VARIABILITY OF THE PRODUCTIVE CAPACITY OF RUBICON SAND FOR RED PINE

Thesis for the Degree of M. S.

MICHIGAN STATE UNIVERSITY
RONALD JULIUS CHURCH

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ABSTRACT

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By

Ronald Julius Church

Soil classification at the series level has been used by foresters as a guide in estimating the productive capacity of the land. Since today's forests must be managed intensively to obtain the maximum production from the land, foresters prefer to be able to predict the productive capacity of a given site, as measured by site index, to within a reasonably narrow range such as one site class, or $\pm$ 5 feet. The site index of red pine in plantations growing on the Rubicon soil series in northern lower Michigan has been reported to be 58 feet at 50 years with a range, i.e. one standard deviation, of $\pm$ 7 feet. This means that the productive capacity of the land is not adequately estimated in term's of intensive forest management when the Rubicon soil series is used as a guide. This thesis therefore, is an investigation of the variability of the productive capacity of Rubicon sand for red pine plantations.

The study area was confined to two counties in the northwestern portion of the lower peninsula of Michigan. The landforms in the area are mainly outwash plains and moraines, which are Wisconsinan in age.

Site index curves were developed from stem analysis data in this study. Harmonized site index curves were based on the following equation that was developed: (site index) = -4.017 +

$1.399(age) + .005197(age)^2$. Polymorphic site index curves were also generated but did not result in important differences in terms of management objectives.

The site index for each plot was determined from the above mentioned curves and from other published curves which represented broader geographical ranges and/or native stands of red pine. It was found that various site index curves yield similar site index values for red pine on Rubicon sand. However, the variation in site index between plots ranged from 7.8% to 11.8%, with the different curves,or an average of 10.2%.

In a similar fashion, volume at age 50 was used to estimate the productive capacity of the land. Volume was a more sensitive indicator than site index. Like site index however, the average volume as determined by different methods was similar but the variation between plots was greater and ranged from 11.3% to 19.4%.

Stepwise regression analysis was employed to find meaningful correlations between site index for red pine and numerous properties of Rubicon sand and non-soil site factors. The site factors which were associated with 71% of the variation in site index are: pH of the B22 horizon, thickness of the A horizon, basal area, percent gravel in the profile, and average percent fine sand of the A plus B horizons. Thus, these factors are apparently the most important characteristics of Rubicon sand known to be correlated with variations in site index for red pine. Until more is known about the site factors associated with more of the variation in red pine site index, or variation in Rubicon sand, there is little hope for improving on soil classification for red pine site quality estimation on this soil.

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TABLE OF CONTENTS

Concl

List

Appen

II

IV
V

Table

I

II

III

IV

V

VI

VII

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Red pine (*Pinus resinosa* Ait.) is an economically important species and has been planted extensively throughout the northern half of the lower peninsula of Michigan. The Department of Natural Resources of Michigan has planted about 100,000 acres*. The site index of red pine growing on Rubicon sand (Entic Haplorthod) has been reported to be 58 ± 7 feet (van Eck, 1958). As an estimate of the productive capacity of Rubicon sand, this site index is quite variable. If the site index were within one site class, that is, if it varied less than ± 5 feet, it would be a more reliable guide. Present population and industrial expansion is forcing foresters to produce more timber from less land. As a result, forest managers need more accurate and reliable estimates of the land's productive capacity. It is the purpose of this thesis to investigate site factors associated with the causes of the variability in site index of red pine plantations growing on Rubicon sand.

The variability in the site index of red pine growing on Rubicon sand could be the result of many factors. These factors, for the purposes of this study, can be divided into two groups:

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*Personal communication with Mr. William B. Botti, Staff Forester, Forest Cultivation, Michigan Department of Natural Resources.

non-soil and soil factors. Of the two groups the non-soil factors are the most difficult to measure, because of their complex nature, or the time necessary to measure them. These factors include climate, planting stock quality, genetic variation, handling of the seedlings during planting, etc. Another factor, which is not inherent to the site, is the site index curves used to determine the site index values. Inaccuracies in the site index curves, especially on the younger or older portions of the curves, result because the growth pattern of the individual trees in question are not similar. Soil factors, by comparison, are relatively easy to measure. Because soils are stable site features, they can be quantified and described in detail. There can be little doubt that as the medium for root growth, the soil is perhaps the most important site factor. An understanding of the effects which the above site factors have on site productivity is an imperative prerequisite to intensive forest management.

BACKGROUND

Because soil scientists and foresters have technical jargon peculiar to their respective fields it is often difficult for them to communicate to one another. In an attempt to bridge this gap I would like to clarify some concepts which need to be understood by both professions viz., the soil scientists' system of classification and the foresters concept of site.

Soil Classification System

The current soil classification system in the United States, also referred to as, Soil Taxonomy, is a classification according to properties of natural soil bodies. The soil taxonomy is designed to bring out the relationships of these natural bodies to their natural and cultural environment (Soil Survey Staff, 1975). The six categories used in the system in decreasing rank and increasing number of differntiae and classes, are: order, suborder, great group, subgroup, family, and series. The soil phases are further subdivisions of any category, not in the system, but even phases of series are important to land use (Thomas and Burroughs, 1973).

The Soil Taxonomy (Soil Survey Staff, 1975) defines the categories as follows: the higest category, order, is divided into 10 classes based on the presence or absence of diagnostic horizons or features resulting from the combined influence of the soil forming factors. These factors are climate, and living organisms acting on parent material over time as conditioned by relief. The next category, <u>suborder</u>, describes properties such as the degree of wetness or dryness, and/or the mineralogy of the soil. Next, the <u>great groups</u> describe the soil horizons, the moisture and temperature regimes, and the similarities in base status. The next category, <u>subgroup</u>, is divided into three groups of classes: (1) typic, the central concept of the great group, (2) intergrades, or transitional forms to other orders, suborders, or great groups, (3) extra-grades, i.e. soils that have some properties not representative of the great group and that do not indicate transitions to any other known kind of soil. Next, <u>families</u>, groups soils which have similar physical and chemical properties and differences of climate that affect their response to management and manipulation for use. <u>Series</u>, the lowest category, uses differentiae which are mostly the same as those used in the higher categories, but the ranges permitted in the properties are less than is permitted in the higher categories. There are numerous additional differentiae used to define a series that are not used in the higher categories. Series criteria are closely allied to land use interpretations. The soil phase, although not a category in the soil taxonomy, is a further subdivision of a class in any category used for management and interpretive purposes. For example: Rubicon sand, rolling, is a phase of Rubicon.

To illustrate how the soil classification works, the classification of Rubicon sand, the soil used in this study, is described in detail. Rubicon is officially classified as: sandy, mixed, frigid, Entic Haplorthod.

Order: Spodosol.

The order is indicated by the last two letters of the name. (Haplorth<u>od</u> = Sp<u>od</u>osol). Spodosols are mineral soils which contain a spodic horizon, i.e. an horizon in which amorphous mixtures of organic matter and aluminum, with or without iron, have accumulated.

Suborder: Orthods.

Orthods are more or less freely drained Spodosols that have an horizon of accumulation of Al, Fe, and organic carbon in which no one of these elements dominates. All suborders have two syllable names.

Great Group: Haplorthods.

These are more or less freely drained Orthods of midlatitudes that have an albic and spodic horizon or, commonly, have only a spodic horizon below an Ap horizon (plowed layer). The spodic horizon may rest on a lower sequum that has an argillic horizon (layer of clay accumulation), or on relatively unconsolidated materials, or on rock. All great groups have three or more syllables in their name.

Subgroup: Entic Haplorthods.

These are soils which:

a) Do not have argillic horizons below the spodic horizon.

b) Do not have mottles in the spodic horizon, due to water table fluctuations.

c) Do not have an horizon 15cm thick (6"), below the spodic horizon or within 1m (40") of the surface, which has a brittle matrix.

d) Do not have a lithic contact within 50cm (20") of the surface.

e) Do not have a black intermittent upper subhorizon that has a ratio of free iron (elemental) to carbon that is less than 0.2.

f) Have less than 6% organic carbon in the upper 10cm (4") of the spodic horizon.

g) If a plow layer exists and extends into the spodic horizon it must have at least 1.2% more organic carbon than the spodic horizon.

In parts of the United States where mean annual soil temperature regimes are frigid, less than 8° C (47° F), the albic horizon (light colored horizon) of these soils commonly is prominent. All subgroups have at least two capitalized words in their names.

Family: sandy, mixed, frigid, Entic Haplorthod.

sandy - implies that the texture of the fine earth is sand, loamy sand or coarser, but not loamy very fine sand or very fine sand or finer; rock fragments make up less than 35% by volume.

mixed - implies that there is less than 40% of any mineral other than quartz or feldspars.

frigid - implies (1) that the difference between the mean winter and summer temperatures at a depth of 50cm (20") is greater than 5° C (9° F) and, (2) the mean annual soil temperature is less than 8° C (47° F).

Series: Rubicon.

For the official series description see Appendix I. This outlines the specific, narrow range of soil properties characteristic of this class in the lowest category of Soil Taxonomy. The name is from a geographic feature near the place it was first recognized.

Type: Rubicon sand.

This is a kind of phase of the soil series, and implies that the plow or surface layer is sand.

In Michigan, as an aid to interpreting the soils information for land use purposes, similar soil series are grouped into what are known as soil management groups. These groups are based on soil properties to depths of 150cm (5 feet), and are designated by a number and letter combination. The number indicates the profile texture and the letter indicates the natural drainage class. The numbers range from 0 to 5, where 0 represents the fine clays (more than 60% clay) and 5 represents the sands. The letters are "a" for well drained, "b" for imperfectly drained, and "c" for poorly drained. Some soils are composed of strata with contrasting textures. In this situation a fraction instead of a whole number is used. For example, a loamy sand material 50 - 100cm (20 - 40 inches) thick over clay loam to loam, on a well drained site would be classified as 4/2a. For the sandy soils a decimal system is used to indicate the degree of profile development. The numbers range from 5.0 to 5.7, where 5.0 represents a sand with a well developed profile and 5.7 differs by having a very poorly developed soil profile. Rubicon sand is in the soil management group 5.3a.

The above information, plus Rubicon's suitability for timber production, can be found in any soil survey in Michigan where the Rubicon series has been mapped.

Site

Site in its narrowest sense is that area where a stand, or group of trees, is growing. It has been defined in many ways by many researchers working with site and site quality. Heiberg and White (1956) credit Tansley as proposing an acceptable concept of site, "the sum of the effective conditions under which the plant, or plant community lives." Tansley, an ecologist, used the term "habitat" which is equivalent to the foresters term "site". Rowe (1953) in describing the more dynamic and holistic concept of site has found it to be "the complex interrelation and interaction of all features, inorganic and organic, past and present, which have resulted in the given forest stand". This idea parallels closely the ecologists idea of ecosystem. The forest scientist, however, is primarily concerned with the forest tree segment of the ecosystem (Spurr, 1964).

Site has been defined by many others, e.g. Carmean, 1975; Thomas and Burroughs, 1973; Husch, et al., 1972; Coile, 1952; Hills, 1952; etc. From their definitions two senses of site evolve: (1) as an area for supporting tree growth and, (2) as the capacity of that land to produce a forest stand. The latter sense, or concept of site, is termed site quality. Absolute site quality is theoretically measured by the maximum amount of wood produced upon an area by forest trees (Spurr, 1952). It is this concept of site, that of productivity, which is of primary concern to the forest manager.

LITERATURE REVIEW

Importance of Site Quality

A survey of industrial forest managers by DeBell et al. (1977) emphasizes the need for intensive forest management. In summary their survey showed that "use of most cultural practices is increasing markedly, and that anticipated investments in such practices are estimated to increase annual harvests through 1985 by 14 percent above the 1970 level...." It is important then, for intensive forest management, to be able to accurately estimate the potential of an area to grow trees as well as its relationship to the management of the trees to be planted. The productivity of a site for tree growth is usually evaluated on a stand basis. Considered in this way, site quality expresses the average productivity of a designated land area for growing forest trees (Husch, Miller, and Beers, 1972). The relationship of site quality to the growth of forest trees is a difficult one to measure. The factors of the site and the plants themselves are interacting and interdependent, making it difficult to assign single cause and effect relationships. What then, should or can be measured? In general, site quality can be evaluated in two ways: (1) by measuring one or more individual site factors which are considered closely associated with tree growth and/or,

(2) by measuring some characteristics of the trees or lesser vegetation considered sensitive to the sum total of the individual site factors (Spurr, 1952; Husch, Miller, and Beers, 1972).

Hills (1952) cautions that the site is not merely the sum of its parts, rather, it is "a whole which is something more than the sum of its parts." In his holistic approach to the evaluation of site, Hills integrates the complexities of "climate, relief, geological materials, soil profile, ground water, and communities of plants, animals and man".

Carmean (1975) believes that the holistic approach should be used with caution because an integration of the various factors of the environment and vegetation at each level of classification makes the system difficult to comprehend. Arbitrarily rating climate, moisture and nutrients is questionable; as a result, the various "moisture regimes" are not well defined by means of standard quantitative soil moisture methods.

Circumventing these inherent problems of the holistic approach other researchers have elected to examine site quality indirectly by measuring the sites' observable characteristics and their effect on wood production, and/or directly by measuring the total quantity of wood produced as a reflection of the site factors. Comprehensive reviews of their site research were published by Coile (1952) and more recently by Carmean (1975). In summary, indirect factors affecting site quality are: climate, topography, landform type, geographical location, activities of man and other organisms, lesser and competing vegetation, quality of seed or nursery stock and soils. Of the above factors, soils have been the most extensively studied because they are the medium on which the trees grow. Its properties are quantitatively defineable and are relatively stable. The relationship of the other factors such as climate, seed or nursery stock quality, etc., are either too difficult to measure, too unstable or are so general in nature as to have little practical significance. Direct measures of site quality are: vegetative growth, growth patterns and associations, the volume of wood produced, and height growth at a given age as an index of site quality. Recently, site research has been facilitated by the use of computers and hopefully in the future the more complicated relationships of site quality will be understood.

Wambach and Lundgren (1965) recognize site quality as the basic silvicultural variable. They credit Davis with the following:

> The forest manager should be site-conscious....Site quality has a profound effect on the volume, value and species of timber that can be best grown on an area. It affects regeneration and cultural practices such as cleaning, thinnings, prunings, and improvement cuttings. Management practices should be related to site.

Perhaps site quality can best be thought of in terms of economics. Forest management for timber production in the United States is profit oriented and the ultimate goal of decision making is to use the land as effectively as possible to produce maximum economic return (Ralston, 1958; Mader, 1968).

Establishing a site's quality indicates to the forest manager what to expect from the land. For example, Cooley (1970) found that cone production and growth were increased more by heavy thinning than by fertilizing in 53- to 55-year-old natural red pine stands growing on medium sites and in a 20-year old stand on a good site. Mason and Tigner (1972) studied an outbreak of lodgepole needle miner in central Oregon and found that the degree of infestation is influenced by a combination of environmental and physiological factors that vary significantly under different forest-site conditions.

Total Site Factors Affecting Site Quality

Site in itself is not just one factor nor is it the sum of all factors; rather, it is the sum of all the effective factors (Heiberg and White, 1956). There are three basic methods used to evaluate site. One method uses the volume of wood produced, another uses the height growth at some specified age, and lastly, one based on plant indicators.

The mean annual yield for normally stocked stands at the culmination of growth has long been considered the ideal measure of site quality (Spurr, 1952). In the site study of red pine plantations initiated by Mader and Owen (1961), of the Department of Forestry and Wildlife Management at the University of Massachusetts, an attempt was made to consider different aspects of growth to determine if the correlations with site factors differed depending on the growth measure used. Better correlations occurred using periodic volume growth estimates than with total height at 25 years, periodic height growth, or volume at 25 years. In later studies, Mader (1963 and 1968), again found that cubic foot volume growth curves appear to be one of the most useful means for making growth comparisons.

The basic assumptions made by those who advocate the use of measured volume production as the most exact means of site evaluation differ in several respects from those who use height growth. The major assumption is that height growth and volume growth are not necessarily directly related. Another assumption is that when differences in volume production measured in well stocked stands do not agree with differences in observed height growth, these variations are not caused by density factors or lack of full production on the site but are, in fact, real differences in productivity, and therefore height growth is basically unable to fully reflect differences in volume growth potential (Mader, 1963).

According to Carmean (1975), when adequate yield information is lacking, as is the case for many species in the United States, site index has been used to considerable advantage as an indicator of the forest land capability. Site index is simply the height of the dominant and codominant trees at a reference age usually 50 or 100 years. The height of free-grown trees of a given species and of a given age is more closely related to the capacity of a given site to produce wood of that species than is any other one measure. The height growth of the dominant and codominant trees has usually been taken as representative of stand height for site index work. Because site index is so important for both directly and indirectly estimating site quality, forest researchers and forest managers should understand that even when suitable dominant and codominant trees are available, the accuracy of site index estimates may be affected by several stand and tree conditions. Furthermore, an understanding of the methods used for constructing site index curves is important. The reason is that the kind of data and the computation methods used will determine the accuracy of site index curves, and thus, determine the precision of the site index estimations (Husch, 1963; Spurr, 1964; Carmean, 1975).

Site index is not a foolproof method and its weaknesses are well known. First and foremost, the technique is sound only if the average site quality is the same for each age class. Second, it is assumed that the shape of the height-growth curve is the same for all sites. Third, it cannot be safely used on stands less than 15 to 20 years old. Fourth, the terms dominant and codominant are subjective and two foresters may differ widely in their concept of what constitutes dominant and codominant trees. Fifth, it is difficult to see the tops of trees in a tall and dense stand and it is therefore, difficult to measure their heights accurately. Finally, silvicultural practices such as thinning may also change the average height of the dominant and codominant trees without, of course, changing the actual site quality (Spurr, 1952 and 1955; Wakeley and Marrero, 1958).

Stem analysis is another method of arriving at site index. Simply, it is the felling and sectioning of a tree; counting the annual growth rings and measuring the diameter at each cut surface. From this information the past development of a tree's height and age can be determined. This method too, is not without its weaknesses. First of all, it is the means of determining the past growth of individual trees and not a forest stand. Secondly, tree rings represent springwood and summerwood which are presumed to be produced every year, but this is not always the case (Spurr, 1952). Also, the true relationship of height and age may not be accurately represented if the discs are taken at a uniform distance apart because the height from which the disc was taken will frequently not coincide with the total height of the tree at any given age.

Many stands suitable for site index measurements may not contain the tree species for which the site estimates are desired. Suitable dominant and codominant trees of several species may be present, but no useable trees of the particular desired species may occur. For such stands we can use the tree species actually present for estimating site index. Species comparison graphs can be used to convert the site index of the species present to the site index of the desired species. Comparison graphs and site index ratios have been prepared for several forest species in various parts of the United States (Doolittle, 1958; Della-Bianca and Olson, 1959; Carmean and Vasilevsky, 1971; Carmean, 1975).

For tree species that have limbs showing distinct annual whorls the cumulative length of three to five internodes beginning at breast height has been suggested as a measure of site quality particularly for young stands (Ferree et al., 1958; Wakeley and Marrero, 1958; Day et al., 1960). This method has many advantages: (1) it does not require curves of height over age for direct comparison of sites in plantations of different ages; (2) it is not affected by the tree's establishment period; (3) total age or total height need not be known, therefore errors due to their measurement can be eliminated; and (4) it can be measured easily and rapidly (Wakeley and Marrero, 1958). Disadvantages of the method include the effects of short term climatic fluctuations, and the fact that sometimes the early growth of a stand does not accurately reflect later growth particularly when 80 to 100 year rotations are used (Alban, 1972; Carmean, 1975).

Trees as well as the lesser plants comprising the forest understory are all part of the vegetation which can be used to estimate site quality. For this discussion, vegetation will refer to the non-tree segment of the forest flora.

The use of indicator plants, or phytometers, as a means of estimating site quality is based on the theory that certain key species in the forest reflect the overall quality of the site (Husch, 1963). Although the understory plants are apt to be influenced by stand density, past history, and the composition of the forest they have a narrow ecological amplitude and therefore, are useful as site indicators (Spurr, 1964). Husch, et al. (1972) point out that when using phytometers to estimate site quality care should be taken to keep the relationship on broad terms as this method was developed in boreal forests where the stands are extensive and the tree species few.

Using vegetation as an indicator of site quality has not been widely accepted in the United States (Carmean, 1975). Several criticisms have been made of this method which may partially explain why it has not been widely applied in the United States (Coile, 1938): (1) many site types are closely related to features of geology, soil and topography thus land classifications could be based on these features alone rather than on understory vegetation; (2) on similar soils the kind of overstory tree may have a pronounced affect on the understory plants; (3) trees often have deeper root systems than the understory plants thus deeper soil horizons may affect the tree and have little or no affect on the indicator plant; (4) stand density affects the understory plants by controlling the amount of sunlight which reaches the forest floor; and (5) many indicator plants are not evident during the dormant seasons and thus cannot be used.

Mensurational methods have been proposed for uneven-aged stands and for stands that lack trees suitable for directly estimating site index using conventional methods. For example, Gevorkiantz and Scholz (1944) in studying the oak forests of the Upper Mississippi Valley found that the acceptable site index relation between age and height of the dominant trees - was not applicable. They showed that the product of the average basal area and average height of the dominant trees when used as an index gave more reliable results, especially for stands which were below normal stocking.

Using the soil series as a method of estimating site quality has met with limited success. Shetron (1969) has found that forest managers would be able to estimate site quality for jack pine on certain soils (Grayling, Graycalm, Montcalm, and Deer Park) whereas on other soils (AuGres, Croswell, and Rubicon) they could not. For the later soils, he suggests refinements be made, especially in depth to mottling in the AuGres and Croswell soils.

van Eck and Whiteside (1963) and Shetron (1969) have found that site index is greatest on well drained management groups 3.0a and 4.0a but it decreased as the soil texture became finer or coarser. The data presented by Shetron showed that the site indexes of jack pine, sugar maple, red oak and big tooth aspen all followed this general trend.

Studying red pine in northern lower Michigan, van Eck (1958) found that site indexes varied little over a wide range of moderately coarse to fine soil profile textures, but showed considerable variation between soil series within the coarser textured groups. Studying other tree species in the same area, Shetron (1969) found that the soil series of the coarser textured groups only accounted for part of this variability.

Individual Site Factors Affecting Site Quality

Another approach to evaluating site quality is to examine one or a few factors considered to be important. Much work has been done in this area and many reviews of the literature, summarizing the results, exist. A review of the early literature was presented by Coile (1952) and, of the more recent literature by Carmean (1975).

Many factors of the site such as soil, climate, geographic location, altitude, stock quality, and others affect site quality. Of all the factors, soil has received the most attention because it is the principle medium in which the trees grow and its properties are relatively easier to examine and quantify (Locke, 1941). Mader (1961) adds that the "understanding of the influence of soils on growth rates and patterns of forest stands is essential to obtain maximum production from forest land." Coile (1952) however, points out that if "all forest land were covered with well-stocked stands of sufficient age for the entire solum and upper stratum to have affected their growth, there would be little practical need for studying the relation between soil properties and growth because the volume of wood per acre at a given age would be a direct measure of productivity..." Since most forests are not of such stocking or age the obvious need to evaluate site factors arises. Which site factors are most important depends on the area and species in question. In general, it can be said that factors which affect the soil moisture and nutrients, and the topography are the most important.

The effect of soil moisture on site quality cannot be over emphasized. White (1958) in his discussion of available water states that, "except in situations of acute nutrient deficiency, a scheme which would estimate the amount and distribution of available water during the growing season would probably most accurately evaluate site."

Soil texture is extremely important in affecting site quality because it has a major influence on the soil moisture, soil chemical, and soil air relationships to root development (Heinselman and Zasada, 1955; Spurr, 1964).

The effect of water table depth has been investigated by many researchers and found to correlate well with tree growth (Wilde and Pronin, 1949; Mader, 1968; Page, 1976). Studying the depletion of subsoil moisture by apple orchards in Nebraska, Wiggans (1964) estimated that in 17 years the trees utilized 70 to 75 inches (178 to 190cm) more water than they were able to secure from annual precipitation. The additional water was removed from the soil to depths of 25 to 30 feet (7.6 to 9.1m).

Related to ground water depth is the soil drainage class. Barrett and Goldsmith (1973) found that the most important factor in predicting white pine growth was the amount of available moisture as measured by drainage class. Mader and Owen (1961) found similar results for red pine in Massachusetts.

Any characteristic of the soil which affects water movement through the profile also has a pronounced effect on site quality. Hannah and Zahner (1970) found that the site index for natural jack pine and big tooth aspen stands, and stem wood production in red pine plantations are significantly higher on soils with prominent texture bands, whether pedogenetic or nonpedogenetic, than on soils where bands are absent or are weakly developed. White and Wood (1958) also studying red pine plantations found marked variation in tree growth as a result of a fine soil layer. Much better growth resulted when the fine soil layer was six feet or less in depth. In Saskatchewan, Canada, Rowe (1953) found that a frozen soil layer was able to affect soil drainage by creating a perched water table as late as July.

Other factors have been found to affect soil moisture to varying degrees. Some of the more important factors are: rainfall, organic matter, Ap horizons as they affect organic matter, and free iron and organic carbon (Minckler, 1943; Wilde and Pronin, 1949: Heinselman and Zasada, 1955; Mader and Owen, 1961; Mader, 1968; Shetron, 1974; Carmean, 1975; Page, 1976).

Much of the work done with soil nutrients has either been done in conjunction with soil moisture or as a result of fertilization. Very little has been done with the naturally available soil nutrients themselves. In a qualitative manner Coile (1952) described soil nutrients as "perhaps a limiting factor in forest growth on deep, excessively drained, siliceous sands in humid climates." This is in harmony with Heinselman and Zasada (1955) who concluded that aspen sites are apt to be poorest on sandy soils, where nutrient levels are low, and where moisture-retaining capacity is also low. They also state that soil reaction, or pH, is probably not a significant site factor for aspen.

More recently, Page (1976) studied the relationships between site index of black spruce and balsam fir, and soil and topographic characteristics in two areas of Newfoundland. After examining 103 variables from 300 sample plots he found that "no one site factor was sufficiently closely related to site index for prediction purposes; in most cases six- or eight-variable equations were necessary to account for more than 60 percent of the observed variation." He also found that the soil nutrient status was not as important as soil moisture but it was more important than effects of topography. Of the soil chemical properties he tested, the following were found to be the most important (in order of decreasing importance): total nitrogen (percent by volume) at 2.5cm (1") depth; C/N ratio at 30cm (1 ft.); total N (percent by volume) at 30cm (1 ft.); and pH at 15cm (6").

When he compared measured site index values to predicted values he found no significant differences.

Topography also affects site quality to a large extent because it influences the soil's physical and chemical properties (Spurr, 1964).

In Newfoundland, Page (1976) found slope percent and the change in elevation to be the most important topographic factors affecting the site quality for spruce and fir. This agrees with many other studies that have found the following topographic factors to be significant (Carmean, 1975); slope position, degree of slope, slope exposure, elevation, distance to bog, and latitude.

The geomorphology and geology of an area is also important. Lutz (1958) points out that landforms and rocks are intimately related to parent material of the soil and therefore indirectly affects its texture, structure, and nutrient status. Finally, once the factors affecting site quality have been established they must be organized and presented so that they will be utilized to their maximum benefit. The soil survey accomplishes this end. Summarizing the soil surveying methods used by the Weyerhaeuser company in the Pacific Northwest Steinbrenner (1973) says, "the soil survey provides information that is basic to sound forest management and its use can only increase as more interpretive detail is developed." Retzer (1958) discussing soil as a factor affecting forest vegetation states that "soil taxonomic units represent the most effective way of stratifying significant physical and natural differences in the landscape."

STUDY AREA AND PROCEDURES

A) Nature of the Study Area

The study area was confined to two counties, Grand Traverse and Wexford, in the northwestern part of the lower peninsula of Michigan. More specifically, 3 plots were located in the southeastern corner of Grand Traverse county and 7 plots were located in the eastern half of Wexford county (See Figure 1). Exact locations and descriptions of each plot can be found in Appendix IV.

Geology

The last ice sheet of the Wisconsinan ice age, or glacial period, formed the surface features of these two counties. Between 23,000 and 12,500 years ago, when this ice sheet melted, it left behind a series of moraines, outwash plains, lakes, and beds of former lakes, and abandoned drainage spillways. Part of one of the most extensive moraine systems in Michigan called, the Port Huron moraine, extends across Grand Traverse county in an east-west direction forming the northern boundary of the lower third of the county. South of this moraine, in the southeast part of the county, is a sandy outwash plain on a high plateau. To the south of this outwash plain in Wexford county, there are other moraines which are bounded by other outwash or till plains that have been dissected by glacial spillways. A conspicuous

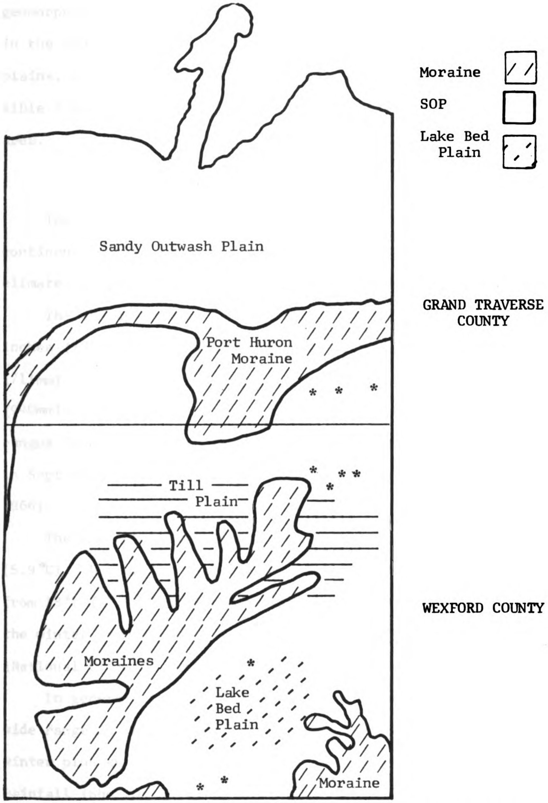

Figure 1. Outline of the Two County Study Area, its Surface Geology and Plot Locations.

* Plot Location

geomorphic feature in Wexford county is a former glacial lake in the southeast portion of the county. In general, outwash plains, which cover extensive areas in both counties, are responsible for the prodigious amount of sandy soils found in the study area.

Climate

The climate of the study area is humid, cool, temperate and continental. The effect of lake Michigan is minimal and the climate, therefore, is considered uniform over the entire area.

The average annual precipitation from 1936 to 1973 was 31.4 inches (798mm). One year in 10 will receive less than 28 inches (711mm) and one year in 10 will receive more than 37 inches (940mm). The average monthly precipitation throughout the year ranges from 1.5 inches (38mm) in February to 3.4 inches (86mm) in September (National Climatic Center, no date; Weber, et al., 1966).

The average annual temperature from 1931 to 1973 was 42.6 °F (5.9 °C). During the year the average monthly temperature ranged from 18 °F (-7.8 °C) in February and 67 °F (19.4 °C) in July. During the winter, average snow fall is 70 to 80 inches (178 to 203cm) (National Climatic Center, no date; Weber et al., 1966).

In general, the climate of the area is characterized by a wide range in temperature between the extremes of summer and winter plus an irregularly distributed and relatively abundant rainfall (Shetron, 1969).

Vegetation

Much of the area today is either being farmed or is forested. According to Weber et al., the trees of the area can be placed into 3 groups: (1) sugar maple (*Acer saccharum*), beech (*Fagus grandifolia*), elm (*Ulmus americana*), and other hardwoods on the loams, sands with well developed spodic B's, and more fertile soils; (2) white pine (*Pinus strobus*) and red pine (*Pinus resinosa*) on the sandier, less fertile soils; and (3) white cedar (*Thuga occidentalis*), balsam fir (*Abies balsamea*), and black spruce (*Picea mariana*) in the swamps (Weber et al., 1966).

Less common trees are: black oak, white oak, quaking aspen, big tooth aspen, balsam poplar, ironwood, yellow birch, paper birch, black cherry, white ash, black ash, basswood, jack pine, tamarack, hemlock, and juniper (Weber et al., 1966).

After the original timber was harvested, large areas were burned; then, through natural seeding, were covered by stands of aspen, oak, pin cherry, and other trees.

The ground cover in the wooded areas consists of bracken fern, sweetfern, dogwood, sumac, and many others. Blueberries, black berries, raspberries, and strawberries grow in cutover areas or swamps that have not been burned (Weber, et al., 1966).

Soils

The soil taxonomy (Soil Survey Staff, 1975) defines soils as:

> the collection of natural bodies on the earth's surface, in places modified or even made by man of earthy materials, containing living matter and supporting or capable of supporting plants out-of-doors. Its upper limit is air or shallow water. At its margins it grades to deep water or to barren areas of rock or ice. Its lower limit... [is] ... to the not-soil beneath....

This concept of soil will be used for the remainder of this thesis.

Soil properties are the result of: (1) the parent material; (2) the climate; (3) organisms, both plants and animals, which live on or in the soil; (4) the topography; and (5) the length of time which has elapsed. Since this study involves a relatively small geographical area the above mentioned soil formation factors are considered uniform throughout the area. Their inter-relationships are complex and involved, and are beyond the scope of this paper. A more detailed discussion of these factors is presented by Buol, Hole and McCracken (1973), and by Jenny (1941).

Rubicon is the only soil series reported on in this study. The official series description of Rubicon can be found in Appendix I. (The series description for Graycalm is also in Appendix I for comparison). Some general comments on Rubicon follow.

The Rubicon series consists of deep, well drained soils formed in sandy glacial or glacio-fluvial deposits. The solum, including the A and B horizons, is generally 20 to 50 inches (50 to 130cm) thick. The degree of spodic horizon development is between that of Kalkaska and Grayling sands. Kalkaska has a dark upper spodic horizon more than 3 inches (7.6cm) thick and Grayling has little or no A2 or spodic horizon development. On poorer drained sites Rubicon is typically associated with Croswell, AuGres, and Roscommon soils. On well drained sites it is usually associated with Kalkaska, Grayling, and Montcalm soils.

B) Selection of Sites

To save a prodigious amount of field work it was necessary to obtain available forest cover type and soils information from both the United States Forest Service and the Michigan Department of Natural Resources prior to going into the field. On the basis of this information possible study areas were located. These areas were then examined in the field and, if they met the following criteria, were established as temporary plots:

1) Plantations had to be 20 years of age or older from seed and even aged.

2) Size of the plantations had to be large enough so that trees in a 1/10 acre plot were not influenced by edge affects.

3) The soil had to be Rubicon sand and be at least 1/10 acre in extent. This was determined on the basis of 5 auger borings to a depth of 5 feet (1.5m). If the first boring proved to be Rubicon sand it then became the plot center. Four additional borings were then made at the edge of the plot, one in each of the four cardinal directions (N,E,S,W).

If the above criteria were met, the area was then established as a temporary plot, and the next step was to collect the data.

C) Field Procedures

1) A soil pit was dug to a depth of 6 feet (1.8m) at the plot center, and the soil profile was described in the standard manner. The profile was then checked further to a depth of 10 feet (3m) or more with an auger. See Appendix IV for the descriptions and laboratory data and notes at each site.

2) Soil samples, of approximately 1 pound (500gms) each, were taken from each soil horizon in the upper 5 feet (1.5m) of the profile.
3) Basal area of the plot was measured from plot center with a 10 factor prism.
4) Five dominant and codominant trees nearest to the soil pit were felled and their heights measured to the nearest inch.
5) Each tree was sectioned into 4 foot (1.2m) lengths starting at one foot (.3m) above ground, with a one inch disc taken from the upper end of each 4 foot section.
6) The percent slope, aspect, plot position, and type of landform were recorded.

D) <u>Laboratory Procedures</u>

1) Soil textures were determined for each sample using dry sieve analysis techniques.
2) Soil samples were analyzed for the presence of P, K, Ca, Mg, and the soil reaction (pH), and organic carbon according to soil testing procedures for available nutrients, at the Michigan State University Soil Testing Laboratory.
3) The annual growth rings were counted and diameters inside bark were measured for each tree section.

E) <u>Computer Analyses</u>

Site index curves were developed from the stem analysis data by generating an equation which best explained the relationship of tree height to age. From this equation a family of curves were also derived (site index curves). This procedure in detail is:

1) The tree data from all plots were pooled.

2) Regression analysis, using the least squares method, was employed to generate several equations to represent the relationship of tree height and age. (Note; in using this method, Freeze (1964) states that the following assumptions must be made: (1) the data is from a population for which the variance is homogeneous i.e., the variance of the Y values (height) about the regression surface (regression line) is the same at all points or with all combinations of X values (age); (2) for the sample units the deviations of the Y values from the regression surface must be independent of each other, i.e., size and direction (+ or -) of the error for one unit should have no relationship to the size and direction of the error for any other unit in the sample, beyond the fact that they are from the same population; and (3) the X values are measured with essentially no error).

3) Covariance analysis was used to determine whether separate prediction equations should be used for each plot or whether all of the plots should be represented by a single equation. This procedure involves comparing the levels and slopes of the equations for each plot with the mean equation for all plots. This step was done mathematically and visually.

a) Mathematically the equations were tested as follows:

	df	Rss	MS
Total of individual plots (i)	df_i	Rss_i	MS_i
Total (all plots pooled) (t)	$-df_t$	$-Rss_t$	$-MS_t$
Difference (d)	df_d	Rss_d	MS_d

$F = MS_d/MS_i$

where;

df = Degrees of freedom

Rss = Residual sums of squares

MS = Mean square

$MS_i = Rss_i/df_i$

$MS_d = Rss_d/df_d$

If the computed F value was larger than the value of F, at the 5% level, in standard F tables, the individual equation should be used to represent the data because the individual equation has a siginificantly better fit.

b) The equations were tested visually by comparing the graphs of the individual plots to the graph of the mean curve. No curves were extrapolated beyond 5 years for which the data was available. (The above steps a and b are summarized in Appendix II, Tables C and E).

4) Each equation was subjected to analysis of variance. If the equation was not significant at the 5% level of probability it was rejected.

5) The equations were subject to a test of linearity to see if a straight line or quadratic equation would best fit the data. (This test is summarized in Appendix II, Table B.)

6) The equation which best described the mean relationship of height and age i.e., the equation with the largest coefficient of determination (r^2), was chosen to generate the mean curve. (These equations and their r^2 values are summarized in Appendix II, Table A).

7) The site index, that is, tree height at age 50 years, for each plot was determined from both the harmonized and the polymorphic curves developed from the data of this study and compared with site index curves developed for other studies.

8) Stepwise regression analysis was employed to screen site factors which were believed to influence site index. They are listed in Appendix III.

F) Volume Determination

The cubic foot volume for each tree was determined for 5 year intervals, by measuring the radius of those discs which fell at the end of a 16 foot (4.9m) log, i.e. discs cut at the heights of 1', 17', 33', and 49' (.3, 5.2, 10.0, 14.9m). The procedure is as follows:

1) The total average radius was measured to the nearest 1/10 inch.

2) The radius was measured for each 5 year's growth counting from the outside inward. (NB: The volumes calculated

for each tree may not be completely accurate because the discs were measured after considerable drying and in some cases slight cracking had taken place.)

3) The radial growth was then plotted on 10 squares to the inch graph paper. Height in feet was placed along the Y axis and twice the radius squared, $(2r)^2$, in square inches was placed along the X axis.

4) To organize the data it was tabulated in the following manner:

<u>TH</u> <u>DH</u> <u>r</u> <u>2r</u> <u>$(2r)^2$</u>

where,

TH = total height in feet at the age in question.

DH = disc height in feet. (The disc taken at 1 foot was placed on the X axis where Y=0).

r = radius inside bark in inches.

2r = diameter inside bark in inches.

5) A connecting line was drawn between two adjacent points such that a negative curve was obtained. A final connecting line was also drawn from the last data point to total tree height.

6) The total volume of the tree was calculated by multiplying the area under the curve (in square inches) by .5454.

7) The volume for each of the trees growing on each plot were averaged and the average volume was used to represent the plot.

8) Regression analysis was employed to express the relationship of volume and age in the same manner as was done for

height and age. A mean curve was developed by pooling the data of all trees.

9) A family of proportional curves were developed from the mean curve.

10) Volume at age 50 was determined from the above graphs.

11) The volume at age 50 thus determined was converted to a per acre basis by multiplying the volume per tree by 200 trees per acre. Two hundred trees per acre was used because plot 3, cut at age 50, was typical of the plots used in this study and contained 198 trees per acre.

12) Trees per acre was determined according to the following formula (after Hanson, 1975): Basal area/.005454 (Diameter outside bark at breast height)^2.

RESULTS AND DISCUSSION

The data from this study will be considered in two groups: the tree and the soil data.

Tree data

The height over age data from stem analyses were plotted as a scatter diagram in Figure 2. In order to group this data into meaningful management units site index curves were developed.

The first step in developing site index curves was to calculate the mean, or guiding, curve which best represents the relationship of all height over age determinations using regression analysis techniques. Two general types of linear equations were tested: straight line, $Y = a + bx$, and curvilinear, $Y = a + bx + cx^2$. A summary of the equations tested and their r^2 values is presented in Table I.

The equation which best fit the data was of the curvilinear, or quadratic, form:

$$Y = a + b(X_1) + c(X_2)$$

where,

Y = height

X_1 = age

X_2 = age squared or $(X_1)^2$

a, b, and c = constants

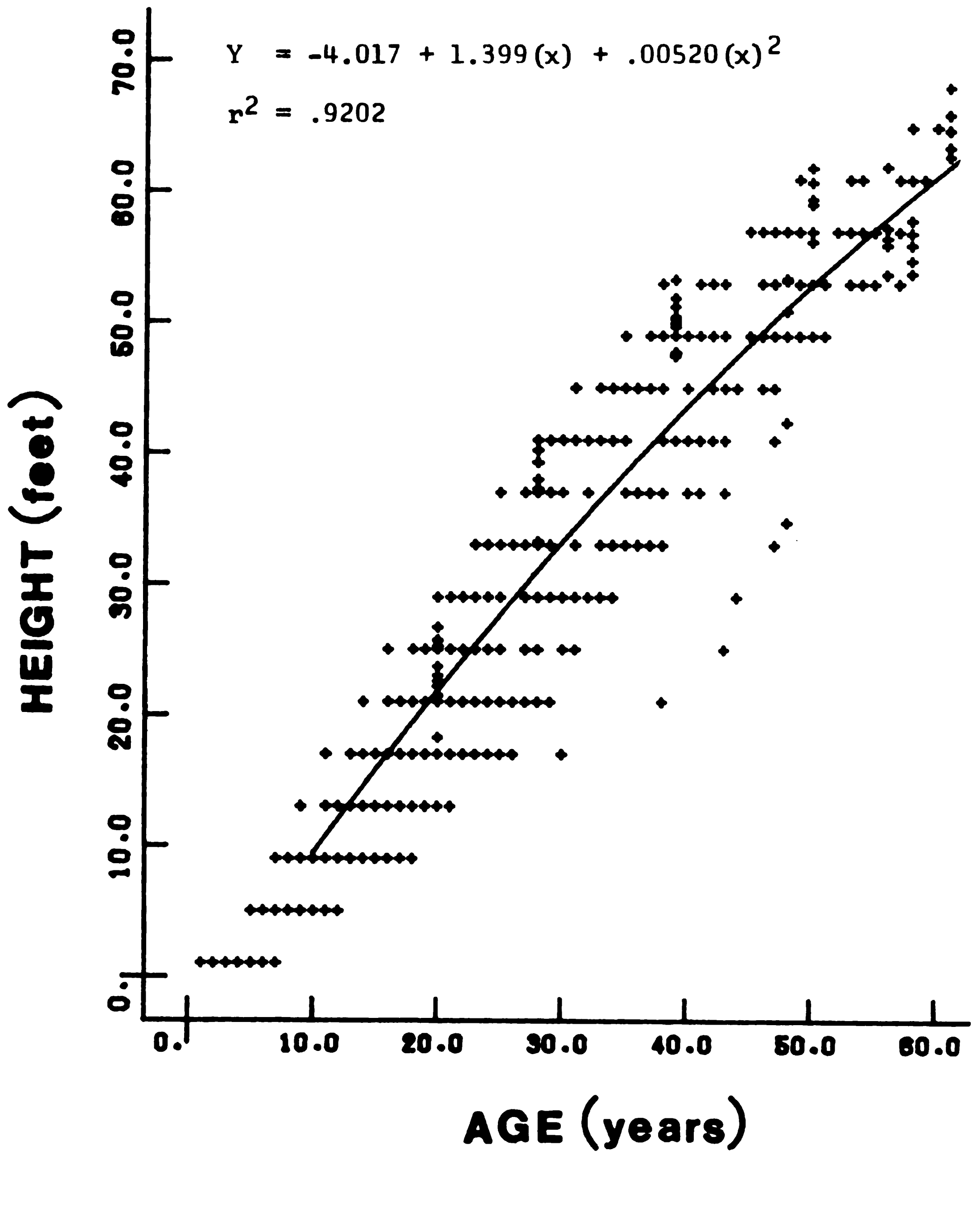

Figure 2. Scatter Diagram of Heights and Ages of All Red Pine Trees Sampled on Rubicon Sand.

Table 1. Summary of Equations Developed from the Pooled Data of

Table I. Summary of Equations Developed from the Pooled Data of Tree Height and Age.

Equation tested			r^2	CV	S.E. (feet)
$Y = a + bx$	=	$Y = -1.037 + 1.103(x)$	.91513	19.0	± 5.05
$Y = a + bx + cx^2$	=	$Y = -4.017 + 1.399(x) - .00520(x^2)$	.92023	18.4	± 4.90
$Y = a + b^1/x$	=	$\log Y = 3.492 - 7.313(^1/x)$	.64236	22.4	± 1.91
$Y = a + b^1/x + c^1/x^2$	=	$\log Y = 3.972 - 16.837(^1/x) + 13.884(^1/x^2)$	.87035	13.5	± 1.48

CV = Coefficient of Variation
SE = Standard Error

"a" was found to be equal to -4.017, "b" equal to 1.399, and "c" equal to .00520 (Table 1 and Figure 2). The standard error of the estimate was calculated to be 4.90 feet. A correlation analysis showed the multiple correlation coefficient (R) to be .95929. The multiple correlation coefficient is a measure of the degree of association of the estimated height with that of age and age squared. The multiple correlation squared, or coefficient of determination, is equal to .9202. This means that approximately 92% of the variation in height is associated with age and age squared. An analysis of variance showed the multiple correlation coefficient to be highly significant.

It can be seen that the curvilinear regression is more representative of tree height-age growth, and explains somewhat more of the association of height and age then does the straight line regression by comparing their coefficients of determination. The curvilinear regression explains more than 92% of the relationship while the straight line regression explains less than 92%.

Is this difference significant or is this relationship adequately explained by the straight line regression alone? A test of linearity showed that there is a significant curvilinearity in the regression (Appendix II, Table B). Therefore, the addition of the age squared term explained a significantly greater amount of the variation between height and age. This equation is graphed in Figure 2.

Because differences exist between plots, the question arises as to whether separate prediction equations should be used for each plot or could all of the plots be represented by a single e

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equation? An analysis of covariance indicated that there is a significant difference between the individual curves and the overall curves (Appendix II, Table C). This means that the data should not be represented by one overall curve because the amount of variation explained by the individual equations is significantly greater than that explained by the overall equation. This analysis tells us that in mathematical terms a significantly better fit will be obtained if more than one equation is used to describe the relationship of height and age. It does not tell us how many equations are necessary, nor if the differences are important in terms of current management objectives.

That more than one equation is necessary indicates that the growth patterns or growth rates are different between plots and polymorphic growth curves should be developed. These growth characteristics were checked visually and, in the case of growth rates, also checked by comparing the tangents or slope coefficients "b" of the individual plot equations. Each plot curve was graphed and compared to the mean, or overall, curve (Appendix II, Table E). These curves show that there are two groups of plots. One group of plots (3, 8, 9, and 10) growing faster then the mean curve of all plots and another group (1, 5, 6, and 7) growing slower than the mean curve. The two remaining plots (2 and 4) were growing similar to the mean curve and might be placed in either group. Regression equations were calculated for both groups. The best fit was obtained with the equation, $Y = a + bx + cx^2$, using plots 3, 8, 9, and 10 for the faster growing plots and plots 1, 2, 4, 5, 6, and 7 for the slower growing plots (Table II). These equations

Table II. Summary Table for the

Table II. Summary Table for the Equations of the Height and Age of the Faster and Slower Growing Groups of Plots.

	Equation							
	$Y = a + bx$		$Y = a + bx + cx^2$		$\log Y = a + b^1/x$		$\log Y = a + b^1/x + c^1/x^2$	
Plots	r^2	C.V.	r^2	C.V.	r^2	C.V.	r^2	C.V.
Set I								
3,8,9,10 (faster)	.9804	8.7	.9836	8.0	.7348	18.8	.9193	10.4
1,2,4,5,6,7 (slower)	.9436	16.0	.9438	16.0	.5890	24.4	.8508	14.7
Set II								
2,3,4,8,9,10 (faster)	.9800	9.6	.9815	9.2	.6982	21.7	.9126	11.7
1,5,6,7 (slower)	.9413	14.7	.9415	14.7	.5971	22.0	.8521	13.4

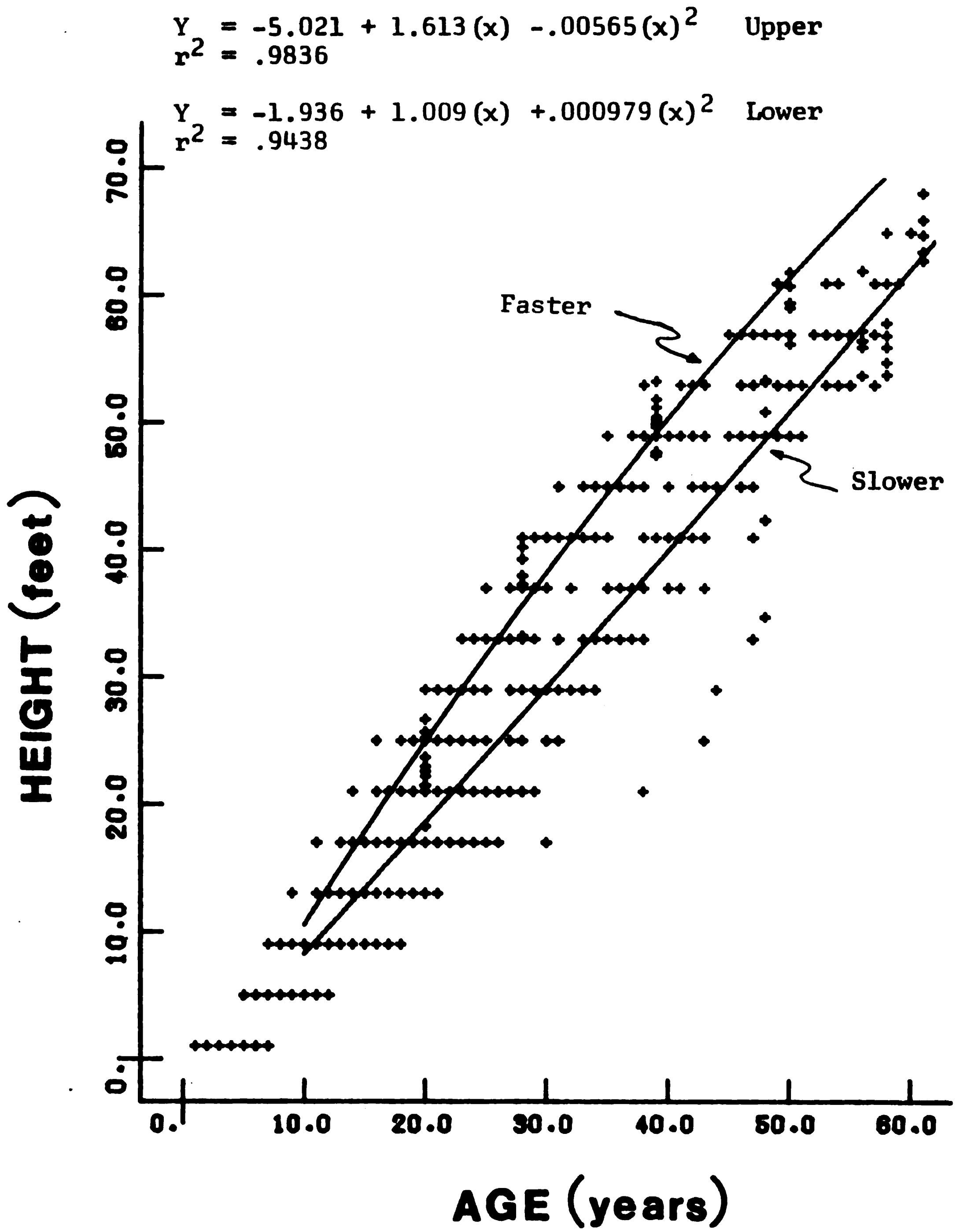

Figure 3. Mean Growth Curve for the Faster and Slower Growing Plots.

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were than graphed as shown in Figure 3. Again, the question was addressed as to whether separate prediction equations should be used for each plot within each group or could each group be represented by a single equation. As before, analysis of covariance showed that a significant difference existed between the individual and overall equations for each group (Appendix II, Table D). This means that the data of each group should not be represented by one equation.

However, before the data was further subdivided an attempt was made to see if the first subdivision of the data, that is, dividing the plots into faster and slower growing groups, had resulted in any important improvements over the mean equation in terms of management. This was done by using the mean curves (the mean curve for all 10 plots and the mean curves of each group of faster and slower growing plots) as guiding curves for developing proportional site index curves. Using the mean equation for all 10 plots resulted in the standard harmonized site index curves (Figure, 4), whereas, using the mean curves for the two groups of plots resulted in the polymorphic site index curves (Figure 5). The mean curve for the 4 faster growing plots was used as the as the guiding curve for the higher site index classes of 60 and 70 while the mean curve for the 6 slower growing plots was used as the guiding curve for the lower site index classes of 40 and 50. The harmonized and polymorphic site index curves were then superimposed (Figure 6).

For site index classes 60 and 70 there is very little difference between the sets of curves. For site classes 40 and 50 some

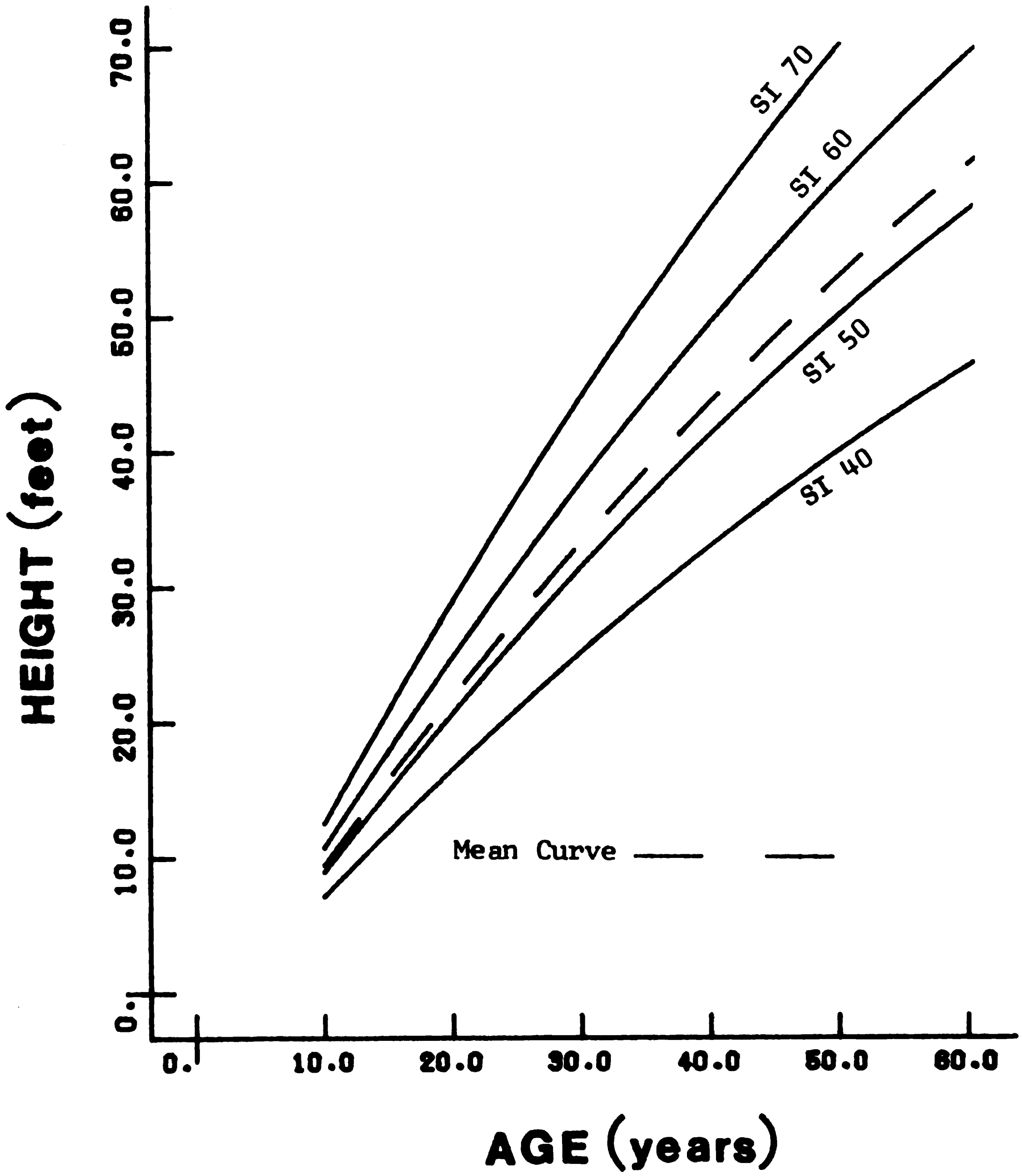

Figure 4. Harmonized Site Index Curves Using the Mean Growth Curve of All 10 Plots Combined as the Guiding Curve.

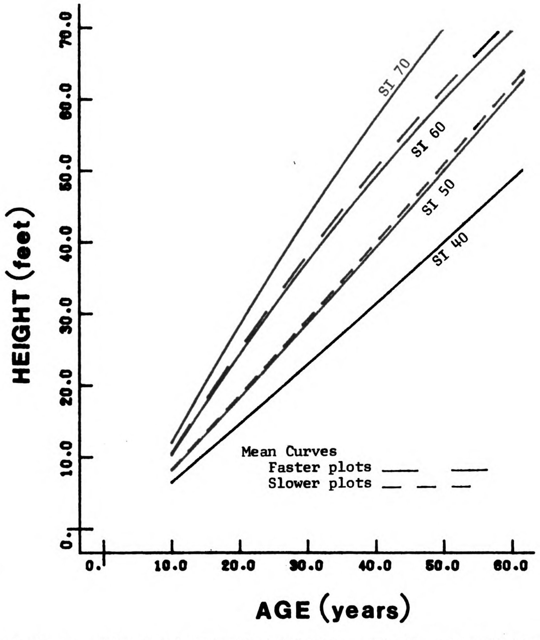

Figure 5. **Polymorphic Site Index Curves. The Mean Growth Curve of the Faster Growing Plots was Used as the Guiding** Curve for Site Index Classes 70 and 60. The Mean Growth Curve of the Slower Growing Plots was Used as the Guide Curve for Site Index Classes 50 and 40.

Figure

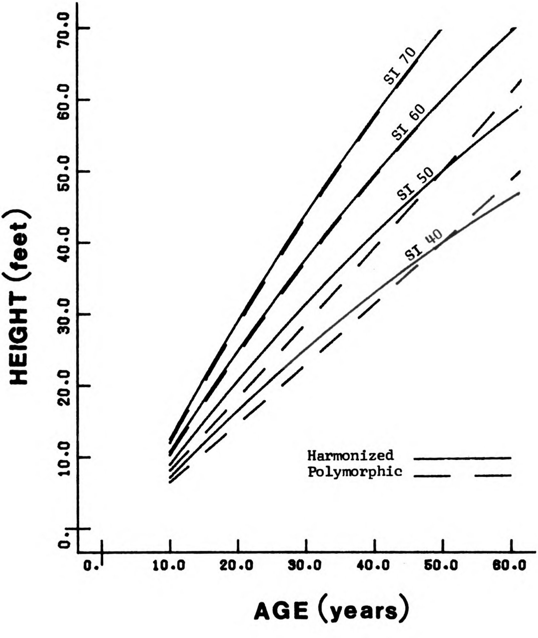

Figure 6. Comparison of Polymorphic and Harmonized Curves.

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differences exist especially when the stands are less than 35 years old. These differences however, are only as much as 5 or 6 feet. After age 35, and when the index curves become more accurate, the differences are less than 5 feet. Therefore, since the difference between the two sets of curves is always less than one site class, little advantage is gained by developing polymorphic site index curves.

As site quality is being measured in terms of tree growth, the comparison of their optimal growth rates is justified (van Eck, 1958). The optimal growth rate is equal to the slope, or tangent, of the regression equation and is referred to as the "b" coefficient. Table III is a list of the "b" coefficients. The largest coefficient is 1.455 and the smallest is 0.962. This means that the fastest average growth rate was approximately 1.5 times as fast as the slowest. However, 70% of the plots fall within the range of 1.103 to 1.372, which means that for most plots the fastest average rate of tree growth is 1.2 times as fast as the slowest.

After observing the small differences between the two sets of site index curves, and the small differences between the average growth rates of each plot, it can be said that in terms of current management objectives, no important advantages are gained when more than one equation is used to describe the relationship of height and age, Table IV (This Study). Further, since the first subdivision of the data into faster and slower growing groups was unimportant, any further subdivision of the data would not bring any further advantages.

Table III. The "b" Coefficients, or Slope Constants, of the Straight Line Equations for the Individual Plots.

Plot	b
1	0.962
2	1.286
3	1.313
4	1.285
5	1.114
6	1.103
7	1.212
8	1.455
9	1.436
10	1.372

Table IV. Comparison of Red Pine Site Index Val

Table IV. Comparison of Red Pine Site Index Values of Plots obtained from Curves Developed for This and Other Studies.

		This Study		van Eck [1]		Shetron [2]	Gevorkiantz [3]	
Plot	Age	Harmonized	Polymorphic	Harmonized	Polymorphic	Harmonized	Harmonized	Range
1	48	48	48	49	48	48	49	1
2	20	55	59	51	66	54	60	15
3	50	60	60	60	60	60	60	0
4	20	55	59	51	66	54	60	15
5	58	49	47	52	52	48	49	5
6	56	51	50	53	54	51	50	4
7	61	55	55	61	61	53	56	8
8	28	64	64	57	65	67	65	10
9	39	63	63	59	61	64	63	5
10	39	60	61	57	59	61	62	5
11[4]	25	(70)	(70)	(62)	(72)	(70)	(58)	
12[4]	25	(80)	(81)	(66)	(77)	(81)	(70)	
	Ave.	56.0	56.6	55.0	59.2	56.0	57.4	
	S.D.	± 5.6	± 6.2	± 4.3	± 6.1	± 6.6	± 6.0	
	C.V.	10.0	11.0	7.8	10.3	11.8	10.5	

1 After van Eck, 1958.
2 After Shetron, 1972, unpublished report for the Mosinee Paper Company, Wisconsin.
3 After Gevorkiantz, 1957.
4 These are site index values for two Graycalm plots. The site index averages and standard deviations do not include these plots.

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Site index values were determined for each plot by reading them directly from the harmonized and polymorphic site index curves developed for this study (Figures 5 and 6). The site indexes for each plot were also determined from other published and unpublished site index curves by Gevorkiantz, Shetron, and van Eck, in Table IV. When all 10 plots are combined it can be seen that the various site index curves yield similar average site index values for red pine on Rubicon sand. On a plot to plot basis however, the site index values are not always similar and this is reflected in the standard deviations and the ranges among the site index curves for individual plots (last column, Table IV). The range in the predicted values agree to within one site class at age 50 years but, disagree before and after age 50 with the amount of disagreement increasing as the plots become younger or older than age 50. However, when van Eck's curves (developed for different soils) are omitted the ranges with the other curves are within ± 3 feet, or one site class. Spurr (1955) and Alban (1972) have also found that red pine has a relatively uniform growth pattern over a wide range of sandy soils.

Because red pine is not growing on the same soil in each of the aforementioned site index studies the question arises as to the uniformity of the growth patterns. van Eck has studied red pine growth on several soils ranging in texture from loams to sands. His published growth curve represents the average of these different growth patterns. Figure 7 compares van Eck's average curve to other studies which concentrated on red pine growth on the sandier soils. After age 35, van Eck's curve bends more sharply than the others.

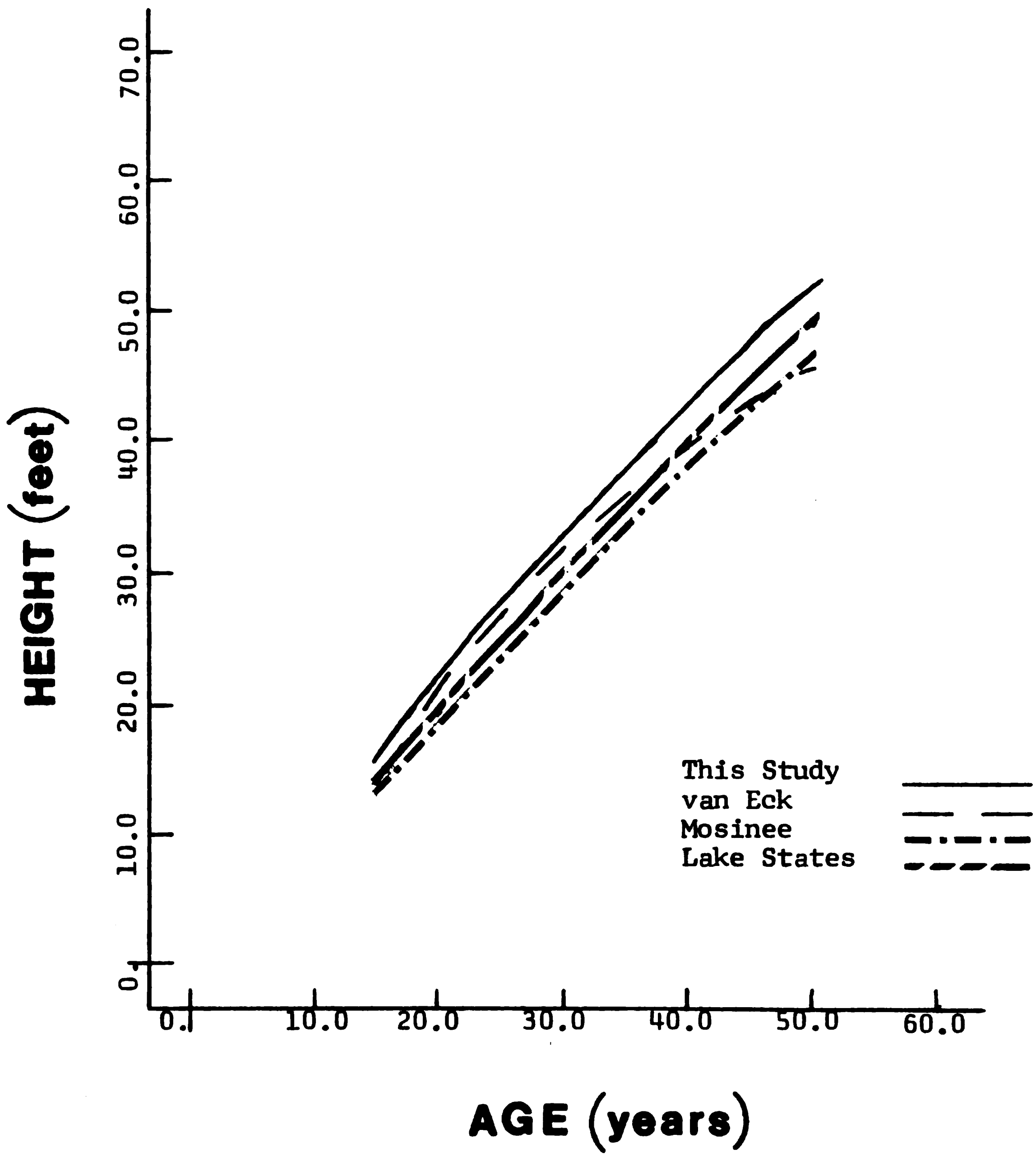

Figure 7. Comparison of the Mean Growth Curves from This and Other Studies.

van Eck has shown that this sharp bend is characteristic of the loamy sites and is distinctly different from the sandy sites. It can be seen then that any site index curve developed for red pine must describe the different growth patterns red pine exhibits on the different soils or groups of similar soils.

Polymorphic growth curves were developed by van Eck to more adequately describe the growth patterns of red pine on the different soils. A comparison of the polymorphic curves of van Eck's study and this study, in Figure 8, show again that the growth rates of red pine differ widely between the two studies. There is a marked difference especially in the early ages. In his discussion, van Eck states that the growth pattern of red pine on Rubicon sand is different than his published curves.

Another method which can be used to evaluate site quality is total volume growth. The comparison of volume growth for this study has 3 shortcomings: (1) the stand density, or basal area, varies widely from plot to plot, (2) the tree ages on each plot were not identical, and (3) some plots had been thinned and others had not. Little can be done about the first problem. Problems 2 and 3 however, were overcome by constructing volume growth curves for each tree. In this way, all trees could be compared at the same age, either before they were thinned or, after the thinning age had been attained, the prediction of volume growth for the unthinned plots was based on the volume growth pattern of the thinned plots. For this study, age 50 years was used as the reference age because it was the age at which the tree heights were compared. Caution should be used when interpreting the volume data because the wide range in basal

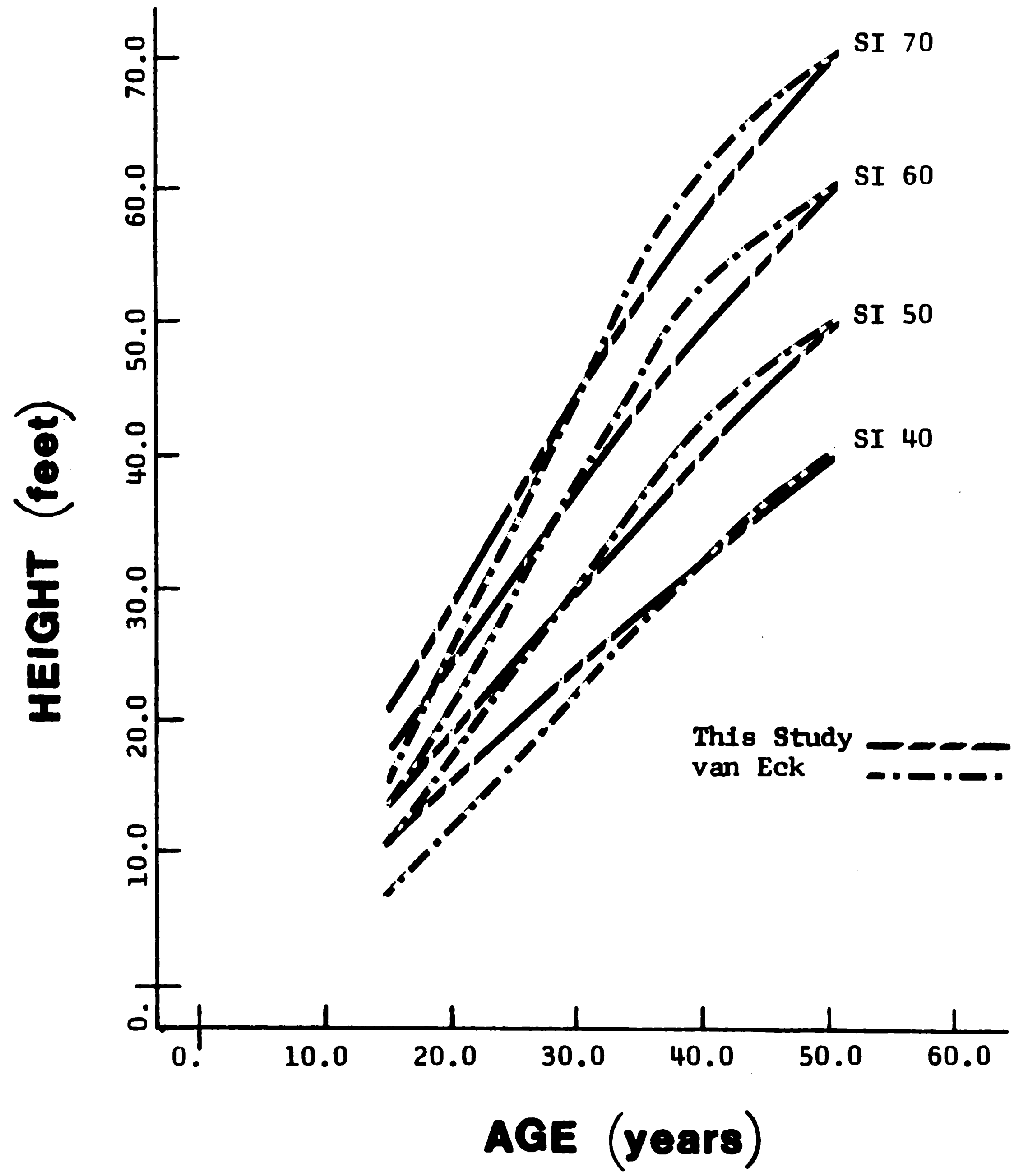

Figure 8. Comparison of the Polymorphic Site Index Curves developed for This and van Eck's Study.

area renders equal comparisons impossible and secondly, individual tree volumes are greatly affected by stand density.

Volume growth should be compared on a per stand, or per acre basis and not on a per tree basis, because as Spurr (1952) states:

> ...the factors which affect growth per tree are not necessarily the same factors that are most important in affecting growth per acre. The diameter and other dimensions of the individual tree are greatly influenced by the competition of its neighbors. The effects of root and crown competition frequently outweigh other factors related to growth of a single tree. On the other hand, growth per acre is very largely a function of site quality. On a given site, a dense stand of many small trees will frequently have about the same volume as a fairly open stand of the same age consisting of a few large trees.

Since basal area per acre cannot be determined for previous ages, by actual measurement, a basal area of 120 ft^2/acre has been assumed for the reference age of 50 years. This assumption is considered reasonable because according to Buckman (1962) it represents a basal area of medium intensity management, and varies little from the actual basal area of plot 3 which is 50 years old. The data are summarized Table V. To derive the data presented in this table the following assumptions were made and are considered reasonable for a stand 50 years old: basal area of 120 ft^2 per acre; 200 trees per acre; diameter outside bark of 10.2 inches; form class of 90 (this is the average form class of the trees in plot 3, which were 50 years old); form factor .42 (suggested by Gerorkiantz and Olsen for trees older than 30 years old).

Table V shows the volume per acre determined by the formulas or tables developed by 3 additional studies and the volume for this study as determined from the graph in Figure 9. Using the

Table V. Comparison of Estimated Cubic Foot Volume of Red Pine at 50 Years of Age.

Plot	Age	S.I.	Gevorkiantz and Olsen [1]	Canada [2]	This Study	Buckman [3]
1	48	48	2218	2520	2100	2121
2*	20	55	-	-	-	-
3	50	60	2772	3120	3280	3335
4*	20	55	-	-	-	-
5**	58	49	2264	2600	2220	2616
6	56	51	2356	2680	2340	2459
7	61	55	2541	2900	2600	3094
8+	28	64	2957	3380	3260	1885
9	39	63	2911	3340	3480	2375
10**	39	60	2772	3140	2640	2314
Average			2598.9	2960.0	2740.0	2524.9
S.D.			± 294	± 335	± 532	± 483
C.V.			11.3	11.3	19.4	19.1

* Sufficient data was not available for these plots. Stand was much less than 30 years.
** The average for these plots is based on only 4 trees where as the others are based on 5.
\+ Estimated values.

1 Lake States For. Exp. Stn., 1955.
2 Forestry Handbook, 1955.
3 Lake States For. Exp. Stn., 1962.

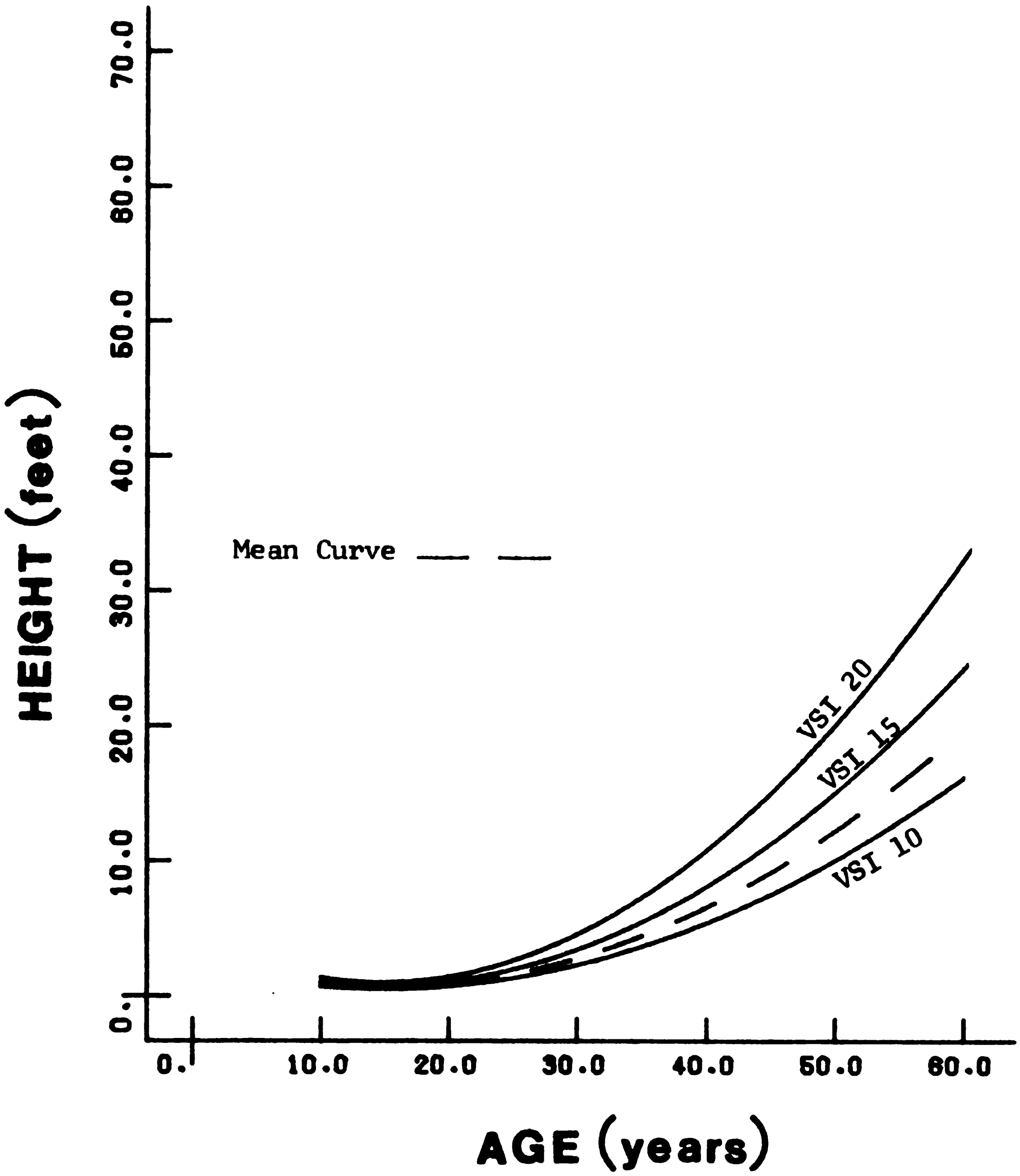

Figure 9. Harmonized Volume Growth Curves Using the Mean Growth Curve of All Trees Combined as the Guiding Curve.

VSI Volume Site Index

method proposed by Gevorkiantz and Olsen, and that proposed for Canadian forests resulted in the lowest variation between plots. Both of these methods are based on the taper or form of the average individual tree. When the method proposed by Buckman or this study were used to determine volume per acre much more variation between plots resulted. Buckman's method utilized the relationship of site index and basal area to volume growth, whereas this study utilized the relationships of volume per tree with age.

The average volume per acre of the 4 different methods ranges from 2524.9 to 2960.0 ft^3/acre. These volume averages are relatively similar indicating, like site index, that red pine growth is uniform on Rubicon sand. The volume per acre growth between plots however, can vary considerably depending on which method is used. The Canadian and, Gevorkiantz and Olsen's methods assume a uniform taper of all trees, whether they occur on "good" or "poor" sites, and the variability in volumes per acre is only about 11% which means that volume and height growth are equally sensitive to site quality. By removing the affect of uniform taper, data in Buckman's study and this study show the variation is almost double the variation of site index between plots, and indicates that volume growth is more sensitive to site quality than site index. The two latter studies are probably closer to actual field conditions because a uniform taper would most likely not exist. However, this was not verified.

In a similar study of red pine, in 1969, Hannah found volume growth to be a more sensitive indicator of site quality than site index. However, whether he used site index or volume growth he rated the site quality of Rubicon sand for red pine as medium.

Soil has been shown to be one of the most important factors affecting site quality (Carmean, 1975). To determine its effect on site quality selected soil properties were compared to site index using stepwise regression analyses. Site index was used although it is probably less sensitive to site quality than volume per acre. It was chosen to be the dependent variable because tree height was measured precisely and accurately in the field whereas, the calculation of volume growth was based on many assumptions which, although they were considered reasonable, may or may not have been true for Rubicon sand. Therefore, for this study, site index is preferred as the dependent variable.

Soil Data

Variation in site productivity due to soil differences is well documented in the literature (Coile, 1952; Mader, 1968; Hannah and Zahner, 1970; Carmean, 1975; Page, 1976). Their work has shown that site index can be correlated with one and sometimes more than one soil property. These soil properties fall into three broad catagories viz., soil physical, soil chemical, and soil topographic features. In this study 31 variables were studied (they are listed in Appendix III). The following soil features will be discussed in detail:

a) Soil texture

b) Depth to water table

c) Gravel content

d) Landforms

e) Soil nutrients

a) Soil Texture

The presence of a fine sand layer (band of fine sand or finer) or slight increases in the amount of sand, barely detectable in the field with ones fingers, usually resulted in a better site.

While looking for suitable areas for plot establishment one area was found that had a loamy sand surface texture. This is a finer texture than that of Rubicon, which is sand, and as a result has a higher water holding capacity. This difference was reflected in the increased competition. Because of the increased competition the red pine growth was inhibited. Red pine probably did not reflect the higher potential because the proper weeding procedures were not undertaken. Thus, the presence of a fine sand layer does not insure a highly productive site.

The affect of finer soil layers can also be seen in the site indexes of red pine growing on Graycalm soils, in Table IV. These soils are similar to Rubicon in all major respects except for a fine sand band and thin, more clayey, horizons between 40 and 60 inches from the surface. The average red pine site index on the two Graycalm sands is 71.4 whereas, on Rubicon it is 55 to 59.

b) Depth to Water Table

The water table depth could be accurately determined on only 2 plots. At plot #2, age 20 years, the ground water was found at a depth of 99 inches (in July) with no apparent drainage mottles above it. At plot #9, age 39 years, the ground water was encountered at 106" (in August) with drainage mottles beginning at 75". The site index for the two sites are 55 and 64 respectively.

For the remaining 8 plots the upper surface of the ground water was not encountered, even to a depth of 10 feet in all plots. Because the water table was encountered at only the two plots, little can be inferred about its relationship to site quality from this study.

van Eck (1958) found that red pine is greatly affected by the soil water regime. He found that the site index of red pine at the foot of a slope was generally much higher than at the mid or upper slope positions. Red pine found on other sandy soils, e.g. Croswell, which have higher water tables than Rubicon, also had higher site index values. However, he was not able to discern the exact affect of the water table because he found that other soil properties varied concommitantly. For example, finer soil textures at lower slope positions and decreased soil depth on the steep positions had an unknown affect on the site index.

In a more extensive study, the Forest Service has found that the water table, even to a depth of 17 feet, has an affect on tree growth (Personal communication with Richard Watson, U.S.F.S., Forest Soil Specialist).

c) Gravel Content

Thin gravel layers as such, were not found on any plot. Gravel pockets however, occurred frequently and were usually associated with root proliferation throughout the gravel pocket. In the field it appeared that these gravel pockets enhanced the site quality but, in the final analysis of the data, the total gravel content was found to be inversely related to site index.

If roots proliferated in the gravel pockets why does the total gravel content negatively affect site index? van Eck (1958) also encountered a curious relationship between gravel content and red pine site index. He states that, "apparently the effect of gravel is of a complex nature: partly one of benefit to trees on coarse textured soils if it was associated with a textural B horizon, partly one of harm to growth if occurring in quantity and larger sizes near the surface, not associated with a finer textured horizon."

d) Landforms

Most study plots were located on sandy outwash plains. Three plots, #4, #8, and #9, were located on border areas between a sandy outwash plain and a moraine, a lake bed plain, or a drainage course spillway, respectively. The site indexes of these 3 plots are 55, 64, and 63. The average site index of these plots is slightly higher than for plots which occurred only on sandy outwash plains. Although the soils in each plot are classified as Rubicon sand, in the border areas where the plots were located, the effects of the soils in the adjacent areas can be seen in the slightly higher site indexes. These differences were attributed to the presence of a band or layer, from less than ½ inch thick to as much as 1 or 1½ ft. thick, of finer texture ranging from fine sand to clay loam, found in the adjacent area. It is possible that the tree roots were able to reach such areas in at least 2 of 3 plots and obtain more water and nutrients, but, this was not confirmed.

One of the original objectives of this study was to compare Rubicon sand in terms of red pine site quality on different landforms. The official description of the Rubicon series states that it occurs on "tills, outwash and lake plains, moraines, and to a lesser extent on old beach ridges and sand dunes...." The author believed that if Rubicon actually occurred on such a wide variety of landforms it could not be used as a reliable measure of site quality. This objective had to be abandoned however, because Rubicon which was supporting red pine could only be found on sandy outwash plains. Only on one occasion was Rubicon found on a landform other than an outwash plain. It was found on a moraine but it was supporting a stand of mixed hardwoods and not red pine. When the different landforms were checked it was found that other soil series usually predominated. These other soils possessed either a higher degree of podzolization (Kalkaska), finer textural subsoil bands (Graycalm), thick finer textural subsoil bands (Montcalm), or finer sand (Rousseau), etc.. Rubicon sand could only be found on two different types of landforms: moraines and outwash plains. Based on this study alone it does not mean that Rubicon occurs on only these landforms but it does indicate that care should be taken when describing or interpreting the range in landforms on which it does occur.

e) Soil Nutrients

The fertility, or nutrient status, of the soil is difficult to estimate because, where trees are concerned, the rooting zone is only vaguely understood. Knowing the volume of soil occupied by the roots during the different stages of tree growth, viz.,

establishment, rapid growth, and mature stages would facilitate the estimation of available soil nutrients. The picture is further complicated by the fact that forest trees can recycle nutrients (Curlin, 1968). To estimate the fertility of Rubicon sand, the soil profile samples from the study plots were analyzed for the following nutrients by the Michigan State University Soil Testing Laboratory: phosphorus, potassium, calcium, magnesium, percent carbon, and soil reaction (pH). The results are summarized in Table VI. The quantity of available nutrients was in the following order: Ca>P>K>Mg. The ratio of the percent carbon in the A, B, and C horizons was approximately 6:2:1, respectively, and the pH of the soil increased from the A to the C horizon.

Stepwise regression analysis was employed to find the meaningful correlations between site index and the numerous soil and non-soil site factors (See Appendix III for the soil and site parameters used in this analysis). Site index instead of tree height growth was used as the dependent variable because its R^2 value (coefficient of multiple determination) is a better estimate of the site quality variation as explained by the independent variables (Carmean, 1975). Using tree height as the dependent variable is less desirable because its close association with age masks the affect of the other site variables (Carmean, 1975). For example, Table I has shown that for this study 92.0% of the variation in height is associated with age alone. This high degree of association means that if all of the other site factors are combined they could only be associated with 8.0% of the variation in height growth. This masking affect of age can be

Table VI. Summary of Available and Exchangable Nutrients of Rubicon Sand. Horizons. These values are the average of all 10 plots.

Soil Horizon	Ave. Depths (Inches)	Pounds per acre				Percent exch. bases			Percent Carbon	pH
		P	K	Ca	Mg	K	Ca	Mg		
A	0-2	19.4	44.7	278.1	28.2	8.2	77.7	14.1	2.67	5.1
B	2-40	49.1	23.0	108.5	16.3	20.0	46.7	33.3	.98	5.6
C	40-60+	22.1	16.0	85.7	12.3	16.4	43.9	39.7	.47	5.8

overcome if tree heights are compared at only one age. Since site index, by definition, is tree height at a given age its use as the dependent variable is justified. In this analysis, the site index values were taken from the harmonized curves developed for this study because the harmonized curves exhibited less variation between plots than did the polymorphic curves.

The results of the stepwise regression analyses show that to explain up to 71% ($r^2 = .70977$) of the site index variation, 5 variables were necessary (See Table VII). These variables, in order of their degree of correlation are:

1) pH of the B22 horizon

2) Thickness of the A horizon in inches

3) Basal area

4) Percent gravel in the profile

5) The average percent fine sand in the A plus B horizons

The equation for this relationship is:

$$Y = 12.36 + 5.52(X_1) + .259(X_2) + .045(X_3) - .36(X_4) + .30(X_5)$$

where,

Y = Site index

X_1 = pH of the B22 horizon

X_2 = Thickness of the A horizon

X_3 = Basal area

X_4 = Percent gravel in the profile

X_5 = Average percent sand of the A plus B horizons

This equation is presented only to show the relative rank of the variables found to be most significant in this study. It must be kept in mind that this study consisted of only 10 plots and

Table VII. Summary of Stepwise Regression Analyses; variables chosen at each step.

Step	Variable Entered	Equation	r^2
1	pH of the B22 Horizon	$SI = -8.937 + 17.969(x_1)$	.43351
2	Thickness of the A Horizon	$SI = -53.200 + 18.26(x_1) + .433(x_2)$	.46931
3	Basal Area	$SI = -43.354 + 15.64(x_1) + .395(x_2) + .051(x_3)$	.59803
4	Percent Gravel	$SI = -20.811 + 12.46(x_1) + .430(x_2) + .388(x_3)$	
		$-.454(x_4)$	.62919
5	Average Percent Fine Sand of the A + B Horizons	$SI = 12.36 + 5.52(x_1) + .259(x_2) + .045(x_3)$	
		$- .360(x_4) + .300(x_5)$	.70977

to state that this equation represents the true relationship of the dependent and independent variables would be misleading. It can be used however as a guide to the site factors which affect tree growth and ultimately the site quality.

As an example of how this might work in the field, plots 1 and 9, with site indexes of 48 and 63, respectively, have been compared. Using the five factors found by this study to be related to site index the data is as follows:

		Plot #1	Plot #9
pH of the B22	=	5.0	6.0
Thickness of the A horizon	=	8	8
Basal area	=	70	90
Percent gravel in the profile	=	13	5
Average percent fine sand (A+B)/2	=	16	39

Next, substituting these values into the formula,

$$Y_{plot\ 1} = 12.36 + 5.52(5.0) + .259(8) + .045(70) - .36(13) + .30(16)$$

$$= 45.3$$

$$Y_{plot\ 9} = 12.36 + 5.52(6.0) + .259(8) + .045(90) - .36(5) + .30(39)$$

$$= 61.5$$

By using only these soil factors plot 9 would be shown to be a better site than plot 1. All of these soil factors, with practice, can be determined in the field.

Soil classifiers, responsible for defining the range of soil characteristics for a given soil series should be aware of what factors are important for tree growth and should describe the soils in such a way that these factors are taken into account. For example, the range in pH for Rubicon might be redefined or further restricted, or the range of the amount of gravel that can occur in a Rubicon profile, which is not specifically stated in the offical Rubicon series description, could also be defined. Because small differences in the amount of gravel may have an affect on site quality the range of gravel accepted could be restricted to, say, less than or equal to 5%. The exact percentage would have to be determined from a larger number of samples. Soils which would then contain more than 5% gravel could be set aside as a separate phase of Rubicon or another series. Or if, after examining a large number of samples, the establishing of a Rubicon phase based on the amount of gravel, could not be justified, other factors such as pH of the B22 horizon or thickness of the A horizon should be considered.

It is equally important for foresters to recognize the soil and non-soil factors which affect the site quality. In ameliorating poor sites it is important to understand why the site is poor. Is it a result of edaphic or non-edaphic site factors? It has been argued by many that basal area has relatively little affect on site index except in extreme cases (Carmean, 1975). Data from this study supports this argument. In the previous equation basal area (X_3), was one of the factors found to affect site index even though its affect was small: $+ .045(X_3)$.

Being able to recognize some of the more influential and subtle characteristics of the soil such as the pH, percent fine sand in the subsurface horizons, and thickness of the surface horizons will help the forester, as well as the soil scientist, identify the effective site factors.

CONCLUSIONS

Conclusions from this study are:

1) Harmonized site index curves can be used to represent the growth of red pine on Rubicon sand, when stem analysis is used to determine the growth pattern. The growth pattern is adequately represented by the mean curve and little, if any, advantage is gained, in terms of management, by developing polymorphic curves.

2) Site index for red pine can be determined from a number of published site index curves. This study shows that the difference in site index values between these site index curves for any given plot, can be considerable. However, each set of curves yields a similar average site index for red pine, i.e. 55 to 59, for the plots studied.

3) Red pine growth curves are not uniform over a wide range of soil profile textures. More site index curves such as those of this and van Eck's study should be developed for groups of similar soils.

4) When volume per acre is used as the indicator of Rubicon's productive capacity for red pine the results are similar to those when site index is used. Different methods show similar average volume per acre growth of red pine

on Rubicon sand (2524.9 to 2960.0 ft^3/acre), yet, the variation between plots can be considerable (11.3% to 19.4%).

5) Site index and volume per acre are about equally sensitive to Rubicon site quality for red pine if a uniform taper is assumed for red pine. However, if the affect of uniform taper is removed the sensitivity of volume per acre almost doubles (i.e. from 11.3% to 19.4%).

6) Of the properties of Rubicon sand and other factors of the site, those most correlated with variations in red pine site index are: pH of the B22 horizon, thickness of the A horizon, basal area, percent gravel in the profile, and average percent fine sand in the A plus B horizons.

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APPENDICES

APPENDIX I

RUBICON SERIES

The Rubicon series consists of deep excessively drained soils formed in sandy deposits on till plains, lake plains, outwash plains and moraines. These soils have rapid permeability. Slopes range from 0 to 40 percent. Mean annual precipitation is about 30 inches, and mean annual temperature is about 43° F.

Taxonomic Class: Sandy, mixed, frigid Entic Haplorthods.

Typical Pedon: Rubicon sand - on a 3 percent convex south facing slope in a red pine plantation. (Colors are for moist soil unless otherwise stated.)

A1--0 to 1 inch; black (10YR 2/1) sand, flecked with light brownish gray (10YR 6/2); weak fine granular structure; very friable; common roots; very strongly acid; abrupt smooth boundary. (1/2 to 3 inches thick)

A2--1 to 6 inches; light brownish gray (10YR 6/2) sand; very weak medium granular structure; very friable; common roots; very strongly acid; clear smooth boundary. (2 to 7 inches thick)

B21ir--6 to 10 inches; dark brown (7.5YR 4/4) sand; weak medium granular structure; very friable; many roots; medium acid; clear wavy boundary. (4 to 12 inches thick)

B22ir--10 to 18 inches; dark yellowish brown (10YR 4/4) sand; weak coarse granular structure; very friable; common roots; medium acid; clear irregular boundary. (0 to 20 inches thick)

B3--18 to 36 inches; yellowish brown (10YR 5/6) sand; very weak coarse subangular blocky structure; very friable; medium acid; chunks of ortstein occur at depths of 18 to 24 inches and represent about 15 percent of the surface area of the horizon exposed; chunks are 4 to 6 inches in diameter; colors are yellowish brown (10YR 5/6) representing 60 percent of the mass and dark reddish brown (5YR 3/4) and pale brown (10YR 6/3) representing the remaining colors, sand; massive; few roots; weakly to strongly cemented; medium acid; clear irregular boundary. (4 to 20 inches thick)

C1--36 to 60 inches; light yellowish brown (10YR 6/4) sand with some coarse sand in upper portion; single grained; loose; slightly acid.

Type Location: Cheboygan County, Michigan; 0.5 miles west of Highway M-33 on Hackleburg Road, then 200 feet north in the SW1/4, SW1/4, sec. 5, T. 35 N., R. 1 W.

Range in Characteristics: The thickness of the solum ranges from 20 to 50 inches. The reaction of the solum ranges from medium to very strongly acid. Coarse fragments range to as much as 5 percent throughout the solum. Mean annual soil temperature is estimated to range from 43° to 47° F.

The A1 and Ap horizons have hue of 10YR or 7.5YR, value of 2 through 4 and chroma of 1 or 2. The A2 horizon has hue of 10YR or 7.5YR, value of 5 through 7 and chroma of 1 or 2. It has weak granular or weak subangular blocky structure or is single grained. The A horizon is sand or loamy sand.

The B2ir horizon has hue of 10YR, 7.5YR or 5YR, value of 4 or 5 and chroma of 3 through 6. The B3 horizon has hue of 10YR, 7.5YR or 5YR, value of 5 or 6 and chroma of 4 through 6. The amount of ortstein occurring in the B2ir and B3 horizons range from 0 to 20 percent. The structure of the B2 and B3 horizons range from weak granular to weak subangular blocky or it is single grained.

The C horizon has hue of 10YR or 7.5YR, value of 6 or 7 and chroma of 3 or 4. It is medium or coarse sand. The reaction ranges from slightly to medium acid.

Competing Series: These are the Crivitz, Croswell, Deerton, Duel, Graycalm, Karlin, Kiva, Rousseau and Vilas series in the same family and the similar Deer Park, Grayling, Kalkaska and Wallace series. Crivitz soils have finer textured sola. Croswell soils have mottling at depths between 20 and 40 inches. Deerton soils are underlain by sandstone bedrock. Duel soils are underlain by limestone bedrock within the control section. Graycalm soils have Bt horizons. Karlin soils have loamy fine sand or sandy loam in the 10 to 40 inch control section. Kiva soils have stratified coarse sand and gravel at depths ranging from 10 to 24 inches. Rousseau soils developed in fine sands. Vilas soils are developed in medium and coarse sands containing a higher proportion of dark colored minerals, including slates, schists, iron bearing rocks and red sandstone. Deer Park soils are spodic intergrades. Grayling soils lack spodic horizons. Kalkaska soils have a Bh horizon more than 3 inches thick. Wallace soils have a continuous ortstein.

Geographic Setting: Rubicon soils are on till, outwash and lake plains and moraines and to a less extent on old beach ridges and sand dunes along the Great Lakes. Slopes range from 0 to 40 percent. The mean annual precipitation is 27 to 33 inches, and annual temperature is about 40° to 45° F.

Geographically Associated Soils: Croswell, AuGres and Roscommon soils form a common drainage sequence with Rubicon. Kalkaska, Grayling and Montcalm soils are common well drained associates.

Drainage and Permeability: Excessively drained. Surface runoff is slow. Permeability is rapid.

Use and Vegetation: The greater proportion of this soil is forested, including tree plantations. Some areas are idle cropland or in permanent pasture. Only a very small proportion is used for small grains and hay crops. The native vegetation and present natural vegetation is dominantly red pine and aspen with some white and jack pine. Ground cover consists of blueberries, wintergreen, sweet fern and reindeer moss.

Distribution and Extent: Northern half of lower Michigan and upper Michigan. The series is of large extent.

Series Established: Ontonagon County, Michigan; 1922.

Remarks: The Rubicon series was formerly classified as Podzols.

National Cooperative Soil Survey
U.S.A.

GRAYCALM SERIES

The Graycalm series is a sandy, mixed, frigid Entic Haplorthods. Typically these soils have a very dark grayish brown sand A1 horizon, dark brown and strong brown sand B2ir horizons, yellowish brown sand B3 horizons, light yellowish brown sand A2 horizons and yellowish brown sand with bands of brown and reddish brown loamy sand Bt horizons.

Typical Pedon: Graycalm sand on a slope of 1 percent on an outwash plain in a forested area. (Colors are for moist soil unless otherwise stated.)

A1--0 to 3 inches; very dark grayish brown (10YR 3/2) sand; moderate medium granular structure; very friable; many fine roots; very strongly acid; clear wavy boundary. (2 to 5 inches thick)

B21ir--3 to 6 inches; dark brown to brown (7.5YR 4/4) sand; weak fine granular structure; very friable; common fine roots; strongly acid; clear irregular boundary. (3 to 12 inches thick)

B22ir--6 to 13 inches; strong brown (7.5YR 5/6) sand; weak fine granular structure; very friable; few fine roots; medium acid; gradual wavy boundary. (0 to 12 inches thick)

B3--13 to 22 inches; yellowish brown (10YR 5/6) sand; single grained; loose; few fine roots; slightly acid; gradual wavy boundary. (0 to 10 inches thick)

A2--22 to 35 inches; light yellowish brown (10YR 6/4) sand; single grained; loose; very few fine roots; slightly acid; abrupt broken boundary. (10 to 25 inches thick)

A&B--35 to 60 inches; light yellowish brown (10YR 6/4) sand (A2); single grained; loose; lamellae and bands of brown (7.5YR 5/4) and reddish brown (5YR 5/4) loamy sand (Bt); weak medium subangular blocky structure; friable; bands are 1/4 to 2 inches in thickness with a total accumulation of 5 inches; 5 percent by volume of pebbles; slightly acid.

Type Location: Clare County, Michigan; 2310 feet west and 700 feet north of the southeast corner of Sec. 6, T. 20 N., R. 4 W.

Range in Characteristics: The thickness of the solum ranges from 40 to greater than 60 inches. Depths to the Bt horizon ranges from 35 to 48 inches. The pebble content throughout the pedon ranges from 0 to 5 percent by volume. The solum ranges from very strongly acid to slightly acid. The mean annual soil temperature is estimated to range from 44° to 47°F. The A1 horizon has hue of 10YR or 7.5YR, value of 3 or 2 and chroma of 1 or 2. In cultivated areas the Ap horizon has hue of 10YR or 7.5YR, value of 3 or 4 and chroma of 2 or 3. Some pedons have an A2 horizon, 1 to 4 inches thick. It has hue of 10YR or 7.5YR, value of 6 or 7 and chroma of 1 through 3. The A horizons are sand or loamy sand. The Bir horizon has hue of 7.5YR or 10YR, value of 4 or 5, and chroma of 4 through 6. It is sand or loamy sand. The B3 horizon has hue of 7.5YR or 10YR, value of 5 or 6 and chroma of 4 to 6. It is sand or loamy sand. The A2 horizon has hue of 10YR, value of 6 and chroma of 2 to 4. The Bt horizon is in bands 1/16 to 2 inches thick. The total accumulation within a depth of 60 inches is less than 6 inches. The Bt horizon has hue of 10YR, 7.5YR or 5YR, value of 4 or 5 and chroma 4 through 6. It is loamy sand or light sandy loam. Some pedons have a C horizon with hue of 10YR, value of 6 or 7 and chroma of 3 and range from slightly acid to mildly alkaline.

Competing Series and Their Differentiae: These are the Crivitz, Croswell, Deerton, Duel, Kiva, Pomfret, Rousseau, Rubicon, Seney and Vilas series in the same family and the Chelsea, Leelanau and Montcalm series. Crivitz, Croswell, Deerton, Duel, Kiva, Pomfret, Rousseau, Rubicon, Seney and Vilas soils lack Bt horizons. Chelsea soils lack spodic horizons and are mesic. Leelanau and Montcalm soils have argillic horizons.

Setting: Graycalm soils are on till plains, moraines and outwash plains of Wisconsinan age. Slope gradients range from 0 to 35 percent. The climate is continental, with a mean annual precipitation of about 30 inches. The mean annual temperature is about 43°F. and the mean summer temperature is about 65°F.

GRAYCALM SERIES--2

Principal Associated Soils: These are the nearby Rubicon, Seney, and Grayling soils on the till plains, moraines, and outwash plains, and with Montcalm soils on till plains and moraines.

Drainage and Permeability: Somewhat excessively drained. Runoff is slow or very slow on the nearly level slopes and medium on the steeper ones. Permeability is rapid.

Use and Vegetation: A large part is in forestland. The forest vegetation consists chiefly of oak and hickory with some white pine in the southern part, and jack pine and scrub oak in the northern part of the area. A few white pine are in some areas. A small part is cropped to small grains, corn or hay.

Distribution and Extent: This series occurs in the central and northern part of Lower Michigan and in the eastern half of the Upper Peninsula. This series is of moderate extent.

Series Proposed: Gladwin County, Michigan; 1966.

Remarks: The Graycalm soils were formerly classified as weakly developed Podzol.

National Cooperative Soil Survey
U. S. A.

USDA-SCS-LINCOLN, NEBR. 1976

APPENDIX II

APPENDIX II

Table A

Coefficients of Determination for all Equations Tested

Plot	Using data from age 0: $Y = a + bx$	Using data from age 0: $Y = a + bx + cx^2$	Using data from breast height: $Y = a + bx$	Using data from breast height: $Y = a + bx + cx^2$
1	.8108	.8246*	.7679	.7819
2	.9581	.9775**	.9579	.9637
3	.9872	.9941**	.9849	.9953**
4	.9328	.9400	.9087	.9088
5	.9782	.9789*	.9784	.9789
6	.9703	.9703	.9648	.9655
7	.9923	.9923	.9914	.9917
8	.9862	.9864	.9818	.9825
9	.9777	.9777	.9747	.9880
10	.9881	.9881	.9875	.9889**
1-10	.9151	.9202**	.8974	.9041**

* The addition of the second variable (x^2) is significant at 5%
** The addition of the second variable (x^2) is significant at 1%

APPENDIX II

Table A
(continued)

Plot	Using data from age 0: $\log Y = a + b^1/x$	Using data from age 0: $\log Y = a + b^1/x + c^1/x^2$	Using data from breast height: $\log Y = a + b^1/x$	Using data from breast height: $\log Y = a + b^1/x + c^1/x^2$
1	.6127	.8693**	.7725	.8306**
2	.9023	.9862**	.9189	.9814**
3	.8938	.9955**	.9892	.9961**
4	.6924	.9445**	.8972	.9311**
5	.8382	.9735**	.9212	.9832**
6	.7925	.9589**	.9228	.9711**
7	.9433	.9853**	.9496	.9910**
8	.8944	.9908**	.9630	.9857**
9	.7939	.9858**	.9477	.9761**
10	.6888	.9260**	.9331	.9917**
1-10	.6424	.8703**	.8385	.9035**

* The addition of the second variable ($^1/x^2$) is significant at 5%
** The addition of the second variable ($^1/x^2$) is significant at 1%

APPENDIX II

Table B

Summary of the Tests for Linearity

Equation	F value (Linear equation for all plots / Quadratic equation for all plots)	Degrees of Freedom
$Y = a + bx$		
$Y = a + bx + cx^2$	41.16**	1/616
$\log Y = a + b^1/x$		
$\log Y = a + b^1/x + c^1/x^2$	1130.70**	1/616

The original hypothesis was that the relationship of height and age is a straight line. In both cases the relationship shows a highly significant degree of curvilinearity thus, the hypothesis is rejected.

** Significant at the 1% level

APPENDIX II

Table C

Summary of Analyses of Covariance. Testing the Difference between Levels and Slopes of the Individual Plot Equations with that of the Overall Mean Equation.

Equation	F value $\left(\frac{\text{Individual Plots}}{\text{All Plots Combined}}\right)$	Degrees of Freedom
$Y = a + bx$	62.35**	18/626
$Y = a + bx + cx^2$	42.49**	27/616
$\log Y = a + b^1/x$	35.43**	18/626
$\log Y = a + b^1/x + c^1/x^2$	60.96**	27/616

** Significant at the 1% level

APPENDIX II

Table D

Summary of Analyses of Covariance of the Mean Curve for the Faster Growing Plots and the Mean Curve for the Slower Growing Plots when Compared to their Respective Individual Plots.

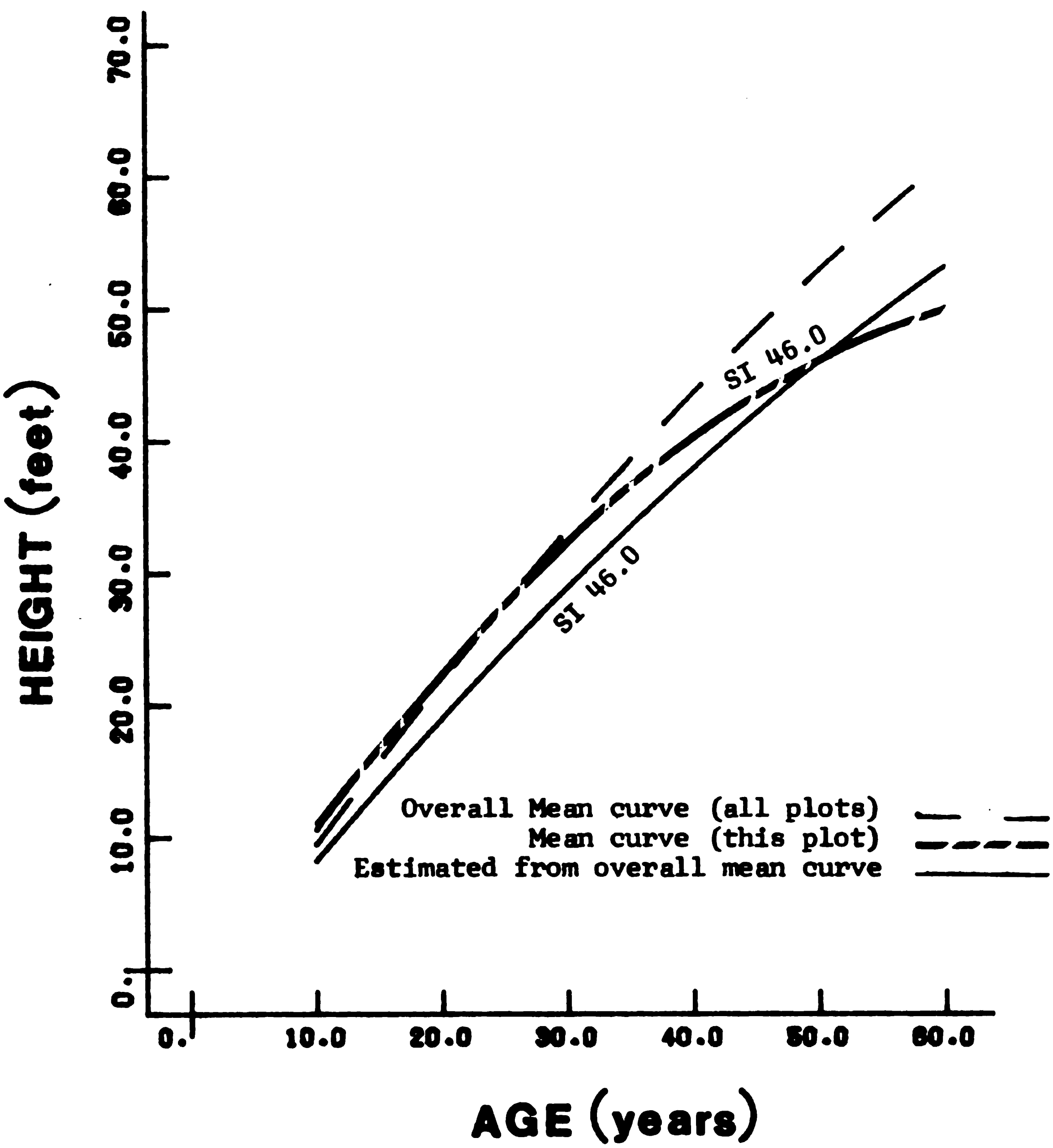
Equation	Plots 3, 8, 9, 10 F value	Plots 3, 8, 9, 10 df	Plots 1, 2, 4, 5, 6, 7 F Value	Plots 1, 2, 4, 5, 6, 7 df
$Y = a + bx$	11.72**	6/265	11.18**	10/377
$Y = a + bx + cx^2$	8.38**	9/264	8.47**	15/376
$\log Y = a + b^1/x$	9.66**	6/265	21.52**	10/377
$\log Y = a + b^1/x + c^1/x^2$	20.47**	9/264	16.72**	15/376

** Significant at the 1% level

df Degrees of Freedom

APPENDIX II

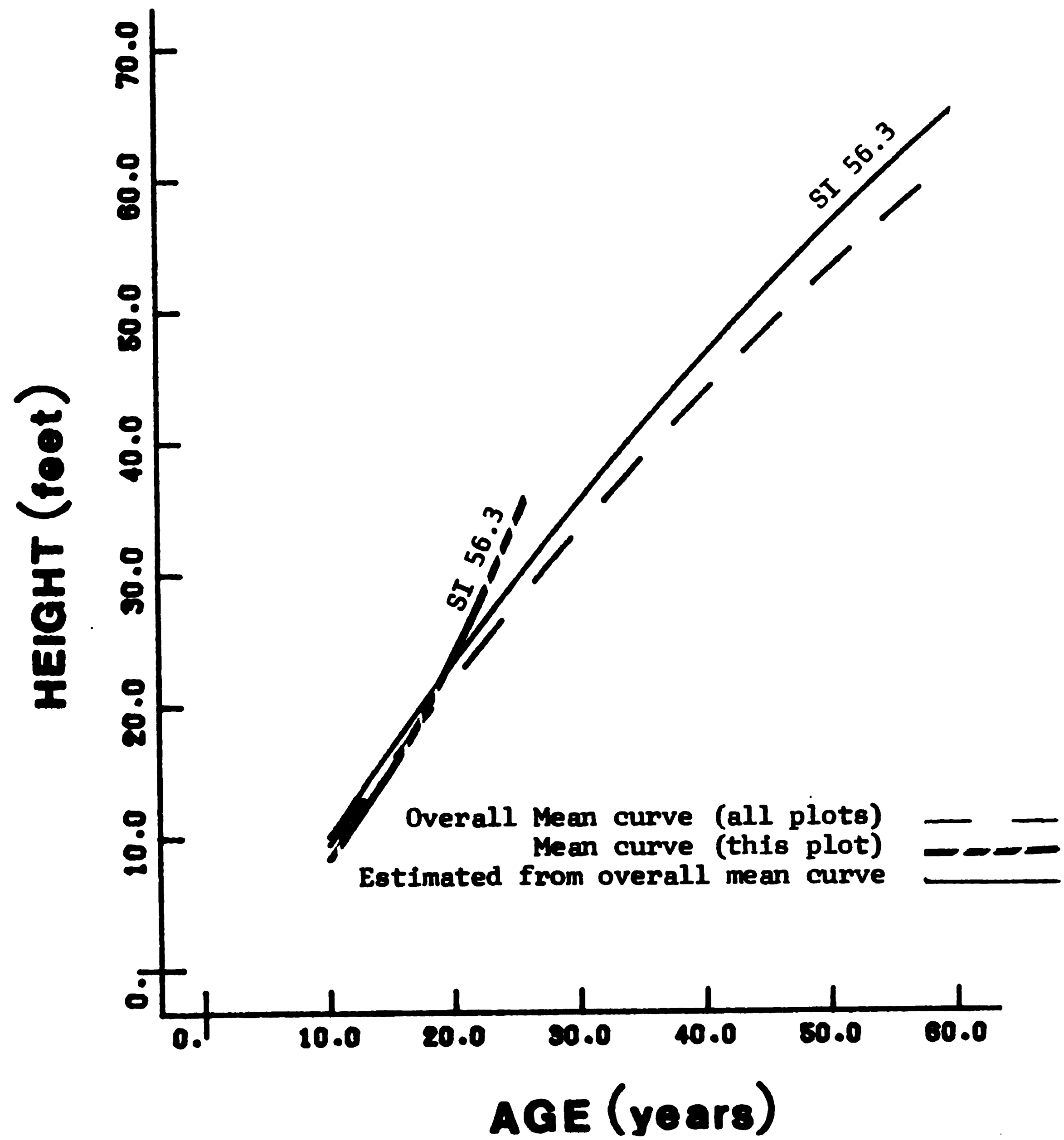
Table E. Comparison of Individual Plot Growth Curves to the Mean Growth Curve of All Plots Combined



PLOT #1

APPENDIX II

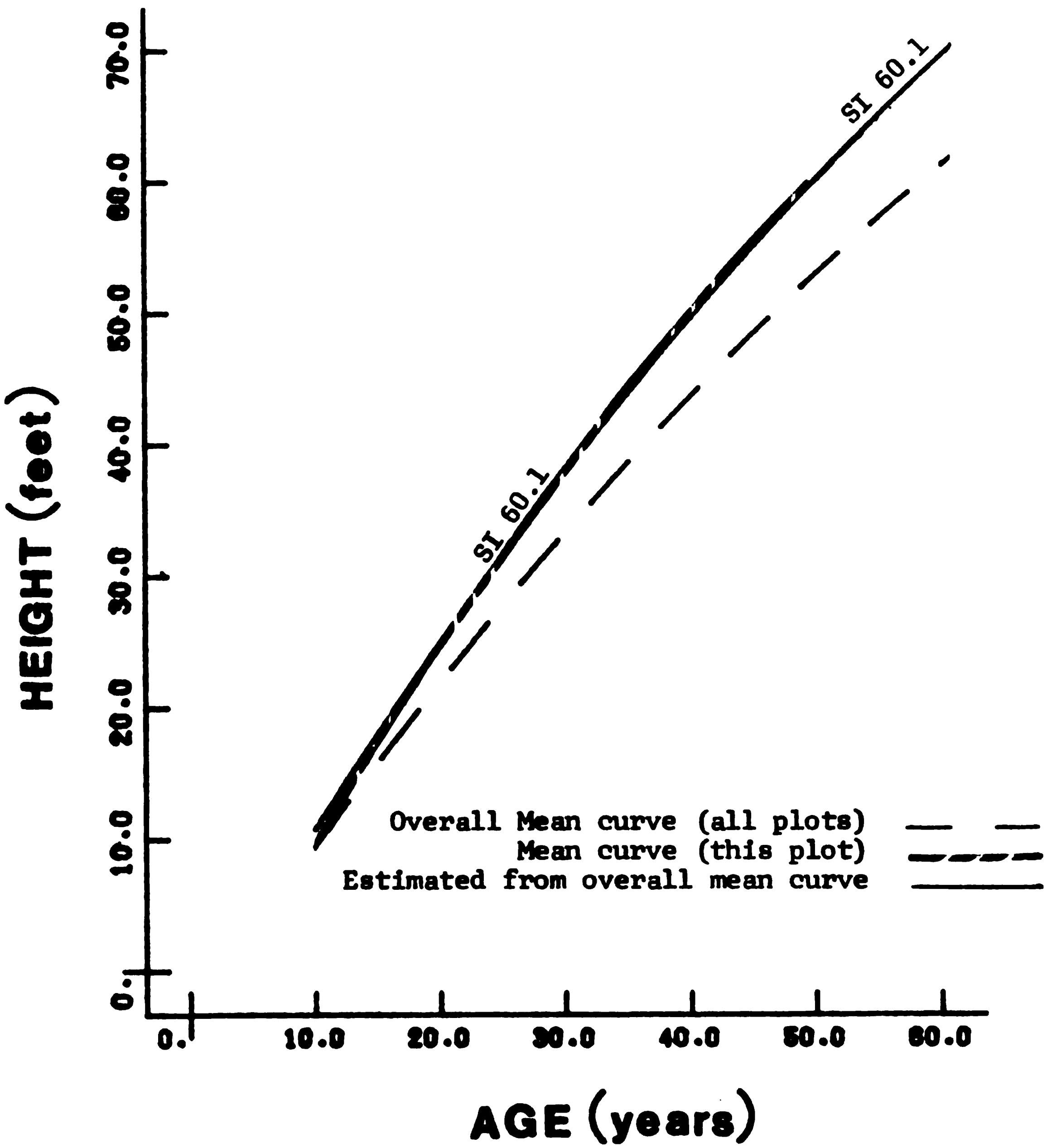
Table E (continued)



PLOT #2

APPENDIX II

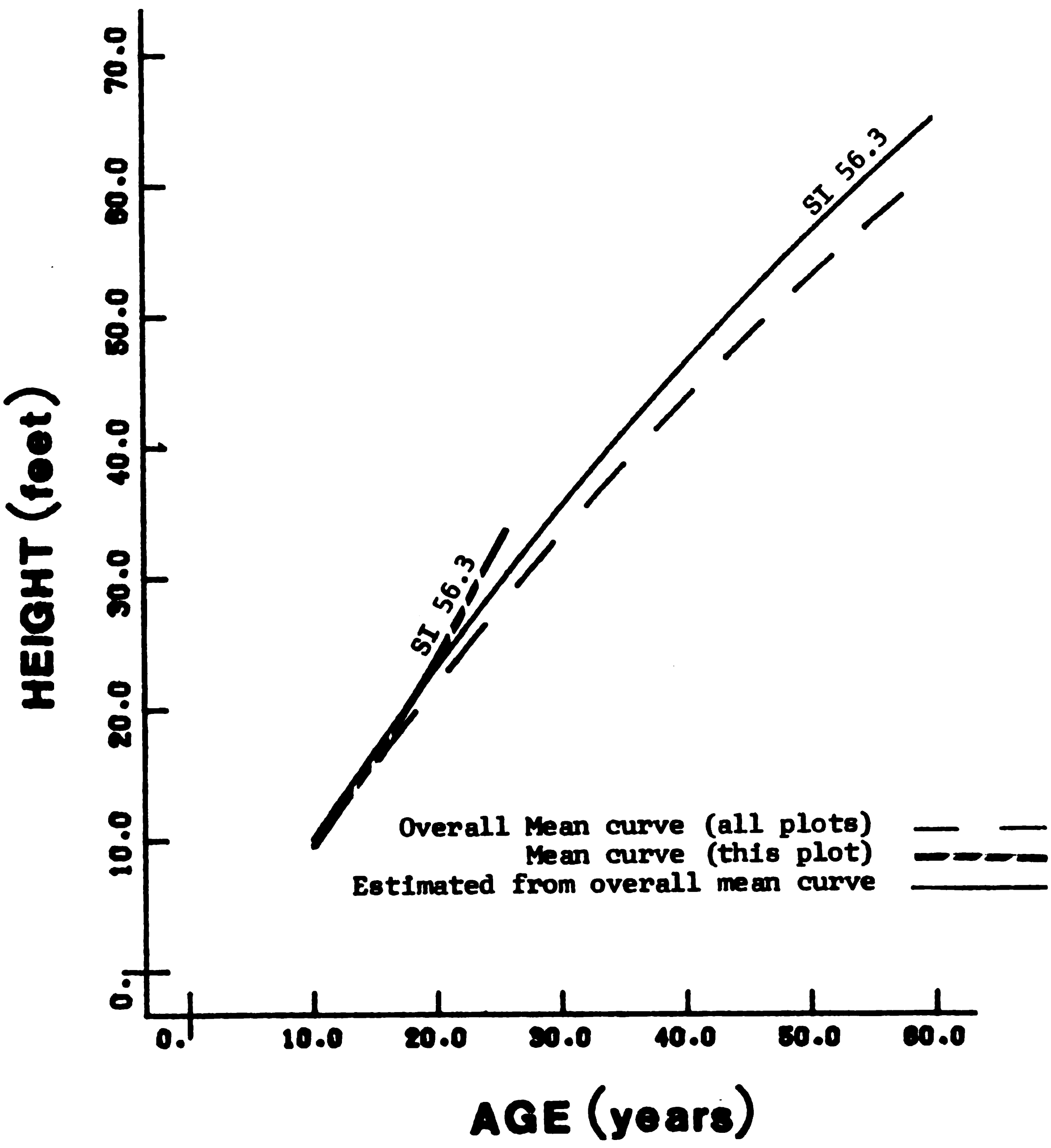
Table E (continued)



PLOT #3

APPENDIX II

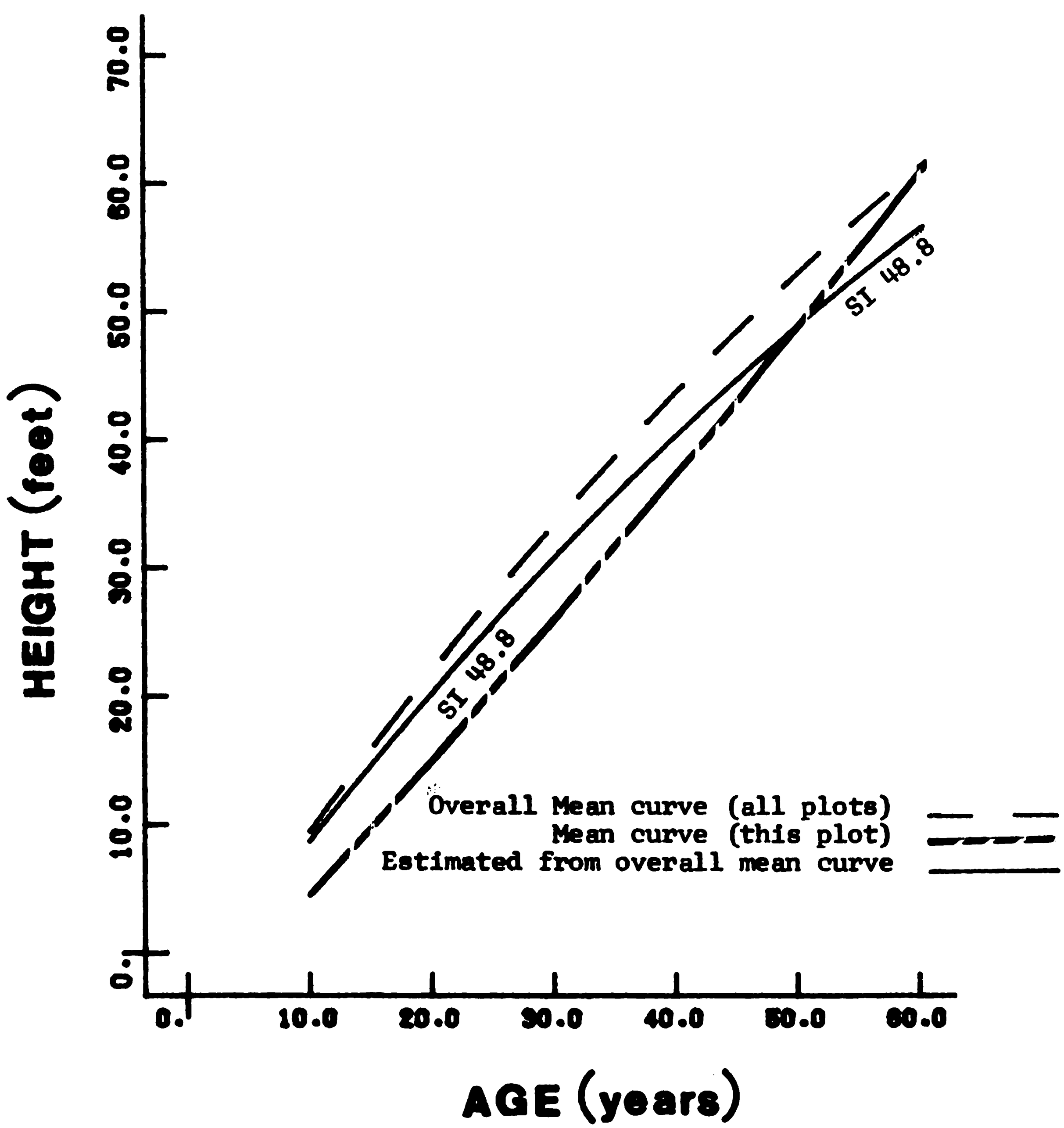
Table E (continued)



PLOT #4

APPENDIX II

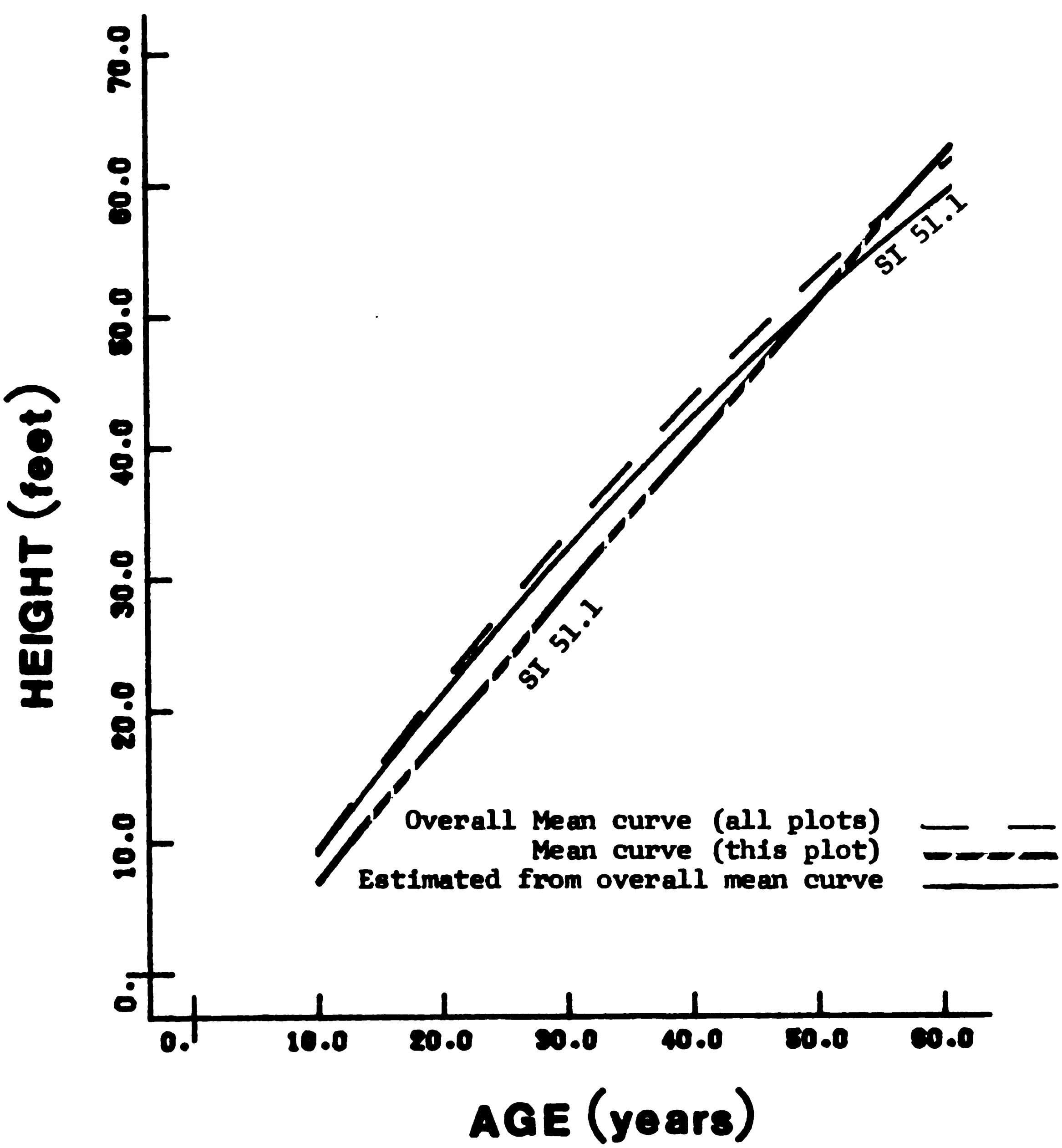
Table E (continued)



PLOT #5

APPENDIX II

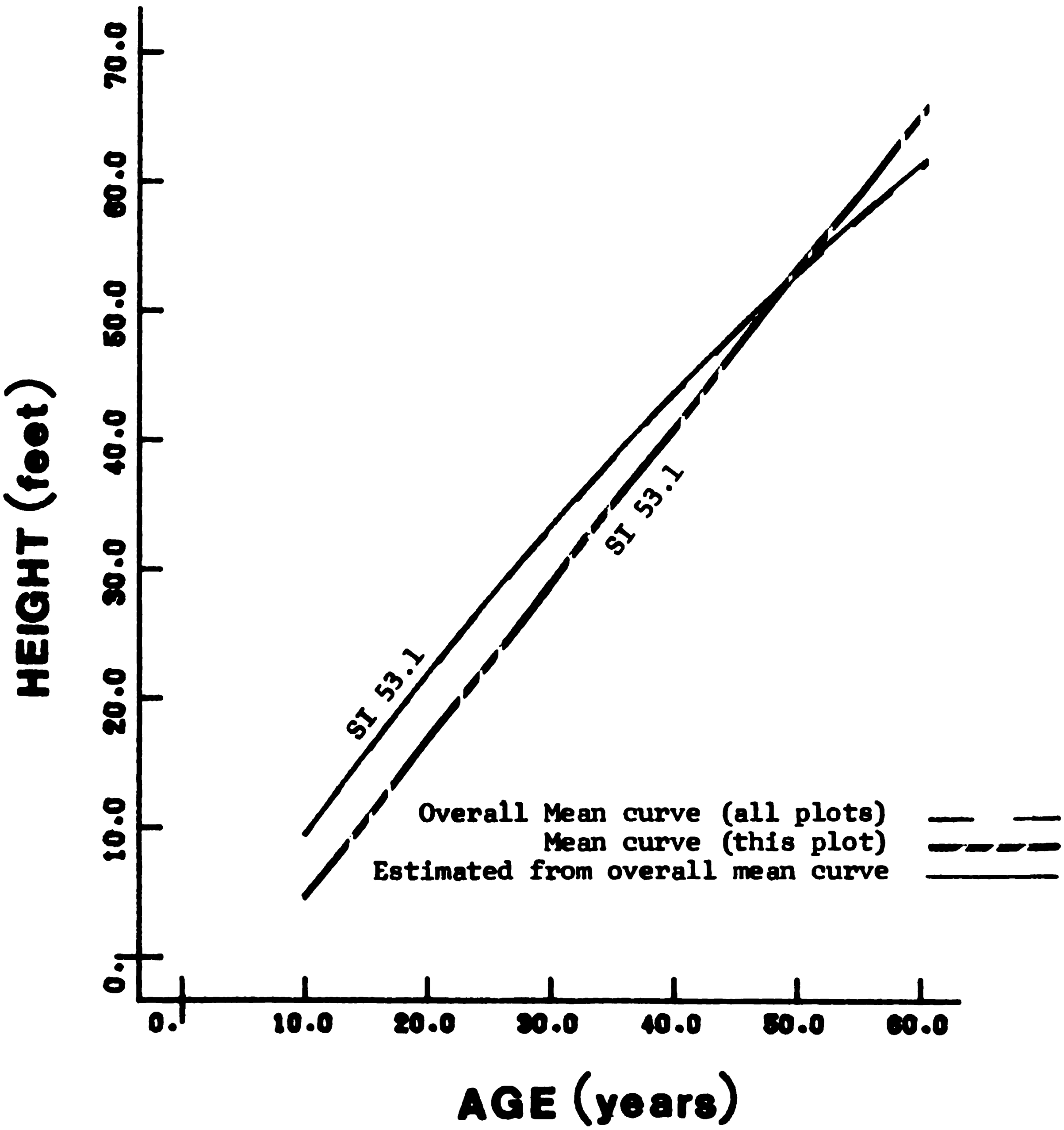
Table E (continued)



PLOT #6

APPENDIX II

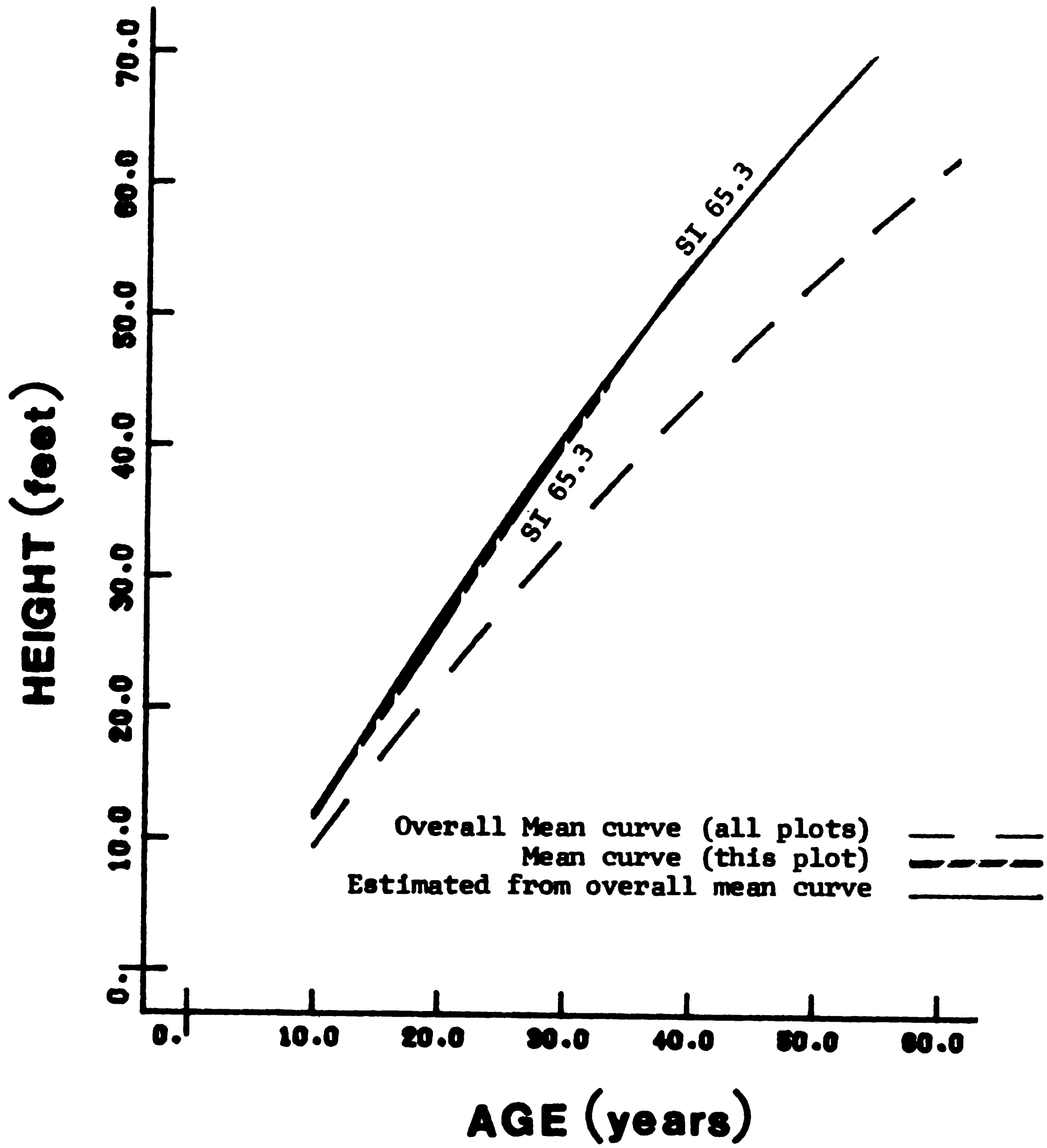
Table E (continued)



PLOT #7

APPENDIX II

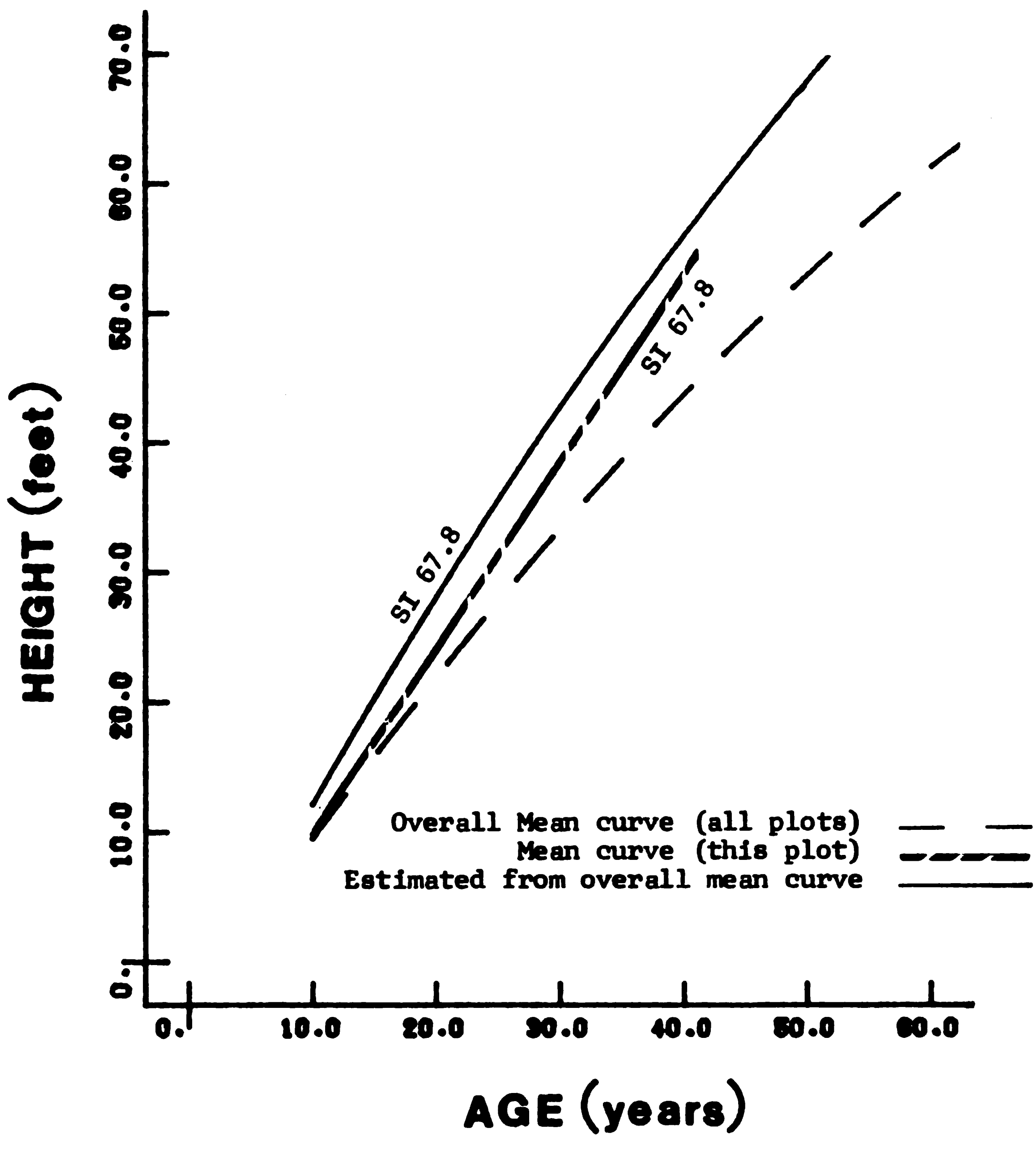
Table E (continued)



PLOT #8

APPENDIX II

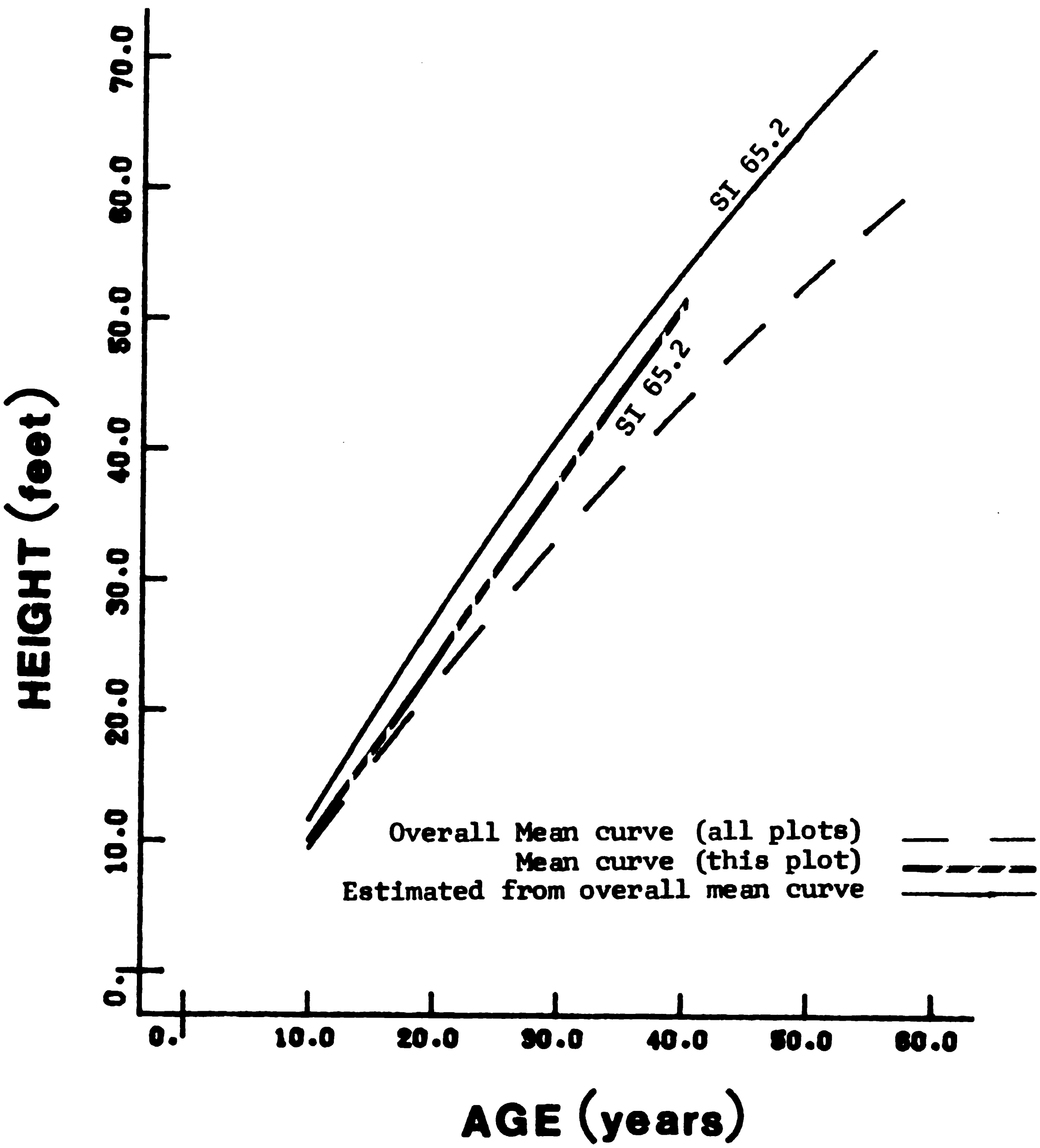
Table E (continued)



PLOT #9

APPENDIX II

Table E (continued)



PLOT #10

APPENDIX III

APPENDIX III

Variables Used in Stepwise Regression Analyses

1. Thickness of the A horizon
2. Thickness of the B horizon
3. Thickness of the A + B horizon
4. pH of the A horizon
5. pH of the B21 horizon
6. pH of the B22 horizon
7. Depth to textural bands
8. Percent gravel in the profile
9. Percent slope
10. Aspect of slope (NE, N, S, SE, SW)
11. Thinned or not thinned
12. Landform (Sandy outwash plain - SOP; SOP bordering on Moraine, Lake Bed, or Drainage Course Spillway)
13. Basal area
14. Depth to maximum percent fine sand
15. Percent fine sand in the A horizon
16. Percent fine sand in the B horizon
17. Percent fine sand in the (A + B)/2 horizon (Average)
18. Average pounds per acre of available phosphorus in the (A + B)/2 horizons
19. Average pounds per acre of available phosphorus in the (A + B + C)/3 horizons
20. Average pounds per acre of exchangeable potassium in the (A + B)/2 horizons
21. Average pounds per acre of exchangeable potassium in the (A + B + C)/3 horizons
22. Average pounds per acre of exchangeable calcium in the (A + B)/2 horizons
23. Average pounds per acre of exchangeable calcium in the (A + B + C)/3 horizons
24. Average pounds per acre of exchangeable magnesium in the (A + B)/2 horizons
25. Average pounds per acre of exchangeable magnesium in the (A + B + C)/3 horizons
26. Average percent exchangeable potassium in the (A + B)/2 horizons
27. Average percent exchangeable potassium in the (A + B + C)/3 horizons
28. Average percent exchangeable calcium in the (A + B)/2 horizons
29. Average percent exchangeable calcium in the (A + B + C)/3 horizons
30. Average percent exchangeable magnesium in the (A + B)/2 horizons
31. Average percent exchangeable magnesium in the (A + B + C)/3 horizons

APPENDIX IV

APPENDIX IV

Notes Taken at Each Plot

Soil type RUBICON **File No.** PLOT #1

Area SE¼ NW¼ SW¼ of T24N, R9W Sec 22, Liberty Twp, Wexford Co.	**Date** 6/27/76	**Stop No.** 1
Classification sandy, mixed, frigid, Entic Haplorthod		
Location from Jct 131 & E10Rd go 3/4 mi E, ¼N, then 2.5chN & 3.0chE to plot		
N. veg. (or crop) R.P. plantation, Jack pine & Oak		**Climate** Continental
Parent material Sand		
Physiography Sandy Outwash Plain		
Relief gently rolling	**Drainage** well drained	**Salt or alkali**
Elevation	**Gr. water** 120"+	**Stoniness** 10-15%
Slope 1%	**Moisture**	
Aspect NE	**Root distrib.**	
Erosion		
Permeability		

Additional notes

A1 horizon salt/pepper color; Stoniness < 1% at 4-18"; Stoniness < 1% at 41-52"; Roots in upper B2 are few, medium; Ortstein < 5%, in tongues, length > width at 40-50"; Light colored bands discontinous throughout pit, strongest near the ortstein; At 94" s; At 105" mineral banding; At 108" mottles, 10YR 2.5/1 c2p and 7.5 YR 4/4 c2d, clay pockets < ½" dia., evidence of decayed roots; at 120"+ clay pockets 7.5YR 4/4 and, fs (cemented) 10YR 6/8.

Hori-zon	Depth	Color		Texture	Struc-ture	Consistance			Reac-tion	Bound-ary	BANDS	Lab pH	% C
		Dry	Moist			Dry	Moist	Wet					
A1	0-3 (1-3)	10YR 6/2	10YR 3/2	S	0		lo		4.5	as		5.0	1.77
A2	3-8		5YR 5/2	S	0		lo		5.0	aw		4.9	.74
B21ir	8-10		5YR 4/4	S	0		lo		5.0	cw		5.6	.90
B22ir	10-23		7.5YR 5/6	S	0		lo		5.0	cw		5.6	.55
B3	23-31	bands (assoc. w/ortstein)	10YR 6/6 10YR 5/6	S	0		lo		6.0	gw	mlf	6.0	.50
C1	31-59	bands	10YR 6/6 10YR 5/6	S	0		lo		6.0	gw	mlf	6.1	.43
C2	59+		10YR 6/6	S	0		lo		6.5			6.3	[illegible]

Plot #1 Continued

APPENDIX IV continued

SOIL DESCRIPTION

Soil type RUBICON File No. PLOT #2

Area SE,SE,SE¼ of sec.19, T24N,R9W. Liberty twp. Wexford Co.	Date 7/9/76	Stop No. 1
Classification sandy mixed, frigid, Entic Haplorthod		
Location from Jct of #10 & #39 Rd go 4chW then 1.3chN to plot		
N. veg. (or crop) Red pine plantation		Climate Continental
Parent material Sand		
Physiography Sandy Outwash Plain		
Relief gently rolling	Drainage well drained	Salt or alkali
Elevation	Gr. water 99"	Stoniness 5-10%,0-25";25"+,<5%
Slope 1-2%	Moisture	Ortstein - 15-20%
Aspect SE	Root distrib.	Tongues - depth 49"
Erosion		
Permeability		

Additional notes

3 bands occur in pit, one at 59" (flf), 62" (flf), 64" (flf); all bands < 5mm thick and are light sl, 10YR 4/4.

Horizon	Depth	Color		Texture	Structure	Consistence			Reaction	Boundary	ROOTS	Lab pH	% C
		Dry	Moist			Dry	Moist	Wet					
A_1	0-1	10YR 4/2	10YR 3/1	salt& pepper S	0	lo			4.5	as	mf	5.3	5.12
A_2	1-8		10YR 3/2	S	0	lo			5.0	as	cf	4.8	1.14
B21ir	8-10		7.5YR 4/4	S	0	lo			5.5	aw	cm	4.9	2.09
B22ir	10-17		10YR 4/3	S	0	lo			5.5	cw	fc	5.7	.79
B23	17-25		10YR 4/4	S	0	lo			6.5	cw	fc	5.7	1.26
B3	25-32		10YR 5/4	S	0	lo			7.0	cw	fc	5.9	.45
C1	32-46		10YR 5.5/4	S	0	lo			7.0	cw	fc	6.0	.65
C2	46+		10YR 6/4	S	0	lo			7.0		fc	6.0	.41

Plot #2 Continued

APPENDIX IV continued

SOIL DESCRIPTION

Soil type RUBICON

File No. PLOT #3

Area SE,SW,NW¼ of sec. 21, T24N, R9W Liberty Twp. Wexford Co.	Date 7/16/76	Stop No. 1
Classification sandy, mixed, frigid, Entic Haplorthod		
Location from Jct 8½ Rd & US131 go ¼ mi W to corner then 3chW & 3½ N to plot		
N. veg. (or crop) Red Pine Plantation		Climate Continental
Parent material Sand		
Physiography Outwash Plain		
Relief gently rolling	Drainage well	Salt or alkali
Elevation	Gr. water 129"+	Stoniness less than 5%
Slope 0.5%	Moisture	
Aspect NW	Root distrib.	
Erosion		
Permeability		

Additional notes

Mineral band after 51", 10YR 4/4, flp; At 84" band, fld, 10YR 4/4; At 88" band, flf, 10YR 4/4; At 99" band, cld, 10YR 4/4; At 104" fs percent increases, bands absent; At 108" band, flf, 10YR 4/4; At 120" band, cld, 10YR 4/4; At 124"-129"+ no bands.

[redacted]

Horizon	Depth	Color		Texture	Structure	Consistence			Reaction	Boundary	ROOTS	Lab pH	% C
		Dry	Moist			Dry	Moist	Wet					
O1	1-0												
A1	0-1	10YR 3/1	10YR 2.5/1	S	0	lo			4.3	as	mf	4.6	7.72
A2	1-4		10YR 5/2	S	0	lo			4.5	aw	cm	4.7	1.31
A3	4-7		10YR 5/4	S	0	lo			5.0	cw	fc	5.5	1.10
B21ir	7-12		7.5YR 4/4	S	0	lo			5.0	cw	fc	6.0	1.02
B22ir	12-23		7.5YR 5/6	S	0	lo			5.5	gw	fc	6.2	.60
C1	23-38		10YR 6/6	S	0	lo			5.5	dw	fc	6.1	.43
C2	38"+		10YR 7/6	S	0	lo			6.5		fc	6.2	.41

Plot #3 Continued

APPENDIX IV continued

SOIL DESCRIPTION

Soil type RUBICON **File No.** PLOT #4

Area	NE,NW,NW¼ of sec 29,T24N,R29W Liberty Twp. Wexford Co.	**Date**	7/18/76	**Stop No.**	1
Classification	sandy, mixed frigid, Enthic Haplorthod				
Location	from Jct 39 & 10 Rds go 4/10 mi E to Service Rd, Go SW 1/10mi then 1chW to plot				
N. veg. (or crop)	Red & Jack Pine Plantation (strips)			**Climate**	Continental
Parent material	Sand				
Physiography	On border betwn Sandy Outwash Plain/Moraine				
Relief	gently rolling	**Drainage**	well drained	**Salt or alkali**	
Elevation		**Gr. water**	112"+	**Stoniness**	5-10% from
Slope	1-2%	**Moisture**			12-36 inches
Aspect	NW	**Root distrib.**			less than 5% elsewhere
Erosion					
Permeability					

Additional notes

At 1 ft. ortstein tongues approx. 9" x 1.5", approx. 5% of pit surf., 5YR 3/3; At 94" Bt bands, f2d, 10YR 4/4, and mottles, f1f, 7.5YR 5/8; At 101" co.s, 10YR 7/6; At 112" strat. co.s and s.

Hori-zon	Depth	Color		Texture	Struc-ture	Consistence			Reac-tion	Bound-ary	ROOTS	Lab pH	% C
		Dry	Moist			Dry	Moist	Wet					
O1	1-0												
A1	0-3	10YR 5/2	10YR 4/2	S	0		lo		5.0	as	mf	5.0	1.50
A2	3-5		10YR 5/3	S	0		lo		5.0	as	mm	5.3	.95
B21ir	5-9		7.5YR 4/4	S	0		lo		5.0	cw	mm	5.5	1.50
B22ir	9-17		7.5YT 5/6	S	0		lo		6.0	gw	cc	5.7	.88
C1	17-45		10YR 6/6	S	0		lo		6.0	gw	fc	6.0	.67
C2	45+		10YR 7/6	S	0		lo		6.5		fc	6.2	.62

Plot #4 Continued

APPENDIX IV continued

SOIL DESCRIPTION

Soil type RUBICON — **File No.** PLOT #5

Area SE.SW.SE¼.of sec 22, T25N.R9W, Fife Lake Twp, Grand Traverse Co	**Date** 8/6/76	**Stop No.** 1	
Classification sandy, mixed, frigid, Entic Haplorthod			
Location from SE corner of sec 22 go 2.7/10 mi W, then go 1 3/4chN to plot			
N. veg. (or crop) Red pine plantation		**Climate** Continental	
Parent material Sand			
Physiography Sandy Outwash Plain			
Relief level-gently rolling	**Drainage** well drained	**Salt or alkali**	
Elevation	**Gr. water** More than 124"	**Stoniness** 12-42" 5%	
Slope 1-2%	**Moisture**		
Aspect NE	**Root distrib.** Many fine roots occurring in pockets where pebble abundance is greatest		
Erosion			
Permeability			

Additional notes

Discontinuous mineral banding from 40-100", flf to f2d, 7.5YR 4/4, abundance of bands increases with depth; A2 discontinuous 10YR 4/2; At 65 to 100" some fs bands; At 100-120" no fs bands.

Horizon	Depth	Color: Dry	Color: Moist	Texture	Structure	Consistence: Dry	Consistence: Moist	Consistence: Wet	Reaction	Boundary	ROOTS	Lab pH	% C
O1	1-0												
A1	0-1	salt & pepper	10YR 3/1	S	0		lo		5.0	as	mf	5.2	6.27
B1	1-2		10YR 4/4	S	0		lo		5.0	as	mf	5.1	2.21
B21ir	2-9		7.5YR 4/4	S	0		lo		5.5	cw	cm	5.6	1.26
B22ir	9-21		10YR 5/6	S	0		lo		6.0	cw	fc	5.8	.82
C1	21-32		10YR 6/6	S	0		lo		6.0	cw	fc	5.9	.48
C2	32+	auger aft. 75"	10YR 6.5/6	S	0		lo		6.5		fc	6.1	[illegible]

Plot #5 Continued

APPENDIX IV continued

SOIL DESCRIPTION

Soil type RUBICON **File No.** PLOT #6

Area NW,SE,NE¼ of sec 24, T25N, R9W Fife Lake Twp. Grand Trav. Co **Date** 8/6/76 **Stop No.** 2

Classification sandy, mixed, frigid, Entic Haplorthod

Location from Jct of Gleaner Hall Rd & County line go 4.5/10mi to dirt rd then go 2.5/10 mi SW to marked tree then 3ch S35 E to plot

N. veg. (or crop) Red Pine Plantation **Climate** Continental

Parent material Sand

Physiography Sandy Outwash Plain

Relief level-gently rolling **Drainage** well drained **Salt or alkali**

Elevation **Gr. water** more than 122" **Stoniness** 10-24" 5-10%; 24"+ less than 5%

Slope 1% **Moisture**

Aspect S **Root distrib.**

Erosion

Permeability

Additional notes

Gravel pockets assoc. with root proliferation; At 22" ortstein 15" x 4", 7.5YR 4/4; At 64" band ls, f2d, 10YR 5/6; At 85" band, flf; At 85" co.s; At 116" s; At 119" to 122" bands, flf, assoc. with stones; At 122"+ bands absent.

Horizon	Depth	Color: Dry	Color: Moist	Texture	Structure	Consistence: Dry	Consistence: Moist	Consistence: Wet	Reaction	Boundary	ROOTS	Lab pH	% C
O1	1-0												
A1	(1-2) 0-1"		Salt & pepper 10YR 3/1	S	0		lo		4.5	aw	mf	5.3	5.38
A2	(4-18) 1-5"		7.5 YR 5/2	S	0		lo		5.0	ai	mm	5.3	1.57
B21ir	5-6"		5YR 5/4	S	0		lo		5.0	as	cc	5.4	1.93
B22ir	6-17"		7.5YR 5/6	S	0		lo		5.5	cw	fc	5.6	1.33
B23	17-28		10YR 5/6	S	0		lo		6.0	dw	fc	5.7	.90
C1	28"+		10YR 6/4	S	0		lo		6.0		fc	6.1	.77

Plot #6 Continued

APPENDIX IV continued

SOIL DESCRIPTION

Soil type RUBICON — File No. PLOT #7

Area	SW, SW, SW¼, of sec 26, T25N, R9W, Fife Lake Twp. Grand Trav. Co.	Date 8/8/76	Stop No. 1
Classification	sandy, mixed, frigid, Entic Haplorthod		
Location	from Jct E - 2 & 131 go E 1 3/10 mi then go N 1 .5/10 mi then go E 1½ ch to plot		
N. veg. (or crop)	Red pine plantation	Climate	Continental
Parent material	Sand		
Physiography	Sandy Outwash Plain		
Relief	level-gently rolling	Drainage well drained	Salt or alkali
Elevation		Gr. water more than 125+	Stoniness 5% 9-24"
Slope	1%	Moisture	Less than 5% 24"+
Aspect	S	Root distrib.	
Erosion			
Permeability			

Additional notes

At 50" one band, ls, flf, 7.5YR 5/6; At 65" band, ls, f2d, 10YR 4/4; At 110"-114" mottles, flf; At 100"-125" strat. fs and s, bits of OM.

Horizon	Depth	Color Dry	Color Moist	Texture	Structure	Consistence Dry	Consistence Moist	Consistence Wet	Reaction	Boundary	ROOTS	Lab pH	% C
01	1-0												
Ap	0-9		10YR 4/3	S	0		lo		5.0	as	mm	5.5	1.83
B21ir	9-13		7.5YR 4/4	S	0		lo		5.5	cw	fm	5.9	1.07
B22	13-24		10YR 5/6	S	0		lo		6.0	cw	fc	5.9	.79
C	24"+		10YR 6/4	S	0		lo		6.5		fc	6.0	.74

Plot #7 Continued

APPENDIX IV continued

SOIL DESCRIPTION

Soil type RUBICON **File No.** PLOT #8

Area NW,SW,NW sec 22, T22N, R9W Selma Twp, Wexford Co		**Date** 8/13/76		**Stop No.** 1	
Classification sandy, mixed, frigid, Entic Haplorthod					
Location from Jct 31 & 32 Rds go S 3/10 mi then E 2ch to plot					
N. veg. (or crop) Red Pine Plantation				**Climate** Continental	
Parent material Sand					
Physiography Sandy Outwash Plain bordering on Lake Bed Plain					
Relief rolling	**Drainage** well drained			**Salt or alkali**	
Elevation	**Gr. water** greater than 118"			**Stoniness** less than 5%	
Slope 5%	**Moisture**				
Aspect NE	**Root distrib.**				
Erosion					
Permeability					

Additional notes

Ortstein tongue at 17" is 2" x 4", 5YR 3/2; Area has been burned over; pH of charcoal 7.0 - 8.0; At 88" band ls to sl, fld, 7.5YR 5/6; At 100"-110" mottles, flf, 10YR 5/6; At 110"-118" bands flf to fld.

Hori-zon	Depth	Color		Texture	Struc-ture	Consistence			Reac-tion	Bound-ary	ROOTS	Lab pH	% C
		Dry	Moist			Dry	Moist	Wet					
O1	2-0"												
Ap	(3-10) 0-6	layer mixed proportion-ally	10YR 3/2 10YR 4/2 10YR 3/3	S	0	lo			5.0	as	mf	5.5	1.76
B21ir	6-12		7.5YR 4/4	S	0	lo			5.0	cw	cc	5.6	1.02
B22ir	12-25		10YR 5/6	S	0	lo			5.5	cw	fc	5.8	.45
C1	25-43		10YR 6/4	S	0	lo			6.0	dw	cc	6.1	.29
C2	43+		10YR 7/3	S	0	lo			6.0		fc	6.1	-

Plot #8 Continued

APPENDIX IV continued

SOIL DESCRIPTION

Soil type RUBICON File No. PLOT #9

Area NW,SW,NE¼ of sec 31,T21N,R10W Cherry Grove Twp. Wexford Co.	Date 8/15/76	Stop No. 1
Classification sandy, mixed, frigid, Entic Haplorthod		
Location from jct FS-5180 & 5402 go N 3ch along 5180 then # 4ch to plot		
N. veg. (or crop) Red Pine Plantation		Climate Continental
Parent material Sand		
Physiography Sandy Outwash Plain		
Relief gently rolling	Drainage well drained	Salt or alkali
Elevation	Gr. water 106"	Stoniness approx. 5%
Slope 2%	Moisture	Ortstein tongue 10-24"
Aspect SW	Root distrib.	and 3" wide (5-10%)
Erosion		5YR 4/4
Permeability		
Additional notes		

At 75" mottles, c2d, 7.5YR 6/8; Honeycomb pattern results when B fingers into C.

Horizon	Depth	Color		Texture	Structure	Consistence			Reaction	Boundary	ROOTS	Lab pH	% C
		Dry	Moist			Dry	Moist	Wet					
O1	1-0"												
A1	0-1"		10YR 3/2	S	0	lo			5.0	as	mf	4.5	4.74
A2	1-7		10YR 6/2	S	0	lo			5.0	aw	mm	4.8	.74
B21ir	7-12		5YR 4/4	S	0	lo			5.5	cw	cc	5.3	1.48
B22ir	12-19		10YR 5/6	S	0	lo			6.0	cw	cc	6.0	.53
B23ir	19-30		10YR 5/8	S	0	lo			6.0	cw	fc	6.2	.55
B3	30-41		10YR 6/6	S	0	lo			6.0	dw	fc	6.4	.15
C1	41+		10YR 6/4	S	0	lo			6.5		fc	6.6	-

Plot #9 Continued

APPENDIX IV continued

SOIL DESCRIPTION

Soil type RUBICON | **File No.** PLOT #10

Area SE,NW,SE¼ of sec 32 T21N, R10W, Cherry Grove Twp Wexford Co. | **Date** 8/20/76 | **Stop No.** 1

Classification sandy, mixed, frigid, Entic Haplorthod

Location from jct FS-5180 & 5498 go E 1 .5/10 mi to blue stump, then S 2ch to plot

N. veg. (or crop) Red pine plantation | **Climate** Continental

Parent material Sand

Physiography Sandy Outwash Plain/Drainage Course - Spillway Border

Relief hilly | **Drainage** well drained | **Salt or alkali**

Elevation | **Gr. water** 128"+ | **Stoniness** less than 5% 0-22" str. fs-gr. 22-120"

Slope 4% | **Moisture**

Aspect S | **Root distrib.**

Erosion

Permeability

Additional notes

A2 discontinous; ls bands at 66", 68", and 71", 10YR 5/8; At 24" weakly cemented tongue, 4" x 4", no color change; Charcoal layer within Ap, ½" - 1" thick; At 90" bands, ls, f2d, bands assoc. with fgr more than with s; At 120"+ bands, ls, cld.

Horizon	Depth	Color Dry	Color Moist	Texture	Structure	Consistence Dry	Consistence Moist	Consistence Wet	Reaction	Boundary	ROOTS	Lab pH	% C	
O1	1-0													
Ap	0-3		10YR 3/3	S	0	lo			5.5	aw	mf	4.5	1.69	
B1	3-9		10YR 4/4	S	0	lo			5.5	cw	cc	4.8	1.47	
B21ir	9-14		7.5YR 4/4	S	0	lo			6.0	cw	cc	5.3	1.09	
B22ir	14-21		7.5YR 5/4	S	0	lo			5.5	cw	cc	6.0	.10	
B23	21-46		10YR 5/6	S	0	lo			5.5	cw	fc	6.2	.26	
C1	46+		10YR 6/4	S	0	lo			6.0		fc	6.4	.03	

Plot #10 Continued

APPENDIX IV continued

SOIL DESCRIPTION

Soil type GRAYCALM File No. PLOT #11

Area SW,SE,NW¼ of Sec 30, T21N, R10W, Cherry Grove Twp. Wexford Co.	Date 8/14/76	Stop No. 1
Classification sandy, mixed, frigid, Entic Haplorthod		
Location from jct #25 Rd & FS-5183 go E 3.5/10 mi to fire break then E 3ch, then N 3ch to plot		
N. veg. (or crop) Red Pine Plantation		Climate Continental
Parent material Sand		
Physiography Drainage Course - Spillway		
Relief gently rolling	Drainage well drained	Salt or alkali
Elevation	Gr. water greater than 133"	Stoniness less than 5%
Slope 3%	Moisture	Ortstein 16-35"
Aspect SE	Root distrib.	5% of pedon
Erosion		
Permeability		

Additional notes

At 50"-58" bands, ls, approx. 2mm thick, 5"-6" long, fld, 10YR 5/4, some 10YR 6/6 banding assoc. with stones but no apparent textural pick up; At 9"-13" charcoal layer, 1" thick; At 30"-50" root proliferation assoc. with gravel pockets; At 88" mottles, 10YR 6/8; At 90"-133" bands, ls, becoming f2d, 10YR 5/4; At 110" percent co.s increases; At 120" co.s absent; At 133" bits of OM found.

Horizon	Depth	Color		Texture	Structure	Consistence			Reaction	Boundary	ROOTS	Lab pH	% C
		Dry	Moist			Dry	Moist	Wet					
O1	2-0												
Ap	0-10		10YR 3/3	S	0	lo			5.0	as	mf	5.5	1.81
A2	10-18		10YR 4/1	S	0	lo			5.5	aw	mm	5.1	1.76
B21ir	18-28		10YR 4/4	S	0	lo			6.0	cw	fc	5.7	.40
B22	28-53		10YR 5/6	S	0	lo			6.5	dw	fc	5.9	-
C1	53+		10YR 6/6	S	0	lo			6.5			5.7	.28

Plot #11 Continued

APPENDIX IV continued

SOIL DESCRIPTION

Soil type GRAYCALM **File No.** PLOT #12

Area NW,NW,SE¼ of sec 30, T21N, R10W, Cherry Grove Twp. Wexford Co. **Date** 8/21/77 **Stop No.** 1

Classification sandy, mixed, frigid, Entic Haplorthod

Location from jct. 25 & FS-5183 go 5.5/10 mi to fire break, then S 2ch along rd, then 2ch E to plot

N. veg. (or crop) Red Pine Plantation **Climate** Continental

Parent material Sand

Physiography Drainage Course - Spillway

Relief	gently rolling	**Drainage**	well drained	**Salt or alkali**	
Elevation		**Gr. water**	128+	**Stoniness**	less than 5% Ortstein 5-10%
Slope	1.5%	**Moisture**			
Aspect	SE	**Root distrib.**			

Erosion

Permeability

Additional notes

At 52"-66" bands, ls-sl, flf-f2d, 1/8" to 1/4" thick, occuring in 2' to 3' intervals;
At 5" charcoal band 1" thick; Ortstein tongue 30" x 3", 5YR 3/4 - 5YR 2/2.

Hori-zon	Depth	Color		Texture	Struc-ture	Consistence			Reac-tion	Bound-ary	ROOTS	Lab pH	% C
		Dry	Moist			Dry	Moist	Wet					
O1	1-0												
Ap	0-5		10YR 3/3	S	0	lo			4.5	as	cm	5.2	1.76
A2	5-9		7.5YR 5/2	S	0	lo			5.0	aw	cm	5.3	.50
B21ir	9-19		5YR 4/4	S	0	lo			5.5	cw	fc	5.7	1.29
B22ir	19-28		7.5YR 5/6	S	0	lo			6.0	cw	fc	5.7	.70
B3	28-41		10YR 5/6	S	0	lo			6.0	cw	fc	5.9	.81
C1	41-128+		10YR 6/4	S	0	lo			6.0		fc	6.0	-

Plot #12 Continued

APPENDIX V

APPENDIX V

SUMMARY OF LABORATORY ANALYSIS DATA

Plot	Nutrients	A	B	C	A	B	C
		Ave lbs/acre			Ave percent Exch. Bases		
1	P	4.5	71.3	11.0	-	-	-
	K	13.0	16.0	13.0	4.3	26.3	28.6
	Ca	228.5	114.0	-	81.9	73.2	-
	Mg	210.0	12.7	10.0	15.9	55.5	71.4
2	P	7.0	26.3	15.0	-	-	-
	K	25.5	9.7	-	3.3	2.1	-
	Ca	400.0	171.3	286.0	78.9	72.1	91.1
	Mg	42.0	39.0	15.5	17.7	25.9	8.9
3	P	29.7	69.0	27.0	-	-	-
	K	29.7	32.0	19.0	3.4	4.9	6.4
	Ca	381.3	285.5	114.0	82.1	84.2	76.7
	Mg	383.0	20.5	15.5	14.5	15.4	16.9
4	P	7.5	36.5	19.0	-	-	-
	K	25.5	13.0	13.0	8.3	28.6	28.6
	Ca	114.0	-	-	75.3	-	-
	Mg	15.5	10.0	10.0	16.5	71.4	71.4
5	P	4.0	23.3	18.0	-	-	-
	K	63.0	25.3	13.0	7.6	27.9	28.6
	Ca	343.0	38.0	-	80.3	22.6	-
	Mg	31.0	13.7	10.0	12.1	49.6	71.4
6	P	4.0	27.0	23.0	-	-	-
	K	101.0	42.0	13.0	14.9	24.4	4.9
	Ca	571.5	76.0	114.0	69.4	46.7	83.0
	Mg	62.5	13.7	10.0	15.6	28.9	12.1
7	P	66.0	78.0	21.0	-	-	-
	K	25.0	19.0	13.0	8.9	18.7	28.6
	Ca	114.0	57.0	-	79.4	39.7	-
	Mg	10.0	10.0	10.0	11.6	41.5	71.4
8	P	47.0	63.0	31.5	-	-	-
	K	38.0	13.0	-	13.0	64.3	-
	Ca	114.0	-	-	75.9	-	-
	Mg	10.0	5.0	-	11.1	35.7	-

SUMMARY OF LABORATORY ANALYSIS DATA
(continued)

Plot	Nutrients	A	B	C	A	B	C
		Ave lbs/acre			Ave percent Exch. Bases		
9	P	5.0	50.0	25.0	-	-	-
	K	50.5	9.5	38.0	9.4	3.5	11.6
	Ca	171.5	114.0	114.0	76.7	84.2	67.7
	Mg	20.5	10.0	21.0	14.0	12.3	20.8
10	P	19.0	46.3	30.0	-	-	-
	K	76.0	50.7	38.0	9.0	9.5	6.9
	Ca	343.0	288.8	229.0	79.1	73.8	80.8
	Mg	31.0	28.7	21.0	11.9	16.7	12.3
11	P	26.0	17.3	28.0	-	-	-
	K	31.5	13.0	-	10.0	28.6	-
	Ca	-	-	-	-	-	-
	Mg	-	10.0	10.0	-	71.4	100.0
12	P	27.0	61.0	37.0	-	-	-
	K	19.0	21.3	13.0	6.4	76.7	16.9
	Ca	114.0	76.0	114.0	15.0	53.0	32.0
	Mg	15.5	10.0	10.0	4.9	83.0	12.1