. It is possible that there are large differences in local climate within the study area. Because summer thunderstorms follow west-east paths in the Foothills, it is reasonable to assume that in a given growing season, some localities receive more precipitation than others. It is difficult to appraise the effects of differences in aspect, exposure, and altitude in this region. There is therefore, an indeterminable amount of variation in pine growth due to local climate variation, which cannot be accounted for in this analysis. As indicated in earlier discussion, a review of Laycock's (1960) climatic maps showed that the study area lies within a relatively homogeneous climatic region.
5. No allowance has been made for errors due to stand history factors, those which could differentially affect stocking levels and height growth from plot to plot. Although all plots were located in pine stands with no outward appearance of disturbance, there remains, nevertheless, the possibility that events in the life of the stand could affect the growth and yield of sampled stands.
6. A potentially important source of error which deserves close attention is the degree to which a body of site and tree growth data satisfies the assumptions underlying regression analysis:

6.1 That the regression be linear:
Graphical plots of site factor correlations with tree growth which were used in this study were linear. The plots of growth and number of trees per acre showed slight curvilinearity but a straight line gave the best fit of the data. No transformations were used because they did not improve the data.

6.2 That the variable part of the dependent variable that is not defined by the regression line be normally distributed about the regression line in a random manner and be independent of the independent variable (Snedecor, 1956). This condition is partially met in that the 1960 and 1961 samples were taken at random and were distributed widely over the study area. Four repetitions were taken in the 1960 sample. Wold and Jureen (1959) wrote that this condition can only be satisfied through the replication and randomization procedures of careful experimental design.

7. The soil tests which were employed in this study were modern techniques which are used to describe physical and chemical properties of agricultural soils. It is possible that some of the tests are not suited to studies of forest soils. Lutz and Chandler (1946) wrote,

"no simple techniques are known for definitely ascertaining either the amount of soil nutrients available to forest trees or nutrient deficiencies." (p. 374)

"Chemical analyses may show total quantities of the various constituents present, or they may indicate only the amounts which are readily soluble or available. Total analyses are of little value in determining amounts of available nutrients. Partial analyses indicating available amounts of the various elements are more useful, but even with this type of information it is impossible to arrive at a definite conclusion as to actual nutrient availability to trees growing in the forest. The highly empirical nature of chemical tests of available nutrients should be recognized." (p. 375).

It would seem that further soil nutrient–tree growth relationships may be revealed as testing techniques are developed for forest soils. Similarly, as the soil moisture–tree growth relationships are better understood, improved soil testing techniques should permit stronger correlations to be made. With reference to the present study, there may be an indeterminable error in the correlation matrix results and in the prediction equations due to the inadequacy of soil tests. If the results are interpreted with the methods and their potential limitations in mind, the preliminary usefulness of the data will be realized.

Site indices

Several site indices have been used in this study in an effort to discover the most appropriate measure for growth prediction. Dominant height at an index age has traditionally been the most popular measure of forest land productivity for most coniferous tree species in western Canada. Vincent (1961) has noted that it has been in use in North America since 1917 and while some foresters have used the index with some understanding of its limitations as a result of animal and insect damage, density effects, growth rate variation, frost damage, and suppression, others have not given sufficient attention to these effects. Mogren[1] has suggested that because height growth in pine occurs early in the life of the tree and levels off at a much earlier age than is generally appreciated, caution should be taken when using the height/age index in 60-year old pine stands. Smithers (1956) has pointed out that because of the relationships between stocking level and dominant height in dense lodgepole pine stands in the Subalpine Region of Alberta, it would be undesirable to use dominant height in the customary manner as an index of forest land productivity. In the present study, it has been shown that dominant height can be predicted for age classes between 35 and 115 years provided that the stocking level value is given. The parent materials were ranked in order of decreasing productivity using dominant height, average height, basal area per acre, and total volume per acre (Table 5). The Lobley soil series is the most productive condition for all indices; the Horburg and Caroline are taken to be of equal productivity; that is, they cannot be distinguished statistically. It would seem that in spite of the inadequacies of height/age as a site index, the other indices used in this study do not permit a finer breakdown.

Average height (mean of heights of five trees of average stand diameter) is closely related with dominant height. Because it is a value used in the compilation of total volume per acre, it is also correlated with that index. There is no indication that average height is a better indicator of site quality than the

[1] MOGREN, E. W. Personal communication with the writer. March 21, 1961.

dominant height index and several field measurements and calculations are required to determine average height. However, equations 2 and 4 in Table 6 are significant at the 5% level and have relatively high R^2 values compared to those of the other site indices. It seems that height growth can be predicted with higher accuracy than basal area and total volume per acre using the methods in this report. When plot data from stands representing different height classes on the study area were entered in equations 2 and 4, the predicted dominant heights and average heights in Table 8 were obtained.

TABLE 8. EXAMPLES OF PREDICTED DOMINANT HEIGHTS AND AVERAGE HEIGHTS. EQUATIONS 2 AND 4.

Plot number	Predicted dominant height	Observed height
61018	36.7 feet	34.0 feet
61051	59.4 feet	55.0 feet
60092	63.4 feet	61.0 feet
61017	69.6 feet	76.0 feet
Plot number	**Predicted average height**	**Observed height**
61018	31.3 feet	30.0 feet
60025	56.0 feet	54.0 feet
61053	57.2 feet	55.0 feet
61043	68.0 feet	71.0 feet

Basal area per acre has been suggested as a site index for dense lodgepole pine stands in the Subalpine Forest Region of Alberta, "because of the apparent close relationship between basal area per acre and site irrespective of variations in number of trees per acre" Smithers (1956). Results of the present study indicate that there is no correlation between number of trees per acre and basal area growth in fully stocked stands. However, there is evidence to show that it may be difficult to find out whether or not a stand is fully stocked before measurements are made to appraise site quality. Correlation data from thirty-six plots on each of the Horburg and the Lobley soil series do not show a relationship between stocking level and basal area levels. But on the Caroline soil series basal area is positively correlated with number of trees per acre. This can be interpreted to mean that some stands which were taken to be fully stocked were, in fact, understocked. This points up one possible weakness in basal area as a site index, i.e. unless the number of trees per acre which constitutes full stocking at different ages is known for each soil series, there is the possibility of underestimating the basal area site index. Equations 6 and 13, in Tables 6 and 7 respectively, are significant at the 5% level but with lower R^2 and F values than those of the equations for dominant height and average height. Examples of predicted basal area values are given in Table 9.

Total volume per acre and merchantable volume per acre are site indices which give an estimate of the wood volume at the forest manager's disposal. For this reason they may be used in conjunction with dominant height to give more complete information on productivity. As with basal area per acre, the total volume per acre and merchantable volume per acre indices should only be used in fully stocked stands. Further study will be required before optimum stocking levels can be described for given age classes on different soil series. Equations 8 and 10 (Table 6) are significant at the 5% level with R^2 and F values which are intermediate between those of the equations for height growth and the equations for basal area per acre. Equation 14 (Table 7) is significant at the 5% level with a relatively low R^2 value compared to the other equations in Table 7. Examples of predicted total and merchantable volume are given in Table 9.

TABLE 9. EXAMPLES OF PREDICTED BASAL AREA, TOTAL VOLUME AND MERCHANTABLE VOLUME PER ACRE. EQUATIONS 6, 8, AND 10.

Plot number	Predicted basal area	Observed basal area
61054	131.9 square feet	129 square feet
61018	109.2 square feet	122 square feet
60100	123.4 square feet	110 square feet
61050	158.7 square feet	156 square feet
Plot number	**Predicted total volume**	**Observed total volume**
60028	4010 cubic feet	4450 cubic feet
61032	5856 cubic feet	5940 cubic feet
61034	3019 cubic feet	2540 cubic feet
Plot number	**Predicted merchantable volume**	**Observed volume**
61052	45.8 cords	42 cords
60028	42.0 cords	54 cords
60033	39.3 cords	41 cords

The 1960 work was conducted in stands which appeared to be fully stocked; they were not obviously overstocked or understocked. However, in the analysis, it was suggested that stocking level may have a variable effect on tree and stand growth depending upon the parent material. In Appendix II C it is seen that on the Horburg soil series, an increase in number of trees per acre is associated with a decrease in productivity in terms of dominant height, average height, and total volume per acre. In the case of the Caroline soil series Appendix II C, an increase in number of trees per acre is associated with an increase in productivity, in terms of basal area and total volume per acre. On the Lobley soil series, stocking level was not correlated with productivity. These relationships were confirmed in graphical plots. Even though there is not sufficient data to test and appraise the variable effect of stocking level on productivity, it is suggested that sites on Horburg soils may tend to overstock to pine and sites on Caroline soils may tend to understock, possibly as a result of site conditions at the time of stand establishment. Thus it would seem that stocking level should be taken into consideration in forest growth predictions. Provision is made for this in the multiple regression equations which were developed in this study.

In summary, it is suggested that dominant height be used as a site index in the study area but only in pine stands up to full stocking. The correlations of number of trees per acre and dominant height on different soils series require further clarification before optimum stocking for each age class and soil series can be reported. Basal area per acre is potentially useful as a site index in fully stocked stands. Total volume per acre and merchantable volume per acre are useful as measures of productivity and may be used in conjunction with dominant height.

Application of the results

The findings of this study constitute a preliminary categorization of lodgepole pine productivity in the study area. They can be used in forest management on land included in the Rocky Mountain House and Brazeau Map Sheets and on the adjacent portions of the Rocky Mountains Forest Reserve which lie east of the front range of the Rocky Mountains. Application of the results to the north or to the south of the study area is not recommended pending further study of the parent materials in these areas.

The productivity of the Lobley Loam, Heavy Loam soil series may be expressed in terms of pine growth using the prediction equations in this report. Where necessary, the Lobley sites may be mapped according to slope grade and potential productivity values may be assigned to the map units. Even though topographic classes are shown on the soil survey maps of the area, it would be premature to suggest that they could be used to divide the Lobley series into meaningful sub-types. This matter requires further study.

Where qualified predictions of wood yield are required and circumstances are such that adequate data can be gathered, the multiple regression method of relating growth to soil and site factors can be used as described in this report. It requires that the important factors which may be related to growth be considered and that work be concentrated on those factors which are shown to account for variation in growth within the population. For instance, it may be useful to develop prediction equations for pine growth for soil survey map sheets elsewhere in the Foothills Section of Alberta and the following procedure could be used:

1. A stratified, equal-frequency survey of site and growth conditions would be conducted on a given map sheet. Main effects would serve as stratification criteria (e.g. parent material or mapped soil series, slope class). As in the 1960 survey in the present study, an equal number of plots would be measured in each cell. Because this type of survey is time consuming and expensive, careful thought should be given to the selection of soil-site and stand factors which are to be included in the work. In the present study, fifty factors were examined; less than ten of them proved to be of immediate or potential use in growth prediction.
2. Using a correlation matrix table as a guide, a selection would be made of site and stand factors for inclusion in prediction equations.
3. Multiple regression equations would be written from the output of an appropriate computer routine. Analyses of variance and t-tests would be used to test the significance of the regression equations and regression coefficients respectively. Where soil series of different productivities are encountered, separate prediction equations would be written.

   Though the procedure is costly and time-consuming, the results are correspondingly more valid if they are derived correctly and if the assumptions underlying the method are considered.

The preliminary classification of lodgepole pine sites can be employed in typing aerial photographs. Much of the study area has been broadly typed for parent material on the published soil survey map of the Rocky Mountain House Map Sheet (Peters and Bowser, 1960) and the Brazeau Map Sheet which will be published in the near future. In areas which are not included in soil survey maps, the following key could be used in the aerial photo-interpretation of landforms and the respective soil series which were described by Peters and Bowser (1960):

1. (a) terrain flat to undulating 2
   (b) terrain rolling to hilly 3

2. (a) drainage pattern strongly developed.................. 4
   (b) drainage pattern weakly developed or absent........... 5
3. (a) landforms seen as regular to semi-regular barchane dunes . . . Aeolian Sand; Prentice Sandy Loam, Loamy Sand soil series.
   (b) landforms irregular or jumbled........................ 6
4. (a) erosion pattern: wide, rounded gullies; black spruce forest cover . . . Lacustrine; Caroline Loam, Silt Loam soil series, poorly drained.
   (b) erosion pattern: wide, rounded gullies; mixed lodgepole pine and black spruce . . . Lacustrine Caroline Loam, Silt Loam soil series, moderately well drained.
5. (a) erosion absent . . . Outwash plain; Horburg Sandy Loam soil series.
   (b) erosion evidenced by former stream channels . . . Terrace; Horburg Sandy Loam soil series.
6. (a) topography controlled by underlying bedrock . . . Ablation till; Lobley Loam, Heavy Loam soil series.
   (b) topography "knob-and-kettle" . . . Hummocky disintegration moraine; Lobley Loam, Heavy Loam soil series on the well drained sites and Caroline Loam, Silt Loam soil series on poorly drained situations. (Duffy, 1960)[1].

This key is a preliminary means of categorizing parent materials through the identification of landform and serves as an aid in the classification of forest land in the study area into productivity units using the data in Table 5. If the parent material is a till, the equations in Table 6 can be employed to predict growth. Mean productivity data are given for all of the soil series in the key except the Prentice Sandy Loam, Loamy Sand soil series (Table 5).

SUMMARY AND CONCLUSIONS

A two-year field survey and laboratory period was devoted to the investigation of relationships between site factors and growth of lodgepole pine in a study area in the Foothills Section of Alberta. The project was in two parts and each part had three important stages. The 1960 field sample and analysis of data was to determine which site factors were related to important differences in pine growth. A stratified, random sample of site and pine growth conditions was taken in even-aged, 60-year old, fully stocked pine stands on a representative portion of the Foothills Section, namely the area covered by the Rocky Mountain House and Brazeau Map Sheets. Analyses of field and laboratory data were made to find out which site factors are related to pine growth and which site indices might be suitable for prediction of growth in pine stands. A summary was prepared of site factors which are not only related to pine growth, but also are easily measured in the field for purposes of growth prediction.

The purpose of the 1961 field sample and analysis of data was to find out the degree to which site-growth relationships which existed in the 1960 study area pertained over a more extensive area of the Foothills Section. A sample was taken of site and growth conditions on 158 permanent sample plots and other temporary plots in the course of a ten-year re-measurement survey. Analyses

[1] DUFFY, P. J. B. 1960. The use of air photos in the identification of landforms in the Foothills Section of Alberta. Dept. of Forestry, Canada, Forest Research Branch, Unpub. MS., 21 pp.

were made of a portion of the 1961 data together with the 1960 data to determine the usefulness of the site factors as predictive terms. A summary was prepared of relationships on the relatively homogeneous Lobley Loam, Heavy Loam soil series which occurs on a glacial till substrate. The summary was in the form of several multiple regression equations in two sets; one described growth of pine as a function of age, number of trees per acre and site factors and the other set reported growth of 60-year old pine as a function of number of trees, and several site factors.

The important findings of this investigation are:

1. Pine growth in terms of dominant height, average height, basal area per acre, and total volume per acre differs between parent materials and soil series (Table 5). Substantial refinement was imparted to this soil-site study by establishing that these growth differences did exist and by conducting identical but separate surveys on forests on each parent material. This is a development that has not been employed in most soil-site studies to date. In terms of each site index, the Lobley Loam, Heavy Loam soil series on glacial till supports better growth than either the Caroline Loam, Silt Loam soil series on lacustrine substrates or the Horburg Sandy Loam soil series on coarse, gravelly outwash. There is no significant difference in productivity in terms of basal area per acre and total volume per acre between the Caroline and the Horburg series (Table 5). It is possible, however, that the Caroline series is capable of supporting heavier stocked stands of pine. In the data from plots on that series, there is evidence that some of the stands which were sampled were less than fully stocked.
2. It is difficult to determine whether or not a lodgepole pine stand is fully stocked for a given site condition. Since full stocking is a prerequisite to the classification of forest land in terms of basal area per acre or total volume per acre, these site indices are subject to error because of the relationship of stocking level and the indices. Dominant height and average height at an index age are related to stocking level in that overstocking may be associated with lower heights. These site indices may be used without a correction for stocking level only on understocked to fully stocked stands.
3. A multiple regression method for the prediction of pine growth was presented for data from the most productive soil series on the study area, the Lobley Loam, Heavy Loam. For the purposes of this study, the demonstration of the method was confined to the Lobley series, but it is suggested that a similar method could be used to summarize the relationships between pine growth and site and stand factors on other important forest soils on the area. Prediction equations were written for the Lobley soil series (Tables 6 and 7).
4. Using the prediction equations, dominant height and average height can be predicted with greater precision than basal area per acre, total volume per acre or merchantable volume per acre.
5. Glacial tills in the study area were generally calcareous; that is, a lime layer was found at a depth of three to four feet. North of the Brazeau River, the tills were found to be generally non-calcareous. Furthermore, tills in the Edson and Swan Hills district were found to be heavier textured and more strongly structured than tills in the study

area. Independent studies would be required to summarize the site-growth relationships in these areas and for this reason the present study was confined to the study area (Figures 1 and 2).

6. No correlations between aspect and growth were found in this study probably because pure stands of pine are not often found on southern aspects. Pine stands on dry, south-facing slopes were not sampled in this study. More aspects with a northern component were sampled than those with a southern component. Furthermore, the aspect-growth relationship may vary with parent material, slope grade and slope position. Even though aspect may have an effect on the growth of pine, it was not possible to study the effect objectively in this work. Further research on aspect is needed.

SOMMAIRE ET CONCLUSIONS

Deux années de recherches sur le terrain et en laboratoire ont été consacrées à découvrir l'interdépendance entre le type forestier et l'allure de croissance du pin de Murray des contreforts montagneux de l'Alberta. Les travaux comprenaient deux parties, dont chacune était subdivisée en trois étapes importantes. L'échantillonnage et l'analyse des données, effectués en 1960, avaient pour but de déterminer à quel point les facteurs de fertilité influent de façon marquée sur la croissance du pin. On a choisi au hasard des échantillons stratifiés de types forestiers et d'éléments de croissance dans des peuplements équiennes et complets de pins de 60 ans, dans un secteur typique de la région forestière des contreforts montagneux, nommément les secteurs de Rocky Mountain House et de Brazeau. On a fait l'analyse des données recueillies sur place et en laboratoire, afin de découvrir les facteurs de fertilité qui influent sur la croissance du pin et de déterminer les indices de fertilité qui pourraient permettre de prévoir l'allure de croissance des peuplements de pin. On est parvenu à dresser une liste sommaire des facteurs de fertilité qui sont non seulement liés à la croissance du pin, mais aussi faciles à mesurer sur place en vue de calculer l'allure de croissance.

L'échantillonnage effectué en 1961 et l'analyse des données recueillies avaient pour objet de déterminer à quel degré les rapports type/croissance constatés dans l'aire d'étude de 1960 s'appliquaient à une plus grande partie de la forêt des contreforts. On a délimité un échantillon aux fins d'étudier les conditions de fertilité et de croissance dans 158 placeaux permanents et temporaires, au cours de remesurages dendrométriques portant sur dix années. On a analysé une partie des données recueillies en 1961, ainsi qu'une partie de celles qu'on avait rassemblées en 1960, afin de déterminer la valeur des facteurs de fertilité en tant que données de prévision. On a préparé un sommaire de tels rapports pour les sols relativement homogènes du type du limon de Lobley, de la série des sols limoneux lourds, comme il s'en trouve parfois au-dessus d'un substrat de till glaciaire. Le sommaire était présenté sous forme de plusieurs équations régressives multiples, établies en deux séries; l'une d'elle représente la croissance du pin par rapport à l'âge du peuplement, au nombre d'arbres à l'acre et aux facteurs de fertilité, tandis que la deuxième série donne l'indice de croissance du pin de 60 ans en fonction du nombre de sujets à l'acre et de plusieurs facteurs de fertilité.

Voici les découvertes importantes faites au cours de cette étude:

1. L'allure de croissance du pin diffère, en ce qui concerne la hauteur dominante, la hauteur moyenne, la surface terrière à l'acre et le

volume total de bois sur pied à l'acre, selon la composition de la roche-mère et celle du sol (tableau 5). On a pu approfondir dans une large mesure l'étude portant sur les sols et leur fertilité, en établissant que de telles différences de croissance existent et en procédant à des études semblables mais distinctes dans des forêts croissant sur chaque type de roche-mère. Cette méthode n'a presque pas été utilisée auparavant dans les études des sols et de leur fertilité. Du point de vue de l'indice de fertilité de chaque sol, le limon de type Lobley, de la série des sols limoneux lourds, avec substrat de till glaciaire, sont plus favorables à la croissance du pin que le limon du type Caroline, de la série des limons alluvionnaires sur substrat lacustre, ou encore que les sols sablo-limoneux de la série de Horburg sur substrat lacustre et grossier d'origine glaciaire. On n'a noté aucune différence notable de fertilité par rapport à la surface terrière à l'acre et au volume total à l'acre, entre les sols de type Caroline et les sols de type Horburg (tableau 5). Il se peut toutefois que les sols du type Caroline puissent porter des peuplements de pin plus denses. Les données relatives aux placeaux croissant sur des sols de cette série indiquent que certains des peuplements choisis n'étaient pas complets.

2. Il est difficile de déterminer si un peuplement de pin de Murray est complet dans un type forestier donné. Le peuplement complet étant une condition indispensable au classement des sols forestiers selon la surface terrière à l'acre ou le volume total à l'acre, ces indices de fertilité sont parfois erronés, à cause du rapport qui existe entre la densité du peuplement et ces indices mêmes. La hauteur dominante et la hauteur moyenne, pour une classe d'âge correspondant à un indice donné, sont subordonnées à la densité du peuplement, en ce sens que la densité excessive est associée à la hauteur des sujets. Ces indices de fertilité peuvent servir sans correction au calcul de la densité des peuplements uniquement si ces derniers sont incomplets ou complets.
3. La méthode régressive multiple de calcul anticipatif de l'allure de croissance du pin de Murray est présentée afin de fournir des données concernant la série de sols la plus productive de l'aire à l'étude, soit le limon du type Lobley, de la série des sols limoneux lourds. Aux fins de la présente étude, l'applicabilité de la méthode n'a été démontrée que dans le cas des sols de la série Lobley; toutefois, on pourrait utiliser la même méthode pour esquisser le rapport entre la croissance du pin et les facteurs de fertilité et de composition du peuplement, pour les autres sols de la région. Les équations de prédiction ont trait aux sols du type Lobley (tableaux 6 et 7).
4. On peut prédire la hauteur dominante et la hauteur moyenne à l'aide des équations de prédiction avec plus de précision qu'on ne pourrait calculer la surface terrière à l'acre ou le volume total à l'acre, ou encore le volume de bois marchand à l'acre.
5. Les tills glaciaires de l'aire à l'étude étaient en général calcaires, c'est-à-dire qu'une couche de pierre calcaire se trouvait à une profondeur de trois à quatre pieds. Au nord de la rivière Brazeau, de façon générale les tills glaciaires n'étaient pas calcaires. En outre, les tills glaciaires du district d'Edson et des Swan Hills étaient de texture plus compacte et plus nettement structurés que ceux de l'aire à l'étude. Il faudrait procéder à des études distinctes pour étudier l'interdépendance entre le

type forestier et l'allure de croissance dans chacune de ces aires; c'est d'ailleurs pourquoi la présente étude n'a trait qu'à l'aire étudiée (figures 1 et 2).

6. La présente étude n'a révélé aucune corrélation entre l'orientation et la croissance; cela est probablement attribuable à ce qu'on ne trouve que rarement des peuplements purs de pin sur les versants exposés au midi. Aucun peuplement de pin sur pente sèche faisant face au sud n'est compris dans l'étude. L'échantillonnage a porté sur plus de peuplements orientés vers le nord que de peuplements orientés vers le sud. De plus, la corrélation entre l'orientation et la croissance peut varier selon la roche-mère, la pente du terrain et l'orientation de la pente. Bien que l'orientation puisse influer sur la croissance du pin, il a été impossible d'en faire une étude objective au cours des travaux dont il est ici question. Des recherches plus approfondies au sujet de l'orientation s'imposent.

APPENDIX I

Glossary of Terms

Alluvium: a sand, silt, and gravel mixture which has been moved and redeposited by river flow.

Colluvium: poorly sorted material near the base of long slopes; moved by gravity, frost action, soil creep and local wash.

Effective thickness: total thickness of a soil horizon or profile minus the stone content, in inches.

Effective depth: total depth to a given horizon minus stone content, in inches.

Glacial till: a heterogeneous mantle of stones, gravel, sand, silt and clay deposited by a glacier.

Homoscedasticity: constant variance.

Lacustrine: fine materials, mostly silts and clays, settled out in still water.

Land type: a land pattern composed of repeated occurrences of a landform.

Landform: a topographic and geologic feature of the landscape, recognized and identified by its form and nature as determined by its relief and geological materials respectively.

Parent material: the unconsolidated mass in which the soil develops.

Physiographic site classification: the categorization of forest land productivity using topography and soil factors as classification criteria within a homogeneous regional climate.

Site: the edaphic, climatic, and biological environment as it affects the forest stand.

Site classification: the categorization of the environment for a particular purpose, e.g. forest land productivity.

Site factor: one portion of the environment which can be measured, evaluated, and related to forest growth.

Site index: a measure of the site potential, e.g. dominant height at an index age.

Soil-site factor: a characteristic of the soil profile which can be measured, evaluated and related to forest growth.

Stand factor: a characteristic of the forest stand which can be measured, evaluated, and related to forest growth, e.g. age, stocking level.

APPENDIX IIA

Soil moisture data

MEAN LEVELS OF "SOIL MOISTURE FACTORS" IN THE B_t HORIZON BY PARENT MATERIAL, SLOPE CLASS, AND POSITION CLASS*

	Available Moisture Surface 36 inches	Per cent silt plus clay, B_t horizon × effective thickness B_t horizon/10	Average per cent organic matter in profile	Effective thickness, B_t horizon	Per cent silt plus clay in the B_t horizon	Effective depth to the C horizon, inches
Till (Lobley soil series)............	5.7	53.6	0.15	9.1	63.1	18.0
Slope class 0-5%	—	50.2	—	7.8	64.3	17.2
Position class 0-33%	—	65.8	—	9.2	—	—
34-67%	—	56.5	—	9.3	—	—
68-100%	—	42.3	—	4.2	—	—
Slope class 6-15%	—	58.8	—	12.0	63.2	19.6
Position class 0-33%	—	30.3	—	11.0	—	—
34-67%	—	48.0	—	16.0	—	—
68-100%	—	50.8	—	8.5	—	—
Slope class 16+%	—	47.2	—	7.7	61.7	17.2
Position class 0-33%	—	56.8	—	8.8	—	—
34-67%	—	42.0	—	7.0	—	—
68-100%	—	42.8	—	7.2	—	—
Alluvium (Horburg soil series)..........	4.7	17.2	0.18	4.0	49.8	13.2
Slope class 0-5%	—	13.5	—	5.0	39.6	15.9
Position class 0-33%	—	20.0	—	7.7	—	—
34-67%	—	8.7	—	2.0	—	—
68-100%	—	10.2	—	5.0	—	—
Slope class 6-15%	—	20.3	—	3.8	52.7	11.3
Position class 0-33%	—	19.5	—	3.7	—	—
34-67%	—	21.0	—	4.0	—	—
68-100%	—	10.5	—	3.7	—	—
Slope class 16+%	—	17.8	—	3.2	57.0	12.5
Position class 0-33%	—	22.7	—	4.2	—	—
34-67%	—	18.0	—	3.0	—	—
68-100%	—	12.7	—	2.2	—	—
Lacustrine (Caroline soil series)..........	7.1	85.2	0.12	13.0	70.2	27.9
Slope class 0-5%	—	62.7	—	11.8	69.4	23.3
Position class 0-33%	—	73.5	—	11.7	—	—
34-67%	—	64.0	—	14.5	—	—
68-100%	—	50.5	—	9.0	—	—
Slope class 6-15%	—	107.9	—	15.2	71.8	32.7
Position class 0-33%	—	67.8	—	10.2	—	—
34-67%	—	103.8	—	13.5	—	—
68-100%	—	152.3	—	21.7	—	—
Slope class 16+%	—	85.0	—	12.2	69.5	27.8
Position class 0-33%	—	53.5	—	8.7	—	—
34-67%	—	88.3	—	11.5	—	—
68-100%	—	113.3	—	16.2	—	—

*For 108 plots (36 plots on each of three parent materials), Rocky Mountain House and Brazeau Map Sheets. Alberta.

APPENDIX II B

Soil nutrient data

MEAN NUTRIENT LEVELS IN THE B_t HORIZON, BY PARENT MATERIAL AND SLOPE CLASS*

Parent material	Slope Class (per cent)	pH, B_t horizon	Extractable phosphorus, B_t horizon, parts per 2 million	Exchangeable potassium, B_t horizon, parts per 2 million
Till (Lobley soil series)	0-5	—	16.8	271.5
	6-15	5.56	28.3	432.2
	16+	—	13.8	300.8
Alluvium (Horburg soil series)	0-5	—	27.2	155.7
	6-15	6.13	15.9	114.5
	16+	—	13.8	95.2
Lacustrine (Caroline soil series)	0-5	—	53.0	494.8
	6-15	5.56	59.1	594.3
	16+	—	32.6	401.5

*For 108 plots (36 plots on each of three parent materials), Rocky Mountain House and Brazeau Map Sheets, Alberta.

APPENDIX II C

CORRELATION MATRIX RESULTS FOR TILL (LOBLEY SOIL SERIES)*. SIGNIFICANT CORRELATIONS ONLY (R GREATER THAN .330).

	Dominant height	Average height	Basal area per acre	Total volume per acre
1. Effective depth to the C horizon	.360	.420	—	—
2. Depth to lime	.519	.550	—	.341
3. Extractable phosphorus in the A_e horizon	.409	.429	—	—
4. Total nitrogen in the A_e horizon, per cent	.396	.416	—	—
5. Slope position	—	−.465	—	−.373
6. Effective thickness of C/ horizon	—	—	−.379	—
7. Exchangeable potassium in the A_e horizon	—	—	−.347	—
8. Exchangeable potassium in the C horizon	—	—	−.341	—
9. Effective thickness of the B_f horizon	—	—	—	−.454
10. Available moisture in the surface 36 inches	—	—	—	−.386
11. pH B_t horizon	—	—	—	−.351

*For 36 plots in 60-year old pine stands on the Rocky Mountain House and Brazeau Map Sheets, Alberta.

APPENDIX II C

CORRELATION MATRIX RESULTS FOR ALLUVIUM (HORBURG SOIL SERIES)* SIGNIFICANT CORRELATIONS ONLY (R GREATER THAN .330).

	Dominant height	Average height	Basal area per acre	Total volume per acre
1. Effective thickness, B_t horizon	.375	.529	—	.407
2. Effective depth to the C horizon	.452	.550	.512	.573
3. Depth to lime	.377	—	—	—
4. Per cent clay, A_e horizon	−.371	—	—	—
5. Per cent silt plus clay, B_f horizon	−.417	−.375	—	—
6. Per cent clay, C/ horizon	−.347	−.359	—	—
7. Per cent silt plus clay, C/ horizon	−.400	−.403	.512	—
8. Per cent clay, B_t horizon	−.469	−.393	—	—
9. Per cent silt plus clay, B_t horizon	−.443	−.471	—	—
10. Extractable phosphorus, A_e horizon	.389	—	.629	.537
11. pH, B_f horizon	.423	.400	—	.352
12. Extractable phosphorus, B_f horizon	.406	.422	—	—
13. pH, C/ horizon	.428	.442	—	.368
14. Total organic matter, B_t horizon	.361	−.391	—	—
15. Total organic matter, C horizon	.379	−.383	—	—
16. Number of trees per acre	−.647	−.761	—	−.370
17. Cumulative thickness, L, F, and H horizons	—	−.404	—	—
18. Per cent silt plus clay, A_e horizon	—	.407	—	—
19. Exchangeable potassium, A_e horizon	—	.397	.402	.458
20. Effective thickness, C/ horizon	—	—	.556	.440
21. Total depth to C horizon	—	—	.354	.391
22. Exchangeable potassium, B_t horizon	—	—	.336	.345
23. Per cent silt plus clay × effective thickness of C/horizon	—	—	—	.330
24. Total nitrogen, A_e horizon	—	—	—	.333

*For 36 plots in 60-year old pine stands on the Rocky Mountain House and Brazeau Map Sheets, Alberta.

APPENDIX II C (continued)

CORRELATION MATRIX RESULTS FOR THE LACUSTRINE CONDITION (CAROLINE SOIL SERIES)*. SIGNIFICANT CORRELATIONS ONLY (R GREATER THAN .330).

	Dominant height	Average height	Basal area per acre	Total volume per acre
1. Per cent clay, B_t horizon	.371	.330	.326	.449
2. Per cent clay, C horizon	.403	—	—	—
3. Total nitrogen, A_e horizon	−.546	—	−.576	−.528
4. Total organic matter, A_e horizon	−.485	—	−.474	−.520
5. Per cent clay, C/ horizon	.409	—	—	—
6. Extractable phosphorus, B_f horizon	—	.391	—	—
7. Extractable phosphorus, C/ horizon	—	.397	—	—
8. Per cent clay, A_e horizon	—	—	−.388	—
9. Exchangeable potassium, A_e horizon	—	—	−.390	—
10. Total organic matter, B_f horizon	—	—	.369	—
11. Total organic matter, C/ horizon	—	—	.419	—
12. Total organic matter, B_t horizon	—	—	.441	.396
13. Per cent silt plus clay, B_t horizon	—	—	—	.455
14. Exchangeable potassium, B_t horizon	—	—	—	.380
15. Number of trees per acre	—	—	.737	.587

*For 36 plots in 60-year old pine stands on the Rocky Mountain House and Brazeau Map Sheets, Alberta.

CORRELATION MATRIX RELATING SOIL AND SITE FACTORS TO LODGEPOLE PINE GROWTH*

	2	3	4	5	6	7	8	9	10	11	12	13
1	.497	.292	−.115	.042	.062	- .056	.224	−.687	−.594	−.385	−.565	−.634
2	—	−.035	−.127	−.065	−.092	−.069	−.113	−.778	−.825	−.028	−.486	−.438
3	—	—	−.187	.066	.121	−.237	−.272	.005	.066	−.130	.007	−.058
4	—	—	—	.109	.056	.186	−.080	.074	.045	−.026	−.054	.016
5	—	—	—	—	−.005	−.128	.066	−.124	−.114	−.344	−.322	−.307
6	—	—	—	—	—	−.113	−.128	.091	.092	−.113	−.004	−.000
7	—	—	—	—	—	—	.204	−.122	−.155	−.002	−.214	−.113
8	—	—	—	—	—	—	—	−.063	.014	−.115	−.164	−.150

Key:

1. $\frac{1}{\text{age}} \times 10^4$
2. number of trees per acre/10
3. depth of lime
4. slope position
5. slope grade
6. depth Grey Wooded A_e horizon
7. pH, B_t horizon
8. per cent silt plus clay, B_t horizon × effective thickness B_t/10
9. dominant height
10. average height
11. basal area per acre
12. total volume per acre
13. merchantable volume per acre.

*For 70 sample plots on the Rocky Mountain House and Brazeau Map Sheets, Alberta. r>.239 significant at 5% (underlined)

APPENDIX III A

RANGE OF DATA FOR SITE FACTORS AND PINE GROWTH* 1960 SURVEY

Site factor; growth factor	Till	Alluvium	Lacustrine
1. Slope grade	1-42	1-50	1-36
2. Slope position	10-80	10-90	10-90
3. Aspect	1-9	1-5	1-8
4. Thickness A_{oo} + A_o horizons, inches	1-7	1-8	3-10
5. Thickness A_e (A_{2p}) horizon, inches	1-3	1-4	1-3
6. Thickness B_f (B_p) horizon, inches	1-6	1-8	1-10
7. Thickness C/ (C_p) horizon, inches	1-12	1-8	2-10
8. Thickness B_t (B_2) horizon, inches	3-30	1-10	6-38
9. Total depth to C horizon, inches	12-35	8-38	13-54
10. Effective depth to C horizon, inches	10-34	4-32	12-54
11. Depth to lime, inches	11-50	14-60	No data
12. Per cent clay, A_e horizon	10-20	7-32	12-22
13. Per cent silt + clay, A_e horizon	54-77	20-80	12-78
14. $\frac{13. \times \text{effective thickness } A_e}{10}$	5-21	4-50	7-23
15. Per cent clay, B_f horizon	11-44	7-38	15-34
16. Per cent silt + clay B_f horizon	38-78	19-73	45-78
17. $\frac{16. \times \text{effective thickness } B_f}{10}$	6-36	2-29	7-56
18. Per cent clay, C/ horizon	9-44	6-38	15-34
19. Per cent silt + clay, C/ horizon	25-78	7-72	46-79
20. $\frac{19. \times \text{effective thickness C/}}{10}$	6-80	2-49	15-79
21. Per cent clay, B_t horizon	10-50	3-42	11-75
22. Per cent silt + clay, B_t horizon	45-82	16-70	23-90
23. $\frac{22. \times \text{effective thickness } B_t}{10}$	21-135	4-54	12-382
24. Per cent clay, C horizon	9-45	4-41	11-71
25. Per cent silt + clay, C horizon	18-79	20-62	17-92
26. Available moisture, surface 36 inches; in inches	3.3-9.5	No data	4.0-9.8
27. pH, A_e horizon	4.8-5.8	4.4-6.2	4.7-5.1
28. Extractable phosphorus, A_e horizon, p.p.2m	23-200	15-69	28-69
29. Exchangeable potassium, A_e horizon, p.p.2m	90-600	50-230	100-220
30. Total nitrogen, A_e horizon, per cent	.053-.098	.044-.078	.052-.087
31. Total organic matter, A_e horizon, per cent	1.2-3.4	1.4-2.8	1.1-2.6

*108 plots on three parent materials. Rocky Mountain House and Brazeau Map Sheets, Alberta. 1960.

APPENDIX III A (continued)

RANGE OF DATA FOR SITE FACTORS AND PINE GROWTH* 1960 SURVEY (Contd.)

Site factor; growth factor	Till	Alluvium	Lacustrine
32. pH, B_f horizon	4.9–6.6	4.9–6.2	4.9–6.0
33. Extractable phosphorus, B_f horizon, p.p.2m.	5–200	9–200	6–98
34. Exchangeable potassium, B_f horizon, p.p.2m.	130–600	70–370	30–360
35. Total organic matter, B_f horizon, per cent	0.8–3.8	0.3–3.4	0.8–2.7
36. pH, C/ horizon	5.0–6.5	4.9–6.2	4.8–6.0
37. Extractable phosphorus, C/ horizon, p.p.2m.	3–120	13–190	6–64
38. Exchangeable potassium, C/ horizon, p.p.2m.	90–310	80–370	70–330
39. Total organic matter, C/ horizon, per cent	0.9–3.6	0.3–3.4	0.8–2.7
40. pH, B_t horizon	4.7–6.7	5.4–7.0	4.8–7.0
41. Extractable phosphorus, B_t horizon, p.p.2m.	4–40	6–72	4–37
42. Exchangeable potassium, B_t horizon, p.p.2m.	140–300	100–300	120–340
43. Total organic matter, B_t horizon, per cent	0.6–2.4	0.4–5.0	0.6–2.7
44. pH, C horizon	5.0–7.5	5.6–7.8	5.1–7.2
45. Extractable phosphorus, C horizon, p.p.2m.	2–37	3–41	2–37
46. Exchangeable potassium, C horizon, p.p.2m.	100–310	40–260	100–320
47. Total organic matter, C horizon, per cent	0.3–1.8	0.8–5.2	0.4–1.8
48. Depth of abundant rooting	7–44	8–60	8–54
49. Dominant height, feet	51–70	41–68	49–66
50. Average height, feet	44–68	36–50	43–58
51. Basal area per acre, square feet	87–192	76–189	85–166
52. Total volume per acre, cubic feet	1960–5040	1550–4795	1380–3950
53. Number of trees per acre	330–1780	520–1700	470–1330

*108 plots on three parent materials. Rocky Mountain House and Brazeau Map Sheets, Alberta. 1960.

APPENDIX III B

RANGE OF DATA FOR SITE FACTORS AND PINE GROWTH. 70 PLOTS ON THE LOBLEY LOAM, HEAVY LOAM SOIL SERIES. 1960 AND 1961.

Site factor; pine growth	
1. Depth to lime, inches	11–60
2. Slope grade	1–42
3. Slope position	2–80
4. Depth of the Grey Wooded A_e horizon	3–33
5. pH, B_t horizon	4.7–7.2
6. Per cent silt + clay, B_t horizon × effective depth, $B_t/10$	7–144
7. Age, years	35–115
8. Number of trees per acre	330–4570
9. Dominant height, feet	27–80
10. Average height, feet	18–73
11. Basal area per acre, square feet	95–202
12. Total volume per acre, cubic feet	960–7100
13. Merchantable volume per acre, cords	14–76

APPENDIX IV

ANALYSES OF VARIANCE OF REGRESSION EQUATIONS.

Equation number	Source of variation	Degrees of freedom	Sum of squares	Mean square	Table F	
					F	sig. at 5%
1 (dominant height)	Regression	8	5,297.8727	662.2341	25.04	2.10
	Deviations	61	1,613.1273	26.4447		
	Total	69	6,911.			
2 (dominant height)	Regression	3	5,159.9443	1,719.9814	64.83	2.75
	Deviations	66	1,751.0557	26.5311		
	Total	69	6,911.			
3 (average height)	Regression	8	5,837.7366	729.7171	23.33	2.10
	Deviations	61	1,907.5634	31.2715		
	Total	69	7,745.3			
4 (average height)	Regression	3	5,797.3017	1,932.4339	65.47	2.75
	Deviations	66	1,947.9983	29.5151		
	Total	69	7,745.3			
5 (basal area per acre)	Regression	8	12,335.9778	1,541.9972	3.07	2.10
	Deviations	61	30,682.6222	502.9938		
	Total	69	43,018.6			
6 (basal area per acre)	Regression	2	10,991.3559	5,495.6780	11.50	3.14
	Deviations	67	32,027.2441	478.0186		
	Total	69	43,018.6			
7 (total volume per acre)	Regression	8	498,065.2433	62,258.1554	8.82	2.10
	Deviations	61	430,679.3567	7,060.3173		
	Total	69	928,744.6			
8 (total volume per acre)	Regression	3	445,797.7013	148,599.2337	20.31	2.75
	Deviations	66	482,946.8787	7,317.3772		
	Total	69	928,744.6			
9 (merchant-able volume per acre)	Regression	8	5,152.2001	644.0251	8.58	2.10
	Deviations	61	4,577.1999	75.0361		
	Total	69	9,729.4			
10 (merchant-able volume per acre)	Regression	3	4,960.3487	1,653.4496	22.88	2.75
	Deviations	66	4,769.0513	72.2584		
	Total	69	9,729.4			
11 (dominant height at 60 years)	Regression	5	498.8666	99.7733	8.18	2.53
	Deviations	30	366.1334	12.2044		
	Total	35	865.0			

APPENDIX IV (continued)

ANALYSES OF VARIANCE OF REGRESSION EQUATIONS

Equation number	Source of variation	Degrees of freedom	Sum of squares	Mean square	Table F	
					F	sig. at 5%
12 (average height at 60 years)	Regression	5	896.8119	179.3624	12.81	2.53
	Deviations	30	420.1881	14.0063		
	Total	35	1,317.0			
13 (basal area per acre at 60 years)	Regression	5	8,301.0210	1,660.2042	7.63	2.53
	Deviations	30	6,527.2790	217.5760		
	Total	35	14,828.3			
14 (total volume per acre at 60 years)	Regression	5	71,367.4939	14,273.4988	3.47	2.53
	Deviations	30	123,406.1061	4,113.539		
	Total	35	194,773.6			

APPENDIX V

COMPUTER OUTPUT, MULTIPLE REGRESSION PROGRAM.

Equation number	Standardized partial regression coefficient	Standard error of regression coefficient	t	Table t sig. at 5%
1.	$b_1 = -.429917$	.080403	−5.3469310*	2.001
	$b_2 = -.5671445$	.078112	−7.2606846*	
	$b_3 = -.1137003$	.071077	1.5996945	
	$b_4 = -.0023070$	.065129	−0.0354213	
	$b_5 = -.1411022$	.063302	−2.2290169*	
	$b_6 = .0400379$	.064370	0.6219972	
	$b_7 = -.0490563$	.068979	−0.7111797	
	$b_8 = -.0379478$	.072235	−0.5253403	
2.	$b_1 = -.3849237$	.071650	−5.3722935*	1.996
	$b_2 = -.5963193$	.071739	−8.3123702*	
	$b_5 = -.1466204$	.062319	−2.3527283*	
3.	$b_1 = -.2893889$	.079618	−3.6347209*	2.001
	$b_2 = -.6830598$	.077348	−8.8309282*	
	$b_3 = .1130392$	.070382	1.6060720	
	$b_4 = -.0240123$	.064493	− .3723248	
	$b_5 = -.1416880$	.062684	−2.2603536*	
	$b_6 = .0231045$	.063741	.3624740	
	$b_7 = -.0710255$	.068305	−1.0398315	
	$b_8 = -.0045628$	.071529	− .0637899	
4.	$b_1 = -.2301627$	.071387	−3.2241735*	1.996
	$b_2 = -.7205219$	.071475	−10.0807243*	
	$b_5 = -.1512669$	.062090	−2.4362353*	
5.	$b_1 = -.4708837$	.140548	−3.3503266*	2.001
	$b_2 = .1784576$	.136542	1.3069744	
	$b_3 = .0367001$	.124245	.2953846	
	$b_4 = -.0203538$	.113848	−.1787794	
	$b_5 = -.3139582$	.110655	−2.8372595*	
	$b_6 = -.0725896$	.112521	−.6451178	
	$b_7 = .0015459$	.120578	.0128211	
	$b_8 = .0104429$	.126269	.0827032	
6.	$b_1 = -.3708325$	.105505	−3.5148241*	1.996
	$b_5 = -.3283195$	.105505	−3.1118777*	
7.	$b_1 = -.4264321$	.113330	−3.7627569*	2.001
	$b_2 = -.3076405$	.110099	−2.7942043*	
	$b_3 = .1367194$	.100184	1.3646857	
	$b_4 = -.0735773$	.091801	− .8014908	
	$b_5 = -.3037335$	.089225	−3.4041034*	
	$b_6 = -.0547374$	.090730	− .6032972	
	$b_7 = -.1157312$	.097226	−1.1903260	
	$b_8 = -.1098542$	.101816	−1.0789501	
8.	$b_1 = -.3976715$	.102646	−3.8741972*	1.9964
	$b_2 = -.3093483$	.102774	−3.0099972*	
	$b_5 = -.3258938$	.089279	−3.6502732*	
9.	$b_1 = -.5612579$	.114148	−4.9169383*	2.001
	$b_2 = -.1773501$	.110894	−1.5992719	
	$b_3 = .1177355$	.100907	1.1667727	
	$b_4 = -.0106738$	.092463	− .1154389	
	$b_5 = -.2916840$	.089870	−3.2456289*	
	$b_6 = -.0097893$	.091385	− .1071209	
	$b_7 = -.0563758$	.097928	− .5756844	
	$b_8 = -.0475826$	.102551	− .4639910	
10.	$b_1 = -.5237620$	.099658	−5.2556065*	1.9964
	$b_2 = -.1967785$	.099781	−1.9720939	
	$b_5 = -.2982462$	.086680	−3.4407709*	

*Significant at .05 level.

APPENDIX V (continued)

COMPUTER OUTPUT, MULTIPLE REGRESSION PROGRAM. (continued)

Equation number	Standardized partial regression coefficient	Standard error of regression coefficient	t	Table t sig. at 5%
11.	$b_1 = -.5309158$	.133581	−3.9744903*	2.028
	$b_2 = .3269275$	.133586	2.4473135*	
	$b_3 = -.0450971$	.127622	− .3533631	
	$b_4 = -.1416106$	.124699	−1.1356183	
	$b_5 = -.1203520$	.123446	−.9749373	
12.	$b_1 = -.5347148$	.115977	−4.6105298*	2.028
	$b_2 = .2803479$	.115981	2.4171749*	
	$b_3 = .0140933$	.110804	.1271917	
	$b_4 = -.2980727$	.108265	−2.7531608*	
	$b_5 = -.1397516$	.107177	−1.3039262	
13.	$b_1 = .7019134$	.136379	5.1467780*	2.028
	$b_2 = .3611310$	.136385	2.6478830*	
	$b_3 = -.1323036$	.130296	−1.0154079	
	$b_4 = -.1483414$	.127311	−1.1651857	
	$b_5 = -.0978211$	.126032	− .7761612	
14.	$b_1 = .1044372$	.163310	.6395013	2.028
	$b_2 = .2939507$	.163317	1.7998784	
	$b_3 = -.1772440$	.156026	−1.1359914	
	$b_4 = -.3016629$	.152452	−1.9787417	
	$b_5 = -.2958421$	.150919	−1.9602612	

*Significant at .05 level.

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