A SILVICAL STUDY OF CERTAIN FACTORS CONTRIBUTING TO THE DIFFERENTIAL HEIGHT GROWTH OF PLANTATION-GROWN TULIP POPLAR (LIRIODENDRON TULIPIFERA L.)

By

Robert Dean Shipman

A THESIS

Submitted to the School of Graduate Studies of Michigan
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ABSTRACT

A comprehensive silvical study of plantation-grown tulip poplar (*Liriodendron tulipifera* L.) was conducted at the Fred Russ Experimental Forest in Cass County, Michigan, during the growing seasons 1951-52. This investigation included the results of both field and laboratory studies in an effort to determine the silvical requirements of plantation-grown tulip poplar. A knowledge of the growth habits of this species under the climatic conditions of southwestern Michigan seemed advisable. In the vicinity of the experimental area there is a large number of farmers and private land owners who are interested in converting abandoned farm land into tree farms as a continued investment. Since tulip poplar is a desirable species from the standpoint of economical reforestation, the present study was initiated to determine the feasibility of recommending tulip poplar plantings for such enterprises.

The research work was carried out on a 15 year old-20 acre tulip poplar-catalpa plantation. Observation of the tulip trees in this particular plantation reveal a marked differential rate of height growth on trees of the same age and density. This difference in height growth is associated with the presence of an old-growth hardwood stand adjoining the plantation on the south and west. The experimental area was arbitrarily divided into two distinct sites (Area X and Area Y) for research purposes. Edaphic (physical and chemical), microclimatic, and quantitative soil microbiological data were obtained at the same sampling plots in both areas. The approach to the problem was to determine what factor or set of factors were contributing to the marked differential height growth of plantation-grown tulip poplar.

Laboratory experiments on the physical-edaphic factors of the two compared sites, revealed only two properties of an actual and statistically significant difference. These two related factors, the amount of fine clay and the water-holding capacity, were the only physical-edaphic factors which differed significantly between Area X and Area Y. Ten physical-edaphic properties were studied in detail and treated statistically by analysis of variance. The physical soil factors investigated in relation to height growth were soil texture, specific gravity, volume weight, porosity, hygroscopic coefficient, water-holding capacity, moisture equivalent, soil evaporation loss, depth of lateral root penetration, and the water table fluctuation.

A statistical treatment of seven important chemical-edaphic factors in each area indicated no outstanding actual or statistically significant difference between the areas of good and poor height growth of tulip poplar. Further verification of the lack of any chemical soil difference was substantiated by a study of seven individual major nutrient elements.

A growing season study of seven microclimatic factors in relation to soil factors of both areas indicated in virtually every case that the integrated elements of evaporation, relative humidity, air temperature, surface soil temperature, percent available moisture, and light intensity, were closely related to the marked differential height growth of tulip poplar, insofar as these factors conditioned the soil-moisture regimen. Supplemental studies on growth rates, sunscald, bark thickness, herbaceous plant succession, and soil microbiological counts further substantiated the effect of microclimate on soil-moisture requirements.

The continuous soil-moisture regimen throughout the growing season was found to be the principal limiting factor contributing to the marked differential height growth of plantation-grown tulip poplar.

Robert D. Shipman

CONTENTS

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STATEMENT OF THE PROBLEM

Tulip Poplar (*Liriodendron tulipifera* L.) is one of the most valuable hardwood trees from the standpoint of the forester. According to Harlow (1941), this species may reach a maximum height of two-hundred feet with a maximum diameter of twelve feet. The average-sized old growth tree is approximately one-hundred feet tall and four to six feet in diameter. The bole is straight, tall, clear of side branches for a considerable distance above ground level, and in forest stands it supports a rather narrow, open crown. Its root system is usually deep and wide-spreading and best growth is obtained on moist but well-drained soils of loose texture and of moderate depth. In old forest stands it is never very abundant and occurs usually in mixture with other hardwoods. In Michigan, it is often associated with beech, maple, basswood, black cherry, and the oaks. Some seed is produced annually and the minimum commercial seed bearing age of this species is fifteen to twenty years; the average germinative capacity is low (about 10 to 12 percent).

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2. Names and dates refer to "Literature Cited."

Another silvical characteristic of this species is the decided intolerance of the tree, and often it will not compete successfully even with the oaks. Natural seedlings occur most frequently in abandoned fields or other places where a mineral seedbed is available and competing vegetation sparse. Since this species is highly desirable as a forest tree, with its fairly rapid growth and other desirable silvical characteristics, attempts are being made to grow and plant large numbers of seedlings. Because of its utility for numerous wood products, its low susceptibility to serious diseases and insects, this species will continue to be a popular one in reforestation and plantation enterprises.

In southern Michigan, which represents the northernmost limit of its range in this state, tulip poplar has been planted in several experimental forests under varied spacing conditions and in both pure and mixed plantations. One such experimental tulip poplar plantation is located at the Russ Experimental Forest in Volinia Township, Cass County, Michigan. The dissertation here presented deals specifically with a 15 year old-20 acre tulip poplar-catalpa plantation on the Russ Forest.

This plantation was established in order to observe the growth and silvical requirements of this species under the environmental conditions of southwestern Michigan. It is a well known fact that many of the abandoned agricultural soils in this area are relatively poor in nutrients and so low in colloids and organic matter that they possess undesirable physical and chemical qualities for agricultural use. Tulip poplar trees were planted on these abandoned lands in order to observe the magnitude of these apparent deficiencies with respect to trees, and to study the response of tulip poplar to factors other than soil.

The following ecological study on tulip poplar has been proposed and carried out in conjunction with and supplemental to a research study begun by the Michigan Agricultural Experiment Station under direction of the Forestry Department of Michigan State College. As originally set up, this research project was established to study only the microclimatic and edaphic factors affecting the response and growth of tulip poplar on a 15 year old-20 acre plantation. All data concerned with the two above mentioned factors are the property of Agricultural Experiment Station records and are to be used in this dissertation as supporting criteria only. Specifically, these field data refer to seasonal records of soil moisture, rate of evaporation, relative humidity, soil temperature, and air temperature. All other data of an edaphic, climatic, or biological nature, as well as its interpretation and analysis, are the property of the investigator. Needless to say, in an ecological study of the type here presented, all factors must be integrated and weighted as to their ecological and statistical significance.

Height Growth Differential

It has been observed that trees of tulip poplar in this particular plantation show marked differential rates of height growth on trees of similar age and density (Figs. 1 and 2). An attempt is hereby made to ascertain the extent of the cause or causes for this marked variation in height growth. It is the contention of the author that if these variables can be isolated and proven significant from an ecological and silvical viewpoint, then these findings may become applicable to future plantations of tulip poplar on this and related areas. The answer would

Fig. 1.

A view showing the marked differential height growth of tulip poplar. In the foreground, the diminution in height growth can be observed. In the background, south of the plantation proper, is Woods "B", an old growth mixed-hardwood forest. Trees adjacent to the woods are $1\frac{1}{2}$ - 2 times the height of the trees north of the woods in the same plantation. Note the basal sprouting of tulip trees in the immediate foreground.

Fig. 2.

This view of the experimental plantation shows the gradation in height growth proceeding from the old growth woods in the background to the tulip trees in the foreground. Note the tulip trees in immediate foreground which were "drowned out" as a result of excessive soil moisture.

materially aid the farmer in this region and provide a sound investment for converting abandoned land to forest plantations in southwestern Michigan.

In order to expand and study this problem more comprehensively, another phase of the overall analysis was added. With the consent of the Forestry Department of Michigan State College, it was deemed advisable to carry out a study to investigate some of the soil biological factors that might be involved in the differential height growth. This phase of the study will attempt to determine if any direct correlation exists between the numbers of organisms in the soil and the other factors being studied by the Forestry Department. No attempt will be made to ascertain all of the biological interpretations as related to the difference in height growth. The microbial phase of the study will restrict itself to the investigation of the quantitative microflora of the sampling areas. This portion of the dissertation will attempt to place microbiological studies in such a perspective as to demonstrate the ecology of the soil organism-plant community as related to the forester's concept of site quality. The results of this investigation from its inception in May 1951 to September 1952 form the basis for this study.

REVIEW OF LITERATURE

That tulip poplar (*Liriodendron tulipifera* L.) is a rather critical and exacting species with regard to its site requirements has been demonstrated by virtually all research workers studying the silvical requirements of this species. Tulip poplar has been listed by numerous writers as being an intolerant tree, primarily with respect to its light requirements. More recent research by the present investigator and others shows that tulip poplar must be considered intolerant with certain qualifications. Specifically, this species varies in its degree of intolerance throughout its physiological growth and development. For example, young tulip poplar must have a certain amount of light in early life, but not too much, and in more mature days all the light it can get. Thus, in discussing the silvical requirements of this species with special reference to plantation growth and survival, it would appear that the forester would profit by understanding its requirements at various stages of continuing growth rather than at a fixed stage of maturity.

Literature pertaining to the specific type of dissertation here presented is not voluminous. For this reason, the investigator has sought to find and review information which bears principally upon periphery studies related to the present thesis. Those studies closely related to this investigation are presented first and supplemental studies follow.

Craib (1929) made exhaustive analyses of soil moisture in the open and in the forest at Keene, New Hampshire. He found that in dry periods the soils in open situations contain considerably more moisture than the forest soils, based upon either volume or weight determinations. This means that the loss of water through the combined action of transpiration and evaporation in the forest exceeds that in the open. Forest soils were found to become progressively drier with increase in depth, despite the fact that the tree roots were concentrated largely in the surface layers. In the open, during very dry periods, more moisture is found in the second 10 centimeters of soil than in the first. This is due to the drying effect of the exposure of the first layer to sun and wind. He found the moisture content of the surface layer in the two areas tended to be equal. In this layer the high loss of moisture by transpiration in the forest tends to be equalized by an equally high loss of moisture by evaporation in the open. His work is correlated with the trenching experiments of Toumey (1929).

Stewart (1933) conducted a study to give a picture of the major physical, chemical, and bacteriological differences between the various groups of forest and pasture associations. He studied soil profiles in the field, determined permeability of soils in the field, and conducted other physical and chemical soil investigations. The bacteriological work consisted of the determination of the amounts of NO_3 and NH_3 formed after storage, counts on Azotobacter and the presence or absence of legume organisms.

Auten (1945) conducted a study on 77 natural, second-growth yellow poplar stands varying in age from 12 to 61 years in Tennessee, Kentucky, Ohio, Indiana, and Illinois, for the purpose of setting values on soil properties and topographic features as a guide in predicting site quality for yellow poplar. He established the fact that the depth of incorporation of organic matter in the surface soil horizon affords a useful criterion of the site index. If the depth of incorporation (A_1 horizon) is less than one inch, tulip poplar does not show satisfactory development; average or better sites for yellow poplar occur where depth of the A_1 horizon is three inches or more. Auten found the depth to tight subsoil was a better criterion of site index for tulip poplar. The presence of a tight subsoil less than twenty-four inches below the surface results in poorer than average sites. Poorest growth of tulip poplar was observed on ridges and exposed sites. Within the range of soils studied, he found no correlation between site index and calcium, magnesium, phosphorus, and potassium content of soils. Also site index was not related to reaction (pH value) of the soil of any horizon.

From 1908 to 1919 Engler (1919) conducted experiments on soil density, pore space, water-holding capacity, water content, permeability and evaporation, correlating in each case the effect of the forest on the factor in question. After an exhaustive eleven-year study, Engler concluded that the combined loss of water from transpiration and evaporation from open soils exceeds that from forest soils, thus making the forest exert a beneficial influence on the water regimen. For this reason he concludes that more moisture is found in forest soils during dry periods of summer than is found in similar open soils. These results were similar to studies made by Burger (1923) with the exception that Burger found that, during the driest periods of the summer months, the forest soil consistently maintained a lower water content than similar agricultural or meadow soils. This, he states, is due to the high rate of water loss through transpiration by the forest.

The work of Engler has been refuted and contradicts the work of various investigators such as Ebermayer (1889), Burger (1923), and Halden (1926). These latter investigators found that the forested areas contained considerably less moisture than the open areas during the growing season. Halden (1926) also found that both in the open and in the forest the surface layer is the more moist, but during periods of drought this distribution in the open may be reversed.

McCarthy (1933) points out that there are many indications in the observed behavior of younger tulip poplar trees, that in early youth the species must have adequate light and moisture. In addition to this, tulip poplar must be favored by climate, both in protection from extremes of temperature and assurance of a reasonably long growing season. Indications of the effect of climate are found in injury to the thin bark of young trees through sun scalds, which have been noted by McCarthy in southern Indiana. In its extreme southern range, yellow poplar grows only on moist sites where it is protected from extreme drying. McCarthy was unable to determine to what degree temperature is a factor in growth.

McCarthy points out that good growth of tulip poplar on sandy soils, as on the Cumberland Plateau of Tennessee, appears to be suitable only if free from excessive drying. He states that thrifty trees are never found on very dry or very wet soils; the tree is characterized by being very exacting in soil-moisture requirements. He found that the influence of chemical composition of soil on the growth of poplar is apparently slight; it grew well on soils high in lime and on those deficient in lime. McCarthy observes that dry site conditions are reflected in a marked reduction of growth rate and lower density of natural stands. On steep hillsides yellow poplar will often exhibit a marked difference in height growth within a distance of 50 feet up or down the slope.

He points out that marked differences in height and diameter growth may occur on eroded fields, with trees of the same age. The rate of diameter growth of yellow poplar is determined by the size of the crown formed and retained by the tree. If a goodly portion of the total height is occupied by the crown, the tree will grow rapidly in diameter, but the bole will taper very sharply within the crown.

Shirley (1929) in discussing the height and diameter growth of trees states, "low light intensities stimulate height growth at the expense of diameter growth, top growth at the expense of root growth, leaf area development at the expense of leaf thickness, and succulence at the expense of strength and sturdiness."

According to Taylor (1917) tulip poplar is exacting in its soil, moisture, and light requirements. It demands a soil that is well drained yet moist. Light sands and heavy clays are unfavorable to its growth.

Tulip poplar will not thrive in the shade; if overtopped for a short time by other trees it soon dies. The clean, smooth trunk is evidence that it cannot tolerate shade.

Toumey and Korstian (1937) made the observation that available water and evaporation work together in causing differences in growth form. Transpiration is a physiological process determined by both external and internal factors. The external factors are evaporation which influences parts above ground, and available soil water which influences the parts below ground. Evaporation thus by affecting soil conditions, also influences the parts of trees below the surface.

A correlation appears to exist between height growth of trees and available water supply. A decrease in the water requirements for optimum growth results in a rapid falling off in height growth, especially during the growing season. Thin soils in which there is a scanty supply of moisture during the growing season produce trees of low height for the species (Coile, 1935). Dry soil and high evaporation cause trees to assume a characteristic stunted growth.

Hicock, Morgan, Lutz, Bull and Lunt (1931) studied the relationship between soil type and vegetation on four experimental tracts, aggregating 210 acres in Connecticut. Woody vegetation was charted on transects and the herbaceous vegetation studied by means of quadrats. Correlation of a given tree species with a specific soil type was largely unsuccessful. By classifying the soils into four broad groups on the basis of moisture conditions, some correlation was evident. Tulip poplar formed less than one percent of the total and three percent of the principal stand. It was found to some extent on all but the driest soils, but was most abundant on soils having a high moisture content. Poplar was not found on muck, and it seemed to show a marked preference for the heavier well-drained soils.

Data obtained by these investigators indicate that the slowly drained soils support a greater number of both species and individuals of herbaceous and shrubby plants than the rapidly drained soils. Attempts were largely unsuccessful in using plants as indicator types, except in broad soil divisions based upon soil-water relations. They found mesophytic species on the slowly drained loams and xero-mesophytic plants on the more rapidly drained and drier soils. The general lack of correlation between certain plants and soil types was possibly due to the fact that the general excellence of climatic factors may compensate to some extent for poverty of certain soil conditions.

This would be particularly true within rather narrow limits of soil variation.

Kienholz (1941) studied the seasonal course of height growth in certain hardwoods in Connecticut. The seasonal course of height growth of trees, first year sprouts, and second year sprouts was measured during four growing seasons. Most of the species started height growth late in April or very early May; there was a surprisingly little difference between the different species examined in the time of starting growth. Kienholz grouped the hardwoods into two main classes on the basis of their seasonal height growth behavior. The second class is represented by gray and white birch; scattered measurements indicated that tulip poplar has similar growth curves. Growth for species allied to tulip poplar started in late April, rose gradually to a peak of maximum growth in mid-June, fell off gradually to cease in mid-August -- a growing season of 110 days. Ninety percent of the height growth was completed in about 60 days from May 20 to July 20. The seasonal progress of growth was graphically shown by plotting average daily increment in millimeters against weekly periods. The curve of growth of any given species was quite similar from year to year, especially the time of reaching the peak of most rapid growth.

Diller (1930) conducted an investigation on the relation of temperature and precipitation to the growth of beech in northern Indiana. He determined the average annual ring width for ten dominant beech trees in each of seven beech-maple woodlands for the period 1913-1933. From his results, yearly variations in the width of annual rings for a 20-year period were inversely correlated with the average temperature for the month of June. Yearly variations in the width of the annual rings for the same period were correlated directly in certain woodlands with the total precipitation for the month of

June at stations nearest the woodlands studied. Diller found that in most cases, drought years showed their effects on growth the following year probably due to an accumulated deficiency in soil moisture, whereas wet years showed an increase in growth the same year. He surmises that if this period of drought years continues over an extended period there probably would be a gradual retrogression of the beech-maple type with the corresponding advance of the oak-maple and oak-hickory forest types.

Bogue (1905) determined the average width of the annual rings of 42 trees near Lansing, Michigan, for the years 1892 and 1904 and found a correlation between precipitation and width of annual rings. He states that an abnormally large or small annual precipitation is evidenced by the tree growth the following year.

Stewart (1913) compared the width of annual rings of an oak stump at York, New York, with weather records at Rochester, 25 miles north. Greater correspondence was found between variations in rainfall for June and July and ring width than between rainfall for the entire growing season and ring width.

Pearson (1918) compared the annual height growth of Ponderosa Pine saplings and the precipitation for various periods. He found that spring precipitation (April and May) was apparently the controlling factor. Factors reflecting the atmospheric conditions including evaporation showed a close, though not consistent, relation to height growth. The height growth varied inversely with the temperature probably because of the influence of temperature on transpiration and therefore on the relative water supply.

A recent study by Tryon and Myers (1952) shows that periodic precipitation throughout the summer months (May 1 to June 30) for a locality in West Virginia, was highly correlated with width of annual ring for tulip poplar. Nine tulip poplar trees in the co-dominant and dominant crown-classes were examined for radial growth by means of increment cores for the period 1929 to 1949. Results indicated a better relationship between radial growth and precipitation during May 1 to June 30, the early portion of the growing season, than for the period most nearly covering the entire growing season, May 1 to August 31. Correlation coefficients for the first period was 0.675 and that of the latter 0.559. Growth ring borings on trees taken on other species in the stand showed no apparent correlation with precipitation, indicating that these species are less sensitive to low soil moisture than the yellow poplar.

Minckler (1941, 1943) reported on first-year survival of tulip poplar on old-field plantations in the Great Appalachian Valley. Seedlings of 1-0 stock of tulip poplar were planted on one-fourth acre experimental plots, each plot containing 297 trees. Analysis of the data was based upon percentage survival per plot at the end of the first growing season. Three soil types, two slope aspects and two growing seasons were used as criteria for survival. Minckler found that in a very dry year, tulip poplar gave only fair survival on limestone south slopes and failed entirely on shale south slopes. White pine was much less able to tolerate heavy vegetative competition than was yellow poplar. Mortality caused by drought was greatest for tulip poplar on shale and limestone south slopes. When all soil type-aspect classes were considered together, ash and walnut constituted the highest survival group, yellow poplar was second, and white pine and shortleaf pine were third. The importance of the condition of the B soil horizon was illustrated by the following comparisons on various sites. On friable, plastic, and stiff B horizons, yellow poplar mean height growth in two years was 2.5, 1.5, and 0.8 feet respectively. These results show the response of height growth to condition of reduced rainfall on yellow poplar is much greater on soils with a relatively hard and impervious B horizon; tulip poplar showed better growth on northerly than on southerly slopes. In general, the height growth of tulip poplar was related to depth of the A soil horizon. For yellow poplar, 35 plantations with an A horizon depth of seven inches or over grew 30 percent more than 41 comparable plantations with a corresponding depth of less than seven inches. Nine plantations on sites abandoned six years or more grew 1.5 feet as compared with 0.8 feet on 41 plantations located on sites abandoned less than six years. The dry-year plantings of yellow poplar showed a marked reduction in growth as compared to wet-year plantings. Yellow poplar dry-year plantings grew as well as wet-year plantings on friable soil, but only 62 percent and 36 percent as well respectively on plastic and stiff soils.

Pearson (1930) attempted to ascertain whether the upper foot of soil actually becomes drier under or near groups of trees, than in open situations. His results were obtained at the Southwestern Forest Experiment Station. He found in every instance that there was more moisture at depths of six and twelve inches under the tree groups than just outside the crowns to the east or west. Shade and leaf litter probably explain the higher moisture content under the trees. Pearson concluded that in forests of the Southwest, heat appears to be scarcely less important than moisture. Soil moisture is a critical factor in the early life of seedlings in the Southwest, but after the roots have penetrated a foot or more the effects of deficient moisture are manifested more in slow growth than in actual death.

Kozlowski (1949) studied the effects of shading on apparent photosynthesis for seedlings of tulip poplar. In order to test the effect of reduced light intensity on the photosynthetic capacity of tulip poplar, seedlings of this species were grown under cheesecloth shades at five different light intensities. Photosynthetic rates of tulip poplar, expressed as milligrams of CO_2 per square decimeter of foliage per hour, were determined and analyzed statistically from a Latin square arrangement. An analysis of variance indicated no real differences could be attributed to the shading pretreatment alone. Photosynthetic rates of yellow poplar showed no significant differences between shade grown and light grown groups. He found that yellow poplar reached a very high percentage of photosynthesis at low light intensity. The effect of light intensity was statistically significant for pine and red maple, but not for tulip poplar.

Elliott (1915) points out that two-year seedlings grew as well as could be expected for the first year in an open field bordered on one end and along its two sides by virgin forests which cast a shadow over the border of the field. At the end of the fourth year practically all were dead except those enjoying the shade of the adjacent forest; the condition of those in partial shade varied in the ratio of their nearness to the forest; the plants in the rows next to the woods being far the best. Elliott surmised that the "forest floor" had something to do with the result.

No matter how exacting for light the tulip tree may be when past the age of its infancy, it can have too much light and sunshine in its early life. He suggests red pine or European larch as "nurse trees" for tulip poplar plantations, set out a few years before the tulip trees to give the needed shade, these to be planted in alternate rows or alternately in the rows. If pure tulip is desired, remove the nurse trees in thinning. Elliott says that young tulip poplar must have a certain amount of light in early life, but not too much, and in later life all the light they can get.

HISTORY OF RUSS EXPERIMENTAL FOREST

The sampling area under consideration represents a forest plantation in Cass County, southwestern Michigan, which was planted to tulip poplar by Mr. Fred Russ in 1938, using hand-planting methods. The Russ Forest of 580 acres was donated to Michigan State College in 1942 by Mr. Fred Russ of Cassopolis, Michigan. It includes most of the area formerly known as the Newton Farm, an early government land grant to the Newton family in whose hands the property remained for 99 years. Some 220 acres are covered with mature timber and 320 acres are in plantations. An extract from the diary of Mr. Fred Russ, donor, is quoted as follows:

> "In June, 1935, I bought 580 acres of the Newton Farm -- known as the Newton Woods. There were about 240 acres of woods on the part I bought.
>
> Soon after the purchase I decided to plant the north half of the southeast quarter section 29 to Tulips. This 80 acres had about eight acres of young trees mostly Beech and Maple in the southwest corner. The rest of the land had been run quite badly. It was land where Tulips grew naturally and the 80 acres just south of it has some of the largest Tulips in this part of Michigan. The water level on this land is about six feet below the surface. It is a silt sand with some clay in the subsoil. It was probably a lake bottom at one time."

The latter portion of the above diary extract refers to the area in which the present investigation was carried out. With the exception of Mr. Russ' diary and several personal accounts given by local residents, the information concerning this plantation is rather scant. The only other information relative to the growth and condition of this plantation is a survival and growth study made in 1949 by

Mr. C. Ingersoll Arnold, Forester, Russ Forest.[3] This study is restricted to height and diameter measurements and extent of survival following pathological injury. No attempt was made in the above report to determine the cause or causes for differences in height growth, other than speculation.

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3. Arnold, C. Ingersoll. Early Survival, Growth, and Disease in Tulip Tree Plantations in Southern Michigan. Unpublished manuscript. Michigan State College, January, 1949.

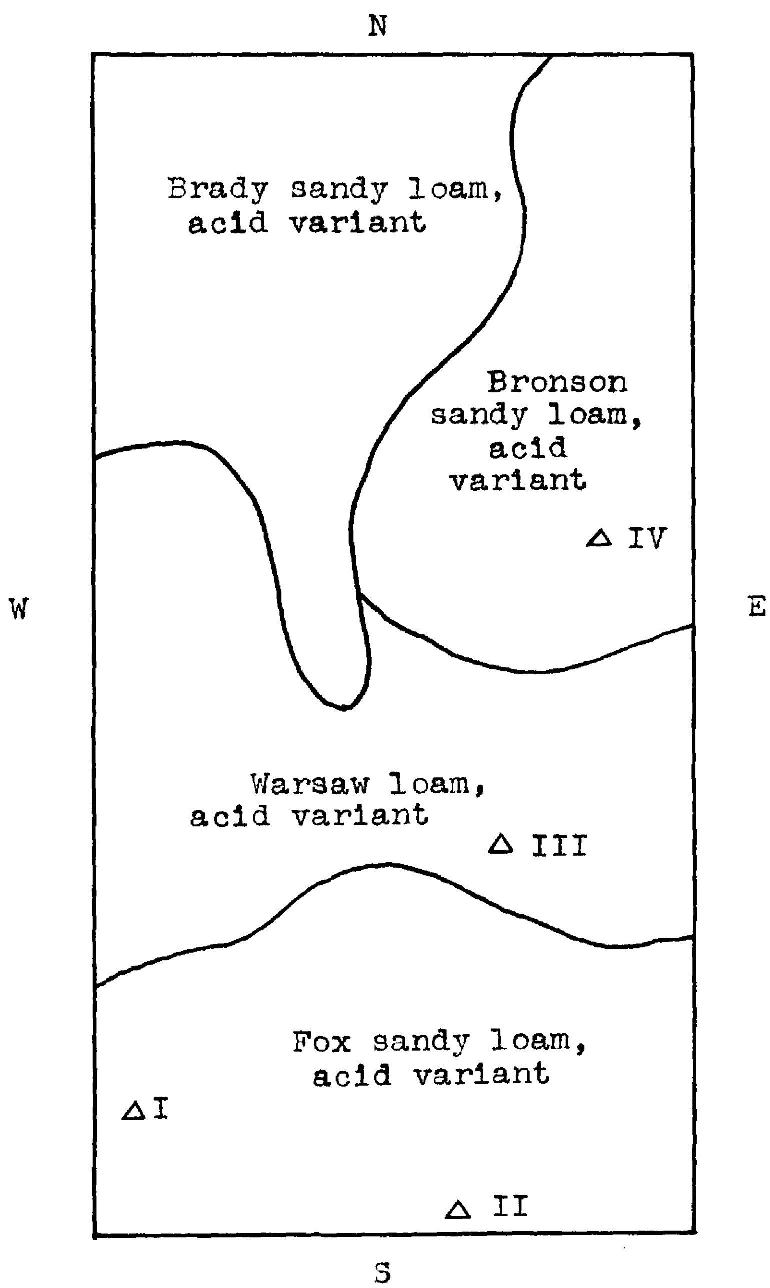
DESCRIPTION OF EXPERIMENTAL AREA

All descriptive data for the plantation under consideration as well as information on the hardwood forest adjacent to the experimental area refer to a 15 year old-20 acre mixed tulip poplar-catalpa plantation (Fig. 3). This area lies within the Gray-Brown Podzolic soil group of southwestern Michigan. The topography is mainly level or gently undulating with an elevation of approximately 900 feet above sea level. The experimental area consists of an outwash plain and other sandy drift of glacial origin. The soil was formed from sand and gravel deposited by water issuing from the ice border between the inner and outer ridges of the Kalamazoo Moraine. Soils in this area are generally free from large boulders or stones. The soils on the experimental plot are acid variants of three rather closely related soil types, the Fox sandy loam, Warsaw sandy loam, and Bronson sandy loam (Map 1). In isolated spots, loam or clayey loam may overlie the gravelly subsoil as a result of past mixing of the profile by plowing. The area is drained by meandering Dowagiac Creek and the overall drainage is moderate to good, with the exception of several depression spots. Detailed profile descriptions of each soil type are included for ready reference to edaphic and microbial relationships.

The fields in question had been heavily farmed for many years prior to the tulip poplar planting. Very little attention had been given to rebuilding the soil with fertilizer of any type. As a result, the soils were so depleted that for the last few years prior to the disposal of the

MAP 1.

SOILS MAP OF THE PLANTATION-GROWN TULIP POPLAR EXPERIMENTAL AREA WITH ITS CORRESPONDING SOIL BOUNDARIES



LEGEND:

△ = Climatic Station

Scale: 1" = 220'

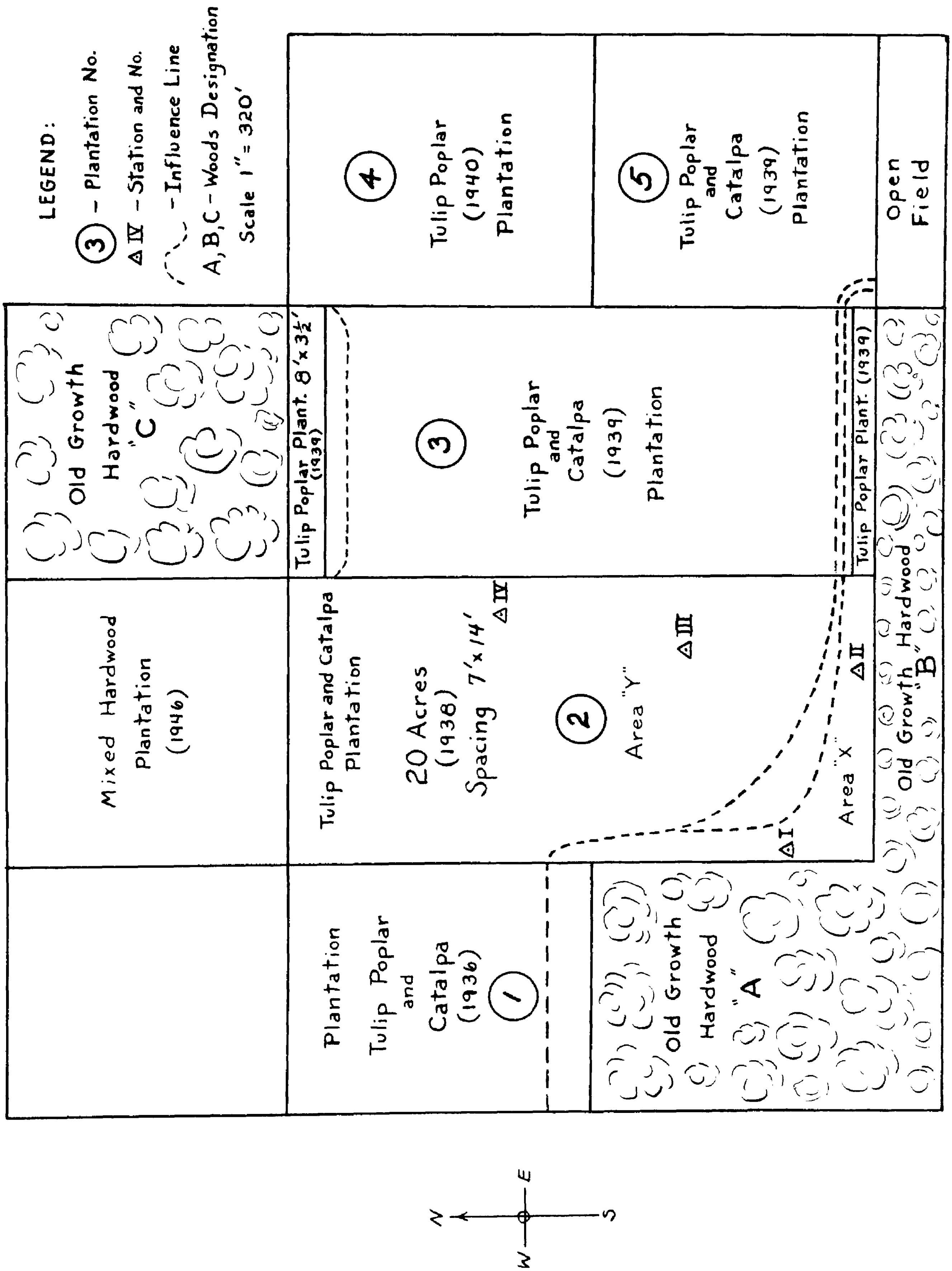
Fig. 3.

A general view of the experimental area looking southwest. This photo was taken April 19, 1952, prior to budding of the trees. Note the absence of cultivation between rows and the extent of forest litter.

This particular portion of the 15 year old- 20 acre plantation is designated as Area "Y", or the area of poor height growth.

MAP NO. 1a

MAP OF THE PROBLEM AREA AND ADJOINING LANDS



property by the original owner, the land was unable to produce paying crops. Wheat and corn were the two chief crops grown, and no thought was given to crop rotation or soil enriching agents. Where the soil had never been used for agricultural purposes, the top soil was a rich, black, sandy-clay loam occurring as a remnant of the old prairie of southwestern Michigan.

In 1938, twenty acres of tulip poplar were planted on the $E\frac{1}{2}$ of $N\frac{1}{2}$ of $SE\frac{1}{4}$ of Sec 29, T5S, R14W, Cass County, Michigan. These trees were home grown by Mr. Russ and planted in the spring. Trees were set 14'8" apart with staggered rows 7'4" apart, and cultivated the first year only. There was a very low mortality of young seedlings the first year. In 1939, catalpa trees were planted in rows between the tulip poplar and were not cultivated. These trees have since shown very poor growth and survival. By October, 1941, the tulip poplar trees were mostly four feet to eight feet tall with some of them twelve feet or more. The first, third, fifth, and seventh rows across the north end of the plantation were grown from seed taken from the large tulip poplar south of the plantation. The total number of tulip trees living and dead in the entire twenty acres is 8463, or 423 trees per acre. Reference to Maps 1a and 2.give an accurate description of the experimental area and the adjacent hardwood stand. An aerial photograph (Fig. 4) taken in 1950 has been included to show the forest cover and surrounding land.

The 15 year old-20 acre plantation running 660' east-west and 1320' north-south is bordered by a dense, mature, mixed hardwood forest located north, south, and west of the plantation. Those tulip poplar trees which are planted close to the fringe of Woods A, B, and C (Maps 1a and 2) are one and one-half to two times the average height of trees of the same age, density, and same plantation further removed from the woods (Table 1). The average diameter growth is one and one-half times greater on trees located close to the old-growth woods. This observation of the difference in height growth thus necessitates the establishment of a line to distinguish tulip trees lying inside and outside this line.[4] The "influence line" is used to designate possible cause from effect. This term was selected in order to avoid any presupposition as to the source of the cause for reduced or increased height growth on opposite sides of the "influence line." Having established the fact from observation that the difference in height growth is strikingly marked, the term "incidence" was selected to denote a cause or set of causes for this difference, but not yet verified by investigation.[5] Accordingly, four straight-line transects were run (two in each cardinal direction) in order to tally the heights and diameters of tulip trees along these transects (Map 2). Some criteria was needed to describe these transects in terms of both influence and incidence, and four classes or degrees of incidence were set up for each transect in tabular form (Table 1).

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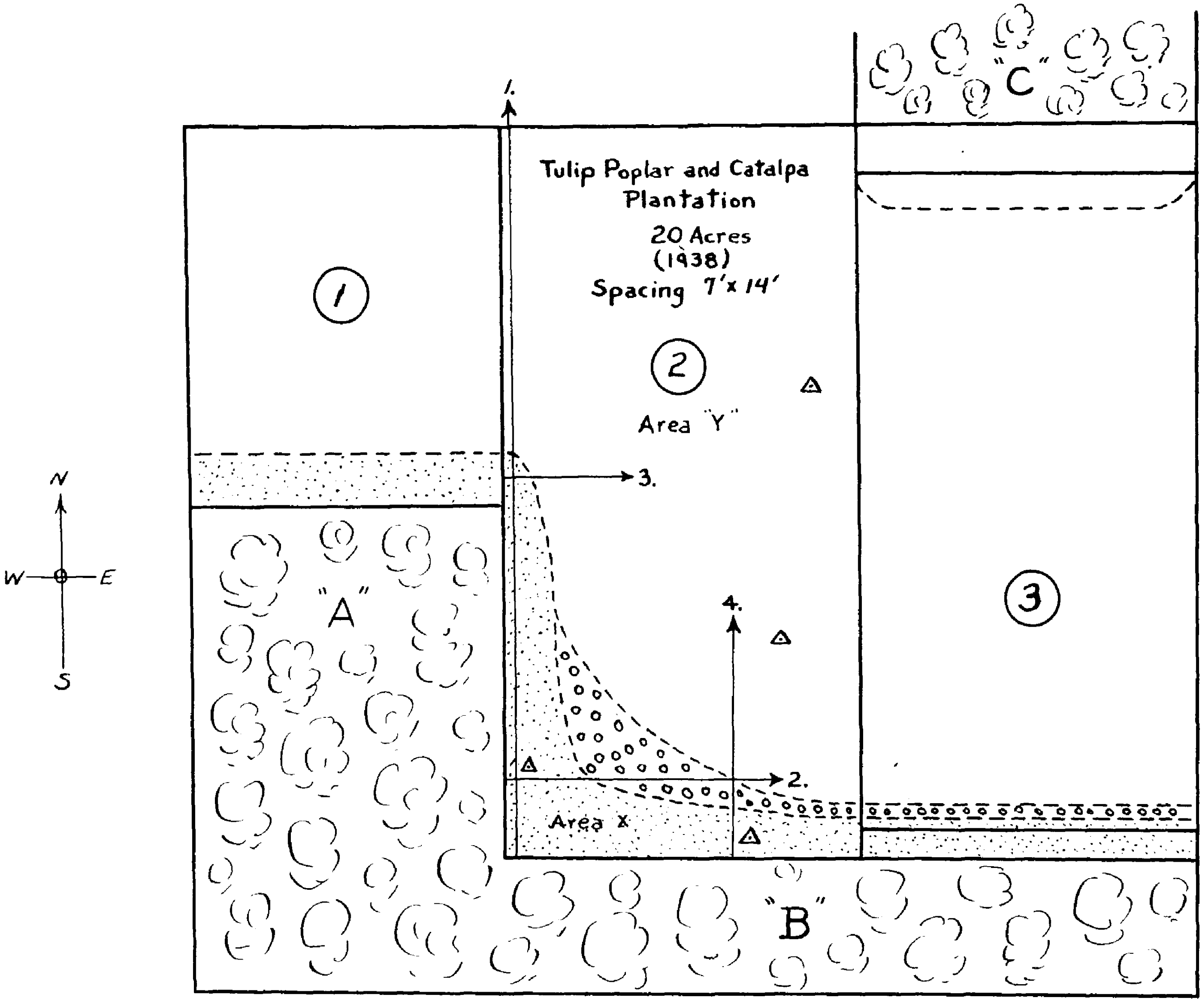
4. In this study, the "influence line" of the woods is used to denote an effect or result, so as to preclude any presupposition of its cause or causes.

5. The term, "incidence," is used to denote some causal factor or set of factors. These causes may be in terms of protection offered by the woods, such as shading, reduced temperature, reduced evaporation, or reduced wind velocity.

MAP NO. 2



MAP SHOWING HEIGHT - DIAMETER TRANSECTS AND INFLUENCE AREAS

LEGEND:

Scale 1"= 320'

(2) - Plantation No.

Δ - Station

A,B,C - Woods

→ 2. - Transect and No.

- Influence Line

- Severe Sunscald

- Intermediate Scald

- No Sunscald

TABLE 1.

INCIDENCE CRITERIA

Transect Number	Average Height in Relation to "Influence" Line Inside	Outside	Direction and Extent of Incidence Along Transect
1	47.0 ± 4.2'	23.5 ± 8.5'	From SW plus no incidence
2	36.0 ± 14.0'	25.0 ± 8.3'	From S and SW
3	23.0 ± 7.1'	17.1 ± 6.1'	No incidence N, S, and E (some incidence W)
4	28.0 ± 9.2'	19.0 ± 2.5'	Incidence S plus no incidence from S
Average	33.5 ± 8.6'	19.8 ± 6.3'	

Using the above incidence criteria as a basis, the average heights and diameters as well as the heights and diameters of individual trees were plotted to show the effects of presence or absence of woods on opposite sides of the "influence line." In addition, profile diagrams were plotted to scale in order to further bring out the relationship of the incidence criteria used, and the apparent effect of this incidence. The standard deviation was computed for height and diameter in all four transects on both sides of the "influence line."

For purposes of simplification and further reference to the two areas separated by the "influence line," two distinct portions of the experimental area exist as:

AREA X - The area exhibiting good height growth, little or no sunscald, good diameter growth, and lying adjacent to Woods A and B. (Figs. 4, 5, and 6).

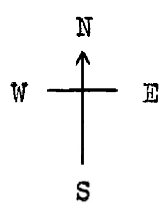
AREA Y - The area exhibiting poor height growth, extreme sunscald with subsequent wind breakage, poor diameter growth, and occupying a position in the center of the plantation distant from the old-growth woods. (Figs. 3, 4, and 7).

Fig. 4.

An aerial photograph taken August 10, 1950, showing the experimental plantation and adjacent mature, mixed-hardwood forest. A white arrow designates the rectangular 20 - acre experimental plot.

X = Area of good height growth

Y = Area of poor height growth



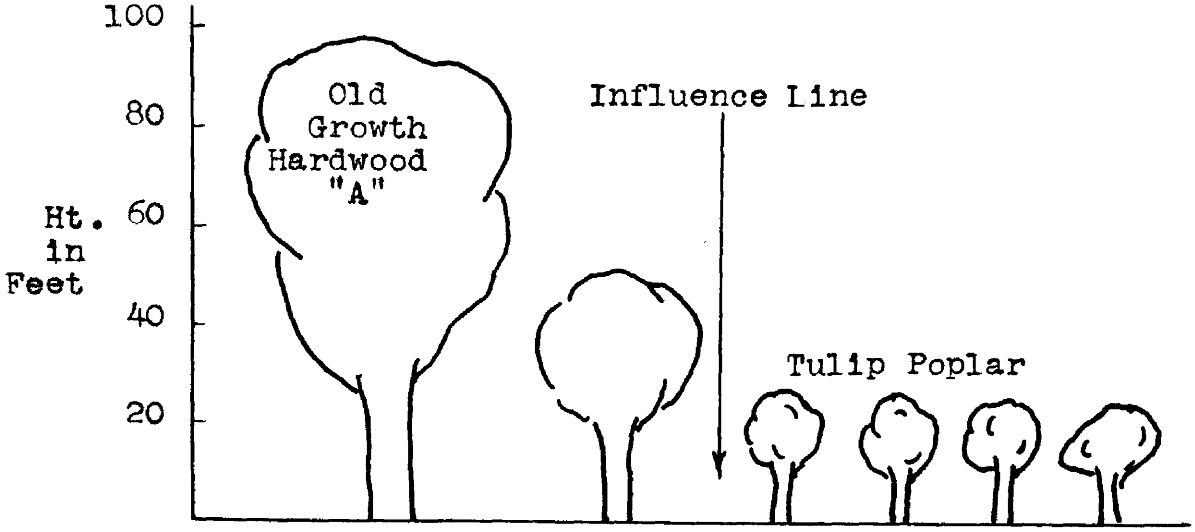
Scale: 1" = 750'

Graphical Representation of Four

Straight-Line Transects Taken in the Experimental Area **

** Transect number designations correspond to the same transects shown on Map 2.

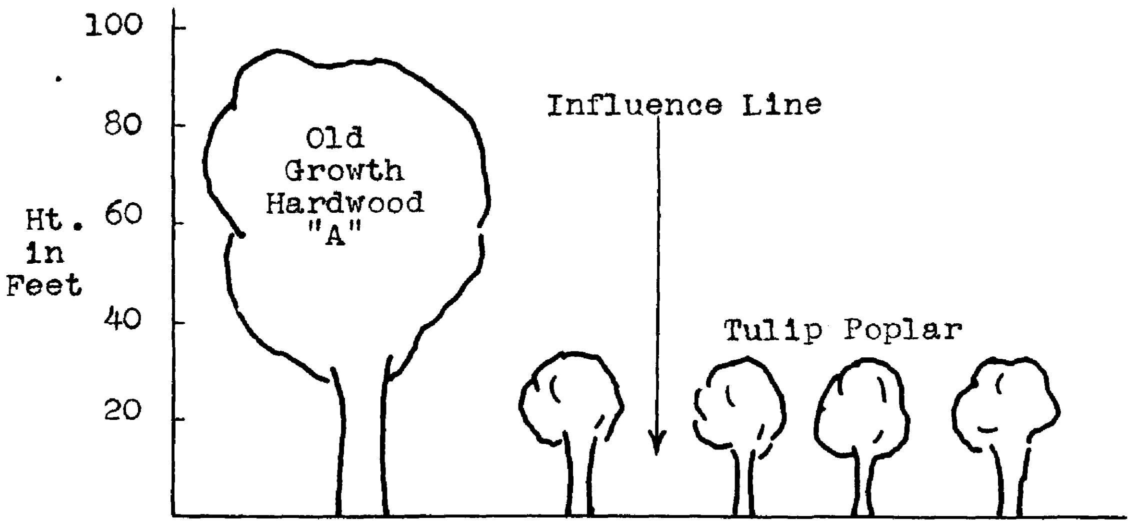
TRANSECT NO. 1



PROFILE DIAGRAM ALONG A SOUTH TO NORTH TRANSECT SHOWING INCIDENCE FROM SOUTHWEST PLUS NO INCIDENCE

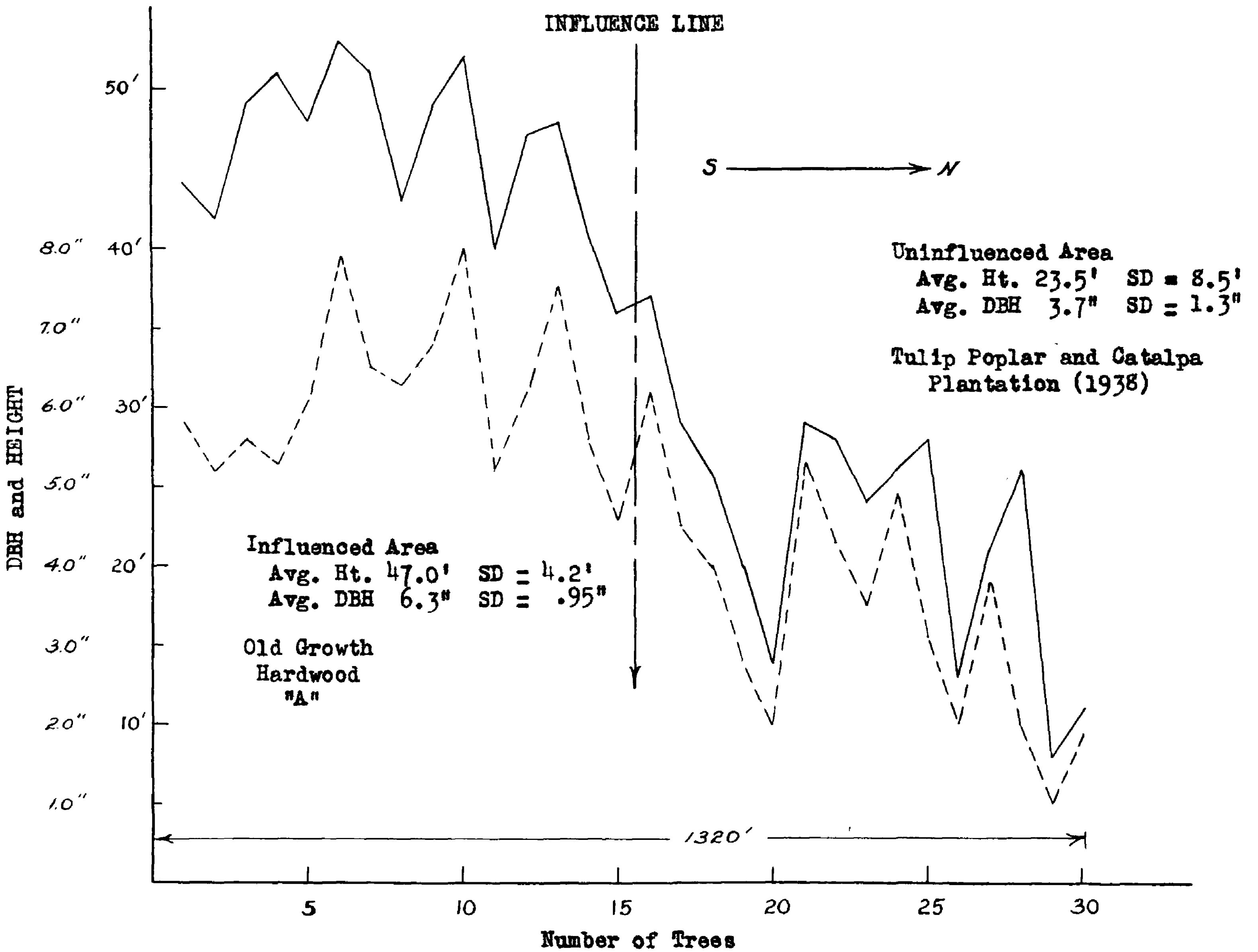
1320'

TRANSECT NO. 2



PROFILE DIAGRAM ALONG A WEST TO EAST TRANSECT SHOWING INCIDENCE FROM SOUTH AND SOUTHWEST

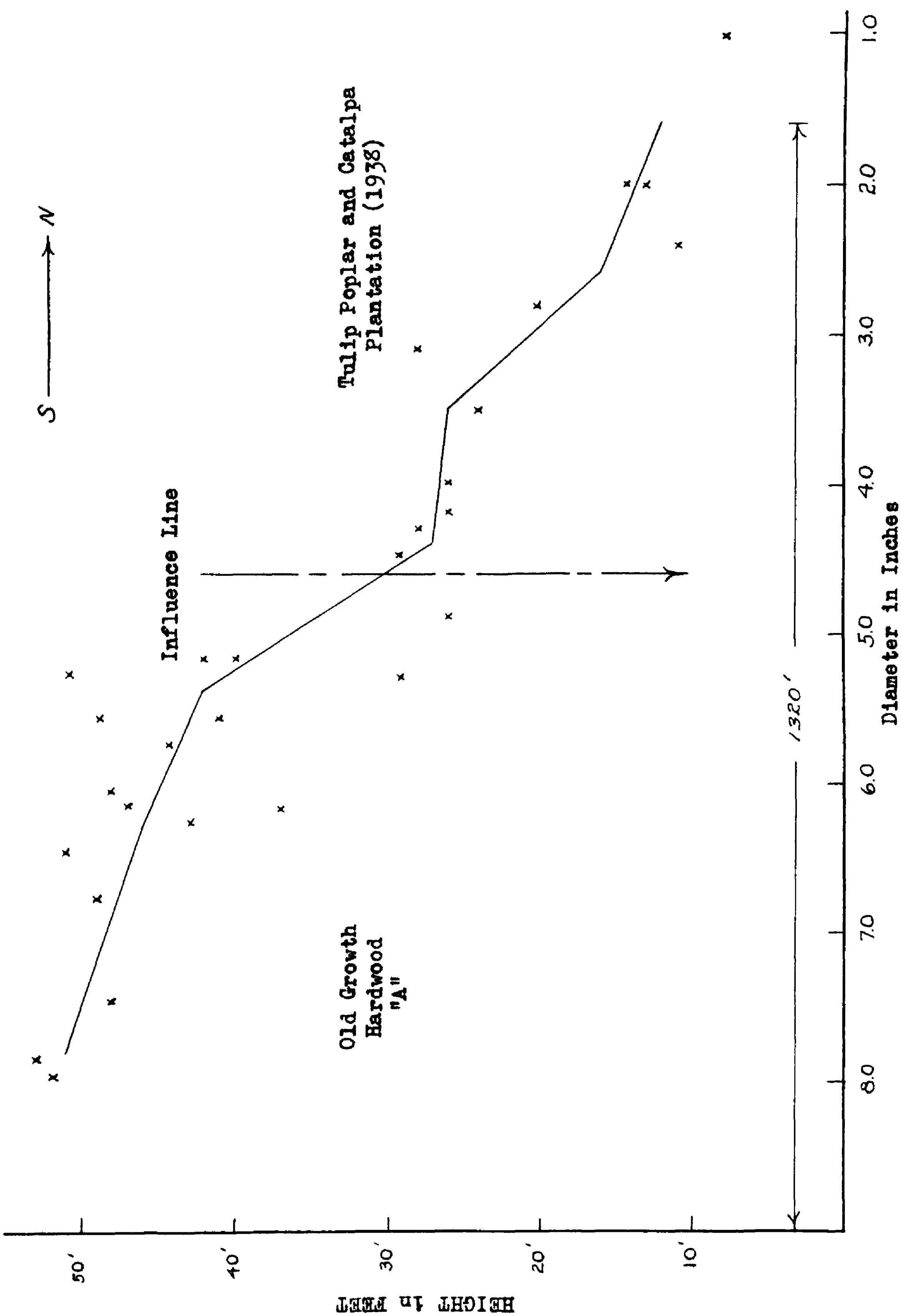
520'



A HEIGHT - DIAMETER TRANSECT OF INDIVIDUAL TREES IN RELATION TO DISTANCE FROM OLD GROWTH HARDWOOD

SD = Standard Deviation

TRANSECT NO. 1

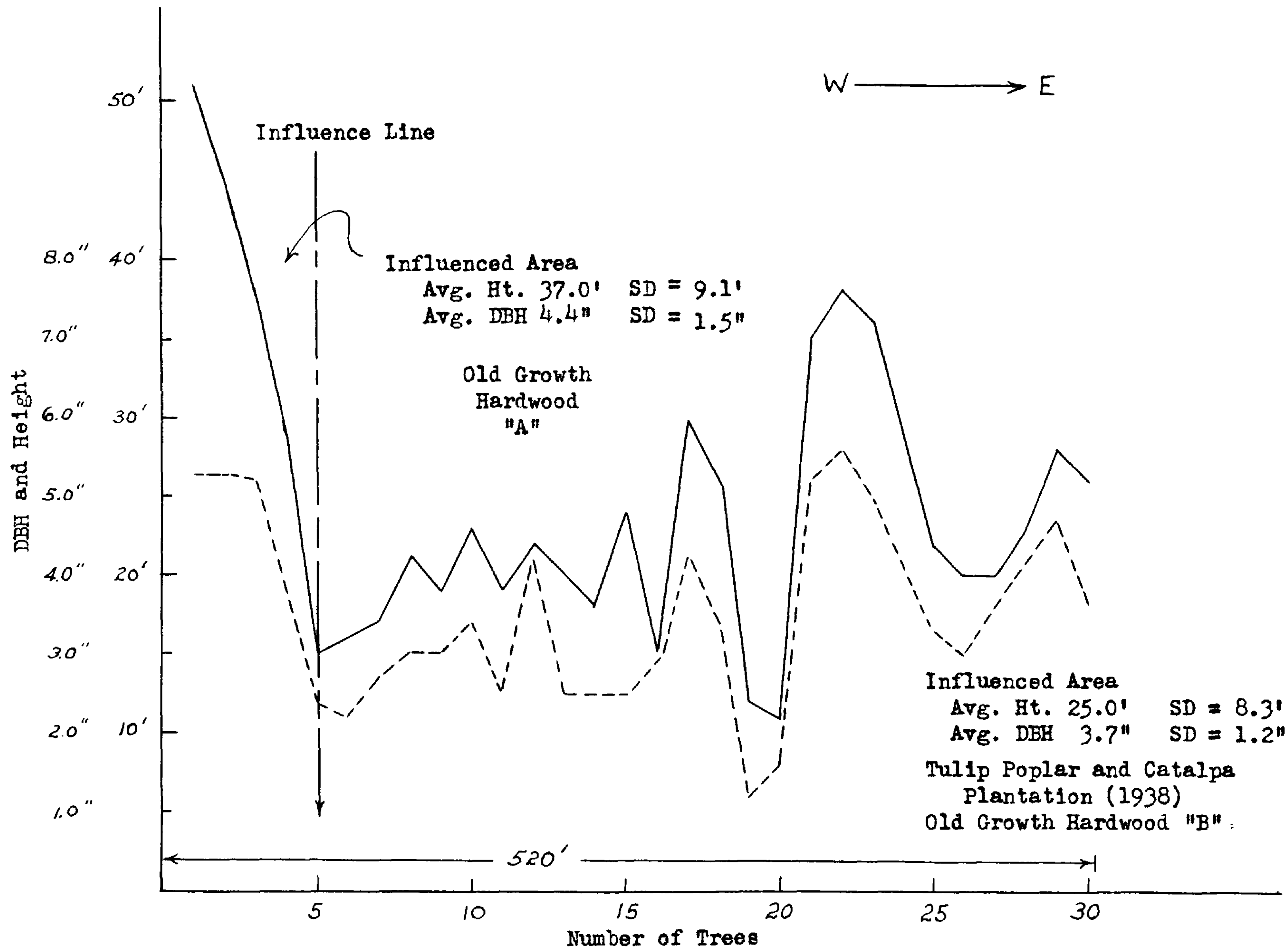


AN AVERAGE HEIGHT - DIAMETER RELATIONSHIP ALONG A SOUTH TO NORTH TRANSECT WITH TREES OF THE SAME AGE

Fig. 5.

A view taken in Area X (good height growth). The average diameter of tulip poplar in this area is 6.3 inches with an average height of 47.0 feet. Note the old growth hardwood (Woods "A") in the background adjoining the plantation.

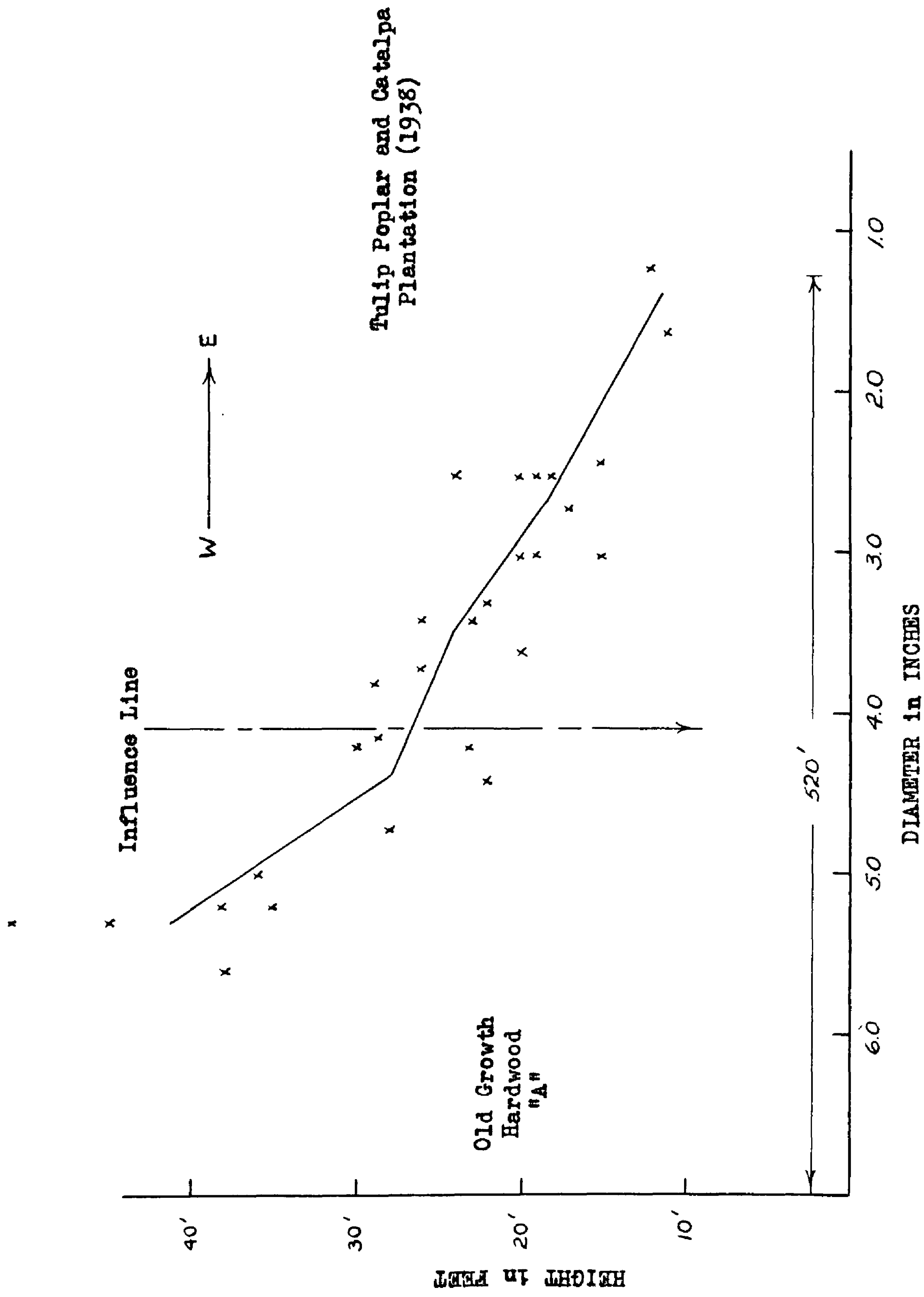
TRANSECT NO. 2



A HEIGHT - DIAMETER TRANSECT OF INDIVIDUAL TREES IN RELATION TO DISTANCE FROM OLD GROWTH HARDWOOD

SD = Standard Deviation

TRANSECT NO. 2

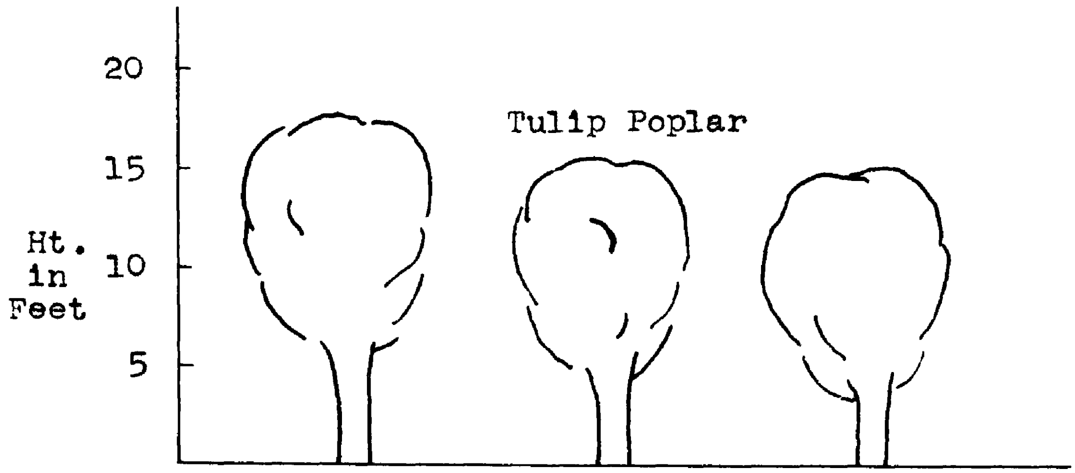


AN AVERAGE HEIGHT - DIAMETER RELATIONSHIP ALONG A WEST TO EAST
TRANSECT WITH TREES OF THE SAME AGE

Fig. 6.

A typical view of Area X looking northwest. The catalpa tree interplanting shows very poor growth. Compare the leaf litter on the forest floor with the litter shown in Fig. 3. This photo was taken in April, 1952, prior to budding of the trees. No sun-scald is observable in this area.

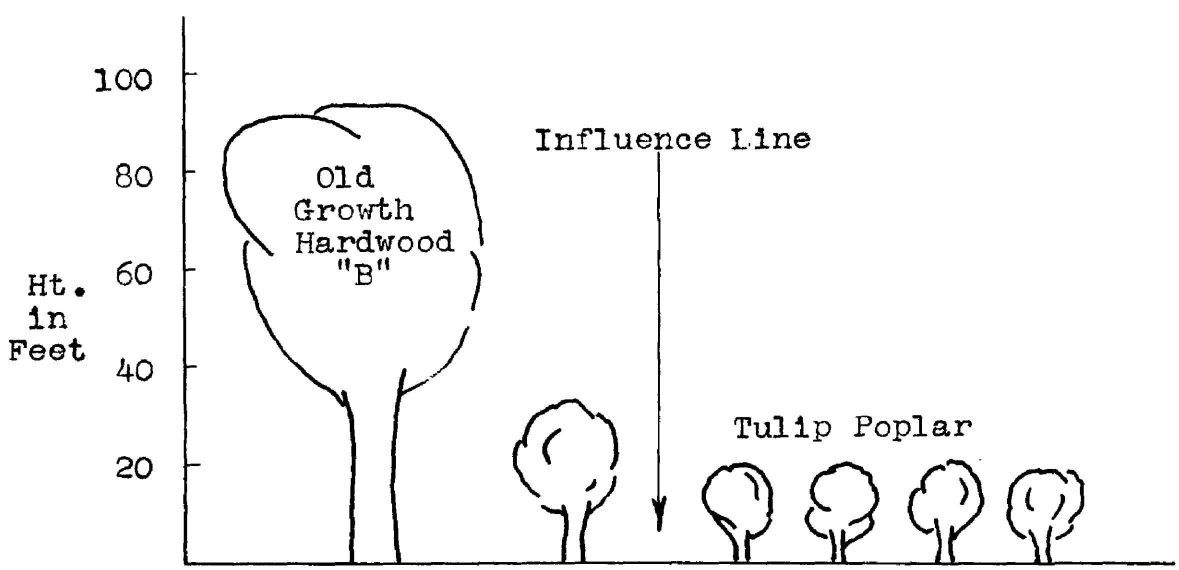
TRANSECT NO. 3



PROFILE DIAGRAM ALONG A WEST TO EAST TRANSECT SHOWING ABSENCE OF INCIDENCE N, S, AND E.

240'

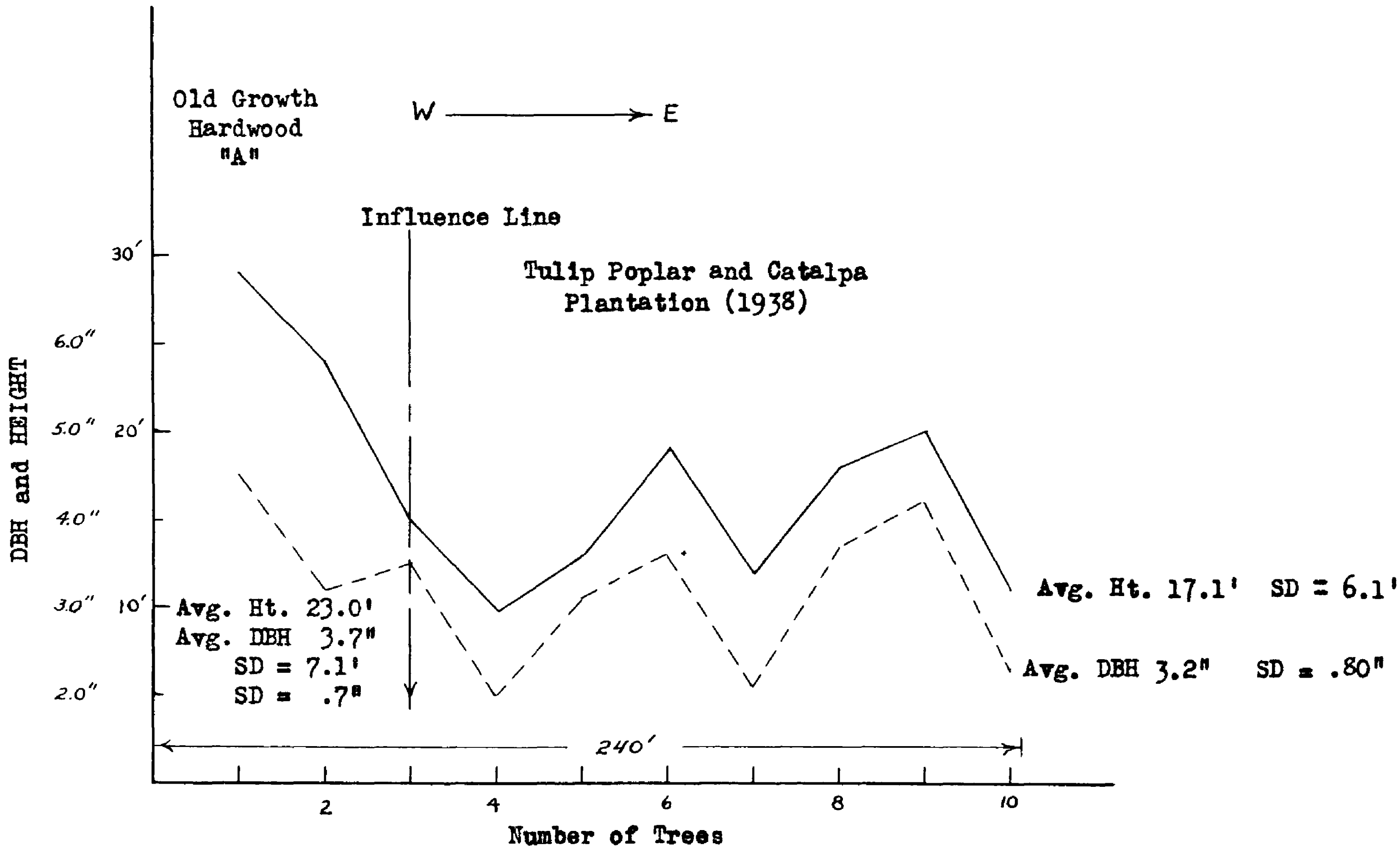
TRANSECT NO. 4



PROFILE DIAGRAM ALONG A SOUTH TO NORTH TRANSECT SHOWING INCIDENCE FROM SOUTH PLUS NO INCIDENCE

440'

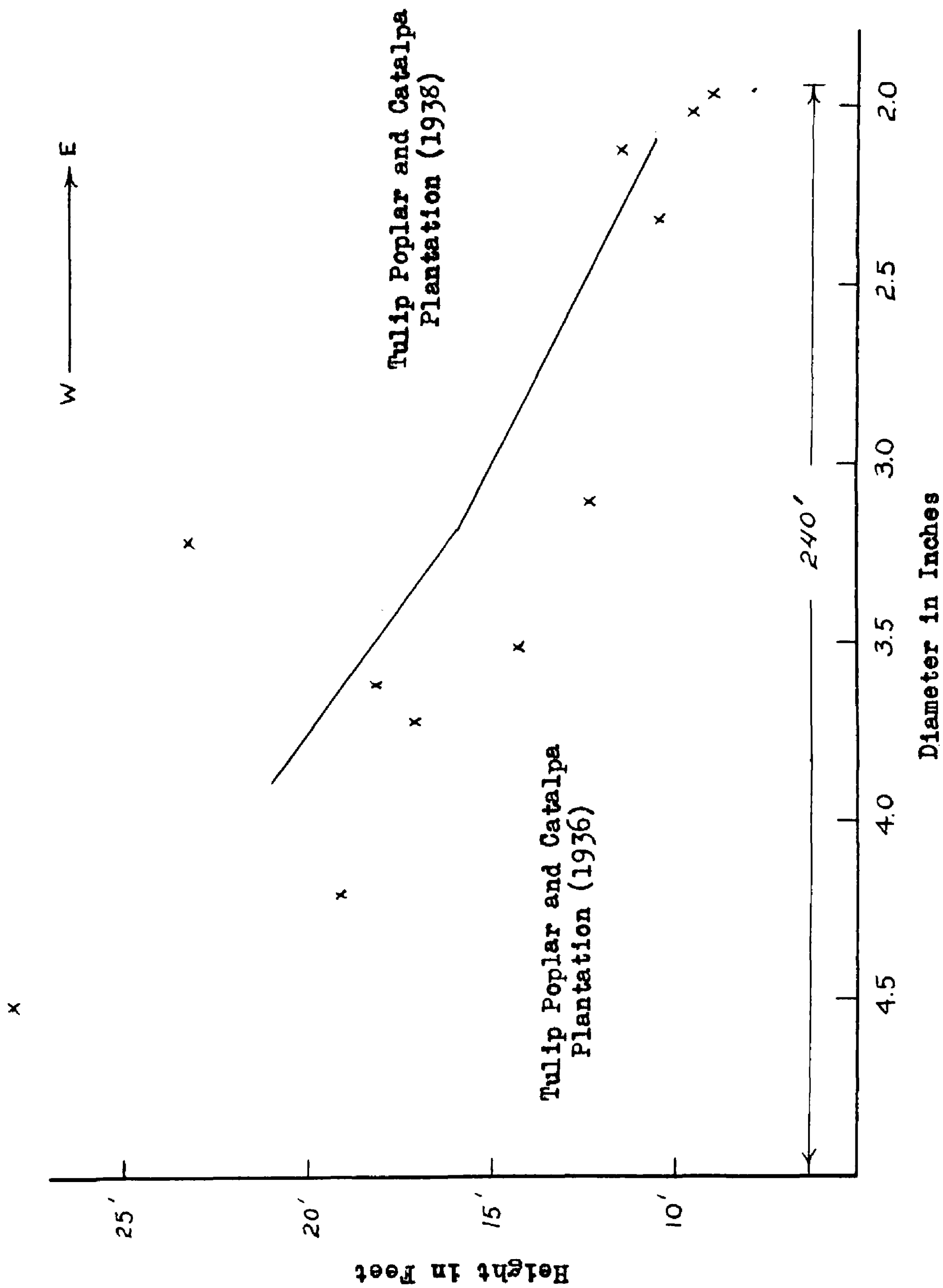
TRANSECT NO. 3



A HEIGHT - DIAMETER TRANSECT OF INDIVIDUAL TREES IN RELATION TO DISTANCE FROM OLD GROWTH HARDWOOD

SD = Standard Deviation

TRANSECT NO. 3

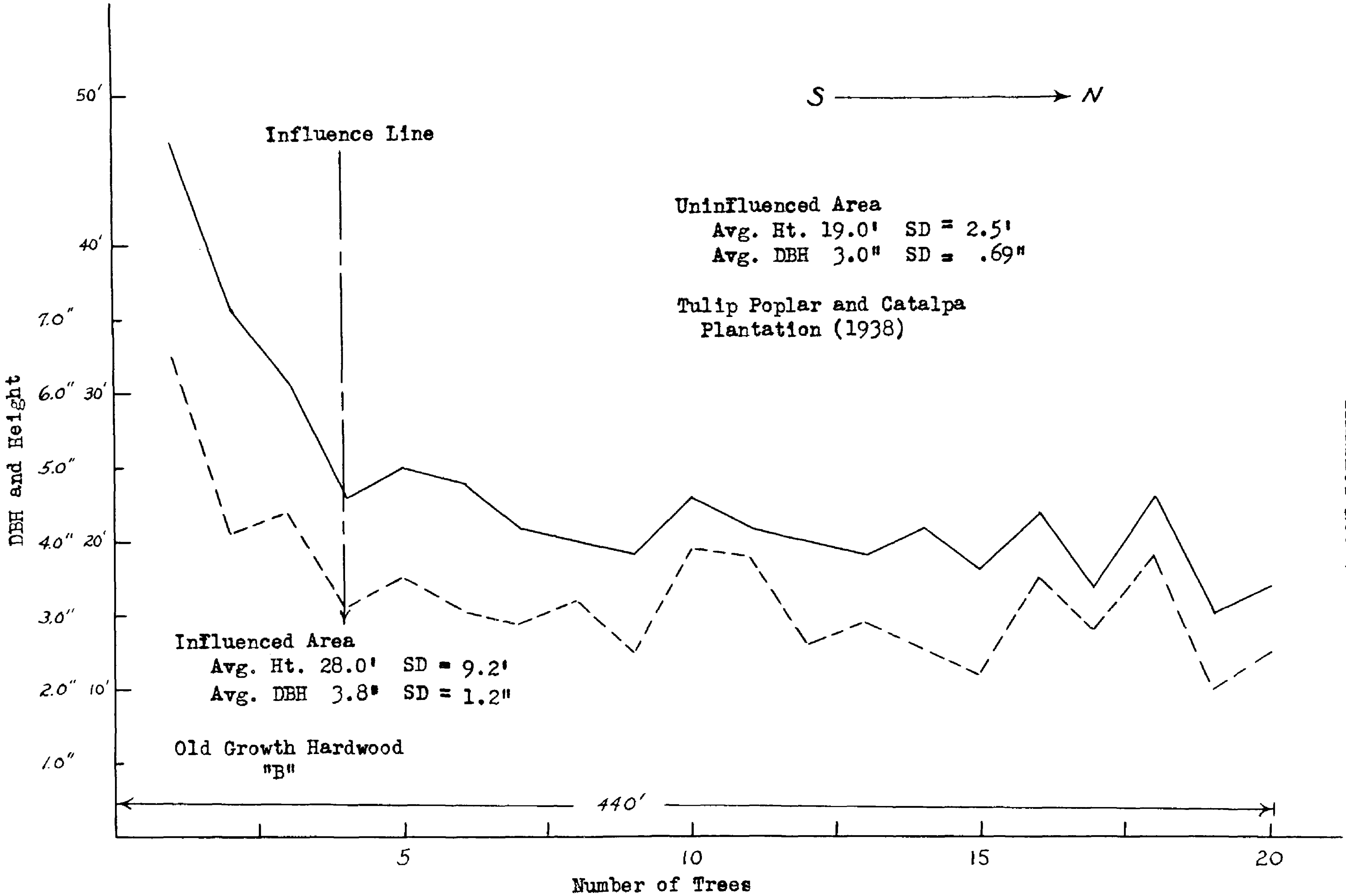


AN AVERAGE HEIGHT - DIAMETER RELATIONSHIP ALONG A WEST TO EAST TRANSECT WITH TREES OF THE SAME AGE

Fig. 7.

A view taken in the area of poor height growth (Area Y). Sunscald is observable on the tulip poplar to the right of the photo. Note the dark patches appearing as burns; these are mats of Haircap Moss (Polytrichum commune Hedw.). The tulip poplar in this area exhibits extensive sprout growth from the base of the trees; this abnormality is the result of sunscald and tree cricket activity. The average height of trees in this area is 17.1 feet with an average diameter of 3.2 inches.

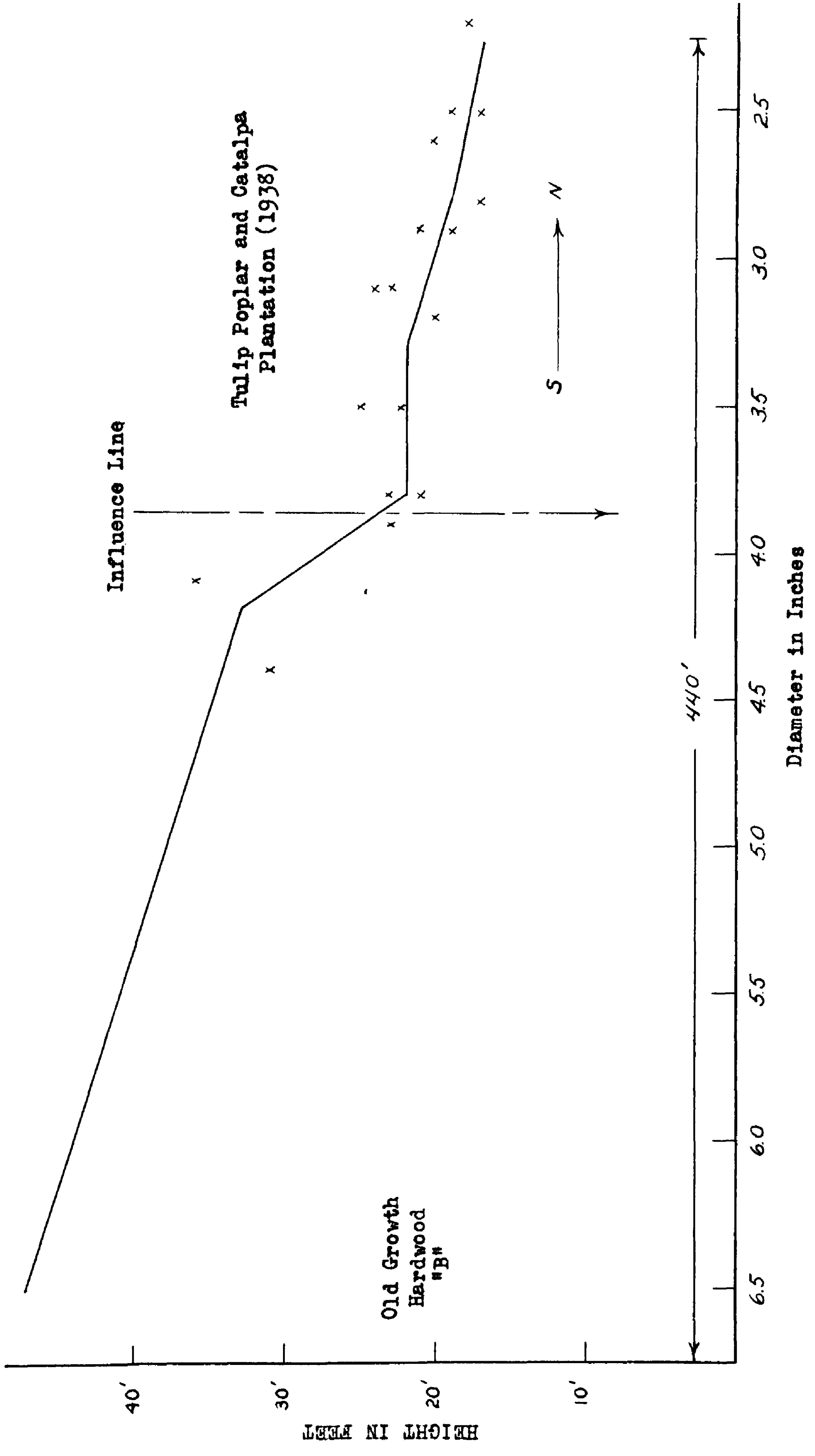
TRANSECT NO. 4



A HEIGHT - DIAMETER TRANSECT OF INDIVIDUAL TREES IN RELATION TO DISTANCE FROM OLD GROWTH HARDWOOD

SD = Standard Deviation

TRANSECT NO. 4



AN AVERAGE HEIGHT - DIAMETER RELATIONSHIP ALONG A SOUTH TO NORTH TRANSECT WITH TREES OF THE SAME AGE

SCOPE OF EXPERIMENTAL WORK

The study as originally conceived by the Forestry Department in June, 1951, was devised to measure the edaphic and atmospheric factors within the tulip poplar plantation. During the summer of 1951 four sample plots were established as climatic stations. Two of these stations were located on the south and west sides of the plantation bordered by woodland where the trees exhibit the greatest height growth; the remaining two stations were located near the center of the plantation where the trees show little height growth. Measurements taken daily by the Forestry Department throughout two growing seasons beginning in 1951 were the following: (1) atmospheric factors, and (2) edaphic factors. The first of these factors include measurement of the evaporation rate by use of the Livingston atmometer bulb; air temperature and relative humidity by use of the hygrothermograph and sling psychrometer. The edaphic factors studied were soil moisture by use of Bouyoucos soil-moisture blocks at depths of six and eighteen inches respectively; soil temperature was taken daily using a soil thermometer at a one inch depth below the soil surface. The field data on the above factors was measured daily where possible.

Although other soil physical determinations were proposed in the original plan of the Forestry Department, the actual collection and analysis of these data were left to the present investigator. The following determinations on the physical-edaphic factors are the joint property of the Forestry Department and the present author: (1) Physical determinations, including total, capillary, and non-capillary porosity, volume weight, maximum water-holding capacity, specific gravity, moisture equivalent, hygroscopic coefficient, soil evaporation, and a mechanical analysis. Further factors include (2) chemical determinations such as organic matter content, pH, total nitrogen, C/N ratio, base exchange capacity, exchangeable hydrogen, total bases, and the nutrient content of individual horizons.

To give greater comprehensiveness and scope to the project, the following biological determinations were deemed advisable: (1) Microbiological determinations, which were included to show quantitative soil organism differences for both the area of good height growth (Area X) and poor height growth (Area Y) with reference to:

a. Depth of soil horizon

b. Seasonal variation in microbial counts

c. The pH in relation to microbial counts

d. Moisture content in relation to abundance of organisms

e. The numbers of fungi, bacteria, and actinomycetes as related to the ecology of each area.

In order to observe the effects of the herbaceous vegetation upon microbial and edaphic factors, a systematic grid sampling of the lesser vegetation was tallied and photographed throughout the growing season as an index to the succession of flowering plants and their possible correlation to the soil moisture content of each habitat.

Observation of the stems of tulip trees in the center of the plantation show that these trees have extreme sunscald damage.[6] In order to

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6. The term "sunscald" as used here refers to damage resulting from an extreme degree of fluctuation in temperature on the young bark. This damage may be the result of combined desiccation effects and repeated passing back and forth through the freezing point.

study the effect and extent of this damage to the plantation, a complete stem analysis of individual trees was made as well as macroscopic cross sections of damaged trees, so as to exhibit the extent, date of sunscald, and its possible relationship to height and diameter growth of the stand.

To obtain the total scope of the ecological problem additional data were obtained on (a) depth to the water table throughout the season (b) kind and extent of forest litter (c) concentration and position of roots in the surface soil horizon, and (d) light intensity measurements at various points within the sampling area.

The study as shown by the above experimental criteria was intended to be comprehensive in its scope. A broad classification of the phases investigated consist of: (1) Laboratory experiments (soil-physical and soil-chemical) (2) Field-plantation experiments (growth, microclimate, and plant succession) and (3) Soil microbiological experiments (quantitative).

These phases will be taken up individually in the above named order. A summary of all factors is presented after discussing each variable.

SOIL SAMPLING TECHNIQUE

Laboratory Experiments - Physical and Chemical

Equipment Used

The soil samples for both the physical and chemical soil determinations were taken with a field soil-core sampler. This sampler has been used extensively by the United States Soil Conservation Service for soils research. The type used in these investigations employs a 3 x 3 inch aluminum cylinder with a weighted driving assembly.

Sampling Procedure

Pits were dug at each sampling station and each soil horizon of the profile was sampled separately. The horizon sampled was based upon the actual depth of a particular horizon as mapped in the field. All samples were taken at or near field capacity. The soil cores obtained were then brought into the laboratory and the physical and chemical determinations made. Where a modification in the technique of making a particular determination was necessary, appropriate notation is made under the experimental method for that procedure.

Plot Description

The sampling areas were set up in such a manner that a statistical analysis could be applied to the data. For most of the soil factors investigated, samples were taken at four main climatic stations designated by Roman numerals, as Stations I, II, III, and IV. Stations I and II are located in the area of good height growth (Area X) and Stations III and IV are in the area of poor height growth (Area Y). At each main station, four substations were established at random and designated as

Substations 1, 2, 3, and 4. Soil horizons for each profile were designated in the usual manner, as A_0 , A_1 etc. The above notation for each soil sample is applied to all the edaphic factors investigated. Thus, an individual sample might be designated as $II3A_2$, which refers to main station, substation, and soil horizon respectively. Reference to all soil profiles is presented under the caption Representative Profile and Description for each soil type as shown later.

Statistical Analysis of Data

The soil experiments (physical and chemical) were so designed that all data concerning a particular soil factor could be subjected to analysis of variance. In all cases, the variance between areas has been segregated from the total variance. The short-cut method for individual degrees of freedom has been used to calculate the mean square and F-value as shown by Snedecor (1946). Experiments were designed for individual comparisons among treatments, where the sum of squares for n treatments is subdivided into n-1 parts, each corresponding to a single degree of freedom; these parts were then tested individually against experimental error. The results of this method give a notable increase in the information furnished by the experiment. This method is applicable where the two sums are made up of the same number of individuals. By comparing the error variance between areas, the presence or absence of significant difference can be detected from the F-test. In order to determine between areas if a significant difference exists, it is necessary to express what constitutes a significant difference in terms of the unit in which the silvical feature was measured. In the case of water-holding capacity, the unit is percent moisture; in the case of available calcium content, the unit is milliequivalents per 100 grams of soil. Thus, by expressing in percent moisture the difference between soil horizons of Area X and Area Y, it is possible to determine between which soil factor a significant difference exists. The method of making these calculations is shown in the formulae which follow:

$$\text{F value} = \frac{\text{mean square treatment}}{\text{mean square error}}$$

$$= \frac{854.00}{37.07} = 24.4 \text{ **}$$

** Since the F-value is larger than 4.60 or 8.86 (from Significance Table) the difference between area treatment means is significant at both the five percent and one percent level.

The mean square treatment for Area X vs. Area Y is derived from the calculation:

$$k = \left[\frac{(t_1 - t_2)^2}{n} - \text{C. T.} \right]$$

where:

k = mean square

t_1 and t_2 = sum of individual items

n = sum of all measurements $\div$ 2

C. T. = correction term

The correction term (C.T.) is obtained by the formula:

$$\text{C. T.} = \frac{(\text{ sum individual items})^2}{\text{total items}}$$

To calculate the error term:

$E = R - K$ where: E = Error

R = Total variance

K = Variation between areas

By examination of the magnitude of the F-value, the extent of the variation can be interpreted. Thus, if the F-value obtained for Area X for any one soil horizon is large in comparison to other horizons of the same soil type, most variation exists at that horizon; similarly, a small F-value indicates less variation for a particular horizon.

At the conclusion of the data obtained for both the physical and chemical factors investigated, a summary table is presented to indicate the relationship of F-values for all soil variables that were studied.

LABORATORY EXPERIMENTS

Physical - Edaphic Characteristics

1. Mechanical Analysis[7]

Experimental Method:

A mechanical analysis of the soils in the experimental area was made by the hydrometer method, employing the technique of Bouyoucos (1936). The soil samples (16 samples per station times four stations = 64 samples) were thoroughly air-dried and passed through a two mm. sieve. For each treatment a fifty-gram sample was used. To disperse the soil the fifty-gram sample was added directly to a stirring cup, and distilled water added. The dispersing agent used was a commercial product known as Calgon, a sodium hexametaphosphate compound. Since this dispersing agent had not been used previously, it was necessary to run a few test samples to determine if the amount of Calgon used per sample was critical with this particular soil type. Having determined by test run that the concentration of dispersing agent used was not significantly different between use of ten cc. to twenty-five cc. inclusive, a fifteen cc. Calgon concentration was employed as a dispersing agent. After soaking and subsequent stirring of the soil with the dispersing agent, the contents were then poured into the special cylinder, shaken, and the time recorded. A temperature correction was applied to each hydrometer reading and a summation of the results for both Area X and Area Y is given in Table 2.

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7. The number preceding the physical soil factor under investigation corresponds to the same factor summarized statistically in Table 21.

TABLE 2.

MECHANICAL ANALYSIS OF FIELD SOILS BY HORIZON IN AREA X AND AREA Y

			Percent		
			Area X (Stations I-II)		
Soil Horizon	Sand	Silt	Silt plus Clay	Clay	Fine Clay
IA_1	61.9	21.9	38.1	3.0	13.2
A_2	76.7	9.1	23.3	1.7	12.5
B_2	73.6	6.0	26.4	1.0	19.4
B_3	91.6	1.0	8.4	1.0	6.4
C_1	94.0	0.0	6.0	0.0	6.0
IIA_1	61.1	22.6	38.9	3.2	13.1
A_2	63.2	17.9	36.8	2.7	16.2
B_2	76.0	4.0	24.0	2.0	18.0
B_3	88.0	0.0	12.0	2.6	9.4
C_1	94.0	0.0	6.0	0.0	6.0
			Area Y (Stations III-IV)		
IIIA_1	56.9	24.5	43.1	3.2	15.4
A_2	61.7	13.1	38.3	7.2	18.0
B_2	70.4	4.4	29.6	2.1	23.1
B_3	94.0	0.0	6.0	1.0	5.0
C_1	95.0	0.0	5.0	0.6	4.4
IVA_1	61.5	20.4	38.5	3.2	14.9
A_2	62.7	15.7	37.3	2.5	19.1
B_2	67.6	10.0	32.4	2.0	20.4
B_3	90.0	0.0	10.0	0.6	9.4
C_1	94.6	0.0	5.4	1.0	4.4

Discussion of Results

The mechanical analysis data reveal the overall sandy nature of samples taken in sixteen different locations. Variation in texture according to the United States Department of Agriculture textural classification is shown on the Representative Profile Descriptions for each soil type. The variation in texture is most marked in the amount of fine clay in the A_1 and A_2 horizons when contrasting Area X with Area Y. This variance in the fine clay content is the basis for the distinction of three soil types of the same drainage catena. The three main soil types represented are acid variants of the Fox sandy loam, Bronson sandy loam, and Warsaw sandy loam. The profile descriptions bring out these relationships more clearly (Figs. 9-12). To determine the extent and significance of the variation in the individual separates, an analysis of variance was made for fine clay, silt plus clay, and total sand, for both Area X and Area Y (Tables 3, 4, and 5).

TABLE 3.

ANALYSIS OF VARIANCE FOR MECHANICAL ANALYSIS AREA X vs. AREA Y

Horizon	Source	Degrees of Freedom	Sum of Squares	Mean Square	F
		Textural Class - Fine clay (less than 2 micron dia.) Basis: 32 samples			
A_1	Total	15	36.10		
	X vs Y	1	16.00	16.00	
	Error	14	20.10	1.43	11.1 **
A_2	Total	15	449.39		
	X vs Y	1	184.96	184.96	
	Error	14	264.43	18.80	14.6 **
		Basis: 4 samples			
B_2	Total	3	13.93		
	X vs Y	1	9.30	9.30	
	Error	2	4.63	2.31	4.02
B_3	Total	3	14.67		
	X vs Y	1	.49	.49	
	Error	2	14.18	7.09	.07
C_1	Total	3	2.56		
	X vs Y	1	2.56	2.56	
	Error	2	0.00	0.00	0.00

** Significant at 5% and 1%

The analysis of variance for the fine clay fraction is highly significant at both the 5% and 1% level in the A_1 and A_2 horizons.[8] Investigators such as Albert (1925) and Bornebusch (1931) have frequently reported that the content of material smaller than .2 mm. in sandy soils has an important bearing on site quality.

TABLE 4.

ANALYSIS OF VARIANCE FOR MECHANICAL ANALYSIS AREA X vs. AREA Y

Textural Class - Silt plus clay
Basis: 32 samples

Horizon	Source	Degrees of Freedom	Sum of Squares	Mean Square	F
A_1	Total	3	16.19		
	X vs Y	1	5.29	5.29	
	Error	2	10.90	5.45	.97
A_2	Total	3	151.49		
	X vs Y	1	59.86	59.86	
	Error	2	91.63	45.81	1.31
B_2	Total	3	42.94		
	X vs Y	1	36.14	36.14	
	Error	2	6.80	3.40	10.62
B_3	Total	3	19.32		
	X vs Y	1	4.84	4.84	
	Error	2	14.48	7.24	.67
C	Total	3	.72		
	X vs Y	1	.64	.64	
	Error	2	.08	.04	16.00

8. When used in discussing experimental data, the word "significant", is applied in a statistical sense. There are various degrees of significance now recognized statistically, but the two most commonly used are at the 1% and 5% levels. The former level, in-indicates that there are ninety-nine chances in one hundred that the difference in means is not due to random sampling in a homogeneous population. This 1% level is referred to as very or highly significant. The latter percent level indicates that there are ninety-five chances in one hundred that the difference in means is not due to random sampling of a homogeneous population, and is commonly spoken of as significant. The F-value is a statistical index to determine the magnitude of the significant level and will be utilized throughout the remainder of this manuscript. The plot replication method of analysis will be followed according to Snedecor (1946).

Although texture, nor any other single soil property, seldom determines the quality of site, it is generally recognized that loam and loamy soils are more favorable for forest growth than either coarse sands or fine clays. It is therefore pertinent to point out that the influence of soil texture on the growth of tulip poplar may be masked by the influence of other factors. The presence of a Warsaw loam soil type in Area Y where the trees are smallest is a rough indication that soil texture alone may not be a limiting factor for the height growth of tulip poplar. Thus, in all the statistical analyses that follow for all soil factors and others, the analysis of variance is used only to point out statistical differences and not to portray their ecological significance. The relationship of texture to other soil factors will be brought out insofar as texture relates to a set of interrelated soil and moisture phenomena.

TABLE 5.

ANALYSIS OF VARIANCE FOR MECHANICAL ANALYSIS AREA X vs. AREA Y

Textural Class - Sand (less than 1000 micron dia.)

Basis: 32 samples

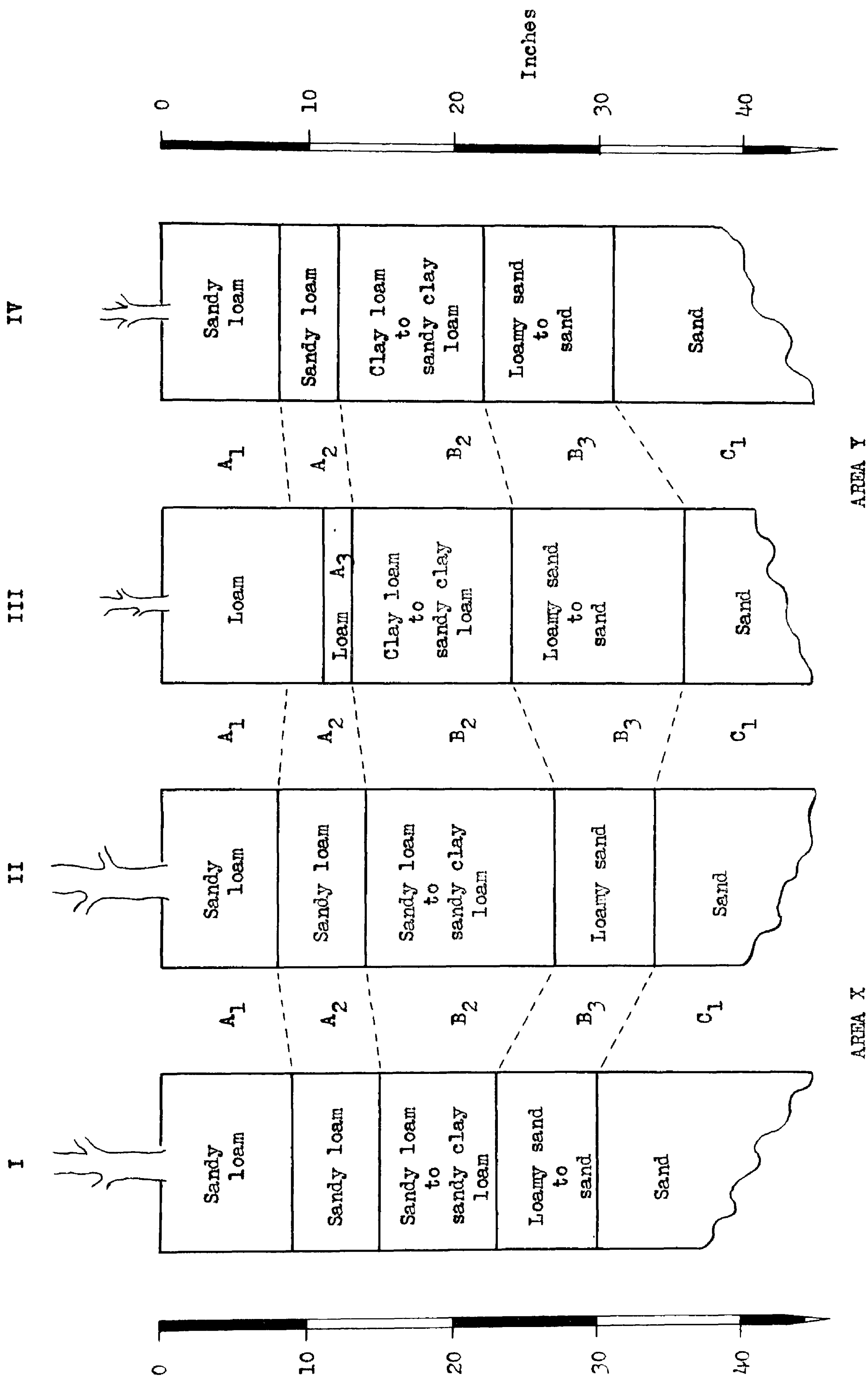
Horizon	Source	Degrees of Freedom	Sum of Squares	Mean Square	F
A_1	Total	15	212.20		
	X vs Y	1	21.62	21.62	
	Error	14	190.61	13.62	1.61
A_2	Total	15	1993.56		
	X vs Y	1	237.16	237.16	
	Error	14	1756.42	125.40	1.90
			Basis: 4 samples		
B_2	Total	3	40.44		
	X vs Y	1	33.64	33.64	
	Error	2	6.80	3.40	9.89
B_3	Total	3	19.32		
	X vs Y	1	4.84	4.84	
	Error	2	14.48	7.24	.67
C_1	Total	3	.72		
	X vs Y	1	.64	.64	
	Error	2	.08	.04	16.0

The graphic relation between comparable depths to all soil horizons for both areas is shown in Fig. 8. Studies by Auten (1937 and 1945) using depth of both the A and B horizons as indices of site evaluation for tulip poplar, have shown no established relationship between thickness of the B horizon and site index. The compactness or density of the B horizon is the character responsible for hindering water movement and permeability rather than thickness. The thickness of the A horizon is not a good criterion of site for tulip poplar; depth to a heavy clay subsoil is a much better measure of the permeability of water. Auten (1945) has shown a high correlation for depth to subsoil and site index. He has shown that on soils whose depth to tight subsoil is less than 24 inches would have a site index of less than 85. If this criterion was applied to the present investigation, the highest site index expected for the best height growth would be 82, assuming that other textural and climatic characteristics were not limiting. The rather striking similarity of depth to comparable horizons and texture is shown in Fig. 8. The depth to subsoil does not vary markedly when contrasting the three related soil types under investigation.

Auten (1937) found a positive correlation between site evaluation and depth of the undisturbed A_1 horizon for soils supporting tulip poplar. Poplar was generally not found on soil whose A_1 horizon was less than one inch thick, and site index increased with thickness of the A_1 horizon between the limits of one and eight inches, approximately three site-index points for each inch of A_1. These findings were valid only on those areas having undisturbed soil. His results were based upon the relation between organic matter incorporation and indirect measure of soil moisture.

In the present investigation, using Auten's criterion of A_1 depth, it

Fig. 8.



GRAPHIC RELATION BETWEEN EQUAL-AGED TULIP POPLAR AND DEPTH TO COMPARABLE SOIL HORIZON IN AREAS OF GOOD AND POOR HEIGHT GROWTH would be possible to achieve a site index of approximately 98 for dominant trees at 50 years. However, this supposition would be valid only when other site requirements could be met, such as good subsoil drainage, adequate soil moisture, and on sites which are not unduly exposed to rapid surface soil air-drying.

The profile study of the present investigation reveals no relationship to thickness of the B horizon. However, there appears to be some correlation between the water-holding capacity of the A horizon and subsequent soil-moisture evaporation. These results, in turn, affect permeability and dryness of the surface soils in both areas. This study shows a correlation between the amount of organic matter and fine clay content of the A_1 and A_2 horizons, with respect to soil-moisture relationships. These profile characteristics are substantiated by statistical significance between Area X and Area Y as shown in Table 3.

Thus, it appears that texture and organic matter incorporation of the A_1 and A_2 horizons, and their attendant soil-moisture holding capacity, is definitely related to other climatic factors such as evaporation, air temperature, soil temperature, and growing season precipitation, in this investigation. The manner in which the A_1 and A_2 horizons are related to the radial and height growth of tulip poplar and the growing season precipitation, is discussed under climatic factors.

SOIL PROFILE DESCRIPTIONS

Soil Profile and Related Characteristics

Area X - Station I

The soil profile exposed in this area represents the site where the height and diameter growth is greatest. This area is immediately adjacent to Woods "A" on the west and Woods "B" to the south. There is no sunscald damage to trees on this site; the lower branches are self-pruned and no sprouting occurs at the base of the trees. Numerous sugar maple seedlings are to be found, and the litter is noticeably greater in amount than that found further out in the plantation. The herbaceous vegetation on the forest floor indicates species which are more akin to the adjoining woods than the flora found in the area of poor height growth.

To a depth of approximately fifteen inches there is a sandy loam of a dark brown color. Below the A horizon and into the B horizon, clay is found, grading into a loamy sand at the B_3 horizon. At a depth of thirty inches and beyond there is a yellowish brown sand, with no lime present. The soil type in this area is a Fox sandy loam, acid variant. The tulip poplar root zone is found exclusively in the A_1 and A_2 horizons to a depth of approximately twelve inches. Most of the water falling on this soil is removed internally; there is a tendency to drying out under extreme exposure, especially where this soil type is not covered with trees.

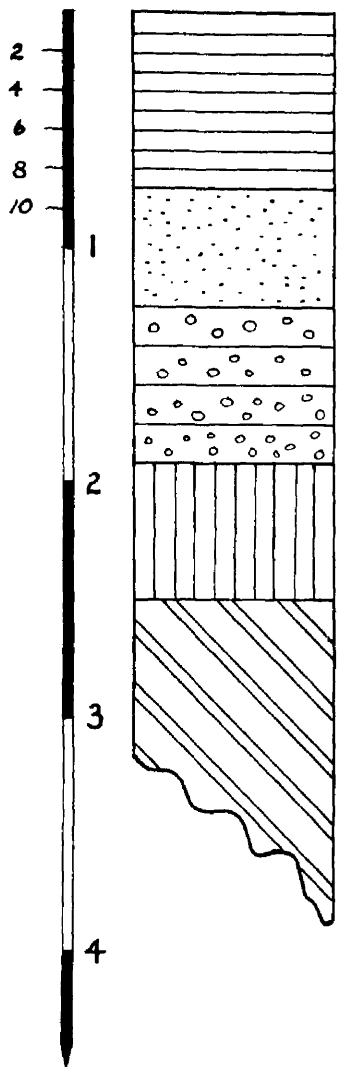
Fig. 9.

SOILS ANALYSIS

REPRESENTATIVE PROFILE AND DESCRIPTION

Area X - Plot I

In. Ft. Profile



Depth	Horizon	Description
0"-9"	A_1	Sandy loam. Dark reddish brown (6YR 3/2). Weak medium granular. pH 5.55
9"-15"	A_2	Sandy loam. Brown-dark brown (7.5 YR 4/2). Weak medium granular to fine crumb. pH 5.33
15"-23"	B_2	Sandy loam to sandy clay loam. Dark brown (7.5 YR 3/3). Med. to coarse nuciform. Some gravel. Dark coatings on structural faces. pH 5.40
23"-30"	B_3	Loamy sand to sand. Reddish brown (6.0 YR 4/3). Very weak nuciform to single grain. Some stratification. No lime present. Dark coatings on structural faces. pH 5.42
30"-38" up	C_1	Sand. Yellowish brown 10 YR 5/4. Structureless. No lime present. pH 5.18

Soil Type - Fox sandy loam , acid variant
Topography - Nearly level
Drainage - Good
Erosion - None
Permeability - Moderately rapid
Classification - Gray Brown Podzolic

Location: E½ of N½ of SE¼ of Sec 29 T5S R14W
Cass County, Michigan

Soil Profile and Related Characteristics

Area X - Station II

The soil profile exposed in this area also exhibits tulip poplar of extreme height growth in contrast to Area Y. This site is adjacent to Woods "B" on the south. Again, there is an abundance of sugar maple seedlings, self-pruning of lower branches, absence of sunscald, and no basal sprouting. The herbaceous vegetation exhibits species which have apparently migrated from the hardwood forest to the south.

This area is similar to Station I with the exception of a few minor differences in depth to the water table. The A horizon is a dark reddish brown, which grades into a loamy sand B horizon. Again, the C horizon at a depth of 34 inches, is a yellowish brown sand. No lime is present in the lower part of the B horizon or the C horizon. The tulip poplar lateral root zone is found entirely within the first thirteen inches of the profile. As before, the soil is a Fox sandy loam, acid variant, well to somewhat excessively drained. Most of the water falling on this soil is removed internally. This soil type tends to be droughty under exposed conditions.

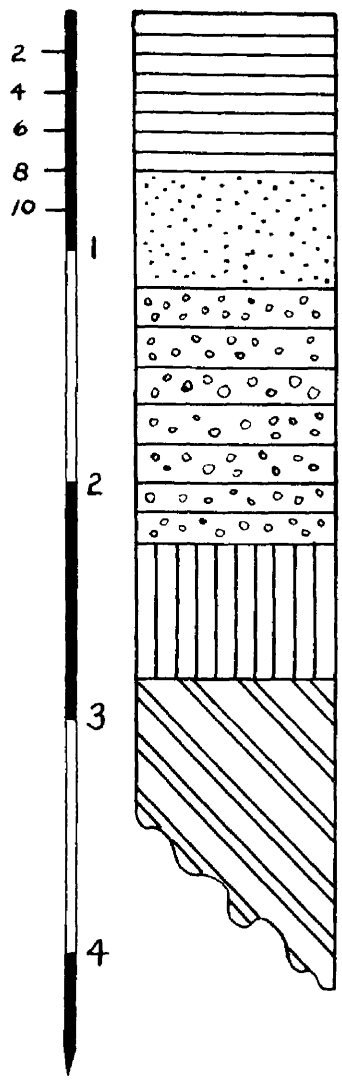
Fig. 10.

SOILS ANALYSIS

REPRESENTATIVE PROFILE AND DESCRIPTION

Area X - Plot II

In. Ft. Profile



Depth	Horizon	Description
0"-8"	A_1	Sandy loam. Dark reddish brown (6 YR 3/2). Weak medium granular. pH 5.39
8"-14"	A_2	Sandy loam. Brown-dark brown (7.5 YR 4/2). Very weak med. granular to fine blocky. Medium platy. pH 5.20
14"-27"	B_2	Sandy loam to sandy clay loam. Dark brown (6.5 YR 3/3). Weak coarse blocky. Gravelly dark coatings on structural faces. pH 5.15
27"-34"	B_3	Loamy sand. Reddish brown (5.5 YR 4/3). Very weak coarse blocky to single grain. Gravelly dark coatings on structural faces. pH 5.14
34"-43" up	C_1	Sand. Yellowish brown (10 YR 5/4). Single grain. No lime present. pH 5.40

Soil Type - Fox sandy loam, acid variant
Topography - Nearly level 1% to N
Drainage - Good
Erosion - None
Permeability - Moderately rapid
Classification - Gray Brown Podzolic

Location: $E\frac{1}{2}$ of $N\frac{1}{2}$ of $SE\frac{1}{4}$ of Sec 29 T5S R14W
Cass County, Michigan

Soil Profile and Related Characteristics

Area Y - Station III

A profile exposed in this area is representative of the site for poor height growth of tulip poplar. No woods of any type are adjacent to this area. Sugar maple seedlings are absent, there is extreme sunscald damage and subsequent wind breakage, basal sprouting of the trees, and a predominantly grass and annual weed herbaceous vegetation. Although there is some overlap of herbaceous species with that of Area X, practically no species occur here which are found in the old growth hardwoods.

The soil type is a Warsaw loam to sandy loam, a remnant of the old prairie soil of southwestern Michigan. The A horizon is a dark gray to black loam extending some thirteen inches to the B horizon. There is no actual A_2 horizon, being replaced by a transitional A_3 horizon. The latter is a very dark loam. At a depth of fourteen inches the B_2 is reached, where there is a definite clay layer. The bottom of the B horizon is a loamy sand, and at 36 inches the yellowish brown sand is reached. The lateral root zone of tulip poplar extends to approximately fifteen inches in depth; the water table is closer to the surface than in Area X. External drainage or surface runoff is slight; internal drainage is moderate to rapid.

The Warsaw soil type which is representative of Area Y is designated by Veatch (1927) as the "dry" prairie region of southwestern Michigan. A description of the soil profile here presented, closely coincides with that of Veatch. Also such features as topography, geology, organic matter content, clay content, precipitation, temperature, and drainage are nearly identical to that described by the above author. With reference to the B_2

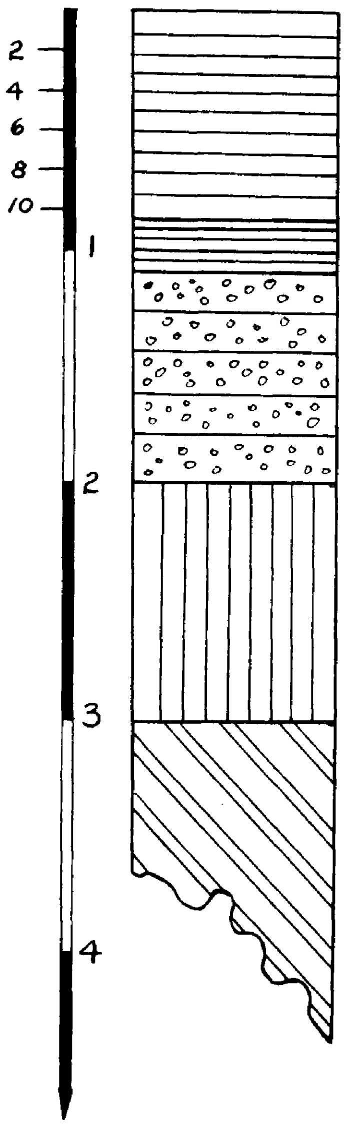
horizon, Veatch points out that this horizon becomes very compact under certain conditions, so much so that it is referred to locally as "hard pan". The colloidal or clay content present is strongly cohesive or adhesive and possesses very high tensile strength upon drying. The soil holds only relatively small amounts of water, but slightly higher than the associated forested sands. The upper part of the substratum is dry or very low in moisture and the whole profile is penetrable to tree roots.

Chemical analyses of the Warsaw type reveal no unusual or abnormal pecularities in composition. The organic matter and nitrogen contents are somewhat higher than for comparable forested soils and the amounts of various individual nutrients are not different from those of originally forested soils of similar texture throughout southern Michigan. Veatch found the A_1, A_3, and B_2 horizons strongly to very strongly acid in reaction. The most marked difference in the profile of the Warsaw and the profile of a forested soil associated with the prairie, is the organic content of the surface horizons; otherwise they are similar chemically and physically and in profile arrangement. It appears from observation that there may be slightly more compaction in the B horizon of the prairie soil.

In fertility and productiveness the dry prairie soil is considered to be intermediate, being somewhat higher than the forested sands, and less than the forested more level clay soils of this region. Lack of sufficient moisture at critical periods of the growing season is probably the chief limiting factor in production of high yields of agricultural crops. In pedologic terminology, the Warsaw soil type is "mature", and supports a theory that the prairies were originally treeless. The profile indicates that the soil developed under conditions of relatively low moisture, variable in the surface horizon, relatively low in the B horizon, and very low in the C horizon, beginning at depths of two to three feet. According to Veatch (1927) there is no evidence in the soil profile of the peculiarities common to excessive moisture or waterlogging if these conditions ever existed. There is no evidence to support a contention that some chemical condition in the prairie soil inhibits tree growth.

REPRESENTATIVE PROFILE AND DESCRIPTION

Area Y - Plot III



Depth	Horizon	Description
0"-11"	A_1	Loam. Very dark gray to black (5.0 YR 2.5/1.5). Medium granular. pH 5.85
11"-13"	A_3	Loam. Dark brown (7.5 YR 3/1.75). Transitional. pH 5.16
13"-24"	B_2	Clay loam to sandy clay loam. Dark brown (7.5 YR 3/2). Medium to coarse nuciform. Dark coatings on aggregates. Gravelly. pH 5.02
24"-36"	B_3	Loamy sand to sand. Brown to dark brown; one band dark brown at bottom (6.5 YR 4/3 to 7.5 YR 3/2) at bottom. Very weak nuciform to single grain. Dark coatings on aggregates. Gravelly. pH 5.17
36"-46" up	C_1	Sand. Yellowish brown with dark brown in thin bands. (10 YR 5/4 to 7.5 YR 3/2 in thin bands). Single grain over stratification. No lime present. pH 5.42

Soil Type - Warsaw loam or sandy loam, acid variant
Topography - Nearly level 1% to N
Drainage - Good; Water table $2\frac{1}{2}$'
Erosion - None
Permeability - Moderately rapid
Classification - Prairie

Location: $E\frac{1}{2}$ of $N\frac{1}{2}$ of $SE\frac{1}{4}$ of Sec 29 T5S R14W
Cass County, Michigan

Soil Profile and Related Characteristics

Area Y - Station IV

As in the preceding soil type, the profile exposed at Station IV is representative of the site for poor height growth of tulip poplar. This profile was made in the approximate center of the plantation, free from any adjoining woods. Again, sugar maple seedlings are absent, sunscald damage is severe, basal sprouting of the trees is prevalent, and a herbaceous grass vegetation is dominant.

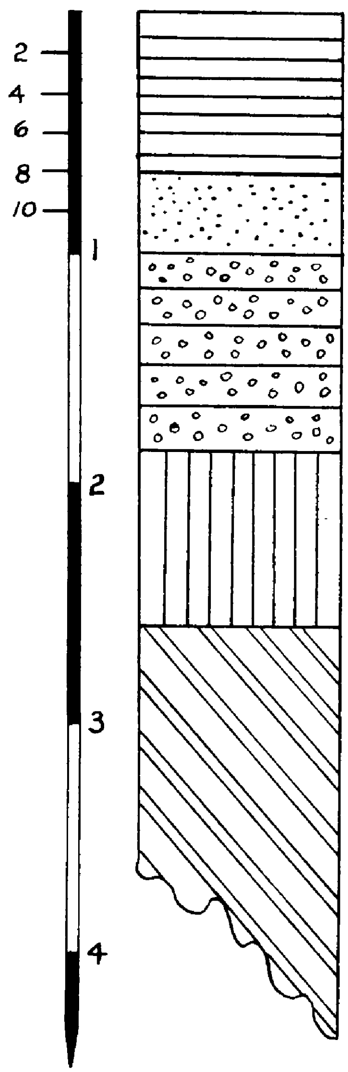
The profile description follows much the same pattern as for the Fox sandy loam. However, the Bronson sandy loam, acid variant, here described, is only moderately well-drained in contrast to the well to excessively drained Fox series. A clay loam to sandy clay loam exists at the B_2 horizon, grading into a loamy sand at the B_3 horizon. As in the three soil types present, a coarse sand is found at approximately 31 inches. At the time of sampling of this profile, the C_1 horizon was completely saturated with water. Practically all of the water falling on this soil type is removed internally; internal drainage is moderate to rapid in the upper part of the soil and slow in the lower part, due to a relatively high water table.

Fig. 12.

SOILS ANALYSIS

REPRESENTATIVE PROFILE AND DESCRIPTION

Area Y - Plot IV



In. Ft.	Profile	Depth	Horizon	Description
		0"-8"	A_1	Sandy loam. Dark reddish brown (6.0 YR 3/2). Weak medium granular. pH 5.35
		8"-12"	A_2	Sandy loam. Dark brown (7.5 YR 4/2). Weak medium granular to fine blocky. pH 4.94
		12"-22"	B_2	Clay loam to sandy clay loam. Brown to dark brown (7.5 YR 4/3). Medium to coarse blocky. Gravelly. pH 4.70
		22"-31"	B_3	Loamy sand to sand. Dark reddish brown (5.0 YR 3/3). Very weak coarse blocky. pH 4.83
		31"-40" up	C_1	Coarse sand. Pale brown to dark reddish brown (mottled). (10 YR 6/3 to 6.0 YR 3/3). Saturated water. No lime present. pH 5.82

Soil Type - Bronson sandy loam, acid var.
Topography - Nearly level
Drainage - Moderate; Water table 2½'
Erosion - None
Permeability - Moderately rapid
Classification - Gray Brown Podzolic

Location: E½ of N½ of SE¼ of Sec 29 T5S R14W
Cass County, Michigan

2. Specific Gravity or Real Density

Experimental Method:

The specific gravity was determined on thirty-two samples in duplicate representing the A_1 and A_2 horizons for each of four sampling stations, according to the technique of Lutz (1944). Soils from the field were air-dried and passed through a two mm. sieve; these samples were then placed in a picnometer with freshly boiled distilled water. By repeated evacuation in a vacuum desiccator the interstitial air was gradually replaced by water. After all the air had been removed from the soil, appropriate temperatures and time were recorded and the specific gravity determined by dividing the weight of the oven-dry sample by the volume of soil. A summation of the values obtained for two horizons is presented in Table 6.

TABLE 6.

SPECIFIC GRAVITY OF THE "A" HORIZON OF SOILS IN AREA X AND AREA Y

Horizon	Oven-dry Weight (gms.)	Volume of Soil (ml)	Specific Gravity
	Area X (Stations I-II)		
IA_1	17.42	6.77	2.60
IA_2	20.50	8.12	2.52
IIA_1	19.54	7.62	2.55
IIA_2	21.86	8.42	2.61
	Area Y (Stations III-IV)		
$IIIA_1$	21.02	7.37	2.39
$IIIA_2$	17.11	6.23	2.74
IVA_1	19.23	6.85	2.84
IVA_2	17.85	6.73	2.76

Discussion of Results

The specific gravity, or real density of a soil is unaffected by structure, and thus the specific gravity differs from the volume weight of soils. Wide variation in mineral soils does not exist as shown by the preceding data. The average specific gravity for Area X, which includes both the A_1 and A_2 horizons, is 2.58; the specific gravity for Area Y of the same horizons is 2.64. These values represent only a difference of .06 between the two areas, and obviously is insignificant even though there are three individual soil types represented. The values obtained in Table 5 are used in the formula for computing the total porosity.

To determine the statistical difference in specific gravity of the soils for the area of good and poor height growth of tulip poplar, an analysis of variance follows in Table 7. Neither the A_1 nor the A_2 horizon shows any statistical significance.

TABLE 7.

ANALYSIS OF VARIANCE FOR SPECIFIC GRAVITY AREA X vs. AREA Y

Basis: 32 samples

Horizon	Source	Degrees of Freedom	Sum of Squares	Mean Square	F
A_1	Total	15	.27		
	X vs Y	1	.02	.02	
	Error	14	.25	.018	1.1
A_2	Total	15	.41		
	X vs Y	1	.01	.01	
	Error	14	.40	.028	.36

3. Volume Weight or Apparent Density

Experimental Method:

The volume weight was determined on thirty-two field samples taken in situ by use of a soil core sampler according to Baver (1948). Core samples were taken from the A_1 and A_2 horizons in each area. After determining the weight of each core at field capacity, a disk of filter paper and cheesecloth was firmly attached to one end of the core. By means of an overflow cup the volume of soil and cylinder were obtained. The filled cores were placed in a pan of water and allowed to saturate for 24 hours. For these undisturbed cores, oven-dry weights were calculated as a final step in the procedure and from the above technique the volume weight was determined by dividing the oven-dry weight of each sample by the volume of soil. This method differs essentially from the specific gravity

TABLE 8.

VOLUME WEIGHT OF THE "A" HORIZON OF SOILS IN AREA X AND AREA Y

Horizon	Oven-dry Weight (gms.)	Volume of Soil (ml.)	Volume Weight
	Area X (Stations I-II)		
IA_1	453.15	344.25	1.31
IA_2	599.14	371.00	1.60
IIA_1	509.83	359.00	1.41
IIA_2	606.29	374.00	1.62
	Area Y (Stations III-IV)		
$IIIA_1$	491.77	367.50	1.33
$IIIA_2$	533.22	364.00	1.46
IVA_1	488.10	363.25	1.34
IVA_2	633.17	375.75	1.56

determination in the fact that the included pore space is measured, thus giving lower values than for specific gravity. The volume weight expresses the ratio between the dry weight of a given volume of undisturbed soil and the weight of an equal volume of water. The values obtained in Table 8 represent the number of times a particular sample is heavier than an equal volume of water.

Discussion of Results

Since the volume weight determination includes the air space it is evident from the above calculations that in every case the A_1 horizon shows smaller values than the A_2, an indication of the greater air capacity in the topmost horizon. The average volume weight for Area X is 1.49 and for Area Y it is 1.42. A slight difference of .07 is recognizable in the two areas, despite the fact that loam soils are evident in Area Y.

TABLE 9.

ANALYSIS OF VARIANCE FOR VOLUME WEIGHT AREA X vs. AREA Y

Basis: 16 samples

Horizon	Source	Degrees of Freedom	Sum of Squares	Mean Square	F
A_1	Total	15	.03		
	X vs Y	1	.00	.00	
	Error	14	.03	.002	.00
A_2	Total	15	.24		
	X vs Y	1	.05	.05	
	Error	14	.19	.013	3.84

In order to further check the statistical significance of the two areas under consideration, an analysis of variance was made to determine the magnitude of differences. No significant differences in either the A_1 or A_2 horizon were apparent for volume weight.

According to Lutz and Chandler (1946) the volume weight of the A_1 horizon of forest soils is commonly less than 1.00. This value is considerably lower than the values obtained and is in accord with the fact that the soils being investigated are not strictly "mature" forest soils, and are less porous than forest soils insofar as the volume weight is concerned. The high volume weights obtained are an indication of the structure of these soils since the low pore volume indicates higher volume weights. Also the high volume weights indicate in a general way the low organic matter as well as the high content of sand in these soils.

4. Pore Volume (Total, Capillary, and Non-capillary)

Experimental Method:

The pore volume was determined on thirty-two duplicate field samples taken in situ by use of a soil core sampler. These samples were taken from the A_1 and A_2 horizons for Area X and Area Y. After determining the saturated weight of each core, the cylinders were placed on a pF table at a soil pF of 1.6 for twenty-four hours. The cores were weighed after draining on the pF table and then oven-dried according to Baver (1948). From these determinations the percent total porosity, non-capillary porosity, and capillary porosity were calculated. Total porosity was obtained by dividing the specific gravity minus the volume weight by the specific gravity and multiplied by 100. To get the percent capillary porosity, subtract the total porosity minus the non-capillary porosity. A summation of pore volume values is given in Table 10.

TABLE 10.

POR VOLUME OF THE "A" HORIZON OF SOILS IN AREA X AND AREA Y

Horizon	Capillary	Non-capillary	Total Porosity
	Percent porosity		
	Area X (Stations I-II)		
IA_1	24.9	25.2	50.1
IA_2	21.0	16.3	37.3
IIA_1	25.9	17.5	43.4
IIA_2	26.4	11.7	38.1
	Area Y (Stations III-IV)		
$IIIA_1$	26.0	21.5	47.5
$IIIA_2$	29.1	15.3	44.4
IVA_1	28.0	22.2	50.2
IVA_2	26.7	13.8	40.5
	Average Values Combined Stations		
$I\text{-}IIA_1$	25.4	21.3	46.8
$I\text{-}IIA_2$	24.1	13.6	37.8
$III\text{-}IVA_1$	27.0	21.8	48.9
$III\text{-}IVA_2$	27.9	14.6	42.5
I-II A_1A_2	24.8	17.4	42.3
III-IV A_1A_2	27.5	18.2	45.7

Discussion of Results

The relative proportions of air and water in a soil will constantly change. It is convenient to employ the concept of large and small pores which determine to a great extent the aeration and internal drainage of the soil. The above values are best evaluated by averages of the combined stations in duplicate for the three main classes of pore volume. The values obtained in Table 10 indicate that there is greater non-capillary, capillary, and total pore space in Area Y than in Area X. This is true for both the A_1 and A_2 horizons in every case, and corroborates the volume weight determinations. However, the magnitude of the differences is not great. The relative proportion of capillary to non-capillary pore space is more marked in the A_2 horizon than in the A_1 horizon in both Area X and Area Y. An analysis of variance (Table 11) indicates no significant difference in pore volume of any classification by comparing the values of Area X and Area Y.

TABLE 11.

ANALYSIS OF VARIANCE OF PORE VOLUME FOR SOILS OF THE "A" HORIZON IN AREA X vs. AREA Y

Basis: 16 samples

Horizon	Source	Degrees of Freedom	Sum of Squares	Mean Square	F
		Percent capillary porosity			
A_1	Total	15	58.05		
	X vs Y	1	10.39	10.39	
	Error	14	47.66	3.40	3.05
A_2	Total	15	418.59		
	X vs Y	1	56.63	56.63	
	Error	14	361.96	25.85	2.19
		Percent Non-capillary Porosity			
A_1	Total	15	292.29		
	X vs Y	1	.96	.96	
	Error	14	291.33	20.80	.04
A_2	Total	15	303.23		
	X vs Y	1	3.70	3.70	
	Error	14	299.53	21.39	.17
		Percent Total Porosity			
A_1	Total	15	291.44		
	X vs Y	1	17.64	17.64	
	Error	14	273.80	19.55	.90
A_2	Total	15	542.00		
	X vs Y	1	89.30	89.30	
	Error	14	452.70	32.30	2.76

Baver (1940) points out that the total porosity of soils is usually in the neighborhood of fifty percent. The average values obtained in all samples here investigated ranges from a low of 37.3 percent to a high of 50.2 percent total porosity. Pore volume decreased from the A_1 to the A_2 horizon for all classes of porosity in both areas. In Area X the capillary pore space is 7.4 percent greater than the non-capillary pore space; Area Y has a similar situation with a 9.3 percent greater capillary pore space. The nature or kind of pore space will determine the field capacity, internal drainage, and amount of aeration. The air capacity of soils is often considered as being equivalent to the non-capillary pore volume. Capillary pore volume may be expressed as equivalent to the field capacity. The nature of the non-capillary pores is facilitated by measurements of the rate of infiltration of water. A large number of inter-communicating non-capillary pores usually means high infiltration rates. The air capacity is also related to soil texture.

5. Hygroscopic Coefficient

Experimental Method:

To determine the hygroscopic coefficient, as outlined by Baver (1948), twenty field samples were taken at five soil horizons in Area X and Area Y. The samples were air-dried and five grams of each was placed in weighed weighing cans. The uncovered cans were placed in an oven at 105° C for twenty-four hours, weighed, and the hygroscopic coefficient determined. An index of the surface activity of soils is thus obtained, or the amount of water adsorbed on the surface of soil particles in an atmosphere of water vapor of known relative humidity. The coefficients obtained are supposed to mark the upper limit of the hygroscopic moisture range at approximately a pF of 4.5. A summation of results is given in Table 12.

TABLE 12.

HYGROSCOPIC COEFFICIENT VALUES FOR FIVE SOIL HORIZONS AREA X AND Y

Horizon	Weight oven-dry soil	Weight water lost	Hygroscopic Coefficient
		Percent	
		Area X (Stations I-II)	
IA_1	6.47	.03	.46
A_2	5.56	.025	.45
B_2	5.51	.055	.998
B_3	5.91	.01	.17
C_1	5.59	.005	.09
IIA_1	4.67	.02	.43
A_2	5.55	.03	.54
B_2	4.95	.03	.61
B_3	5.78	.015	.26
C_1	4.77	.01	.21
		Area Y (Stations III-IV)	
IIIA_1	4.75	.04	.84
A_3	5.70	.06	1.05
B_2	6.09	.075	1.23
B_3	6.06	.005	.08
C_1	5.91	.005	.084
IVA_1	5.07	.025	.49
A_2	4.94	.04	.81
B_2	4.65	.03	.64
B_3	5.98	.02	.33
C_1	5.34	.005	.09

Discussion of Results

In spite of the unsatisfactory nature of hygroscopic moisture values, Puri (1925) and Keen (1931), this constant has found wide use. In the present investigation, the values obtained for the A_2 and B_2 horizons of Area Y are higher than those in Area X. In general, the highest values of hygroscopic coefficient are found in soils having a high content of colloids. The relationship between the mechanical analysis and the hygroscopic coefficient is definitely brought out here as evidenced by the higher values of Area Y (Station III). In general, higher values are found in all horizons for Area Y. A statistical analysis (Table 13) indicates no significant differences.

TABLE 13.

ANALYSIS OF VARIANCE OF HYGROSCOPIC COEFFICIENT FOR FIVE SOIL HORIZONS AREA X (GOOD HEIGHT GROWTH) vs. AREA Y (POOR HEIGHT GROWTH)

Basis: 25 samples

Horizon	Source	Degrees of Freedom	Sum of Squares	Mean Square	F
A_1	Total	3	.110		
	X vs Y	1	.050	.050	
	Error	2	.060	.030	1.67
A_2	Total	3	.2227		
	X vs Y	1	.1898	.1898	
	Error	2	.0329	.0164	15.73
B_2	Total	3	.245		
	X vs Y	1	.014	.014	
	Error	2	.231	.115	.012
B_3	Total	3	.0354		
	X vs Y	1	.0001	.0001	
	Error	2	.0353	.0176	.005
C_1	Total	3	.0115		
	X vs Y	1	.0042	.0042	
	Error	2	.0073	.0036	1.17

6. Maximum Water-Holding Capacity

Experimental Method:

In order to determine the maximum water-holding capacity of the three soil types under investigation, sixty-four samples were collected from the profiles representing five horizons in Area X and Area Y. These samples were air-dried and passed through a two mm. sieve. A thirty gram sample was then placed in square moisture equivalent boxes and filter paper placed in the bottom of the box. The containers were placed in a one cm. layer of water and allowed to saturate for twenty-four hours, after which time they were drained for thirty minutes, weighed, and the percentage moisture determined at the maximum water-holding capacity, as outlined by Baver (1948).

As a comparison between using air-dry samples and soils in their natural condition, thirty-two more samples were collected in situ by means of a core sampler according to the original method of Schumacher (1864). The same procedure was carried out on the core samples, and the water-holding capacity determined on soils of the same area but in their undisturbed condition. This comparison of methods was deemed advisable since various investigators have shown wide differences in the two methods. By air-drying and sieving a sample, the non-capillary, intercommunicating pore space and natural structure of the soil is altered. For these reasons, it is preferable to collect soils in situ for water-holding capacity determinations. The natural cores were taken from all horizons with the exception of the C_1. A condensed summary of the values for air-dry and natural cores, including percentage differences for the "A" and "B" horizons in the two methods, is given in Table 14.

TABLE 14.

MAXIMUM WATER-HOLDING CAPACITY OF SOILS REPRESENTING FIVE SOIL HORIZONS IN AREA X AND AREA Y

Soil Horizon	Water-holding Capacity (Air-dried and sieved)	Water-holding Capacity (Natural condition)	Avg. Difference Air-dry vs. Natural
	Percent Moisture		
	Area X (Stations I-II)		
IA_1	58.1	42.5	15.6
A_2	46.9	26.3	20.6
B_2	44.3	23.3	21.0
B_3	28.3	22.7	5.6
C_1	28.5	--	--
IIA_1	56.9	35.2	21.7
A_2	44.4	24.2	20.2
B_2	39.3	25.9	13.4
B_3	31.3	23.3	8.0
C_1	29.5	--	--
	Area Y (Stations III-IV)		
IIIA_1	59.6	38.9	20.7
A_3	63.6	32.7	30.9
B_2	52.5	27.6	24.9
B_3	30.1	20.9	9.2
C_1	28.0	--	--
IVA_1	57.4	38.9	20.5
A_2	57.3	29.2	28.1
B_2	46.7	25.5	21.2
B_3	36.0	24.5	11.5
C_1	29.0	--	--

Discussion of Results

Since the continuity of water supply for forest trees is fully as important as the total amount, a measure of the water-holding retention of individual soil horizons is very important. The water retained in soils after gravitational water has drained off, or the capillary and hygroscopic water, may become critical for certain species of trees. This is especially true where the soils are subject to high evaporation and subsequent drying out at certain periods of the growing season. Trees growing in soils of low fertility require larger amounts of water than trees growing in fertile soils, based upon the water requirement for each unit of dry matter produced. In humid regions, coarse sandy soils having deep water tables are often poorer sites than soils of medium or fine texture. In a consideration of soil-moisture relationships one must always consider the nature of the deeper soil horizons and underlying strata, since the lower horizons often determine the replenishment of water at critical periods. Pearson and Marsh (1935) have pointed out that layers of fine-textured material lying several feet below the soil surface may be highly important in tree growth. The water-holding values obtained in this investigation show a definite relationship to soil texture and to the depth of the underlying water table. An analysis of variance of the water-holding capacity by horizons shows a definite significance in the A_2 horizon of air-dry and natural cores, when Area X and Area Y are compared. No statistical significance is found between Stations I and II or between Stations III and IV for the A_2 horizon, but a marked difference is found between combined Area X and Area Y. This analysis substantiates the findings of the textural classification (mechanical analysis). The statistical analysis is presented in Table 15.

7. Moisture Equivalent

Experimental Method:

Moisture equivalent determinations were made on twenty field samples representing five horizons for Area X and five horizons for Area Y. The method of Briggs and Shantz (1912) was utilized in all determinations,

TABLE 15.

ANALYSIS OF VARIANCE OF THE MAXIMUM WATER-HOLDING CAPACITY FOR AIR DRY AND NATURAL SOIL CORES IN AREA X vs. AREA Y

Horizon	Source	Degrees of Freedom	Sum of Squares	Mean Square	F
		Air-dried and sieved samples Basis: 32 samples			
A_1	Total	15	96.4		
	X vs Y	1	4.2	4.2	
	Error	14	92.2	6.58	.64
A_2	Total	15	1345.0		
	X vs Y	1	854.0	854.0	
	Error	14	491.0	35.07	24.4**
		Basis: 4 samples			
B_2	Total	3	90.16		
	X vs Y	1	60.84	60.84	
	Error	2	29.32	14.66	4.15
B_3	Total	3	32.47		
	X vs Y	1	10.56	10.56	
	Error	2	21.91	10.95	.96
C_1	Total	3	1.25		
	X vs Y	1	.25	.25	
	Error	2	1.00	.50	.005
		Natural Core Samples Basis: 16 samples			
A_1	Total	15	233.51		
	X vs Y	1	.02	.02	
	Error	14	233.49	16.66	.001
A_2	Total	15	471.37		
	X vs Y	1	130.37	130.37	
	Error	14	341.00	24.35	5.35*
		Combined Stations I-II			
A_2	Total	15	840.18		
	Substations	6	283.55	47.26	
	Location	1	25.00	25.00	
	Error	8	531.63	66.45	.38
		Combined Stations III-IV			
A_2	Total	15	1112.54		
	Substations	6	477.08	79.51	
	Location	1	156.24	156.24	
	Error	8	479.22	59.90	2.61

** Significant at 1% and 5%

* Significant at 5%

with appropriate modification where needed. Thirty grams of air-dry soil, previously passed through a two mm. sieve, was placed in the bottom of screened moisture equivalent boxes. These boxes were then placed in a one cm. layer of water and allowed to saturate for twenty-four hours. After draining for thirty minutes the boxes were placed in a centrifuge for thirty minutes at a speed of 2440 revolutions per minute, equivalent to 1000 times the force of gravity. The boxes were then weighed and samples oven-dried; the moisture equivalent was then calculated from the above results. A summation of the values obtained by horizon is given in Table 16.

Discussion of Results

The moisture equivalent is one of the most frequently used constants for expressing the moisture relations of soils. In centrifuging the samples, the force is considered to remove the water held in the larger pores. In this investigation the moisture equivalent is utilized to express soil texture. According to Veihmeyer and Hendrickson (1931) it gives a fairly reliable measure of the field capacity of fine-textured soil. The values would no doubt be higher in this study when using the moisture equivalent as a measure of the field capacity, since the soils studied are of a coarse texture. The values of Table 16 show a fairly close correlation with the values obtained for the mechanical analysis. Greatest differences occur in the A_2 and B_2 horizons, and the highest values occur in Area Y at Station III, where the soil type approaches a loam to clay loam. From these results it is expected that the soils of Area Y would reach field capacity sooner than the soils of Area X. Moisture equivalent values increase with increase in colloidal content

TABLE 16.

MOISTURE EQUIVALENT VALUES FOR FIVE SOIL HORIZONS AREA X AND AREA Y

		Percent	
		Area X (Stations I-II)	
Horizon	Wt. oven-dry (gms.)	Wt. water lost (gms.)	Moisture Equivalent
IA_1	29.55	1.99	6.73
A_2	29.66	1.39	4.70
B_2	30.03	1.70	5.66
B_3	29.41	.23	.78
C_1	37.87	.09	.25
IIA_1	30.85	2.14	6.93
A_2	29.37	1.44	4.90
B_2	29.60	1.74	5.86
B_3	31.04	.70	2.25
C_1	27.89	.08	.28
		Area Y (Stations III-IV)	
$IIIA_1$	29.26	2.28	7.79
A_2	30.57	3.49	11.40
B_2	30.61	3.28	10.73
B_3	30.32	.23	.74
C_1	28.71	.15	.54
IVA_1	29.04	2.03	6.99
A_2	20.08	1.34	6.67
B_2	28.21	1.86	6.68
B_3	29.81	.39	1.31
C_1	28.56	.08	.28

as borne out by comparing the clay content of the above three soil types. An analysis of variance (Table 17) shows no significant statistical difference between the moisture equivalents of Area X and Area Y.

8. <u>Soil Moisture Evaporation</u> (Ground Cover Absent)

Experimental Method:

Soil cores in situ were taken at five distinct soil horizons representing twenty individual cores from Area X and Area Y. The samples were saturated in a two cm. layer of water for twenty-four hours and then

TABLE 17.

ANALYSIS OF VARIANCE OF MOISTURE EQUIVALENT FOR AREA X vs. AREA Y

Percent Moisture
Basis: 20 samples

Horizon	Source	Degrees of Freedom	Sum of Squares	Mean Square	F
A_1	Total	3	.65		
	X vs Y	1	.31	.31	
	Error	2	.34	.17	1.80
A_2	Total	3	29.14		
	X vs Y	1	17.93	17.93	
	Error	2	11.21	5.60	3.21
B_2	Total	3	16.88		
	X vs Y	1	8.67	8.67	
	Error	2	8.21	4.10	2.11
B_3	Total	3	1.48		
	X vs Y	1	.24	.24	
	Error	2	1.24	.62	.30
C_1	Total	3	.0509		
	X vs Y	1	.016	.016	
	Error	2	.0349	.0174	.91

weighed. Using the saturated weight as a basis, the cores were then air-dried for a total period of eleven days. Room temperature and relative humidity were taken in order to insure a constancy for each determination. Measurements in the loss of weight due to evaporation were taken at two-day intervals in order to determine the loss in amount and relative rate of water loss from undisturbed cores without ground cover. These values were than plotted for the combined A and B horizons for each sampling area using average vlaues. Recordings of the loss in soil water were made until the loss in weight reached a constant amount. The objective of this experiment was to determine the evaporation loss on undisturbed cores without ground cover or transpirational losses. These values are given in Table 18.

TABLE 18.

ACCUMULATIVE AMOUNT AND RATE OF SOIL MOISTURE EVAPORATION FROM SOIL CORES WITHOUT GROUND COVER IN AREA X AND AREA Y

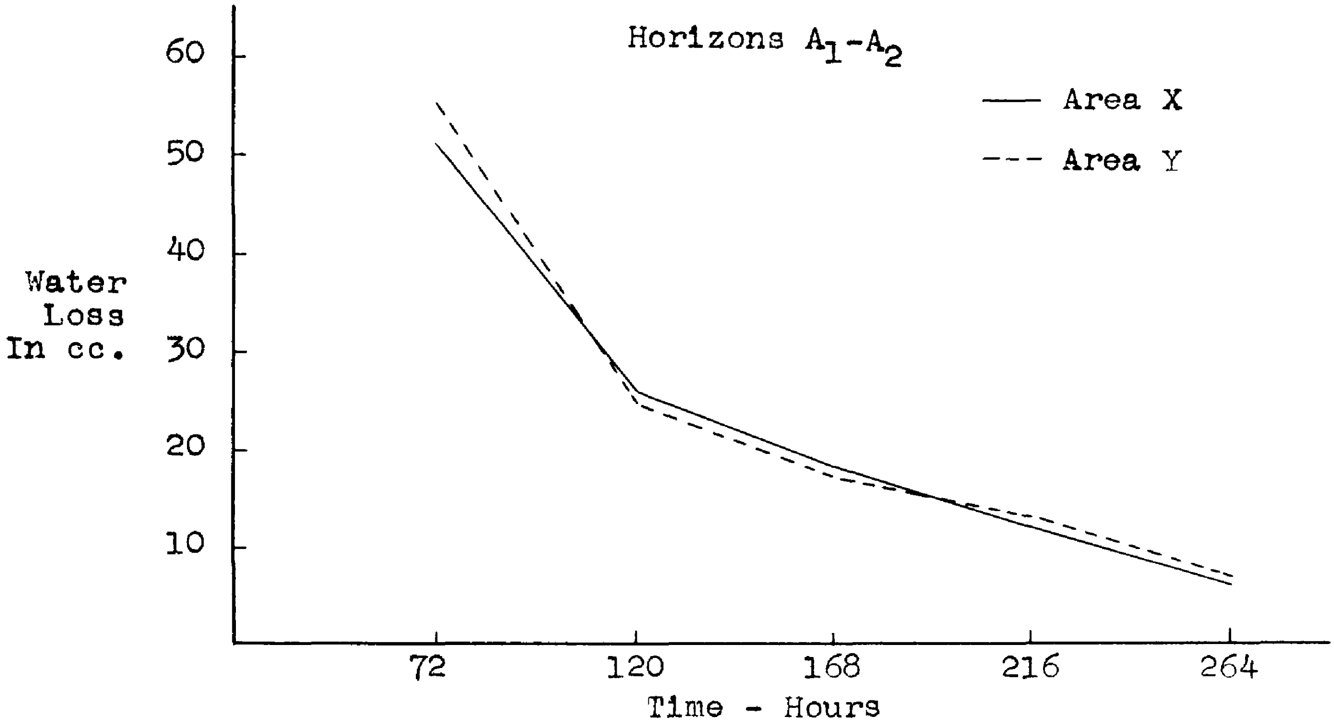
Horizon	Wt. Saturated Core	72 Loss	120 Loss	168 Loss	216 Loss	264 Loss	Total Accumulative Loss
		Water loss - grams air-dry					
		Area X (Stations I-II)					
		Time in hours					
IA_1	982.2	57.6	28.6	16.9	13.8	7.0	123.9
A_2	1043.2	65.7	23.0	19.5	10.6	4.9	123.7
B_2	1092.6	54.4	30.2	16.5	9.8	4.5	115.4
B_3	1079.4	43.3	19.7	13.2	11.0	6.7	93.9
IIA_1	1060.0	38.8	23.9	20.8	13.6	9.4	106.5
A_2	1058.5	42.7	29.0	17.8	10.5	5.0	105.0
B_2	1067.3	42.9	24.4	16.0	12.5	7.0	102.8
B_3	1051.3	64.6	22.2	11.2	9.7	3.5	111.2
						Total I-II	882.4
		Area Y (Stations III-IV)					
$IIIA_1$	1035.8	47.9	25.9	20.0	17.0	8.0	118.8
A_2	1027.3	53.3	22.5	13.3	9.7	8.0	106.8
B_2	1067.5	46.1	25.6	16.3	19.5	12.0	119.5
B_3	1055.7	49.7	22.5	10.5	7.0	3.9	93.6
IVA_1	1023.7	55.4	27.8	16.5	13.0	6.0	118.7
A_2	984.8	66.8	24.8	21.2	13.0	7.5	133.3
B_2	1044.0	44.0	22.5	23.4	15.1	5.6	110.6
B_3	1020.8	87.7	16.1	8.3	5.2	5.0	122.3
						Total III-IV	923.6

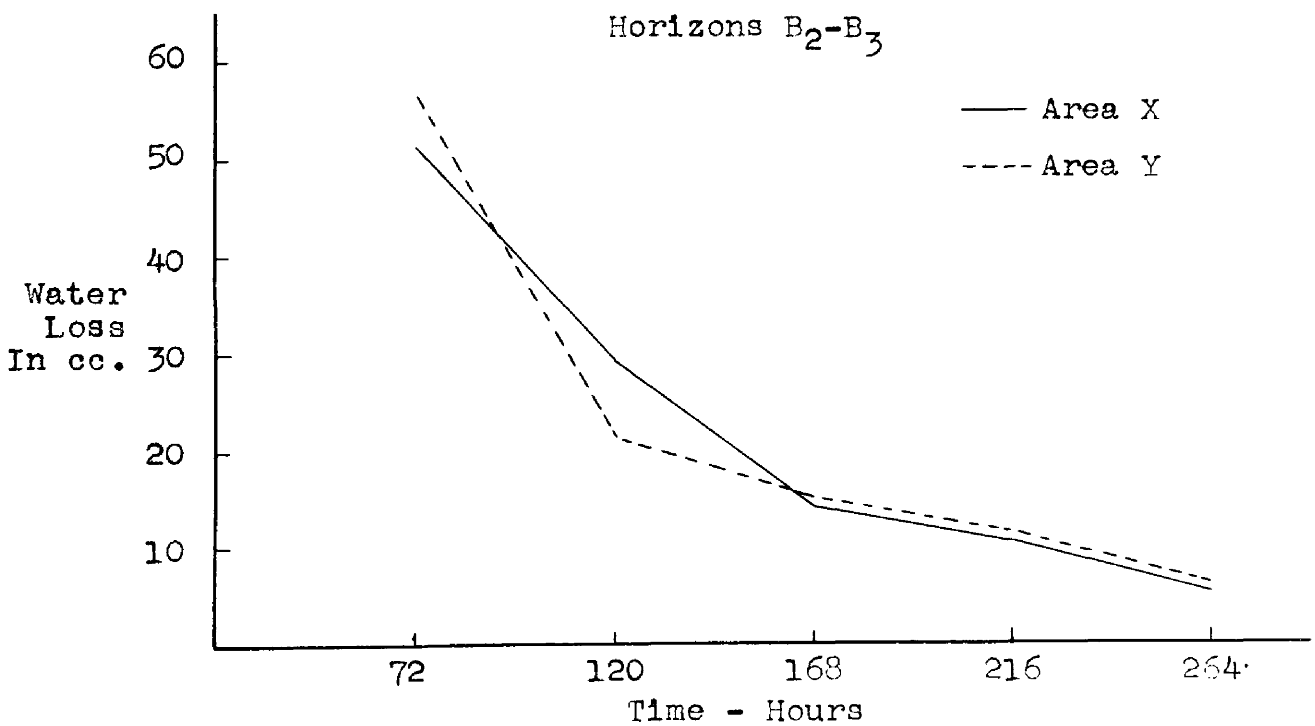
Discussion of Results

The results on the relative amount of evaporation show that Area Y has a higher evaporation loss for the entire profile than Area X. The accumulated amount of water lost in grams for an eleven-day period for Area Y is 923.6 grams as compared to a loss of 882.4 grams in Area X. This total profile evaporation loss represents a total accumulated loss

Fig. 13.

THE AMOUNT AND RATE OF SOIL MOISTURE EVAPORATION LOSS USING NATURAL SOIL CORES WITHOUT GROUND COVER IN AREA OF GOOD HEIGHT GROWTH AND POOR HEIGHT GROWTH





differential of 41.2 grams between Area X and Area Y. Expressed as a percentage loss from saturation, the total loss would be 11.18 percent for Area Y and 10.46 percent for Area X. If the evaporative surface is considered as being only the A_1 and A_2 horizons, then the accumulative loss difference between the two areas would be 7.1 grams for the A_1 and 11.4 grams for the A_2 horizon.

A similar situation exists with reference to the rate at which evaporation takes place. For Area X, the loss in water for the first forty-eight hours of evaporating time in the combined A_1-A_2 horizons is at the rate of .52 grams per hour, whereas the rate for Area Y is .64 grams per hour. After the initial loss for a period of ninety-six hours, the rate and amount of water loss tends to level off in both areas at about the same magnitude. Approximately the same rate of loss differences in the combined B_2-B_3 horizons is evident for both Area X and Area Y. The actual amount of water loss is greater in the A horizon than in the B horizon for both areas. Curves showing the rate and amount of water loss bring out these relationships more clearly (Figs. 13 and 14).

8. Soil Moisture Evaporation (Simulated Ground Cover)

Experimental Method:

In order to obtain data concerning the soil water evaporation loss with a simulated ground cover, the same core samples were used as those for evaporation loss without ground cover. After saturating the cores, a sawdust mulch simulating actual ground cover was then applied to each core. The amount of sawdust and depth applied to samples from Area X was twice the amount added to samples of Area Y. This sawdust ratio of 2:1 is approximately the actual ratio of litter (weight basis) that is found in the forest plantation. The object of the simulated ground cover measurements was to determine what effect the forest litter would have upon the amount and rate of evaporation from undisturbed horizons, exclusive of transpirational losses. The loss in weight was recorded for a total period of eleven days. These results are given in Table 19.

Discussion of Results

As before, in the experiment without ground cover, the amount of water loss due to evaporation was greatest in Area Y. The accumulated amount of water loss for the combined profile for a period of eleven days was 1191.1 grams for Area Y as compared to a loss of 1099.1 grams for Area X. This evaporation loss for the entire profile represents a total accumulated loss differential between the two areas of 91.3 grams. The total loss from the saturation point is 13.40 percent for Area Y and 12.07 percent for Area X, when the entire profile is considered.

If the evaporative surface is considered as being only the A_1 and A_2 horizons, the accumulative loss difference between the two areas would be 65.2 grams for the A_1 horizon and 24.0 grams for the A_2 horizon. A similar situation exists with reference to the rate at which evaporation takes place. For Area X, the loss in water for the first forty-eight hours for the combined A_1-A_2 horizon is at the rate of 1.26 grams per hour, whereas the rate for Area Y is 1.76 grams per hour. After the initial loss in water the amount and rate tend to level off at approximately the same magnitude. The amount of water loss is greater in the B horizon than in the A horizon for Area X; however, the water loss is

TABLE 19.

ACCUMULATIVE AMOUNT AND RATE OF SOIL MOISTURE EVAPORATION FROM SOIL CORES WITH SIMULATED GROUND COVER IN AREA X AND AREA Y

Water loss - grams air-dry

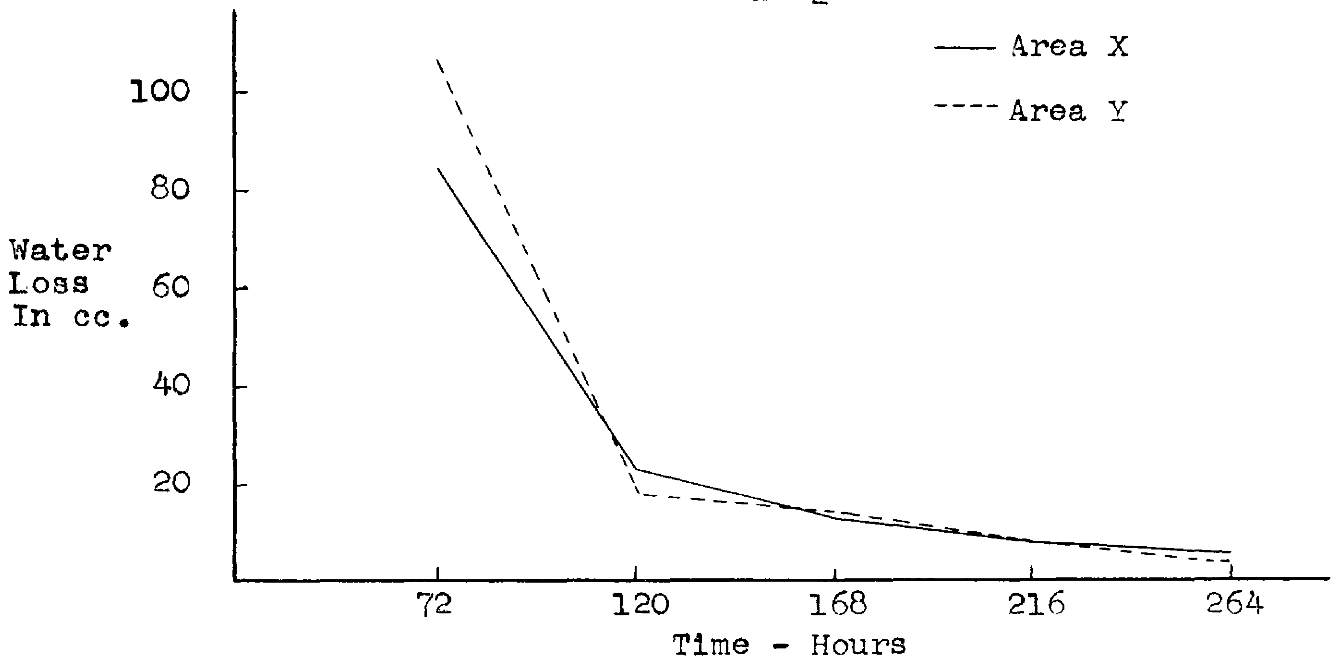
Horizon	Wt. Saturated Core	72 Loss	120 Loss	168 Loss	216 Loss	264 Loss	Total Accumulative Loss
Area X (Stations I-II)							
IA_1	1063.0	94.1	28.9	12.0	10.3	7.2	152.5
A_2	1123.0	83.0	21.0	13.5	7.2	4.0	128.7
B_2	1171.0	82.0	24.4	12.3	8.3	5.0	132.0
B_3	1168.5	94.9	21.9	11.2	6.9	4.1	139.0
IIA_1	1141.0	74.0	19.9	12.8	6.8	3.2	116.7
A_2	1150.0	85.5	21.0	13.1	10.3	7.1	137.0
B_2	1163.0	97.4	22.4	12.2	9.0	7.3	148.3
B_3	1126.0	116.1	8.6	10.7	6.5	3.7	145.6
						Total I-II	1099.8
Area Y (Stations III-IV)							
$IIIA_1$	1111.5	109.0	10.3	12.1	10.3	7.5	149.2
A_2	1100.0	86.3	18.3	13.8	10.9	7.7	137.0
B_2	1138.5	69.3	8.9	17.8	15.0	7.5	118.5
B_3	1123.6	106.3	14.1	13.2	5.7	3.6	142.9
IVA_1	1131.5	135.3	19.5	12.1	10.1	8.2	185.2
A_2	1058.4	95.9	26.7	14.1	9.8	6.2	152.7
B_2	1123.8	89.9	24.9	18.1	10.4	8.3	151.6
B_3	1079.0	112.8	13.7	10.0	6.8	5.7	154.0
						Total III-IV	1191.1

greater in the A horizon than in the B horizon for Area Y. This tends to substantiate the fact that the litter is effective in holding the water at a lower horizon in Area X. In Area Y where the litter is sparse, the soil water tends to evaporate from the surface horizon more readily. However, under actual field conditions, the air turbulence or

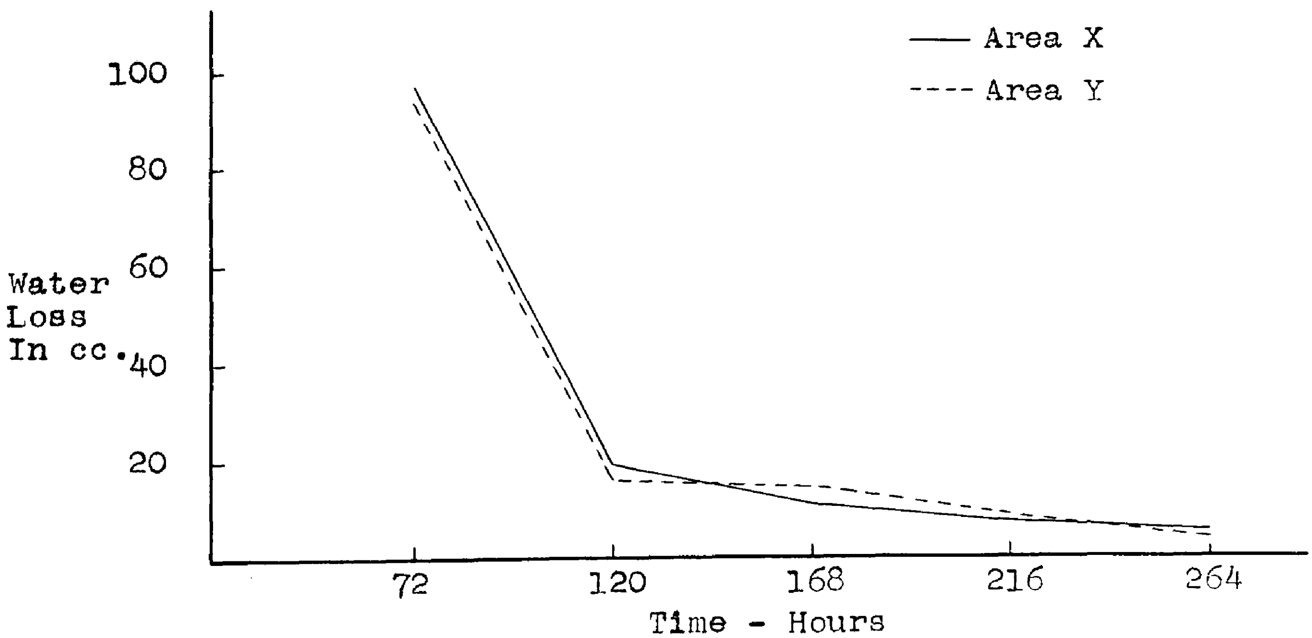
Fig. 14.

THE AMOUNT AND RATE OF SOIL MOISTURE EVAPORATION LOSS USING NATURAL SOIL CORES WITH SIMULATED GROUND COVER IN AREA OF GOOD HEIGHT GROWTH AND POOR HEIGHT GROWTH

Horizons A_1-A_2



Horizons B_2-B_3



wind velocity would be an important factor to consider in conjunction with the litter effect. Air turbulence would be especially important in affecting the rate of soil evaporation.

The results on evaporation loss with and without ground cover do not show any significant statistical differences in either the rate or amount of water loss. Under both set of conditions, however, Area Y lost more water and at a faster initial rate than Area X. Thus, the same relationship exists in both cases with or without ground cover. Since the cores were air-dried at the same temperature and relative humidity in both cases and free of any transpirational losses, it is apparent that soil texture and its attendant pore space must be contributing to the difference in water loss of the two areas. It is reasonable to assume that under higher temperatures of critical periods in the growing season, these differences would be magnified many times. This assumption is definitely borne out by the results taken in the experimental area as obtained with the atmometer bulb throughout two growing seasons. These data are presented under the climatic phase of the investigation.

An analysis of variance for soil moisture evaporation is given by soil horizon in Table 20.

TABLE 20.

ANALYSIS OF VARIANCE FOR ACCUMULATIVE AMOUNT OF SOIL MOISTURE EVAPORATION LOSS FROM SOIL CORES WITH AND WITHOUT GROUND COVER AREA X vs. AREA Y

Basis: 20 samples
Water loss in cubic centimeters

Ground Cover Absent

Horizon	Source	Degrees of Freedom	Sum of Squares	Mean Square	F
A_1	Total	3	163.99		
	X vs Y	1	12.60	12.60	
	Error	2	151.39	75.69	.166
A_2	Total	3	558.46		
	X vs Y	1	32.49	32.49	
	Error	2	525.97	262.98	.123
B_2	Total	3	154.39		
	X vs Y	1	35.40	35.40	
	Error	2	118.99	59.49	.595
B_3	Total	3	590.65		
	X vs Y	1	29.16	29.16	
	Error	2	561.49	280.74	.103

Simulated Ground Cover

Horizon	Source	Degrees of Freedom	Sum of Squares	Mean Square	F
A_1	Total	3	2351.58		
	X vs Y	1	1062.76	1062.76	
	Error	2	1288.82	644.41	1.649
A_2	Total	3	301.69		
	X vs Y	1	144.00	144.00	
	Error	2	157.69	78.84	1.826
B_2	Total	3	706.66		
	X vs Y	1	26.01	26.01	
	Error	2	680.65	340.32	.076
B_3	Total	3	121.21		
	X vs Y	1	37.82	37.82	
	Error	2	83.39	41.69	.907

TABLE 21.

A STATISTICAL SUMMARY OF "F" VALUES FOR EDAPHIC-PHYSICAL CHARACTERISTICS IN AREA X vs. AREA Y

LABORATORY EXPERIMENTS

	Soil Horizon				
	A_1	A_2	B_2	B_3	C_1
Average Depth	0-9"	9-14"	14-23"	23-33"	33" +
Variable Investigated:					
1. Mechanical Analysis					
a. Fine clay	11.1**	14.6**	.13	.07	.00
b. Sands	1.60	1.92	9.89	.67	16.00
c. Silt plus clay	.97	1.31	10.63	.67	16.00
2. Specific Gravity	1.1	.36	-	-	-
3. Volume Weight	.00	3.84	-	-	-
4. Pore Volume					
a. Capillary	3.05	2.19	-	-	-
b. Non-capillary	.04	.17	-	-	-
c. Total porosity	.90	2.76	-	-	-
5. Hygroscopic Coefficient	1.67	15.73	.012	.005	1.17
6. Water-holding Capacity					
a. Maximum air-dry	.64	24.4**	4.15	.96	.005
b. Maximum natural	.001	5.35*	1.36	.027	-
7. Moisture Equivalent	1.80	3.21	2.11	.30	.91
8. Soil Evaporation					
a. Without ground cover	.166	.123	.595	.103	-
b. Simulated ground cover	1.649	1.826	.076	.907	-

** Significant at 1% and 5%

* Significant at 5%

Summary and Implication of Results

Edaphic-Physical Characteristics

Having established the fact from observation and measurement that a marked differential rate of height growth exists in the experimental plantation under investigation, a rather complete laboratory analysis of the physical soil properties was undertaken. The objective of both the physical and chemical edaphic studies was to determine what effect the soil factors might have upon the height growth of tulip poplar, either directly or in combination with other factors. These soil properties were investigated separately and then combined to show their relative application to each other and to related properties. For reasons which are obvious, in an ecological study, no one factor *per se* can be isolated without reference to its associated environment. It is the purpose of the present summary to analyze the implications of the study thus far, and to point out those factors which may be significantly contributing to the entire study.

Three distinct but related soil types of the same soil catena were mapped and plotted by profile. The Warsaw sandy loam and Bronson sandy loam represent the area of poor height growth; the Fox sandy loam is representative of the soils where the height growth is better. From the standpoint of texture, the soils in the area of poor height growth contain a significantly greater amount of fine clay in the A_1 and A_2 horizons than in the area of good height growth. If it is assumed that the fine clay content has an important bearing upon height growth or site quality, then from the textural viewpoint, the soils in the area of good height growth should reveal the higher fine clay content. The results obtained in this study bear out the opposite situation. Thus, soil texture alone must not be a limiting factor causing the difference in height growth. Soil texture may be masked by the contribution of some other factor or set of factors, such as the soil-moisture or chemical relationship. Since it is generally recognized that loam soils are more favorable for forest growth than either coarse sands or fine clays, one might infer that Area Y (poor height growth) would produce the best height growth. Again, this situation is reversed as borne out by the mechanical analysis of the three soil types, since the soil most closely approaching a loam is found in Area Y.

The specific gravity of the soils in both areas did not differ significantly, either in actual value or statistically.

A comparison of volume weights showed very little difference in the two areas investigated. The volume weight values do reveal the fact that in all the soils studied, the values were fairly high, thus pointing out that these soils are not "mature" forest soils. Low organic matter content and high sand content of all soils investigated is indicated by the volume weight values.

Greater non-capillary, capillary, and total pore volume is indicated in the area of poor height growth. This is particularly true for the root zone area, the A_1 and A_2 horizons. The difference in porosity between the two sites is not extreme, however.

Results obtained from the hygroscopic coefficient determination corroborate the results found in the mechanical analysis. In general, higher values were found in all horizons for the area of poor height growth,

TABLE 22.

A COMPOSITE SUMMATION OF PHYSICAL-EDAPHIC CHARACTERISTICS BY SOIL HORIZON FOR AREA OF GOOD HEIGHT GROWTH AND AREA OF POOR HEIGHT GROWTH OF TULIP POPLAR

Soil Horizon	Fine Clay %	Sand %	Silt plus Clay %	Specific Gravity	Volume Weight	Capillary Porosity %	Non-capillary Porosity %	Total Porosity %	Hygroscopic Coefficient %	Water-holding Capacity (air-dry) %	Water-holdong Capacity (natural cores) %	Moisture Equivalent %	Soil moisture Evaporation (cores) ml.
						Area X							
IA_1	13.2	61.9	38.1	2.60	1.31	24.9	25.2	50.1	.46	58.1	42.5	6.73	153
A_2	12.5	76.7	23.3	2.52	1.60	21.0	16.3	37.3	.45	46.9	26.3	4.70	129
B_2	19.4	73.6	26.4	--	--	--	--	--	.99	44.3	23.3	5.66	132
B_3	6.4	91.6	8.4	--	--	--	--	--	.17	28.3	22.7	.78	139
C_1	6.0	94.0	6.0	--	--	--	--	--	.09	28.5	--	.25	--
IIA_1	13.1	61.1	38.9	2.55	1.41	25.9	17.5	43.4	.43	56.9	35.2	6.93	117
A_2	16.2	63.2	36.8	2.61	1.62	26.4	11.7	38.1	.54	44.4	24.2	4.90	137
B_2	18.0	76.0	24.0	--	--	--	--	--	.61	39.3	25.9	5.86	148
B_3	9.4	88.0	12.0	--	--	--	--	--	.26	31.3	23.3	2.25	146
C_1	6.0	94.0	6.0	--	--	--	--	--	.21	29.5	--	.28	--
						Area Y							
$IIIA_1$	15.4	56.9	43.1	2.39	1.33	26.0	21.5	47.5	.84	59.6	38.9	7.79	149
A_2	18.0	61.7	38.3	2.74	1.46	29.1	15.3	44.4	1.05	63.6	32.7	11.40	137
B_2	23.1	70.4	29.6	--	--	--	--	--	1.23	52.5	27.6	10.73	119
B_3	5.0	94.0	6.0	--	--	--	--	--	.08	30.1	20.9	.74	143
C_1	4.4	95.0	5.0	--	--	--	--	--	.08	28.0	--	.54	--
IVA_1	14.9	61.5	38.5	2.84	1.34	28.0	22.2	50.2	.49	57.4	38.9	6.99	185
A_2	19.1	62.7	37.3	2.76	1.56	26.7	13.8	40.5	.81	57.3	29.2	6.67	153
B_2	20.4	67.6	32.4	--	--	--	--	--	.64	46.7	25.5	6.68	152
B_3	9.4	90.0	10.0	--	--	--	--	--	.33	36.0	24.5	1.31	154
C_1	4.4	94.6	5.4	--	--	--	--	--	.09	29.0	--	.28	--

where the higher content of colloids is present. The difference is not statistically significant.

The water-holding capacity of soils in the area of poor height growth reveals a highly significant difference in the A_2 horizon when compared with Area X. This result is in accord with the higher fine clay content of Area Y. The values obtained for this soil property are indicated as significant in both air-dried and sieved samples, as well as with natural soil cores.

A measure of the moisture equivalent in both areas discloses no statistically significant difference between the two sites. However, use of the moisture equivalent as a measure of texture, brings out the fact that the values increased with an increase in colloidal content. Again, the area of poor height growth showed the higher moisture equivalent values.

The results on the measurement of soil water evaporation loss from natural soil cores reveals both a greater amount and initial rate of evaporation loss from the area of poor height growth. Although the actual values show no statistical difference on compared sites, this factor may be extremely important at critical periods of the growing season. The evaporation experiments are limited in their spatial application but are important as an indication of the soil-moisture relationships. It is sufficient to point out at this stage of the investigation, that greater initial losses and rate of evaporation occur in Area Y, both with and without simulated ground cover.

The statistical summary of all physical soil factors under investigation reveals only two properties of statistical significance. These two factors, the amount of fine clay and the water-holding capacity, are the only variables which differ significantly between Area X and Area Y. It is important to note that these two soil properties are definitely related to each other, insofar as the soil-moisture relationship is concerned.

The manner in which the more outstanding physical soil variables relate to the climatic, chemical, and microbiological phases of the present investigation will be discussed and analyzed in the final summary of all factors.

Depth of Root Penetration in Relation to the Physical-Edaphic Characteristics

In order to determine whether any significant differences existed between the areas of good and poor height growth with respect to extent of lateral root penetration, profiles exposing the root system were made in each area (Figs. 15 and 16). These profiles were dug at random locations in each area and the root penetration depths were recorded throughout the growing season in order to arrive at a substantial average root depth penetration. A record of the profiles exposed and their corresponding depths is as follows:

Profile	Date Exposed	Station No.	Depth of Maximum Lateral Root Penetration in Inches
1	April 18, 1952	I	11.0
2	"	II	10.0
3	"	III	15.0
4	"	IV	19.0
5	May 20, 1952	I	15.0
6	"	II	13.0
7	"	III	10.0
8	"	IV	18.0
9	June 20, 1952	I	13.0
10	"	II	12.0
11	"	III	11.0
12	"	IV	16.0
13	July 31, 1952	I	16.0
14	"	II	13.0
15	"	III	12.0
16	"	IV	15.0
17	August 31, 1952	I	12.0
18	"	II	11.0
19	"	III	14.0
20	"	IV	18.0

Station	Average Depth Root Penetration in Inches
I	13.4
II	11.8
III	12.4
IV	17.2

Fig. 15.

A soil profile exposed in the area of good height growth (Area X). The effective depth of lateral root penetration in this area is approximately 11 inches. The concentration of fleshy lateral roots of tulip poplar are found exclusively in the "A" soil horizon. Note the hardwood leaf litter at the soil surface.

In hardwood species such as tulip poplar, the depth and form of root system appears to be correlated with water content of the soil. Tulip poplar is a species with long initial taproots and prominent laterals. Most evidence reveals that this type root system is characteristic of species reaching optimum development on soils which, because of their physical properties and profile characteristics, have a fairly uniform available water content throughout. Such soils are necessarily deep, well-drained and of uniform texture with moderate permeability. According to Toumey and Korstian (1937) tulip poplar draws its water and nutrient supplies very largely from the surface layers of the soil, although this species has a deeply penetrating taproot. This fact is substantiated in the present investigation as shown by exposed profile and root depth penetration measurements. Root position reflects to a great degree the soil moisture conditions, and a study of root habit gives valuable information on the adaptability of various species for a particular site.

Results and Discussion

From the results obtained on the exposure of lateral roots in twenty individual profiles of both Area X and Area Y, no extreme differences were found in depth of root penetration. The greatest root penetration of the four locations exposed was nineteen inches. The average depths obtained for each of four separate stations shows the greatest penetration at Station IV. As indicated by soil type and poor height growth, this soil is the driest of the four stations observed. It is surmised that the deeper root development of this area is indicative of a drier site than other locations in the experimental tract. The water table level at the

Fig. 16.

A soil profile exposed in the area of poor height growth (Area Y). The effective depth of lateral root penetration in this location is approximately 15 inches; the fleshy lateral roots are found exclusively in the "A" soil horizon. Note the dominant grass vegetal litter at the soil surface in contrast to the leaf litter of Area X.

same station is closer to the ground surface than at any other station. It is entirely possible that the deeper root penetration in this location is influenced by saturated soil close to the water table level during the early part of the growing season. Again, during the dry period of August and summer drought, the roots of trees at Station IV may become more deeply penetrating in response to available soil moisture with a corresponding drop in the water table level. The downward growth of roots must keep pace with the loss of moisture from the superficial layers of soil during the period of drought. The root system of tulip poplar, which is fleshy and succulent, is not adjusted to sites which are swampy or to those sites in which the surface layers are subject to desiccation. Thus, the results here obtained denote that tulip poplar is adapting itself, with regard to its root system, to a condition somewhere between the extreme limits of saturation and physiological dryness. The effective zone of lateral root penetration for both Area X and Area Y is found entirely in the A_1 and A_2 soil horizons. The effects of evaporation, soil temperature, and soil moisture for these horizons, in relation to root penetration, will be discussed under climatic investigations. It is interesting to note that the only statistically significant textural soil difference between Area X and Area Y is found in the same horizons (A_1 and A_2) as the effective zone of lateral root penetration. Thus, in discussing the effect of climatic factors on soil-moisture relationships in this study, virtually all relations between growth and soil moisture will refer to the lateral root zone area, since this is the zone where the trees are primarily deriving their nutrients and water supply. The role of feeder roots in relation to water supply in each area was not investigated. This is not to imply that the more deeply entrenched roots (taproots) are not important in supplying water at critical periods of growth. Effective lateral root penetration and its relation to the physical-edaphic characteristics of the experimental area was the objective of this phase of the study.

Water Table Fluctuation in Relation to the Physical-Edaphic Characteristics

Throughout the growing season of 1952, the depth to the underlying water table was recorded for comparison between the area of good and poor height growth of tulip poplar. This fluctuation in depth to the water table is shown in Fig. 17. A continuous drop in water table level, as the season progressed, is graphically recorded for both Area X and Area Y.

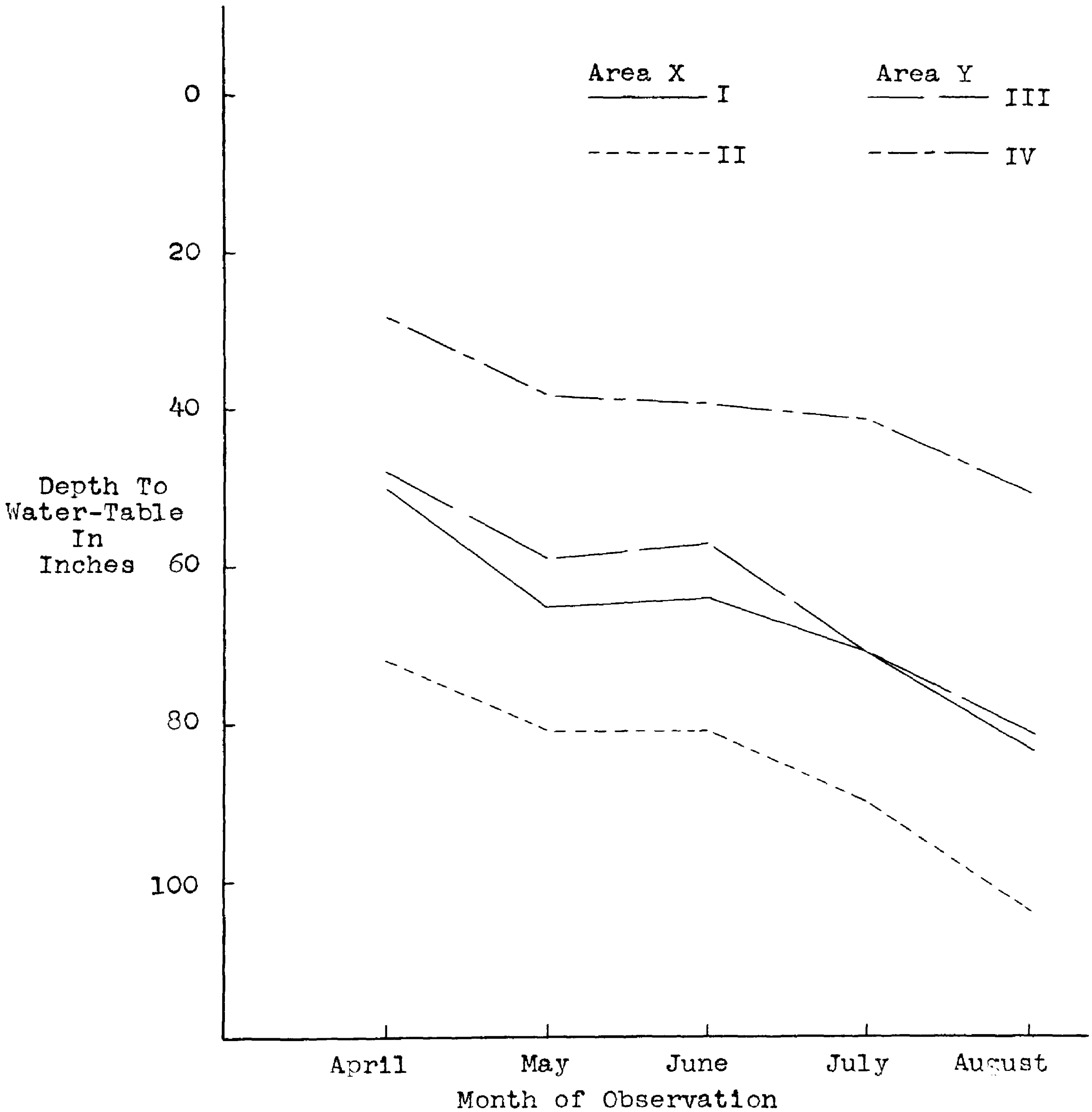
Since it has been shown by several investigators that capillary rise of water from a water table within fifteen feet of the surface is important in providing roots with moisture, fluctuations in the water table for tulip polar are significant in terms of tree growth. The water table in Area X occurs at an average depth of approximately six feet, whereas Area Y has a water table occurring at approximately three feet below the surface.

Results and Discussion

The character of the vegetation has an important effect upon the height of the water table and other factors associated with the water table level. In Area X the trees are more massive in height and volume and hence require more water for transpirational purposes; this water is drawn from the ground water supply or else from the soil before it penetrates to the water table level. This observation, coupled with such recorded climatic factors as reduced soil water evaporation, lower soil temperatures, reduced surface soil temperatures, and a sandy loam soil type, contribute directly to the lower water table level in Area X. In contrast to this situation, Area Y possesses a water table close to the surface as a result of increased capillarity and increased soil evaporation. The soil of Area Y is a deep soil in an absolute sense, but,

Fig. 17.

THE WATER-TABLE FLUCTUATION THROUGHOUT
THE GROWING SEASON OF 1952



because of a relatively impervious layer (high clay content of A horizon) and high water table, it is a shallow soil in a physiological sense, which inhibits normal height growth. A climatic study of the contrast between both areas utilizing such factors as relative humidity, soil evaporation loss, air and soil temperature, soil-moisture relationships and wind movement, bear out the correlation between the water table levels in each area. Experiments have shown that capillary rise of water in soils takes place slowly, but to the greatest height in clay soils, and most rapidly in sandy soils.

From the results of the water table fluctuation in both areas it is apparent that the water table level in plantations of this type becomes important as an index to planting sites, insofar as these data are supplemented with other climatic and edaphic factors. Again, the critical soil-moisture requirements for tulip poplar plantations is evident. Thus, Area Y apparently has all the site requirements necessary to good height growth of tulip poplar, yet the best growth occurs somewhere beyond these limitations, as exhibited by Area X. The two main factors, as evidenced by this study, which are contributing most to the difference in the water table levels of both areas, are evaporation and transpiration of the tulip poplar sites.

LABORATORY EXPERIMENTS

Chemical - Edaphic Characteristics

1. Soil Acidity (pH)[9]

Experimental Method:

Samples for the determination of the hydrogen-ion concentration were taken from five soil horizons on thirty-two randomly selected spots in Area X and Area Y. Ten-gram soil samples were taken in duplicate in July 1951, and sealed immediately in paraffin containers. The pH of each soil was then determined electrometrically by use of the Beckman pH Meter, as shown by Reed and Cummings (1945), and the reciprocal values obtained were averaged for each duplicate set of samples. A soil-water extract in the ratio of 1:1 was used in all duplicate determinations. By means of the United States Soil Conservation Service classification criteria, the relative pH and its corresponding class of acidity was plotted for each area by depth of horizon. The average values obtained by horizon and depth is presented in Table 23.

Discussion of Results

Most forest soils are acid in reaction. This reaction is not always constant but shows variation during the course of the year. However, Nehring (1934) a German investigator, found that variations in pH did not exceed 0.8 pH over a one-year period. Other investigators have found comparable results. Marked differences in pH are often found in different

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9. The number preceding the chemical soil factor under investigation corresponds to the same factor summarized statistically in Table 42.

TABLE 23.

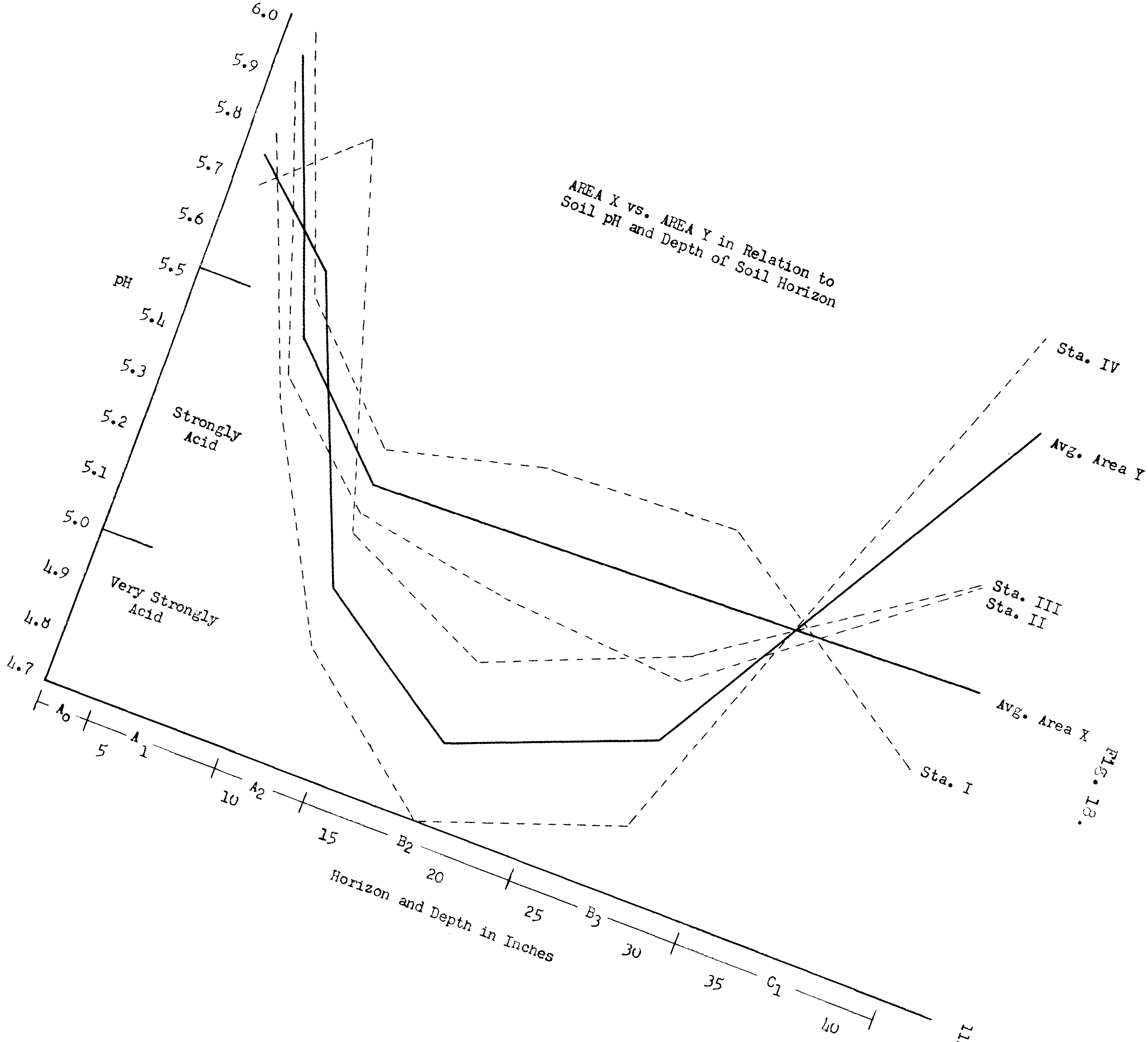
THE HYDROGEN-ION CONCENTRATION OF SOILS REPRESENTING FIVE SOIL HORIZONS IN AREA X AND AREA Y

Logarithm of reciprocal of the hydrogen-ion concentration

Soil Horizon	Average pH	Combined Stations	Average pH	Avg. Difference **
		Area X (Stations I-II)		
IA_1	5.55	I-IIA_1	5.47	-.13
A_2	5.33	A_2	5.26	+.21
B_2	5.40	B_2	5.27	+.41
B_3	5.42	B_3	5.28	+.28
C_1	5.18	C_1	5.29	-.33
IIA_1	5.39			
A_2	5.20			
B_2	5.15			
B_3	5.14			
C_1	5.40			
		Area Y (Stations III-IV)		
IIIA_1	5.85	III-IVA_1	5.60	+.13
A_2	5.16	A_2	5.05	-.21
B_2	5.02	B_2	4.86	-.41
B_3	5.17	B_3	5.00	-.28
C_1	5.42	C_1	5.62	+.33
IVA_1	5.35			
A_2	4.94			
B_2	4.70			
B_3	4.83			
C_1	5.82			

** A minus sign (-) indicates greater acidity than compared area and a plus (+) sign indicates less acid than compared area.

horizons of a particular profile. In the results here obtained, considerable variation within horizons may be seen, but the findings indicate that a comparison of Area X and Area Y show little overall variation. The highest pH found was 5.85 and the lowest was 4.70; these values include all horizons in both areas. Area Y exhibits lower individual horizonal acidities than Area X but both areas are in the category of strongly acid to very strongly



AREA X vs. AREA Y in Relation to
Soil pH and Depth of Soil Horizon
pH
6.0
5.9
5.8
5.7
5.6
5.5
5.4
5.3
5.2
5.1
5.0
4.9
4.8
4.7
Strongly Acid
Very Strongly Acid
Horizon and Depth in Inches
A_0
A_1
A_2
B_2
B_3
C_1
5
10
15
20
25
30
35
40
Sta. IV
Avg. Area Y
Sta. III
Sta. II
Avg. Area X
Sta. I

Fig. 18.

acid, when average values are considered. The B horizon of Area X and Area Y appears to be slightly more acid than the A or C horizons (Fig. 18). Also the greater pH difference between the two compared areas occurs in the B horizon.

A study by Auten (1945) of 77 second-growth yellow poplar stands from 12 to 61 years of age on old fields and cutover areas, showed that if the soil reaction was considered at the root zone depth, most soils were acid. Auten cites an example of a 12-year old stand which grew at the rate of 3.4 feet per year on a soil with a pH of 5.8 at the surface and 5.6 in the subsoil. This situation is analogous to the results of the present investigation, where insufficient time has elapsed for the calcareous yellow poplar litter to alter the reaction to less acid conditions. In time, the litter of this plantation will become richer in lime and change the soil reaction to neutral or slightly alkaline conditions.

According to Lutz and Chandler (1946) there is very little evidence that low pH *per se* is responsible for poor growth of forest trees. Agricultural plants may be sensitive to high concentrations of hydrogen ions but this is less marked for forest tree species. High acidity values, however, may affect the soil fauna and flora, certain physical and chemical factors, and even toxicity of sensitive species. These effects are indirect, but after a period of time may become highly important. An analysis of variance shows the greatest difference in pH between Area X and Area Y occurring in the B_2 horizon. However, no horizon exhibits any statistical significant difference (Table 24).

TABLE 24.

ANALYSIS OF VARIANCE FOR THE HYDROGEN-ION CONCENTRATION OF FIVE SOIL HORIZONS IN AREA X vs. AREA Y

Horizon	Source	Degrees of Freedom	Sum of Squares	Mean Square	F
			Basis: 32 samples pH		
A_1	Total	15	1.21		
	X vs Y	1	.06	.06	
	Error	14	1.15	.082	.73
A_2	Total	15	1.21		
	X vs Y	1	.19	.19	
	Error	14	1.02	.073	2.61
			Basis: 4 samples		
B_2	Total	3	.25		
	X vs Y	1	.17	.17	
	Error	2	.08	.04	4.25
B_3	Total	3	.18		
	X vs Y	1	.07	.07	
	Error	2	.11	.055	1.32
C_1	Total	3	.21		
	X vs Y	1	.11	.11	
	Error	2	.10	.05	2.21

2. Soil Organic Matter

Experimental Method:

Soil samples were collected from Area X and Area Y representing five soil horizons in each area. A total of twenty individual samples was taken and these samples were air-dried and passed through a two mm. sieve. The dry combustion method for analysis of organic matter was employed. Five grams of 60 mesh carbon free alundum and .25 grams of manganese dioxide was added to a two gram sample of soil. These were well mixed and placed in a silica combustion boat and inserted into a hot silica tube furnace,

TABLE 25.

THE AMOUNT OF SOIL ORGANIC MATTER IN FIVE HORIZONS FROM AREA X AND AREA Y

Horizon	Carbon dioxide (gms.)	Percent carbon dioxide*	Organic Matter**
		Percent	
		Area X (Stations I-II)	
IA_1	.100	10.0	2.35
A_2	.041	4.1	.96
B_2	.030	3.0	.71
B_3	.015	1.5	.35
C_1	.012	1.2	.28
IIA_1	.073	7.3	1.72
A_2	.030	3.0	.71
B_2	.028	2.8	.66
B_3	.017	1.7	.40
C_1	.012	1.2	.28
		Area Y (Stations III-IV)	
$IIIA_1$	.113	11.3	2.66
A_3	.050	5.0	1.18
B_2	.035	3.5	.83
B_3	.015	1.5	.35
C_1	.015	1.5	.35
IVA_1	.070	7.0	1.65
A_2	.038	3.8	.90
B_2	.032	3.2	.75
B_3	.013	1.3	.31
C_1	.006	0.6	.14

** Basis one-gram sample

* Percent carbon dioxide converted to organic matter by multiplying by the factor 0.471 (after Schollenberger)

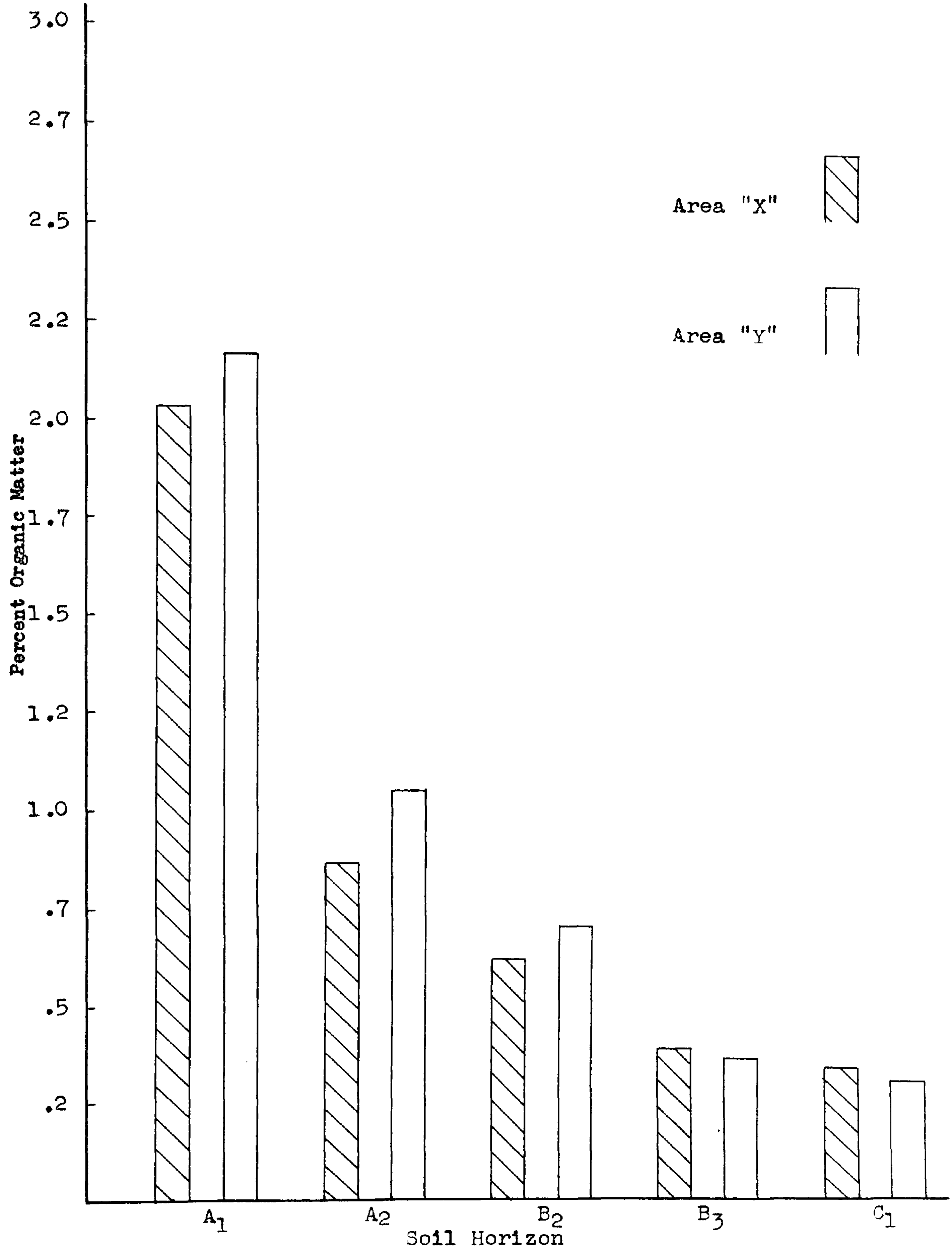
previously heated to about 950° C. After appropriate oxygen flow rate was adjusted, the sample was subjected to various purification processes, and then removed after twenty minutes. Carbon dioxide was collected in a previously weighed ascarite tube and the percent organic matter computed by using the factor 0.471 to convert amount of carbon dioxide to organic matter (after Schollenberger, 1945). The percent organic matter was then reduced to a one-gram basis and plotted to scale (Fig. 19).

Discussion of Results

A dynamic equilibrium exists between the supply of fresh organic debris and its subsequent decomposition. Changes which alter this equilibrium will result in either a decrease or increase of organic matter. The importance of organic matter in affecting the physical and chemical characteristics of soils cannot be overestimated. The composition and the quantity of organic matter in soils is thus extremely variable. Values obtained in this investigation compare quite favorably with the findings of many investigators on similar soil types. A study by Auten (1945) showed that yellow poplar often reproduces and grows rapidly on deep soils from which organic matter has been removed by oxidation and erosion. Thus, if yellow poplar would not reseed, become established, and thrive on soils which have a low organic content, one might deduce that height growth was dependent upon organic matter. Such, however, is not the case. Although organic matter deposited as litter influences growth rate as the accumulation becomes greater, its presence is not a primary cause of increased tree growth, but a result. An examination of the data obtained in Table 25 will immediately show that the amount of organic matter is relatively low in both Area X and Area Y. In all cases the amount decreases with increased depth of the profile. The highest content of organic matter occurs on the Warsaw sandy loam, acid variant type, where a total content of 5.37 percent is found for the entire profile; the highest value of 2.66 percent is also found here in the A_1 horizon. The remaining soil types do not differ appreciably in their content of organic matter for any horizon. An

Fig. 19.

PERCENT OF ORGANIC MATTER EXISTING IN FIVE SOIL HORIZONS FOR THE AREA OF GOOD HEIGHT GROWTH vs. AREA OF POOR HEIGHT GROWTH



analysis of variance shows the greatest difference between Area X and Area Y occurs in the A_2 horizon. However, no statistical significant difference in organic matter exists between Area X and Area Y (Table 26).

TABLE 26.

ANALYSIS OF VARIANCE OF ORGANIC MATTER IN FIVE SOIL HORIZONS FOR AREA X vs. AREA Y

		Percent Basis: 20 samples			
Horizon	Source	Degrees of Freedom	Sum of Squares	Mean Square	F
A_1	Total	3	.73		
	X vs Y	1	.02	.02	
	Error	2	.71	.35	.06
A_2	Total	3	.11		
	X vs Y	1	.05	.05	
	Error	2	.06	.03	1.61
B_2	Total	3	.02		
	X vs Y	1	.02	.02	
	Error	2	.00	.00	.00
B_3	Total	3	.003		
	X vs Y	1	.003	.003	
	Error	2	.00	.00	.00
C_1	Total	3	.03		
	X vs Y	1	.00	.00	
	Error	2	.03	.015	.00

3. Total Nitrogen and Carbon-Nitrogen Ratio

Experimental Method:

Total nitrogen was determined on combined substation duplicate samples for the A and B horizons of Area X and Area Y. Determination was made according to the Kjeldahl procedure (1930). Ten grams of soil were added to Kjeldahl flasks and the organic matter was oxidized by boiling

TABLE 27.

THE RELATIONSHIP BETWEEN THE AMOUNT OF TOTAL NITROGEN AND CARBON IN SOILS OF AREA X AND AREA Y

Percent

Horizon	Percent Nitrogen	Percent Carbon*	Carbon-Nitrogen Ratio	
		Area X (Stations I-II)		
IA_1	.125	2.728	21.82 : 1	
A_2	.047	1.118	23.79 : 1	
B_2	.049	.818	16.69 : 1	
IIA_1	.113	1.991	17.62 : 1	
A_2	.044	.818	18.59 : 1	
B_2	.041	.764	18.63 : 1	
	.419	8.237	117.14 : 1	Totals
		Area Y (Stations III-IV)		
$IIIA_1$	.133	3.082	23.17 : 1	
A_2	.072	1.364	18.94 : 1	
B_2	.060	.954	15.90 : 1	
IVA_1	.121	1.909	15.78 : 1	
A_2	.054	1.036	19.18 : 1	
B_2	.055	.873	15.87 : 1	
	.495	9.218	108.84 : 1	Totals

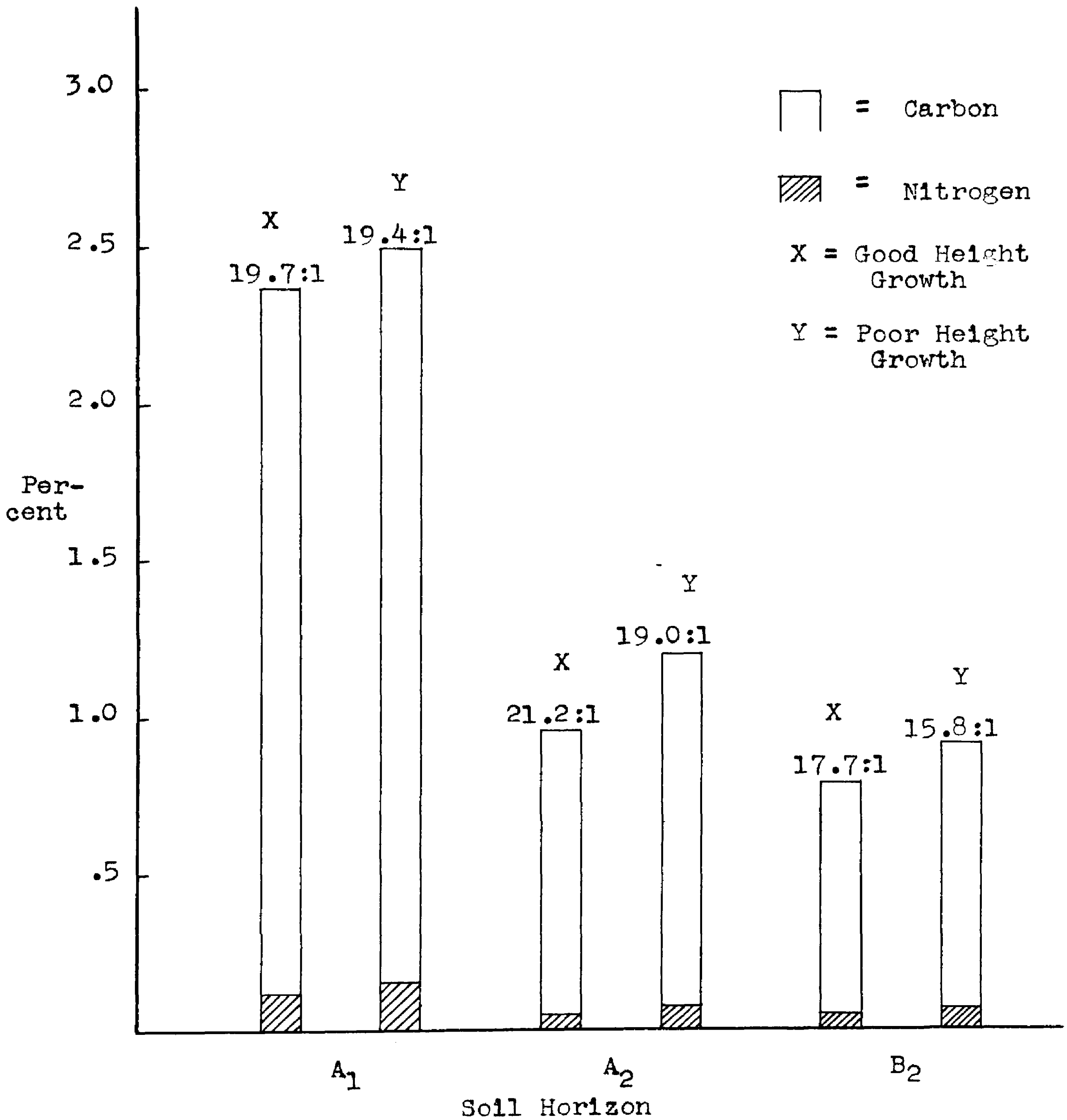
* Derived from equation: $C + O_2 \longrightarrow CO_2$

$$\frac{\text{Atomic weight carbon}}{\text{Molecular weight carbon dioxide}} = \frac{12.01}{44.01} = .2728 \times \% CO_2$$

$$= \text{percent carbon}$$

Fig. 20.

A COMPARISON OF THE CARBON-NITROGEN RELATIONSHIP OF SOILS IN THE AREA OF GOOD HEIGHT GROWTH vs THE AREA OF POOR HEIGHT GROWTH



with sulfuric acid. Appropriate catalysts were added to hasten oxidation. After digestion and cooling, an excess of sodium hydroxide was added and the ammonia was distilled into standard acid. The percent total nitrogen thus obtained includes the ammoniacal and certain nitrate forms of nitrogen that are present.

The percent of carbon was derived from the organic matter determinations. The percent carbon dioxide obtained in the dry combustion method is converted to percent carbon by multiplying each determination by the factor .2728. Results of these calculations are presented in Table 27.

Discussion of Results

The change of nitrogen in combined complex forms to the available soil nitrogen is a biological process influenced by many factors. From an ecological standpoint the carbon-nitrogen ratio of soils is influenced by soil fertility and stand composition. For forest tree species, very little nitrogen is liberated as the nitrate form until the carbon-nitrogen ratio has narrowed as a result of decomposition. An index to the degree of release of nitrogen was obtained in this investigation by utilizing the carbon-nitrogen ratio. The percent of both carbon and nitrogen is higher in the area of poor height growth than in the area of good height growth. Consequently, the C/N ratio is more narrow in Area Y, indicating greater decomposition and release of the nitrate form of nitrogen. The differences in the C/N ratio are not marked between areas. These results disclose that the less dense site (Area Y) with a higher content of organic matter will release more nitrogen than the denser Area X. At any given time the amount of available nitrogen will fluctuate considerably.

Since a determination of total nitrogen includes more than one form of nitrogen, it is not possible to differentiate the ammoniacal from the nitrate forms in this determination. However, a close approximation of the nitrogen content and its availability will be investigated under the microbiological phase of the study.

TABLE 28.

ANALYSIS OF VARIANCE FOR TOTAL NITROGEN CONTENT OF SOILS IN AREA X vs. AREA Y

Percent

Basis: 12 samples (in duplicate)

Horizon	Source	Degrees of Freedom	Sum of Squares	Mean Square	F
A_1	Total	3	.0030		
	X vs Y	1	.0005	.0005	
	Error	2	.0025	.0012	.42
A_2	Total	3	.0045		
	X vs Y	1	.0035	.0035	
	Error	2	.0010	.0005	.70
B_2	Total	3	.002		
	X vs Y	1	.001	.001	
	Error	2	.001	.0005	2.00

4. Cation-Exchange Capacity

Experimental Method:

Soil samples were taken from five soil horizons representing Area X and Area Y according to the method of Schollenberger and Simons (1945). These soils were air-dried and passed through a two mm. sieve. Twenty-five grams of air-dry soil were placed in a 300 milliliter flask and leached with 250 milliliters of 1N ammonium acetate solution and again leached with .1N ammonium acetate. After the soil in the funnel had finished draining, the funnel and moist soil were weighed. The soil in

TABLE 29.

THE CATION-EXCHANGE CAPACITY, EXCHANGEABLE HYDROGEN, TOTAL BASES, AND PERCENT BASE SATURATION OF FIVE SOIL HORIZONS IN AREA X AND AREA Y

Horizon	Cation-Exchange Capacity m.e./ 100 gms.	Exchangeable Hydrogen* m.e./ 100 gms.	Total Bases m.e. / 100 gms.	Percent Base Saturation**	
		Area X			
IA_1	8.20	7.5693	.6307	7.69	
A_2	6.08	5.6152	.4648	7.64	
B_2	10.64	10.1172	.5228	4.91	
B_3	3.32	2.9811	.3389	10.20	
C_1	1.44	1.2177	.2223	15.43	
IIA_1	6.80	6.2766	.5234	7.69	
A_2	6.40	5.8573	.5427	8.47	
B_2	8.40	7.6804	.7196	8.56	
B_3	4.08	3.6975	.3825	9.37	
C_1	1.60	1.2799	.3201	20.00	
	56.96	52.2922	4.6678	99.96	Totals
		Area Y			
IIIA_1	7.72	6.9066	.8134	10.53	
A_2	10.68	9.9733	.7067	6.61	
B_2	11.88	11.0516	.8284	6.97	
B_3	1.36	1.1264	.2336	17.17	
C_1	.24	—	.2368	—	
IVA_1	10.96	10.5143	.4457	4.06	
A_2	8.72	8.1161	.6039	6.92	
B_2	8.28	7.7754	.5046	6.09	
B_3	6.48	6.1655	.3145	4.85	
C_1	8.84	8.6132	.2268	2.56	
	74.92	70.2424	4.9134	65.76	Totals

** Total bases divided by cation-exchange capacity X 100
* Cation-exchange capacity minus total bases

Note: One milligram equivalent (m.e.) denotes the equivalent weight, or the atomic weight divided by the valence.

the funnel was then slowly leached with 260 milliliters of 10 percent NaCl. This salt filtrate was placed in a Kjeldahl flask, twenty milliliters of 2N NaOH were added, and then distilled into fifty milliliters of 4 percent boric acid solution. The distillate was then titrated with 0.1N HCl using bromcresol green as an indicator. From these determinations the milliequivalents of adsorbed ammonia per twenty-five grams of soil were calculated and then converted to adsorbed bases per 100 grams of soil. The cation-exchange capacity in terms of milliequivalents per 100 grams of soil is presented in Table 29.

Discussion of Results

The cation-exchange capacity of soils is largely a function of the kinds and amounts of colloidal material and the total bases present. This property is undoubtedly the most important characteristic of colloidal clay. It is important to recognize that the exchange of cations is associated with the colloidal material and this adsorption and displacement of ions is important in supplying the necessary bases to plants. The cation-exchange reaction is rapid and reversible, and represents the capacity of soil colloids for holding cations. If the exchange capacity is satisfied by metallic cations, the soil is considered to be base-saturated. However, in forest soils of humid regions this condition is rare, since the bases are continually being replaced by hydrogen ions and the soil colloids tend to be base-unsaturated.

The results obtained by soil horizon in Column 1, Table 29 reveals the close relationship of cation-exchange capacity to the amount of fine clay present. This relation is most marked in Area X where the highest fine clay content and cation-exchange capacity are found in the B_2 horizon.

The highest individual cation exchange value is found in the B_2 horizon of Area Y. An analysis of variance reveals that no significant statistical difference is found between Area X and Area Y, although differences in the A_1 horizon closely approaches the five percent significant level. The present investigation shows definitely that the cation-exchange capacity is more closely related to the inorganic colloids than to the organic colloids, as evidenced by the fine clay content of individual horizons.

5. Total Bases and Percent Base Saturation

Experimental Method:

Utilizing the same sampling procedure as for the cation-exchange capacity determinations, twenty-five grams of air-dry soil were leached with 1N and .1N ammonium acetate. This filtrate was collected and evaporated to dryness on a hot plate. The residue was transferred to a porcelain evaporating dish and ignited over a Meker burner. After cooling, a calculated excess of .2N HCl was added and the solution back-titrated with 0.1N NaOH. From these determinations the milliequivalents of soil bases per 100 grams of soil were calculated. To determine the percent base saturation simply divide the total bases obtained by the cation-exchange capacity. The content of exchangeable hydrogen plus the content of exchangeable metallic cations is equal to the total cation-exchange capacity. Conversely, by subtracting the total base exchange from the total cation-exchange capacity, the exchangeable hydrogen is obtained. The percent base saturation of a soil is the degree to which the adsorbing surface of soil colloids is saturated with metallic cations. This soil property, being a function of the total bases and cation-exchange capacity is very important, since it determines in part the availability of the various bases to plants.

Results of this investigation show that the highest individual base saturation exists in the C_1 horizon of Area X. If individual soil horizons are considered with reference to base saturation, the variation between Area X and Area Y is not extreme. An analysis of variance (Table 33) of percent base saturation shows a significant difference at five percent between Area X and Area Y at the C_1 horizon; this is the only statistically significant soil property of the four factors here studied.

In order to show the relationship of these values, the combined data are presented in Table 29. It is interesting to note the combined totals for these four soil properties and how these profile totals relate to the soil type under investigation. The greatest total cation-exchange capacity exists in Area Y (poor height growth). There is a very close relationship here to the amount of fine clay existing in this soil type, both as to individual horizons and total profile. The greatest total exchangeable hydrogen is found in Area Y also. This reveals the close relationship of the pH values obtained for the same soils, since Area Y shows a slightly greater acidity than Area X, when all horizons are averaged. Total base content does not differ much in comparing Area X with Area Y; a slightly larger total base content exists in Area Y but this difference is insignificant. The last soil property, the percent base saturation, reveals a large total profile difference between Area X and Area Y. Although the total difference is insignificant statistically, except at the C_1 horizon, the percent base saturation is definitely more

TABLE 30.

ANALYSIS OF VARIANCE FOR CATION-EXCHANGE CAPACITY FOR GOOD HEIGHT GROWTH (AREA X) vs. POOR HEIGHT GROWTH (AREA Y)

		Milliequivalents per 100 grams soil			
Horizon	Source	Degrees of Freedom	Sum of Squares	Mean Square	F
A_1	Total	3	3.78		
	X vs Y	1	3.39	3.39	
	Error	2	.39	.19	17.8
A_2	Total	3	13.94		
	X vs Y	1	11.97	11.97	
	Error	2	1.97	.98	12.2
B_2	Total	3	9.29		
	X vs Y	1	.31	.31	
	Error	2	8.98	4.49	.069
B_3	Total	3	13.44		
	X vs Y	1	.05	.05	
	Error	2	13.39	6.69	.007
C_1	Total	3	47.50		
	X vs Y	1	8.41	8.41	
	Error	2	39.09	10.54	.43

TABLE 31.

ANALYSIS OF VARIANCE FOR EXCHANGEABLE HYDROGEN FOR GOOD HEIGHT GROWTH (AREA X) vs. POOR HEIGHT GROWTH (AREA Y)

		Milliequivalents per 100 grams soil			
Horizon	Source	Degrees of Freedom	Sum of Squares	Mean Square	F
A_1	Total	3	10.51		
	X vs Y	1	3.19	3.19	
	Error	2	7.32	3.66	.87
A_2	Total	3	27.19		
	X vs Y	1	14.48	14.48	
	Error	2	12.71	6.35	2.28
B_2	Total	3	8.61		
	X vs Y	1	.26	.26	
	Error	2	8.35	4.17	.06
B_3	Total	3	13.00		
	X vs Y	1	.09	.09	
	Error	2	12.91	6.45	.01
C_1	Total	3	46.40		
	X vs Y	1	9.33	9.33	
	Error	2	37.07	18.53	.50

TABLE 32.

ANALYSIS OF VARIANCE FOR TOTAL BASES FOR GOOD HEIGHT GROWTH (AREA X) vs. POOR HEIGHT GROWTH (AREA Y)

Horizon	Source	Degrees of Freedom	Sum of Squares	Mean Square	F
		Milliequivalents per 100 grams soil			
A_1	Total	3	.0759		
	X vs Y	1	.0100	.0100	
	Error	2	.0659	.0329	.33
A_2	Total	3	.0373		
	X vs Y	1	.0300	.0300	
	Error	2	.0073	.0036	8.33
B_2	Total	3	.0778		
	X vs Y	1	.0100	.0100	
	Error	2	.0678	.0339	.34
B_3	Total	3	.0090		
	X vs Y	1	.0050	.0050	
	Error	2	.0040	.0020	2.50
C	Total	3	.0113		
	X vs Y	1	.0062	.0062	
	Error	2	.0051	.0025	2.48

TABLE 33.

ANALYSIS OF VARIANCE FOR PERCENT BASE SATURATION FOR GOOD HEIGHT GROWTH (AREA X) vs. POOR HEIGHT GROWTH (AREA Y)

Horizon	Source	Degrees of Freedom	Sum of Squares	Mean Square	F
			Percent		
A_1	Total	3	21.09		
	X vs Y	1	.15	.15	
	Error	2	20.94	10.47	.01
A_2	Total	3	2.06		
	X vs Y	1	1.66	1.66	
	Error	2	.40	.20	8.30
B_2	Total	3	7.09		
	X vs Y	1	.04	.04	
	Error	2	7.05	3.52	.01
B_3	Total	3	77.73		
	X vs Y	1	1.50	1.50	
	Error	2	76.23	38.11	.03
C_1	Total	3	282.82		
	X vs Y	1	270.10	270.10	
	Error	2	13.72	6.86	39.37*

* Significant at 5%

closely correlated with the area of good height growth than with the area of poor height growth. An analysis of variance of the four soil properties examined is presented in support of the present discussion. These relationships will be discussed further when the complete analysis of all chemical-edaphic factors is considered.

8. <u>Individual Nutrient Elements</u> (Ca, Mg, P, K, Na, Fe, Mn)

Experimental Method:

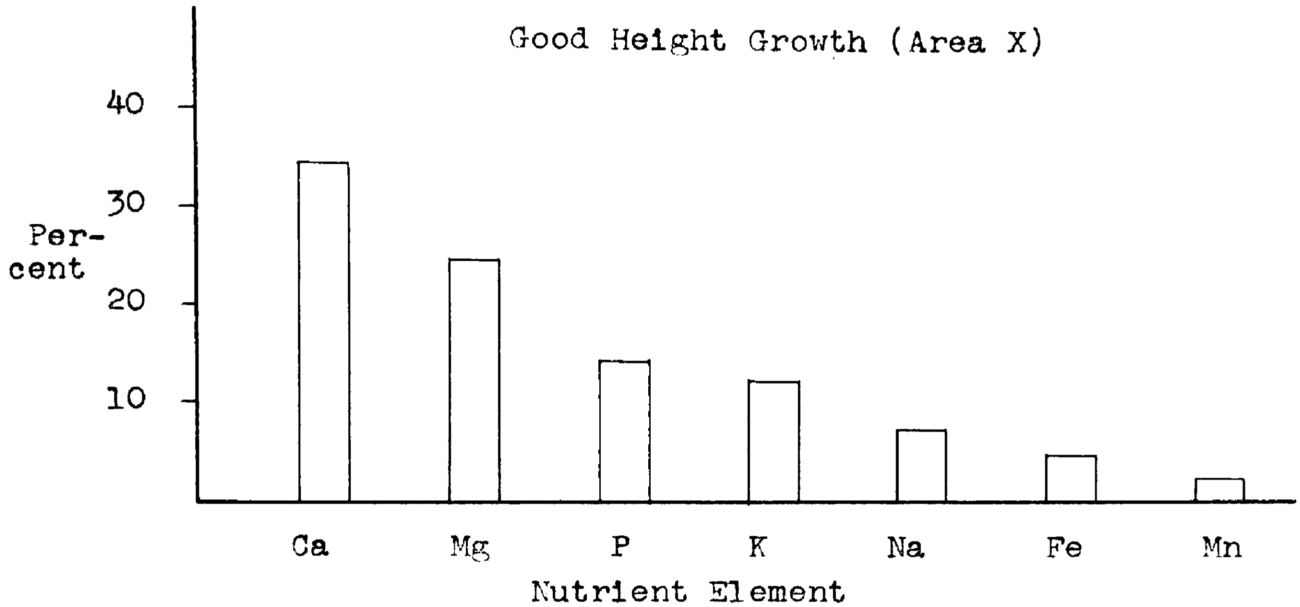
A determination of the amount of calcium, magnesium, and sodium was obtained by use of the flame photometer. Transmission values for each nutrient element were plotted against standard values for that element, and the corresponding nutrient value was read from the standard curve. The parts per million thus obtained were converted to milliequivalents per 100 grams of soil using appropriate conversion values. Analysis of variance for each element was based upon parts per million of that nutrient existing in the soil.

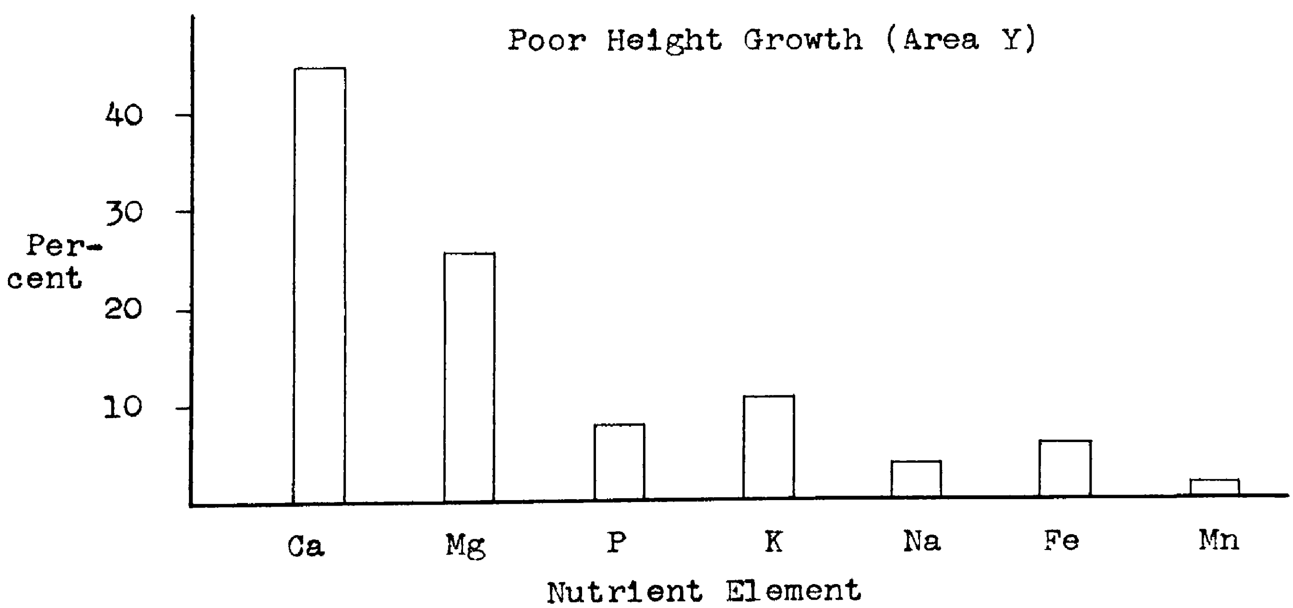
The amount of available phosphorus and exchangeable potassium was obtained by the colorimetric method, utilizing the Lumetron Photo-electric colorimeter. Ammonium fluoride was used as the extracting agent for phosphorus and ammonium molybdate as the reducing agent. For potassium, the soils were extracted with sodium nitrate and reduced with sodium cobaltinitrite solution.

The amount of available iron and manganese was obtained by extracting the soils with hydrochloric acid. To determine the manganese content, sodium bismuthate was used as an oxidizing agent. For available iron,

Fig. 21.

A COMPARISON OF TOTAL INDIVIDUAL NUTRIENT ELEMENTS EXPRESSED AS A PERCENT OF TOTAL PROFILE CONTENT





hydroxylamine hydrochloride was used with O-phenanthroline to keep the iron in the ferrous state.

After converting these elements to milliequivalents per 100 grams of soil, the percentage of the total elements present was determined for each nutrient.

For the sake of brevity, the detailed procedure for obtaining each element is omitted; standard curves for the same elements are not included. A summary of all nutrient elements, occurring by soil horizon in each sampling area is given in Table 34. The relationship of individual elements found in the area of good height growth and poor height growth will now be discussed, followed by a general summary of the edaphic-chemical implications. All percentage figures given for each element refer to the percent of total nutrients that were investigated for combined total profiles.[10]

Calcium relations

Since calcium exerts a profound influence upon the physical, chemical, and biological properties of soils, it is important in forest soil fertility relations. Combined data published by several investigators, such as Kittredge (1933), Lunt (1935), and Chandler (1944) have shown that the calcium content of freshly fallen leaves of tulip poplar is approximately 2.96 percent. This value was surpassed only by basswood, when a consideration of twenty-four tree species were investigated for calcium content of fresh leaves. It has been shown that a high content of calcium in forest

10. Since other nutrient elements such as boron, zinc, sulfur, and copper may be present in the soil in very small quantity, the percent of total nutrients and base saturation is probably slightly higher than percentages given in Table 34.

TABLE 34.

THE NUTRIENT CONTENT OF SOILS BY SOIL HORIZON AND TOTAL PROFILE IN AREA X AND AREA Y

Milliequivalents per 100 grams soil

Horizon	Ca	Mg	P	K	Na	Fe	Mn	Total	
				Area X					
IA$_1$	.3375	.1229	.0257	.0562	.0327	.0193	.0364	.6307	
A$_2$	.1925	.1024	.0737	.0306	.0205	.0247	.0204	.4648	
B$_2$	.1975	.1065	.0873	.0754	.0135	.0412	.0014	.5288	
B$_3$	.0575	.0918	.0446	.0664	.0629	.0143	.0014	.3389	
C$_1$	.0200	.0893	.0368	.0383	.0197	.0168	.0014	.2223	
IIA$_1$	.1900	.1311	.0485	.0613	.0428	.0154	.0343	.5234	
A$_2$	.2200	.1311	.0970	.0332	.0262	.0301	.0051	.5427	
B$_2$	.2950	.1303	.1087	.0997	.0598	.0247	.0014	.7196	
B$_3$	.0600	.1221	.0932	.0639	.0187	.0232	.0014	.3825	
C$_1$	.0400	.1229	.0543	.0485	.0441	.0089	.0014	.3201	
	1.6100	1.1504	.6698	.5735	.3409	.2186	.1046	4.6678	Total
				Area Y					
IIIA$_1$	.5250	.1434	.0349	.0306	.0157	.0157	.0481	.8134	
A$_2$	.4075	.1229	.0485	.0664	.0117	.0483	.0014	.7067	
B$_2$	.4700	.1434	.0370	.1074	.0209	.0483	.0014	.8284	
B$_3$	.0250	.0901	.0332	.0511	.0192	.0136	.0014	.2336	
C$_1$	.0375	.0901	.0485	.0332	.0165	.0096	.0014	.2368	
IVA$_1$	.1900	.1311	.0466	.0345	.0122	.0168	.0145	.4457	
A$_2$	.3200	.1377	.0466	.0383	.0187	.0412	.0014	.6039	
B$_2$	.1675	.1352	.0368	.0754	.0353	.0530	.0014	.5046	
B$_3$	.0415	.1295	.0407	.0511	.0183	.0232	.0102	.3145	
C$_1$	.0225	.1245	.0174	.0281	.0200	.0129	.0014	.2268	
	2.2065	1.2479	.3882	.5161	.1885	.2826	.0826	4.9134	Total

tree litter increases the amount of exchangeable calcium in the soil. There is a distinct tendency for the nutrient calcium to be concentrated in the uppermost layers, and then distributed vertically throughout the horizon according to the degree of leaching and root penetration.

The results of this investigation show that calcium is present in higher concentration than any of the remaining six nutrient elements, with the exception of hydrogen. In Area X, the calcium represents 34.5 percent of the total nutrients found; in Area Y the calcium represents 44.9 percent of the total nutrient supply. The vertical distribution of calcium in the profile of Area X shows a distinct decrease in amount from upper to lower horizons, but at Station I only. At Station II, the calcium is highest at the B_2 horizon. For Area Y, at Station III, the calcium is greatest at the A_1 horizon. At Station IV, the calcium is highest at the A_2 horizon. Thus, the vertical distribution of calcium in these profiles follows no set pattern, but varies considerably. However, the distribution of calcium in individual horizons shows a close correlation to the total base content of the same horizons. A greater total profile calcium content exists in Area Y, though the amount is not significantly greater than Area X. This fact is noteworthy, since the amount of fresh litter in Area X is nearly twice the amount in Area Y. An analysis of variance (Table 35) exhibits no statistically significant difference in the amount of available calcium between Area X and Area Y. However, the F-value denotes the greatest difference occurring at the A_2 horizon. In general, the greatest difference in calcium content is restricted to the surface horizons, when comparing the two sites.

TABLE 35.

ANALYSIS OF VARIANCE FOR CONTENT OF AVAILABLE CALCIUM BY SOIL HORIZON IN AREA X vs. AREA Y

Horizon	Source	Degrees of Freedom	Sum of Squares	Mean Square	F
		Parts per million (p.p.m.) soil			
A_1	Total	3	4023.19		
	X vs Y	1	351.56	351.56	
	Error	2	3671.63	1835.81	.191
A_2	Total	3	1160.50		
	X vs Y	1	992.25	992.25	
	Error	2	168.25	84.12	11.79
B_2	Total	3	2230.50		
	X vs Y	1	210.25	210.25	
	Error	2	2020.25	1010.12	.21
B_3	Total	3	31.58		
	X vs Y	1	26.01	26.01	
	Error	2	5.57	2.78	9.36
C	Total	3	12.50		
	X vs Y	1	0.00	0.00	
	Error	2	12.50	6.25	0.00

TABLE 36.

ANALYSIS OF VARIANCE FOR CONTENT OF AVAILABLE MAGNESIUM BY SOIL HORIZON IN AREA X vs. AREA Y

Horizon	Source	Degrees of Freedom	Sum of Squares	Mean Square	F
		Parts per million (p.p.m.) soil			
A_1	Total	3	3.19		
	X vs Y	1	1.56	1.56	
	Error	2	1.63	.81	1.92
A_2	Total	3	10.47		
	X vs Y	1	2.72	2.72	
	Error	2	7.75	3.87	.70
B_2	Total	3	11.21		
	X vs Y	1	6.50	6.50	
	Error	2	4.71	2.35	2.76
B_3	Total	3	18.49		
	X vs Y	1	.12	.12	
	Error	2	18.37	9.18	.01
C_1	Total	3	17.25		
	X vs Y	1	.02	.02	
	Error	2	17.23	8.61	.002

Magnesium relations

The second highest nutrient element occurring in the profiles of both Area X and Area Y is magnesium. In general, magnesium follows the same vertical distribution as calcium, except that the greatest statistical difference between areas is at the B_2 horizon (Table 36). The larger total amount of magnesium (as with calcium) occurs in Area Y. In Area X, the total profile content of magnesium is 24.6 percent and for Area Y the total content is 25.4 percent. Magnesium, in the profiles studied, shows little variation between horizons in both areas and is not as distinctly restricted by horizon as calcium. It is noteworthy that the combined calcium-magnesium content represents 59 percent and 70 percent of the total nutrients present, for Area X and Area Y respectively. No significant F-value is found for content of available magnesium at any horizon.

Phosphorus relations

Various investigators have emphasized the importance of available phosphorus to soil productivity. However, Hennecke (1935) was unable to establish any clear relationship between the phosphorus content of sandy soils and site quality. The amount of phosphorus in soils is usually small. The present investigation reveals that Area X has a 14.3 percent total profile phosphorus content as contrasted to a 7.9 percent total profile content in Area Y. This percentage difference represents nearly twice the amount of available phosphorus in Area X as that in Area Y. The lighter soils of Area X indicate a correlation between the amount of phosphorus and the fine clay fraction. Thus, in the B_2 horizon which contains the greatest fine clay content, the amount of phosphorus is higher than in other horizons of Area X. For Area Y, this relationship is less marked, and the phosphorus tends to be more evenly distributed throughout the profile, with slightly greater amounts in the upper horizons. The amount of available phosphorus appears to be more closely related to the colloidal clay than to the content of organic matter. The organic matter content appears to follow a decrease in amount from surface to subsurface horizons. From the results obtained, Area Y appears to have more total phosphorus "tied-up" than Area X, since the amounts of colloidal clay and organic matter are highest in Area Y. An analysis of variance (Table 37) shows a significantly different phosphorus content at the 5% level, for the B_2 horizon. This is further evidence of the correlation between the amount of phosphorus and the content of fine colloidal clay in Area X.

Potassium relations

The amount of exchangeable soil potassium is usually plentiful for good tree growth, except in sandy soils. For most soils, the total amount of potassium increases with soil depth. The release of potassium depends upon the status of the potassium equilibrium, amount and kind of clay material present, and the percent base saturation. The potassium equilibrium is rather complex in soils. When potassium is "fixed" it may be tied up by biological fixation, trapped on organic matter coatings, forced into the crystal lattice structure, or tied up in potassium-iron-phosphate complexes. Whether potassium is "fixed" or "released" depends upon the fluctuation of the potassium equilibrium.

The present investigation reveals a total profile content of 12.3 percent potassium in Area X and a 10.5 percent content in Area Y, when percent of total nutrients is considered. Greatest amounts of potassium occur in the B_2 horizon for all four profiles. In all of the soil types

TABLE 37.

ANALYSIS OF VARIANCE FOR CONTENT OF AVAILABLE INORGANIC PHOSPHORUS IN AREA X vs. AREA Y

Horizon	Source	Degrees of Freedom	Sum of Squares (Parts per million (p.p.m.) soil)	Mean Square	F
A_1	Total	3	3.62		
	X vs Y	1	.14	.14	
	Error	2	2.48	1.24	.112
A_2	Total	3	18.96		
	X vs Y	1	16.00	16.00	
	Error	2	2.96	1.48	10.80
B_2	Total	3	41.98		
	X vs Y	1	39.56	39.56	
	Error	2	2.42	1.21	32.69*
B_3	Total	3	23.63		
	X vs Y	1	10.83	10.83	
	Error	2	12.80	6.40	1.69
C	Total	3	8.43		
	X vs Y	1	1.69	1.69	
	Error	2	6.74	3.37	.50

* Significant at 5%

TABLE 38.

ANALYSIS OF VARIANCE FOR CONTENT OF EXCHANGEABLE POTASSIUM BY SOIL HORIZON IN AREA X vs. AREA Y

Horizon	Source	Degrees of Freedom	Sum of Squares (Parts per million (p.p.m.) soil)	Mean Square	F
A_1	Total	3	108.24		
	X vs Y	1	105.06	105.06	
	Error	2	3.18	1.59	66.07*
A_2	Total	3	125.00		
	X vs Y	1	64.00	64.00	
	Error	2	61.00	30.50	2.09
B_2	Total	3	125.55		
	X vs Y	1	2.25	2.25	
	Error	2	123.30	61.60	.036
B_3	Total	3	30.75		
	X vs Y	1	30.25	30.25	
	Error	2	.50	.25	121.00**
C_1	Total	3	35.00		
	X vs Y	1	25.00	25.00	
	Error	2	10.00	5.00	5.0

** Significant at 5% and 1%

* Significant at 5%

here investigated, the amount of available potassium appears to be correlated with the amount of organic matter and the calcium-potassium ratio of the A_1 and B_3 horizons respectively. An analysis of variance shows a definite significant difference at the 5% level for potassium in the A_1 horizon, and a difference at the 5% and 1% levels for potassium in the B_3 horizon. Even though the F-value denotes this horizon differentiation, the total content between Area X and Area Y is not significant.

Sodium relations

Sodium is a common constituent of plants and influences the cation-interrelationship in the plant. It is not definitely known to be essential for plant growth, except for certain plants.

As with potassium, the greatest difference in the amounts of sodium was found in the A_1 horizon in comparing Area X with Area Y. In Area X, sodium represents 7.3 percent of the total bases present and in Area Y sodium represents 3.8 percent of the total bases present. An analysis of variance shows the difference in amount of exchangeable sodium to be significant at the 5% level in the A_1 horizon. Here again, the amount of sodium appears to be related to the cation-exchange capacity, the amount of organic matter, and the potassium-sodium relationship, for the soil types under investigation.

Iron relations

The amount of available iron present in soils is often dependent upon the parent material and the climatic conditions under which the soils developed. Results of this investigation show a rather distinct accumulation of this nutrient in the B horizon, possibly due to leaching effects. A very close relationship seems to exist between the amount of available

TABLE 39.

ANALYSIS OF VARIANCE FOR CONTENT OF EXCHANGEABLE SODIUM BY SOIL HORIZON IN AREA X vs. AREA Y

Horizon	Source	Parts per million (p.p.m.) soil Degrees of Freedom	Sum of Squares	Mean Square	F
A_1	Total	3	32.67		
	X vs Y	1	29.70	29.70	
	Error	2	2.97	1.48	20.07*
A_2	Total	3	5.55		
	X vs Y	1	3.42	3.42	
	Error	2	2.13	1.06	3.23
B_2	Total	3	65.43		
	X vs Y	1	3.80	3.80	
	Error	2	61.63	30.81	.123
B_3	Total	3	76.53		
	X vs Y	1	25.50	25.50	
	Error	2	51.03	25.51	1.00
C_1	Total	3	25.86		
	X vs Y	1	9.86	9.86	
	Error	2	16.00	8.00	1.23

* Significant at 5%

TABLE 40.

ANALYSIS OF VARIANCE FOR CONTENT OF AVAILABLE IRON BY SOIL HORIZON IN AREA X vs. AREA Y

Horizon	Source	Parts per million (p.p.m.) soil Degrees of Freedom	Sum of Squares	Mean Square	F
A_1	Total	3	.74		
	X vs Y	1	.09	.09	
	Error	2	.65	.32	.28
A_2	Total	3	26.65		
	X vs Y	1	23.52	23.52	
	Error	2	3.13	1.56	15.08
B_2	Total	3	35.93		
	X vs Y	1	24.50	24.50	
	Error	2	11.43	5.71	4.29
B_3	Total	3	6.78		
	X vs Y	1	.01	.01	
	Error	2	6.77	3.38	.003
C_1	Total	3	3.03		
	X vs Y	1	.20	.20	
	Error	2	2.83	1.41	.141

TABLE 41.

ANALYSIS OF VARIANCE FOR CONTENT OF AVAILABLE MANGANESE BY SOIL HORIZON IN AREA X vs. AREA Y

		Parts per million of soil			
Horizon	Source	Degrees of Freedom	Sum of Squares	Mean Square	F
A_1	Total	3	43.71		
	X vs Y	1	1.21	1.21	
	Error	2	42.50	21.25	.056
A_2	Total	3	18.43		
	X vs Y	1	9.61	9.61	
	Error	2	8.82	4.41	2.18
B_2	--	--	--	--	--
B_3	Total	3	4.32		
	X vs Y	1	1.43	1.43	
	Error	2	2.89	1.44	1.00
C_1	--	--	--	--	--

iron and the colloidal content of the B_2 horizon. Under the acid conditions of the soils here studied, the iron is relatively soluble. Apparently there is sufficient aeration and drainage to cause leaching of the iron into the B horizon. Since soluble iron is often associated with anaerobic conditions, the larger amounts of this element found in Area Y may be explained on the basis of greater water-holding capacity of this site, less available oxygen, or else due to increased leaching from the upper horizons. Area X represents 4.7 percent of the total nutrients studied and Area Y represents 5.8 percent iron content of all bases present. The amount of organic matter does not appear to be closely related to the iron content of any soil type investigated, since the greatest amount of iron is found in the B horizon. An analysis of variance shows no significant differences between areas.

Manganese relations

Very little is known concerning the importance of manganese in the nutrition of forest trees. However, the amounts of manganese absorbed by trees may be considerable, often exceeding calcium in some types of forest humus. In this study, the manganese exists in the smallest amount of the seven bases considered. Area X represents 2.2 percent and Area Y 1.7 percent of the total nutrients investigated by total profile. Greatest amounts of manganese are found in the A horizon of both Area X and Area Y. This would tend to relate the amount found with the content of organic matter, since low manganese often indicates low organic matter content. The manganese occurring in both areas seems to follow the trend of the profile from surface to subsurface horizons in the same manner as the organic matter. No significant difference exists in the manganese content between areas.

TABLE 42.

A STATISTICAL SUMMARY OF "F" VALUES FOR EDAPHIC-CHEMICAL CHARACTERISTICS IN AREA X vs. AREA Y

LABORATORY EXPERIMENTS

	Soil Horizon				
	A_1	A_2	B_2	B_3	C_1
Average Depth	0-9"	9-14"	14-23"	23-33"	33" +
Variable Investigated:					
1. Soil Acidity (pH)	.73	2.61	4.25	1.32	2.21
2. Organic Matter	.06	1.61	.00	.00	.00
3. Total Nitrogen	.42	.70	2.00	--	--
4. Cation-Exchange Capacity	17.80	12.20	.069	.007	.43
5. Total Bases	.33	8.33	.34	2.50	2.48
6. Base Saturation	.01	8.30	.01	.03	39.37*
7. Exchangeable Hydrogen	.87	2.28	.06	.01	.50
8. Available Calcium	.191	11.79	.21	9.36	.00
9. Available Magnesium	1.92	.70	2.76	.01	.002
10. Available Phosphorus	.112	10.80	32.69*	1.69	.50
11. Exchangeable Potassium	66.07*	2.09	.036	121.00**	5.00
12. Exchangeable Sodium	20.07*	3.23	.123	1.00	1.23
13. Available Iron	.28	15.08	4.29	.003	.141
14. Available Manganese	.056	2.18	.00	1.00	.00

** Significant at 1% and 5%
* Significant at 5%

Summary and Implication of Results

Edaphic-Chemical Characteristics

In considering the implications brought out by the results of the soil-chemical determinations, it is important to recognize that the integration of all possible contributing factors is necessary. The purpose of the present summary is to point out those factors which may or may not be contributing directly to the difference in height growth of tulip poplar.

A comparison of the soil reaction (pH) in both areas does not exhibit any significant variation. Area Y is slightly more acid in reaction than Area X. Both areas are strongly to very strongly acid and the B horizon appears to be slightly more acid than the A or C horizons. The lowest individual pH values are obtained in the B_2 horizon of both areas. Soil reaction *per se* does not appear to be directly contributing to height growth differences. The pH values, however, may be indirectly affecting other site factors such as the soil biological and herbaceous factors.

The percent of organic matter in each sampling area is very low. Greatest statistical differences between areas are found in the A_2 horizon. The amount of organic matter decreases with increased depth for both Area X and Area Y. Slightly greater amounts of organic matter are found in Area Y at the A_1, A_2, and B_2 horizons; the amounts below the B_2 horizon differ very little. No significant statistical difference exists between Area X and Area Y insofar as the direct effect of organic matter content is concerned.

Both carbon and nitrogen are found in greater amounts in Area Y. Also, the carbon-nitrogen ratio is more narrow in this area, indicative of greater decomposition of carbonaceous and nitrogenous material. The difference in the carbon-nitrogen ratio between areas is not extreme. Ratios for both sites fall within the range of approximately 15:1 to 23:1 for any one individual horizon. The greatest statistical difference for total nitrogen content is found at the B_2 horizon, when contrasting Area X and Area Y. As with the content of organic matter, the nitrogen and carbon occur in slightly greater amounts in the area of poor height growth. Decomposition appears to be more rapid in the more exposed and less dense site.

A close correlation exists between the cation-exchange capacity and the amount of fine clay present in Area X. This relationship is less marked in Area Y. A closer relation seems to occur between the cation-exchange and the colloidal complex, than between cation-exchange and the organic colloids. Analysis of variance reveals that the greatest difference between areas for cation-exchange capacity exists at the A_1 horizon. Area Y has a larger total profile exchange capacity than Area X.

The total base content shows no significant difference between areas. A slightly larger total base content is found in Area Y. Largest individual differences are found at the A_2 horizon.

The percent base saturation shows a large total profile variation between Area X and Area Y. This difference is significant statistically at the C_1 horizon. A closer correlation exists in Area X with reference to base saturation than in Area Y.

The greatest total exchangeable hydrogen is found in the area of poor height growth. This reveals the close relationship of the pH values obtained for the same soils, since Area Y exhibits a slightly greater acidity than Area X, when all horizons are averaged.

Thus, a summation of six rather important soil chemical properties by soil horizon tends to show no outstanding direct or statistically significant difference between the area of good height growth and poor height growth of tulip poplar. The data bring out rather vividly the horizonal differences, possible environmental factors responsible for these variations, and the magnitude of the complex of factors which contribute to these differences.

As a further verification of the absence of statistical significance in the above soil properties, a perusal and summation of individual nutrient elements will now be taken up. An attempt will be made to relate the overall major chemical properties to individual nutrient supplies of the same soils. This combining and supplementation of all chemical properties presents an insight into the total complex of chemical-edaphic factors in each area.

Summary of Individual Nutrients

A total of seven individual nutrient elements was investigated and recorded by horizon and total profile content for both the area of good and poor height growth.

Results of this investigation revealed that the total amounts of all nutrient elements did not differ appreciably between Area X and Area Y. A percentage summation, based upon percent of total profile, is presented in Table 43. The total amount of all nutrients was very low for both areas:

TABLE 43.

TOTAL INDIVIDUAL NUTRIENT ELEMENTS EXPRESSED AS A PERCENT OF TOTAL PROFILE CONTENT FOR AREA X AND AREA Y

Percent: Area X	Percent: Area Y
Ca - 34.50	Ca - 44.93
Mg - 24.65	Mg - 25.41
P - 14.34	K - 10.50
K - 12.28	P - 7.90
Na - 7.31	Fe - 5.75
Fe - 4.68	Na - 3.83
Mn - 2.24	Mn - 1.68
100.00 %	100.00 %

The results in Table 43 give the order of magnitude of nutrient elements in Area X as: Ca > Mg > P > K > Na > Fe > Mn. A slight variation in this order exists in Area Y as: Ca > Mg > K > P > Fe > Na > Mn. The striking similarity in both amount and magnitude of nutrient elements is revealed by contrasting the area of good and poor height growth. Although it is not to be assumed that the total amount of nutrient present determines its availability to the tree, the fact that at least one of these areas is exhibiting good height growth is evidence that the total amount is sufficient to satisfy the tree requirements under existing conditions. Thus, since the two areas are so similar in actual content of nutrients, it may be conjectured that both areas have sufficient chemical nutrients to satisfy their tree requirements. However, in the case of Area Y, these results disclose that some other factor may be masking the nutrient supply as a cause for poor height growth.

The statistical summary (Table 42) of all chemical nutrients under investigation reveals that significant differences occur for phosphorus at the B_2 horizon, potassium at the A_1 and B_3 horizons, and sodium at the A_1 horizon. If the nutrient content had been determined by the usual methods of many investigators, only the uppermost horizons would have shown any differentiation. However, by extracting soil samples at the natural horizon for each profile, a clearer diagnosis as to horizon differentiation, leaching effects, presence of fine clay, and organic matter can be fulfilled. The implication of these differences for phosphorus, potassium, and sodium is not to be interpreted directly in terms of limiting factors. Rather, the statistical differences are indications of supplemental factors which limit a particular nutrient element in any one horizon. If the differences had been extreme in their magnitude, it would be justifiable to suspect a possible limiting factor

TABLE 44.

A COMPOSITE SUMMATION OF CHEMICAL-EDAPHIC CHARACTERISTICS BY SOIL HORIZON FOR AREA OF GOOD HEIGHT GROWTH AND AREA OF POOR HEIGHT GROWTH OF TULIP POPLAR

Soil Horizon	Soil Reaction (pH)	Organic Matter %	Total Nitrogen %	Cation-Exchange Capacity m.e. / 100 gms.	Total Bases m.e./100 gms.	Base Saturation %	Exchangeable Hydrogen m.e. / 100 gms.	Calcium m.e. / 100 gms.	Magnesium m.e./100 gms.	Phosphorus m.e. /100 gms.	Potassium m.e. /100 gms.	Sodium m.e. / 100 gms.	Iron m.e./ 100 gms.	Manganese m.e./100 gms.
						Area X								
IA_1	5.55	2.35	.125	8.20	.63	7.69	7.57	.34	.12	.02	.06	.03	.02	.03
A_2	5.33	.96	.047	6.08	.46	7.64	5.61	.19	.10	.07	.03	.02	.02	.02
B_2	5.40	.71	.049	10.64	.53	4.91	10.12	.20	.11	.09	.08	.01	.04	.00
B_3	5.42	.35	--	3.32	.34	10.20	2.98	.06	.09	.04	.07	.06	.01	.00
C_1	5.18	.28	--	1.44	.22	15.43	1.22	.02	.08	.03	.04	.02	.02	.00
IIA_1	5.39	1.72	.113	6.80	.52	7.69	6.28	.19	.13	.05	.06	.04	.01	.03
A_2	5.20	.71	.044	6.40	.54	8.47	5.86	.22	.13	.10	.03	.03	.03	.00
B_2	5.15	.66	.041	8.40	.72	8.56	7.68	.29	.13	.11	.10	.06	.02	.00
B_3	5.14	.40	--	4.08	.38	9.37	3.70	.06	.12	.09	.06	.02	.02	.00
C_1	5.40	.28	--	1.60	.32	20.00	1.28	.04	.12	.05	.04	.04	.00	.00
						Area Y								
$IIIA_1$	5.85	2.66	.133	7.72	.81	10.53	6.91	.53	.14	.03	.03	.02	.01	.04
A_2	5.16	1.18	.072	10.68	.71	6.61	9.97	.41	.12	.05	.06	.01	.05	.00
B_2	5.02	.83	.060	11.88	.83	6.97	11.05	.47	.14	.04	.11	.02	.05	.00
B_3	5.17	.35	--	1.36	.23	17.17	1.13	.03	.09	.03	.05	.02	.01	.00
C_1	5.42	.35	--	.00	.24	.00	.00	.04	.09	.05	.03	.01	.00	.00
IVA_1	5.35	1.65	.121	10.96	.45	4.06	10.51	.19	.13	.05	.03	.01	.02	.01
A_2	4.94	.90	.054	8.72	.60	6.92	8.12	.32	.14	.05	.04	.02	.04	.00
B_2	4.70	.75	.055	8.28	.50	6.09	7.77	.17	.13	.04	.07	.04	.05	.00
B_3	4.83	.31	--	6.48	.31	4.85	6.16	.04	.13	.04	.05	.02	.02	.01
C_1	5.82	.14	--	8.84	.23	2.56	8.61	.02	.12	.02	.03	.02	.01	.00

for a certain nutrient element. Thus, a horizon differentiation for nutrient supply is implied by these results. Any one element considered *per se* is obviously not the one "best" condition for a difference in height growth. The results obtained here are in agreement with a similar study by Auten (1945). Auten found great differences in the quantity of replaceable nutrients for soils on 77 different yellow poplar stands. The differences he found in calcium content of the A_1 horizon were not great enough to justify using calcium as a criterion of site index. No relation could be demonstrated between magnesium, phosphorus, or potassium content of soil and site index. The results of the present investigation on tulip poplar, as with several other studies of this type, conclude that mineral nutrients are essential to growth of tulip poplar, but in the soils examined they do not occur in limiting amounts. The utilization of nutrients by tulip poplar depends not alone on the presence of a particular amount of an element in the soil, as it does upon the integration of other growth factors. From these results it is apparent that unfavorable concentrations of individual chemical elements do not exist as a limiting factor, unless masked by the presence of some factor not investigated.

In appraising the value of the present chemical investigations, various limitations are imposed upon the interpretation of the results. For this study, it is sufficient to interpret the results in comparative terms between two opposing sites for tulip poplar and to relate these differences to other site and habitat factors. For a complete interpretation of results obtained here, more knowledge concerning the soil fertility level of tulip poplar and its corresponding site quality would have to be known. No such detailed chemical knowledge has been refined in recent investigations.

In conclusion, the investigation of fourteen individual soil chemical properties in the area of good and poor height growth of tulip poplar, reveal no outstanding direct or statistically significant differences which are individually contributing to a height growth differential.

The manner in which the nutrient elements are related to the physical, climatic, and biological properties of the same soil types will be presented in the integrated summary of all factors affecting the height growth of tulip poplar.

FIELD-PLANTATION EXPERIMENTS

Growth Rate of Tulip Poplar

Stem Analysis

In order to obtain some estimate of the growth of tulip poplar, several trees representative of both good and poor height growth, were felled and sectioned. By this method, the investigator was able to determine to what extent the external factors of site were contributing to the growth of individual trees, as expressed by height and radial growth. A complete stem analysis of each tree was undertaken by recording the height and diameter growth at the stump and at one-foot sections along the stem. From these data, curves of height against diameter, height against age in years, diameter against age, and growth rates were obtained. These curves represent a graphic expression of growth by relating differences in height and diameter for two different sites, Area X and Area Y. Radial growth was measured for each one-foot section up the stem by recording the width of annual ring along a maximum and minimum radius, using an ocular micrometer and microscope. By this method it was possible to determine corresponding rates of height and diameter growth for each area at a particular year, and thus reconstruct the mean annual growth of the tree. By combining these data with the growing season precipitation, it is possible to ascertain within limits, the effect of precipitation upon height and diameter growth. It was not necessary to obtain a measure of the volume growth of the tree since the present study is primarily concerned with the effect of site upon tree growth. For a single species, such as tulip poplar, variation in height growth due to variations in the site factors are found to be closely correlated with variations in height and diameter growth. Thus, height growth becomes a useful tool as an index of site.

The curves which follow give graphic expression of the difference in site due to climatic and edaphic factors. Since all trees are of the same age and density, these two variables are constant for both sites. This fact lends added validity to the rather direct correlation of height and diameter growth to the effects of the growing season precipitation.

Seasonal Course of Height Growth

Several terminal branches of trees in Area X and Area Y were marked with a crayon in April 1952, prior to the breaking of dormancy. At successive intervals throughout the growing season, the rate of growth was measured in order to determine the effective seasonal rate of growth. The results of these measurements showed that the effective height growth for this species occurred between the dates April 18, 1952 to August 1, 1952. Practically no height growth occurred in either area after August 1, 1952. This information revealed that climatic and edaphic factors operate most effectively on height growth between the above dates for the 1952 growing season. A period of 105 days was the effective growth period for this species under the climatic conditions of the experimental area. Since replication of the seasonal course of height growth for several years is needed, it is impossible to apply the above data to previous or later seasonal growth years. More data are needed, perhaps three to five growing season averages, before any approximate average growing season period can be determined for this area.

TABLE 45.

COMPLETE STEM ANALYSIS FOR TULIP POPLAR ON A GOOD SITE

Area X (Good height growth)

Cross section number and height in feet from ground level	d.o.b. (Tenth inches)	d.i.b. (Tenth inches)	Number of Rings	Bark Thickness
1	6.02	5.62	15	.40
2	5.72	5.32	14	.40
3	5.70	5.29	14	.41
4	5.40	4.93	13	.47
5	5.27	4.86	13	.41
6	5.20	4.80	12	.40
7	5.07	4.73	12	.34
8	5.00	4.70	12	.30
9	4.87	4.60	12	.27
10	4.77	4.50	11	.27
11	4.70	4.40	11	.30
12	4.70	4.40	11	.30
13	4.50	4.20	11	.30
14	4.40	4.10	10	.30
15	4.40	4.17	10	.23
16	4.17	3.93	10	.24
17	4.00	3.75	10	.25
18	4.03	3.80	9	.23
19	3.90	3.65	9	.25
20	3.90	3.60	9	.30
21	3.60	3.40	8	.20
22	3.50	3.30	8	.20
23	3.50	3.32	8	.18
24	3.50	3.35	8	.15
25	3.20	3.00	7	.20
26	2.97	2.80	7	.17
27	2.95	2.80	7	.15
28	2.70	2.55	7	.15
29	2.60	2.45	6	.15
30	2.47	2.30	6	.16
31	2.25	2.10	6	.15
32	2.20	2.03	6	.17
33	2.27	2.12	5	.15
34	1.85	1.73	5	.12
35	1.65	1.55	5	.10
36	1.55	1.40	4	.15
37	1.32	1.20	4	.12
38	1.10	1.00	4	.10
39	1.00	.90	3	.10
40	.90	.80	3	.10
41	.52	.49	3	.03
42	.50	.47	2	.03
43	.30	.27	2	.03
44	.29	.26	2	.03

Total Height 44' 1"

TABLE 46.

COMPLETE STEM ANALYSIS FOR TULIP POPLAR ON A POOR SITE

Area Y (Poor height growth)

Cross section number and height in feet from ground level	d.o.b. (Tenth inches)	d.i.b.	Number of Rings	Bark Thickness
Ground level	5.63	4.90	15	.73
1	4.35	3.80	14	.55
2	4.10	3.65	13	.45
3	3.60	3.25	12	.35
4	3.25	3.00	11	.25
5	3.00	2.60	11	.40
6	2.93	2.65	11	.28
7	2.70	2.52	10	.18
8	2.67	2.40	10	.27
9	2.30	2.10	9	.20
10	2.25	2.00	9	.25
11	1.80	1.62	8	.18
12	1.57	1.40	8	.17
13	1.48	1.35	7	.13
14	1.39	1.23	6	.16
15	1.10	1.00	6	.10
16	.93	.85	5	.08
17	.60	.55	4	.05
18	.45	.40	4	.05
19	.43	.38	3	.05
20	.20	.16	2	.04
Total Height 20' 5"				

Interpretation of Results

Although the curves and graphic material which follow are in some respects self-explanatory, further elucidation of these results will be given in terms of site quality interpretation.

Figure 22: The curve of height against diameter breast high (d.b.h.) expresses the relation between height and diameter for two sites, Area X and Area Y. The area of good height growth (Area X) follows the general

Fig. 22.

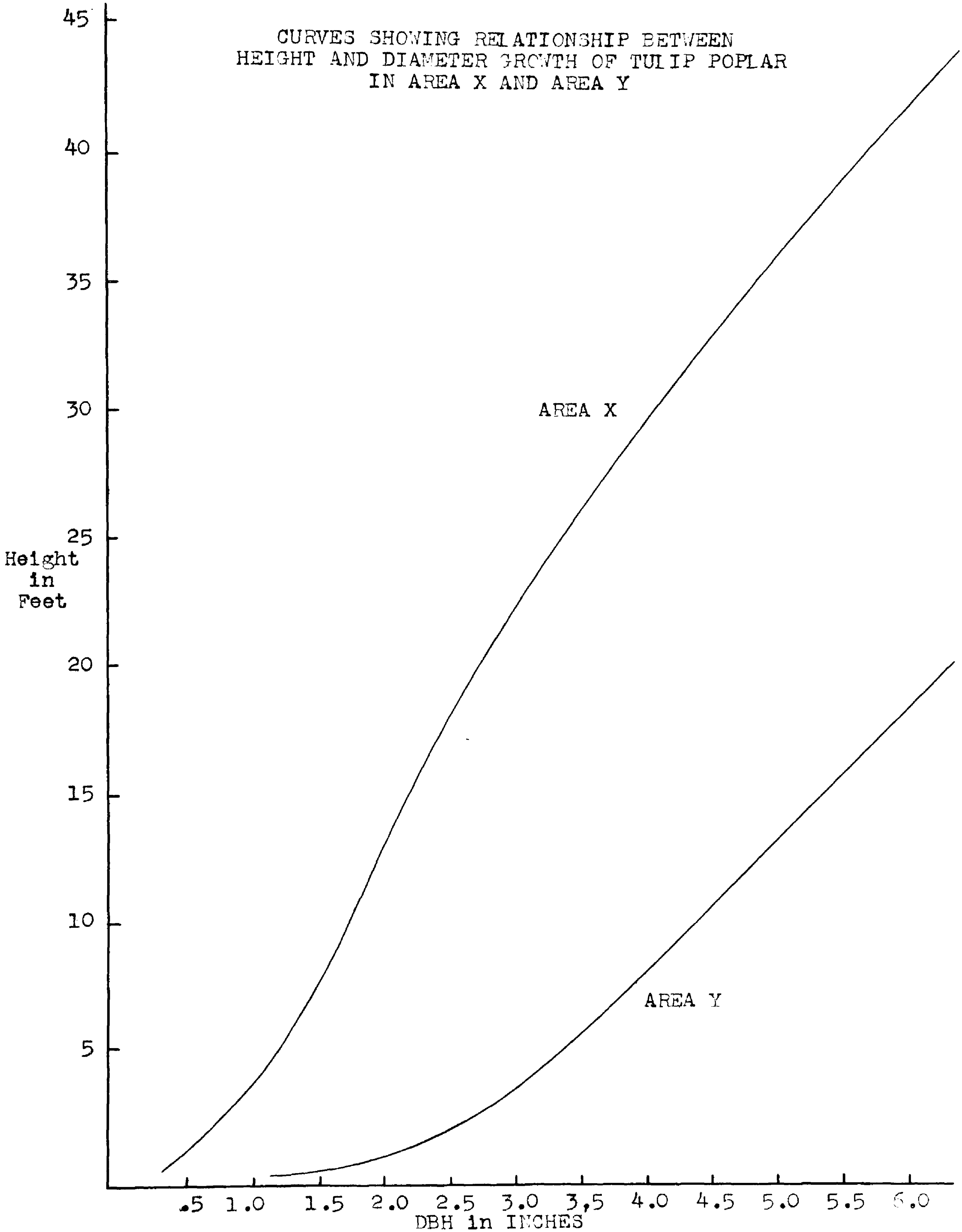
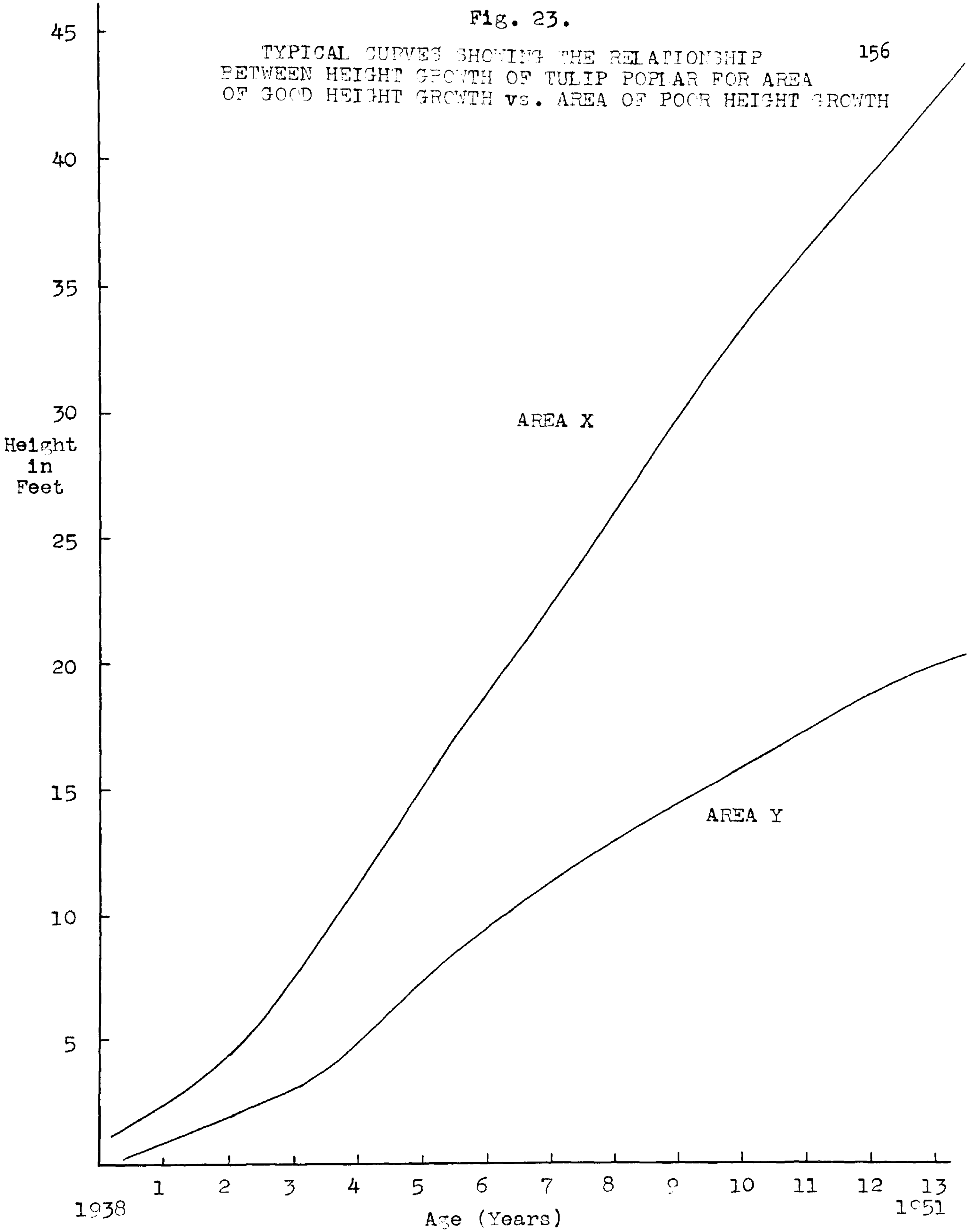

CURVES SHOWING RELATIONSHIP BETWEEN HEIGHT AND DIAMETER GROWTH OF TULIP POPLAR IN AREA X AND AREA Y
AREA X
AREA Y
Height in Feet
45
40
35
30
25
20
15
10
5
.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0 5.5 6.0
DBH in INCHES

Fig. 23.

TYPICAL CURVES SHOWING THE RELATIONSHIP BETWEEN HEIGHT GROWTH OF TULIP POPLAR FOR AREA OF GOOD HEIGHT GROWTH vs. AREA OF POOR HEIGHT GROWTH



sigmoid type of growth, whereas, Area Y departs from this type curve. This difference in form of curve for the two sites involved is a rather direct expression of edaphic and climatic factors controlling the growth of individual trees. The curve for Area X exhibits a rather rapid initial growth in regard to height at the expense of diameter growth; this acceleration in height is increased during the grand period of growth and then tapers off slightly, but still growing at a rapid rate in height. Area Y exhibits a very slow initial height growth and the curve departs from the sigmoid form.

Figure 23: The curves of height growth against age indicate the rate of height growth throughout a 13-year period, as well as height in any one particular year. The trees in Area X show a marked concavity in their initial height growth and then taper off gradually towards the convex type of growth in the grand period of growth. Area Y exhibits less concavity in the initial period of height growth and then shows marked convexity at an early stage of height growth. This indicates that the trees in Area Y are growing at a slower rate of height growth than trees in Area X. The curves disclose that Area Y is "immature" in its inherent growth pattern and trees in this area are not reaching the desired height inherent in the growth pattern for tulip poplar.

Figure 24: The graphic expression of the rate of annual height growth for both sites is given in this chart. The pattern of growth further elaborates upon the findings shown in Figure 23. Thus, a reconstruction of the height growth rate for any one year or period of years is presented in this graph.

Fig. 24.

A COMPLETE STEM ANALYSIS OF TULIP POPLAR SHOWING CORRESPONDING RATE OF ANNUAL HEIGHT GROWTH IN AREA X vs. AREA Y

(1938-1951)

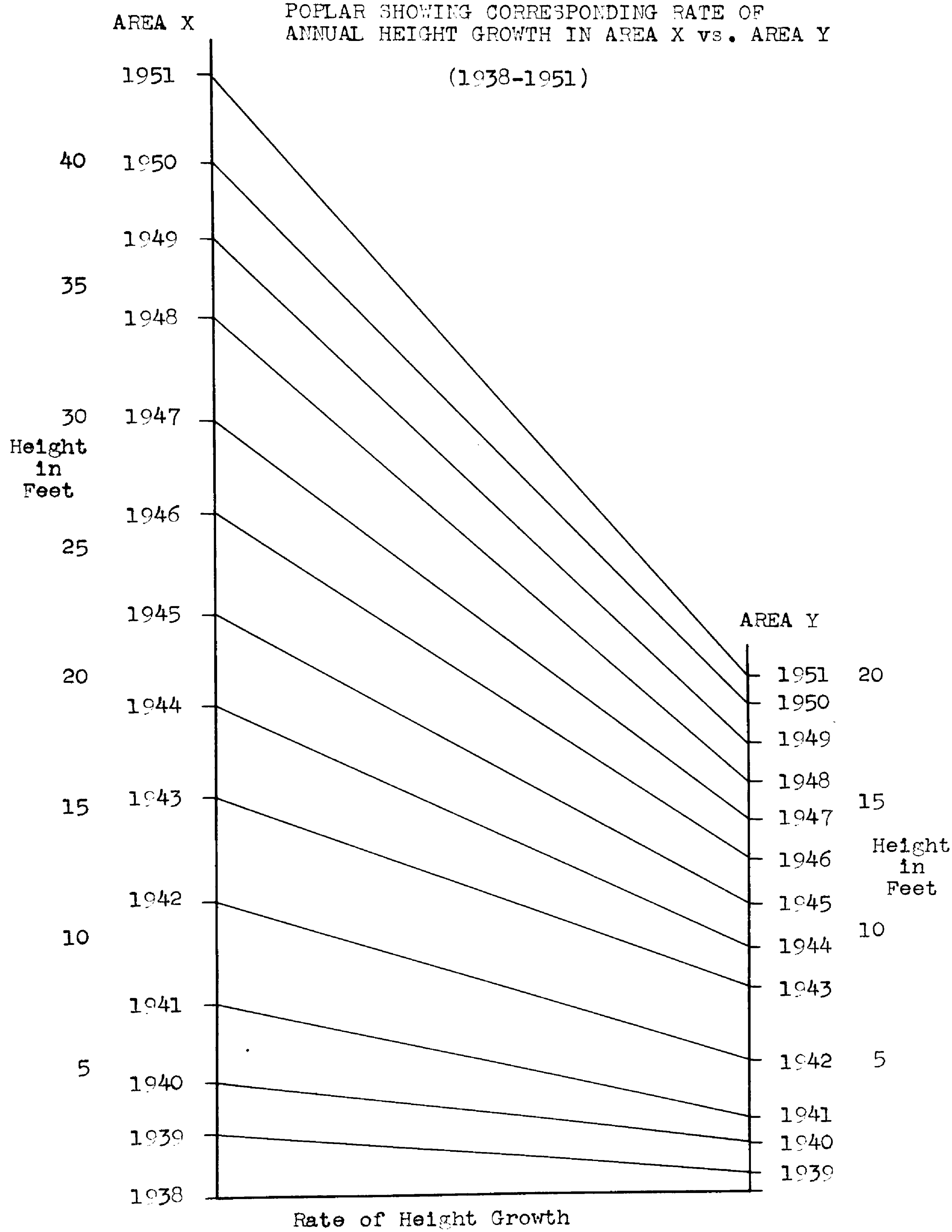


Figure 25: The difference in the annual rate and extent of radial growth by years is presented in this figure. Again, Area X exhibits the usual sigmoid type of radial growth; Area Y follows the pattern of "open growth" tree diameter, with a constant increase in radial thickness at the expense of height growth. It is significant to note the concavity of the curve for Area Y. This rather "unnatural" inherent tendency for growth of tulip poplar connotes a direct expression of unfavorable site quality, when contrasted to Area X. It also signifies that diameter growth is not in proportion to height growth for Area Y, an additional expression of site quality.

Figure 26: This graph is analogous to those of height growth in Figure 24. Diameter growth for contrasted Area X and Area Y exhibits greatest divergence during the somewhat critical stages of seedling development (1946 to 1948).

Figure 27: The curve showing the effect of site quality upon bark thickness for both areas is further evidence of the effect of external factors controlling the growth form of the tree. In Area Y, the bark thickness is greater at the lower portion of the bole than in Area X. Since the trees of both areas are of the same age and density, the bark thickness reveals a response to environmental factors of the site. The bark of tulip poplar is thin, and thus its thickness exhibits a direct response to internal factors. The marked increase in bark thickness in the initial stages of growth in Area Y as compared to Area X, is evidence of the deviation from normal, inherent growth of tulip poplar.

Generally, forest trees which attain their maximum development on sites having an abundance of available soil moisture possess thinner bark

Fig. 25.

TYPICAL CURVES SHOWING THE ANNUAL RADIAL GROWTH OF TULIP POPLAR FOR AREA X AND AREA Y

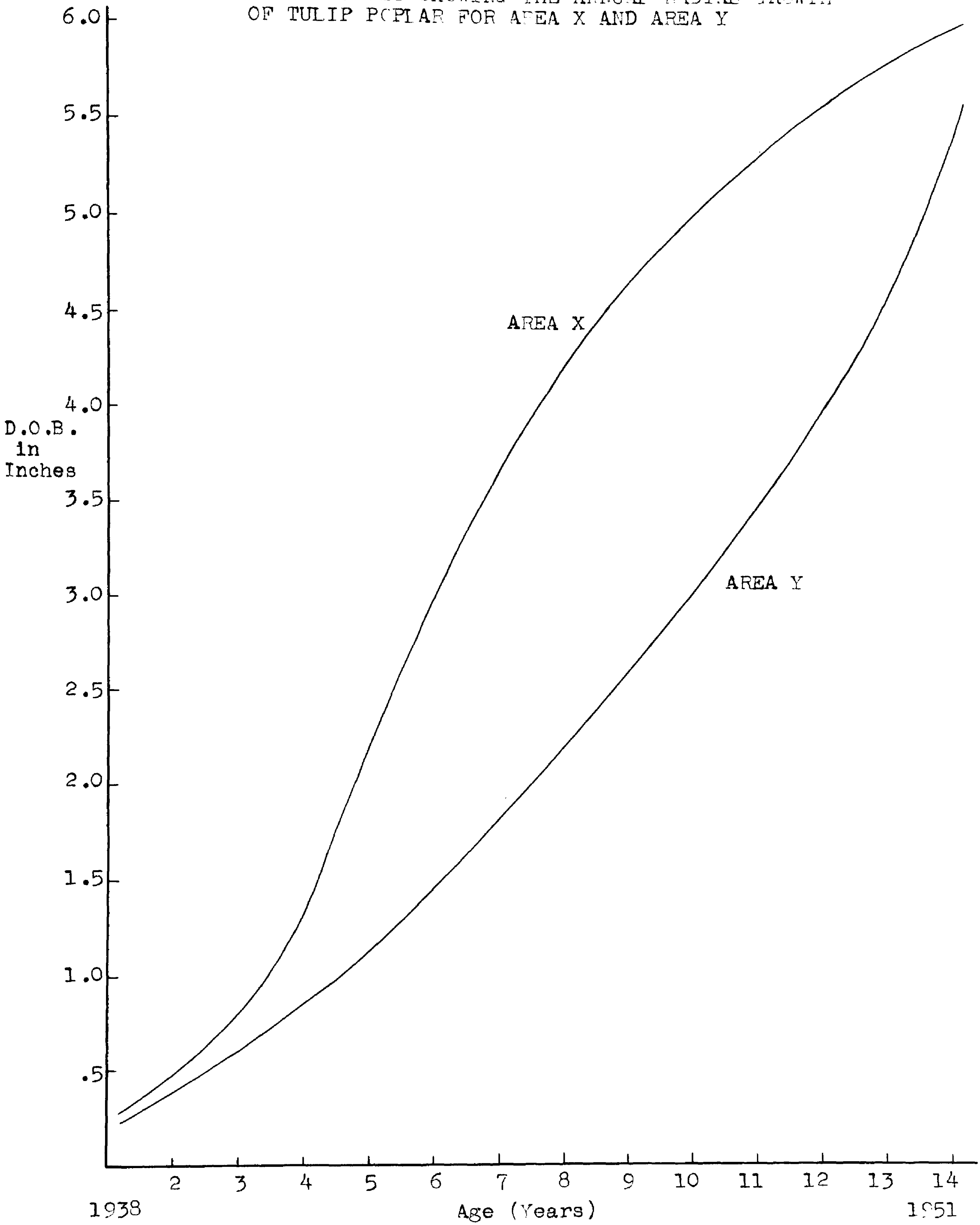


Fig. 26.

A COMPLETE STEM ANALYSIS OF TULIP POPLAR SHOWING CORRESPONDING RATE OF ANNUAL RADIAL GROWTH IN AREA X vs. AREA Y

(1941-1951)

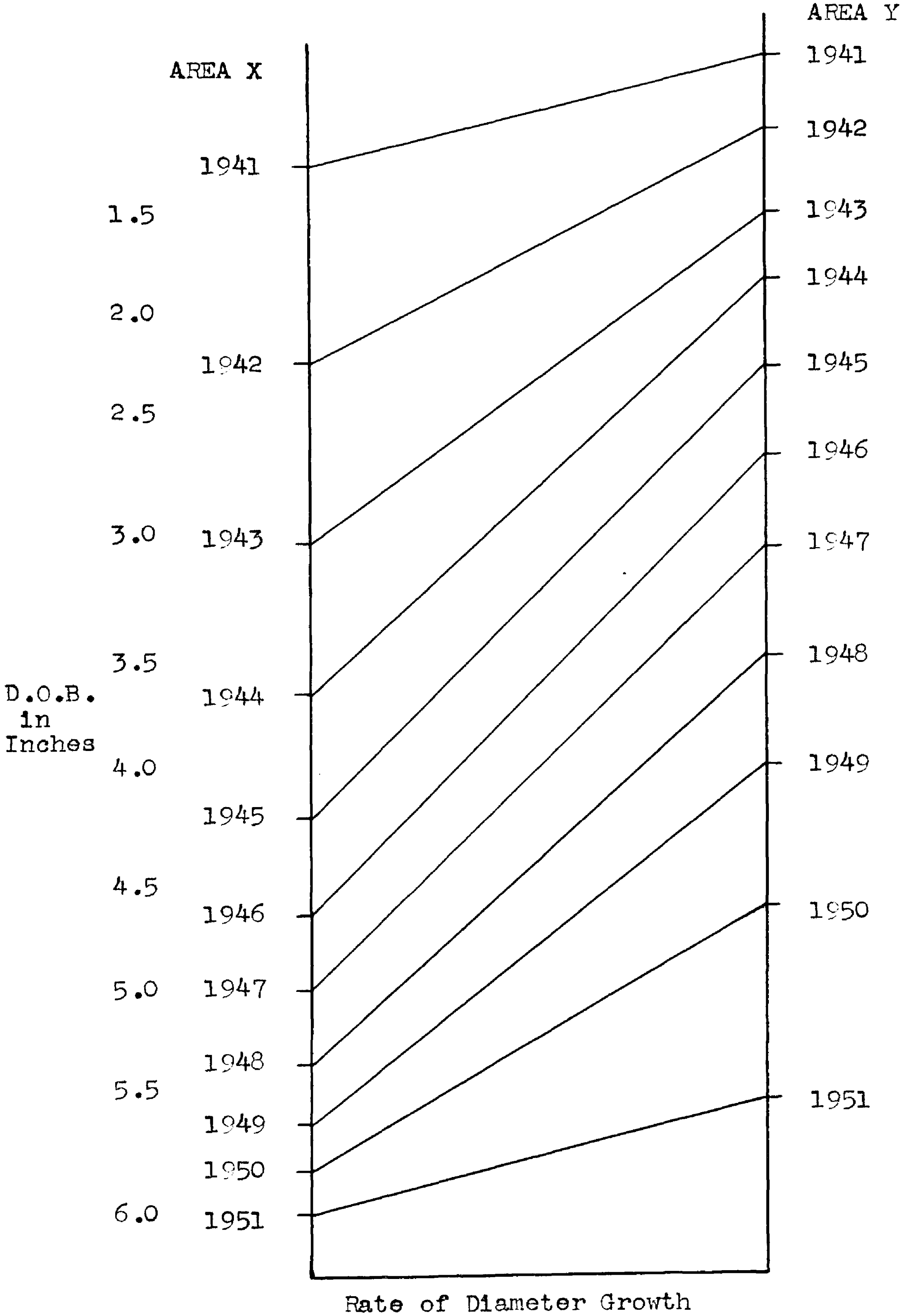
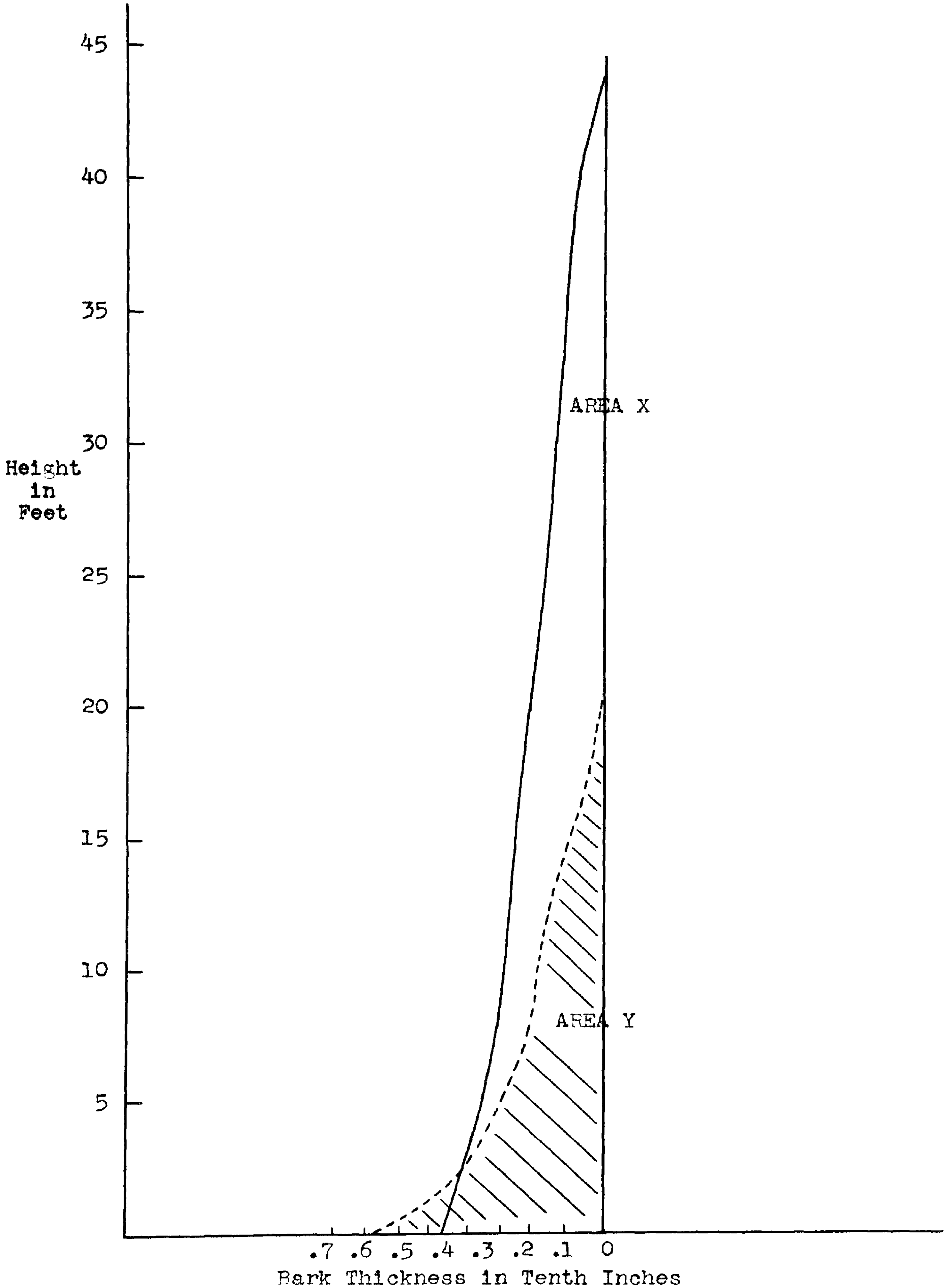


Fig. 27.

THE EFFECT OF SITE QUALITY UPON BARK THICKNESS OF TULIP POPLAR IN AREA X vs. AREA Y



than trees on sites of low available moisture. Thus, a structural variation at the base of the trees in Area Y, as exhibited by greater development of vascular and sclerenchyma tissue, is a variation which adapts itself to regulation of water loss through transpiration. This adaptation is indicative of the physiological "dryness" of the site in Area Y. The formation of greater amounts of cork and bark tissue on the trees of the drier site serves as an effective check on the loss of water from the main axis and branches of these trees. In Area X, the transpiration appears to be optimum for the site as evidenced by the normal taper of the bark and stem. Thus, the external factor of bark thickness as related to transpiration and water-loss, is indicative of the better soil-moisture relationship in Area X.

The Effect of Growing Season Precipitation and Temperature on Height and Diameter Growth of Tulip Poplar for a 11-Year Period

Precipitation

Having studied the general effects of climate and other site factors upon the growth form of tulip poplar by means of a complete stem analysis, an investigation was conducted to ascertain the possible effects of growing season precipitation and temperature on height and radial growth. Precipitation and temperature data were obtained for the growing season for the years 1939-1951. Since the years 1938, 1939, and 1940 were critical for establishment of the young seedlings, these years were omitted from the data and only the period 1941-1951 was considered in relation to growth. The effect of the previous year's precipitation upon height growth was not investigated.

The growing season for Cass County, Michigan, is considered to be from May 6 to October 15 inclusive (162 days). The period between these dates was thus included in relating precipitation and temperature to height and radial growth of tulip poplar. A tabulation of the growing season precipitation and temperature for the years 1939-1951 was obtained from the U. S. Department of Commerce and is presented in Table 47. From these data it is possible to observe the fluctuation in growing season precipitation and temperature for the experimental area for the period 1941-1951. In the vicinity of Dowagiac, Michigan, the greatest precipitation occurs during May and June, while the "dry" period is usually in July and August. This seasonal distribution of rainfall is rather definitely associated with the growth and survival of tulip poplar plantations

TABLE 47.

A TABULATION OF THE GROWING SEASON PRECIPITATION FOR TULIP POPLAR (1939-51)
Station - Dowagiac, Michigan *

Year	May	June	July	August	September	October	Total 6 months	Total Annual
				Rainfall in inches				
1939	1.14	6.08	4.04	7.43	.78	2.79	22.26	37.24
40	4.53	5.78	.76	6.74	.78	2.59	21.18	35.95
41	2.89	3.87	2.63	1.97	2.86	12.76	26.98	40.05
42	3.48	2.43	3.90	6.23	2.75	2.35	21.14	37.71
43	12.38	5.28	4.54	3.60	2.91	1.76	30.47	46.27
44	4.14	3.55	1.34	1.87	2.27	2.60	15.77	28.72
45	6.00	4.49	3.43	2.22	5.39	2.17	23.70	36.38
46	3.76	3.77	.63	1.68	4.90	3.46	18.20	30.29
47	6.27	6.33	2.62	2.19	3.95	.74	22.10	39.58
48	6.55	3.86	2.32	2.22	2.89	1.03	18.87	34.30
49	6.54	6.37	3.40	2.70	2.75	3.31	25.15	36.68
50	1.84	9.44	5.42	.14	4.26	.71	21.81	43.27
1951	4.13	2.73	3.56	4.20	6.35	4.22	25.19	42.02
Total	63.65	63.98	38.59	43.27	42.84	40.49	292.82	
Mean	4.89	4.92	2.97	3.33	3.29	3.11	22.53	

Average of 37 years = 34.77 inches of annual precipitation.
Growing season for Cass County, Michigan = 162 days (May 6 - October 15)

A TABULATION OF THE GROWING SEASON TEMPERATURE FOR TULIP POPLAR (1939-51)
Station - Dowagiac, Michigan *

Year	May	June	July	August	September	October	Mean 6 months	Mean Annual
				Degrees Fahrenheit				
1939	--	71.7	71.9	71.4	67.6	54.4	67.4	--
40	54.8	68.2	72.8	72.0	61.6	54.2	63.9	47.3
41	61.6	69.2	72.5	71.0	65.8	55.4	65.9	50.7
42	59.2	68.4	71.8	68.4	60.9	51.6	63.4	48.6
43	54.5	71.3	73.0	72.2	59.7	50.0	63.5	47.5
44	61.8	69.7	71.6	71.8	65.2	49.5	64.9	49.3
45	53.0	64.7	72.0	71.8	66.1	51.8	63.2	49.6
46	54.1	68.0	74.7	67.6	64.4	56.6	64.2	--
47	53.4	64.0	70.8	81.8	64.4	61.7	66.0	--
48	54.6	65.4	73.5	74.1	67.3	48.7	63.9	48.8
49	63.6	71.6	76.3	71.5	58.6	56.1	66.2	--
50	62.1	68.0	70.2	69.2	64.0	56.5	65.0	48.9
1951	61.9	68.8	72.9	67.7	60.6	54.6	64.4	48.7
Total	639.8	749.1	799.3	787.1	697.0	592.5	710.6	
Mean	58.1	68.1	72.6	71.5	63.3	53.8	64.6	

* U.S. Department of Commerce, Weather Bureau
East Lansing, Michigan

in the vicinity of southern Michigan. The manner in which precipitation affects the height and radial growth of this plantation will now be considered.

By use of the correlation coefficient,[11] in conjunction with graphical interpretation, it was possible to demonstrate the effect of growing season precipitation on the height and radial growth of tulip poplar. This type of correlation is used to measure the dependency of one observation on another; the value of r cannot exceed 1.0, and a unit increase or decrease in one observation will cause a corresponding change in the other observation.

From the complete stem analysis, values for the accumulative radial and height growth were obtained for Area X and Area Y (Table 48). Each of these expressions of site were plotted against the growing season precipitation for a 11-year period. From the same data, the correlation coefficients were derived in order to give a mathematical expression of the graphic data.

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11. The formula for the correlation coefficient is:

$$r_{xz} = \frac{\text{sum } xz - \dfrac{(\text{sum } x)(\text{sum } z)}{n}}{\sqrt{\left[\text{sum } x^2 - \dfrac{(\text{sum } x)^2}{n}\right]\left[\text{sum } z^2 - \dfrac{(\text{sum } z)^2}{n}\right]}}$$

where: r = correlation coefficient
x = height or diameter growth
z = precipitation or temperature
n = number of observations

Results

The height growth of tulip poplar in both Area X and Area Y is very closely correlated to the growing season precipitation as shown in Figure 28. The accumulative height growth and accumulative growing season precipitation were used for this correlation. This dependency of height growth on precipitation in both areas is further validated by an r value of .989 for Area X and a value of .993 for Area Y. However, it is significant to note that the curve for Area Y deviates rather sharply from that of Area X. Thus, it can be concluded that although both areas are linearly dependent upon growing season precipitation, Area Y is not as effective in its utilization of rainfall as Area X, as evidenced by a slower growth rate. This is further proof of the fact that other factors such as evaporation, relative humidity and soil-moisture relations are supplemental to the resulting poor height growth of Area Y. Since the water-holding capacity of Area Y is significantly greater than that of Area X, it is reasonable to assume that as the moisture-holding capacity of the soils decreases, there is an apparent dependency of increased height growth upon precipitation of the growing season. This conclusion is in accord with the fact that tulip poplar is a tree requiring neither excessive nor droughty soil-moisture conditions, for its best height growth.

As with height growth, the accumulative radial growth of tulip poplar is closely correlated to the accumulative growing season precipitation as shown in Figure 29. This dependency of radial growth to precipitation is validated by a correlation coefficient of .979 for Area X and an r value of .710 for Area Y. The lower value for Area Y

Fig. 28.

THE EFFECT OF ACCUMULATIVE GROWING SEASON
PRECIPITATION ON THE HEIGHT GROWTH OF TULIP POPLAR
(1941 - 1951)

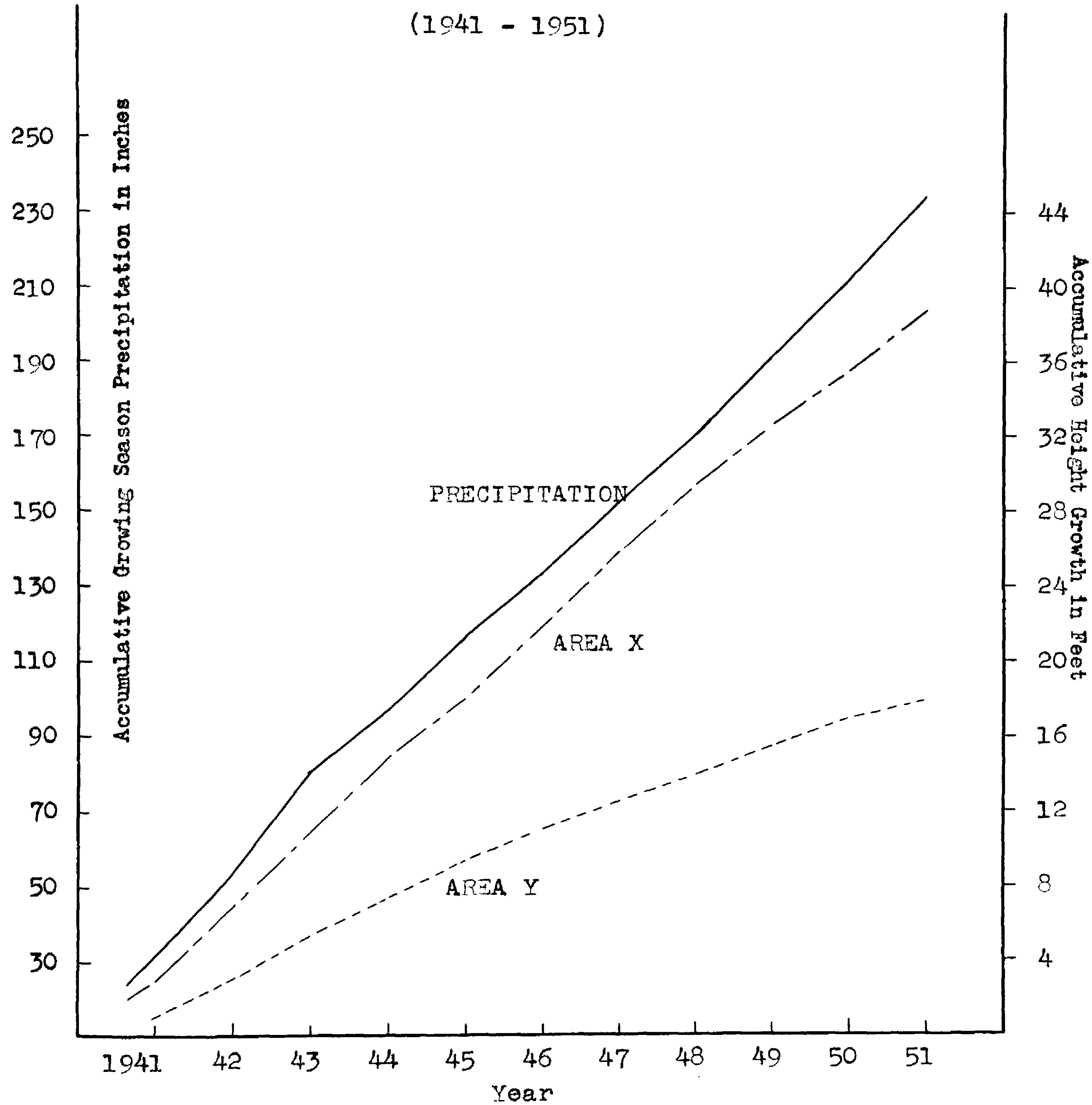
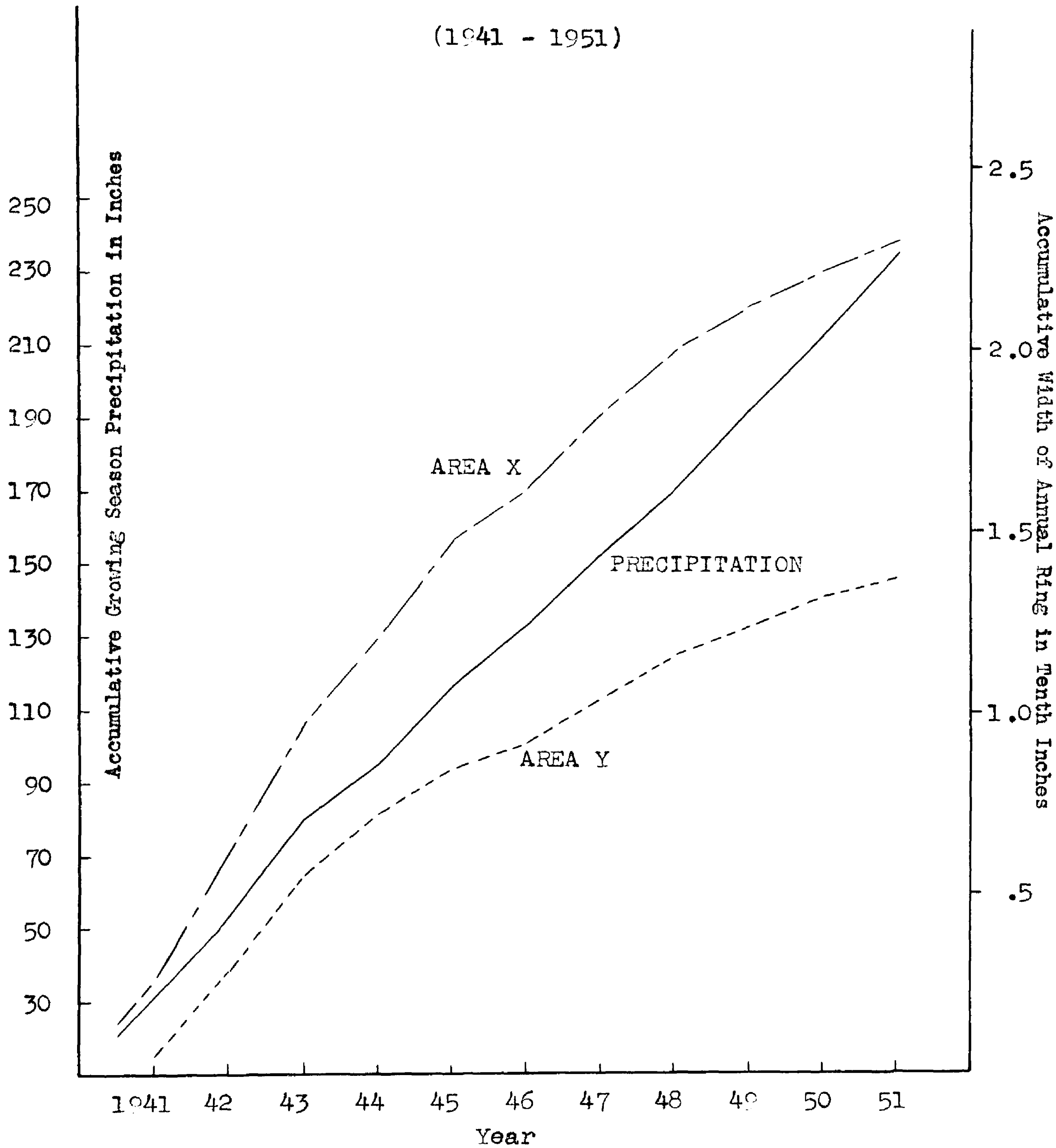


Fig. 29.

THE EFFECT OF ACCUMULATIVE GROWING SEASON PRECIPITATION ON THE RADIAL GROWTH OF TULIP POPLAR (1941 - 1951)



indicates that diameter growth is less highly correlated to precipitation than height growth. Although the standard deviation of the correlation coefficient gives a value of only 1.2 (which is not a significant difference), if a greater number of observations had been made, a significance may have been found. Nevertheless, the data obtained here indicate that Area Y is less effective in utilizing precipitation of the growing season than Area X. These findings are in accord with the inherent growth pattern for tulip poplar as affected by other site factors in conjunction with rainfall.

In order to express more vividly the effects of growing season precipitation on radial growth, a curve was constructed to show the corresponding rise and fall of annual precipitation with the increase and decrease of radial growth. This relationship is presented in Figure 30. For this curve, the average monthly growing season precipitation is plotted against the radial growth of Area X and Area Y. The effects of precipitation on radial growth are rather striking between the years 1942-1948. From 1948 to 1951 the correlation does not seem to be as close; it is surmised that possible crown closure and tree competition may be coming more critical as the trees get older.

The analysis of ring width and height as shown in Table 48 brings out some interesting facts:

1. Both Area X and Area Y show most marked correlation between width of annual ring and precipitation in the years 1941-1943.
2. No direct correlation exists between radial or height growth and total <u>annual</u> precipitation in either Area X or Area Y. This fact further validates the dependency of height and diameter growth upon growing season precipitation.

Fig. 30.

THE EFFECT OF RAINFALL DURING THE GROWING SEASON ON THE RADIAL GROWTH OF TULIP POPLAR

(1941 - 1951)

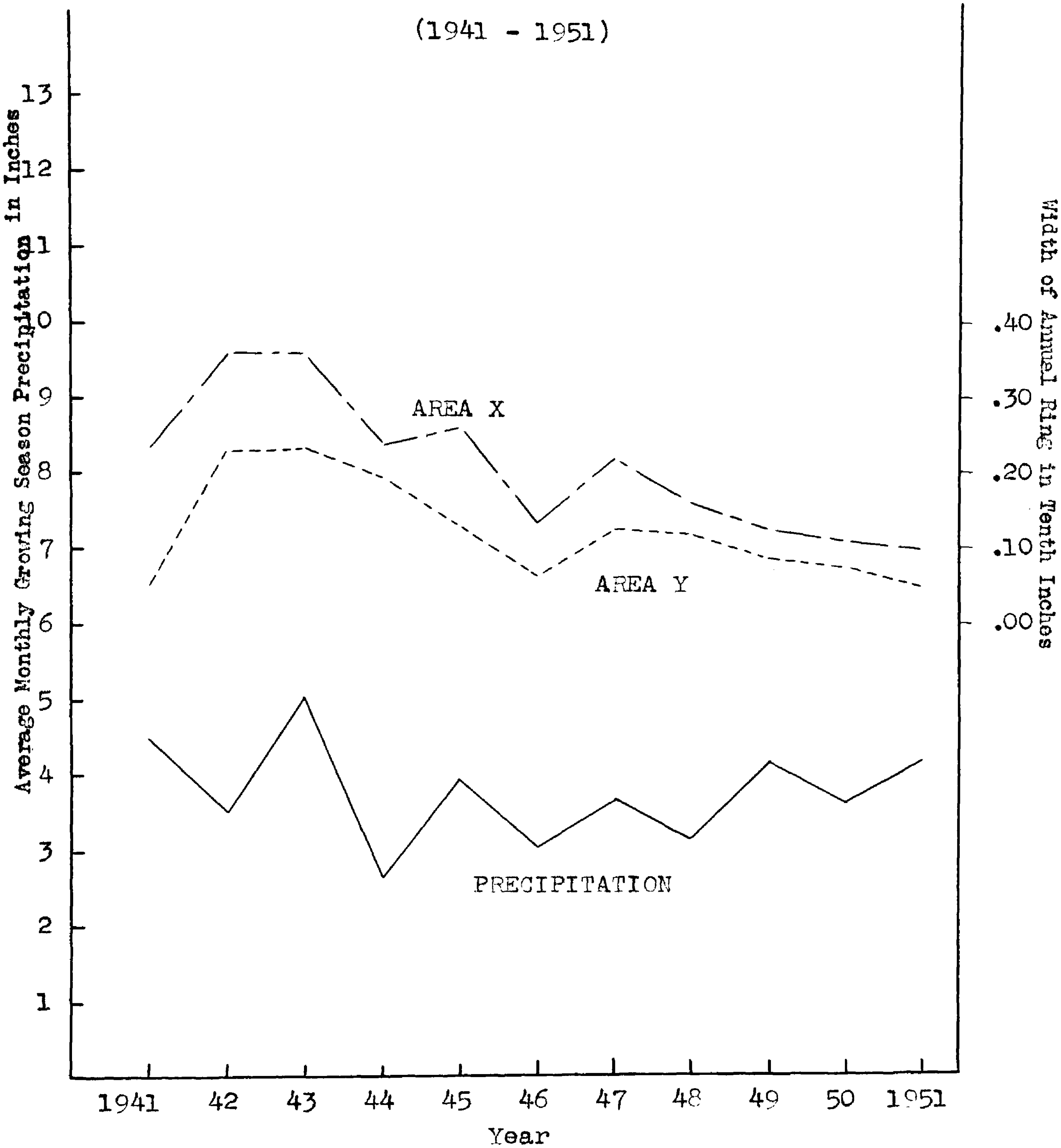


TABLE 48.

RELATIONSHIP BETWEEN GROWING SEASON PRECIPITATION AND GROWTH OF TULIP POPLAR FOR AREA X AND AREA Y

(1941-51)

	Inches Precipitation		Radial Growth (Tenth inches)				Height Growth (Feet)			
			Avg. width annual ring		Accumulative Growth		Avg. annual height growth		Accumulative Growth	
Year	Growing Season	Accumulative	X	Y	X	Y	X	Y	X	Y
1941	26.98	27	.235	.05	.235	.05	3.0	1.00	3.0	1.00
42	21.14	48	.360	.23	.600	.280	4.0	2.00	7.0	3.00
43	30.47	79	.365	.235	.960	.515	4.0	2.50	11.0	5.50
44	15.77	94	.24	.195	1.200	.710	3.5	2.00	14.5	7.50
45	23.70	118	.265	.13	1.465	.840	3.5	2.00	18.0	9.50
46	18.20	136	.135	.065	1.600	.905	4.0	1.50	22.0	11.00
47	22.10	158	.22	.125	1.820	1.030	4.0	1.50	26.0	12.50
48	18.87	177	.16	.12	1.980	1.150	3.5	1.50	29.5	14.00
49	25.15	202	.125	.085	2.105	1.235	3.0	1.50	32.5	15.50
50	21.81	224	.11	.075	2.215	1.310	3.0	1.50	35.5	17.00
1951	25.19	249	.10	.05	2.315	1.360	3.0	1.00	38.5	18.00
	249.38		2.315	1.360			38.5	18.00	Total	
	22.67		.210	.120			3.5	1.60	Mean	

3. No direct correlation appears to exist between width of annual ring or height growth and the total winter precipitation in either area.

4. The highest precipitation recorded for any one year throughout the growing season occurred in 1943. Correspondingly, this same year shows the greatest ring width for both Area X and Area Y. Also, 1943 exhibits the greatest precipitation departure from normal than any other year for the 11-year period.

5. The highest growing season precipitation total recorded for any three consecutive years occurred in 1941-1942-1943, a total of 78.59 inches, which represents 31 percent of the entire growing season precipitation for the 11-year period. Accordingly, the width of annual ring for the same 3-year period for Area X was 42 percent of the total width laid down; Area Y laid down 37 percent of the total ring width for the same period. The peak year of 1943 is graphically shown in Figure 30.

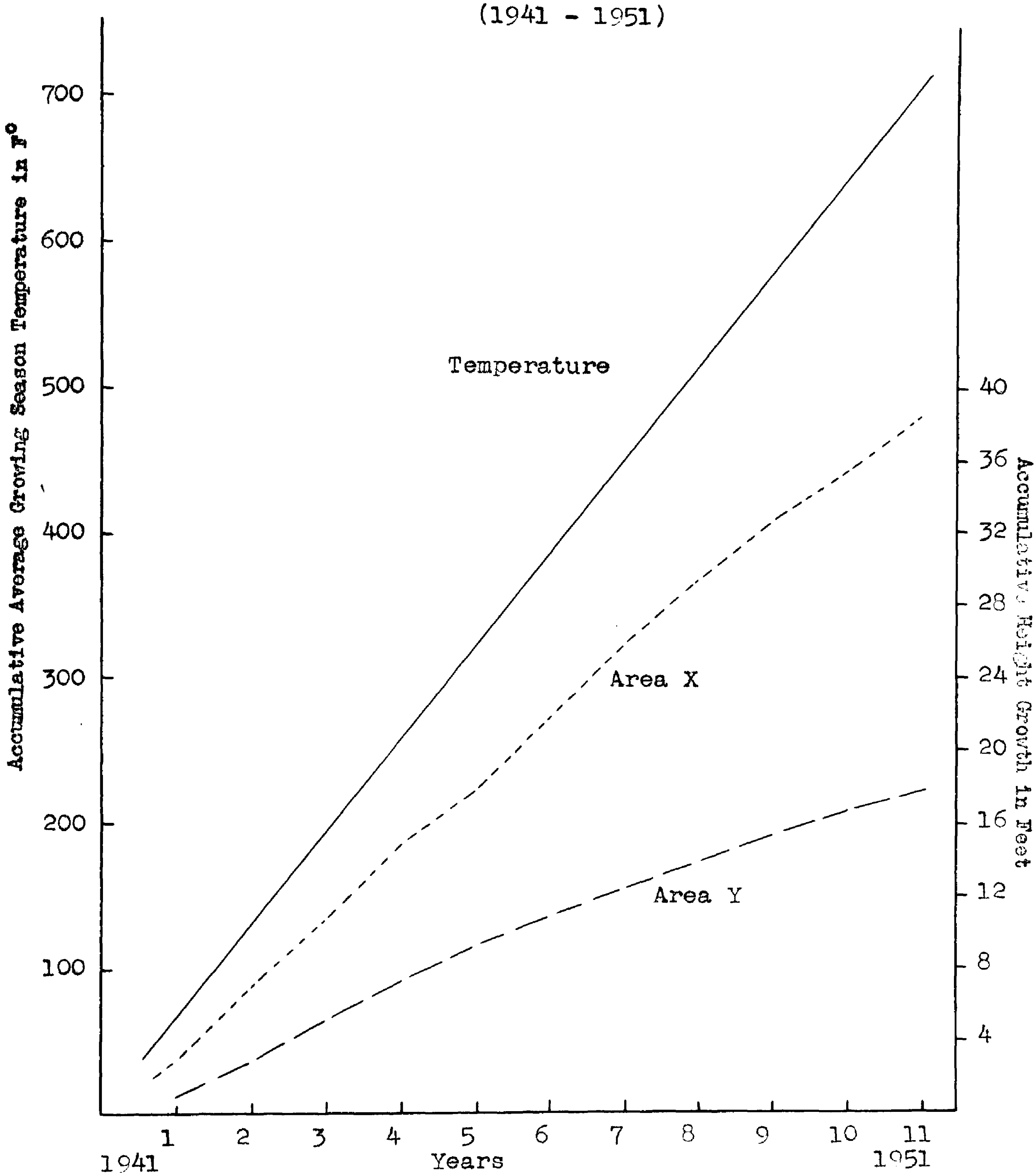
Temperature

From Table 47 the striking uniformity in temperature of the growing season for a 11-year period can be seen. The mean temperatures for all years considered does not vary over three degrees for any one year. This uniformity of temperature is further validated by correlation coefficients of .998 and .999 for the height growth of Area X and Area Y respectively. The diameter growth for the same period exhibits r values of .998 and .974 for Area X and Area Y. From these values the complete and nearly perfect linear dependency of height and diameter growth to growing season temperature can be shown. Although the mathematical expression of growth portrays the dependency of growth upon any climatic element, it does not show the effective use of that element. Thus, as shown in Figure 31, the curves of height growth for both Area X and Area Y deviate from the temperature curve at a rapid rate. Area Y, for example, deviates from the temperature curve at a more rapid rate than Area X. By plotting the average monthly temperature of the growing season against any one year of the 11-year

Fig. 31.

THE EFFECT OF ACCUMULATIVE GROWING SEASON TEMPERATURE ON THE HEIGHT GROWTH OF TULIP POPLAR

(1941 - 1951)



period, the corresponding rise and fall in temperature is correlated with increase or decrease of the radial growth. This relationship is shown in Figure 32.

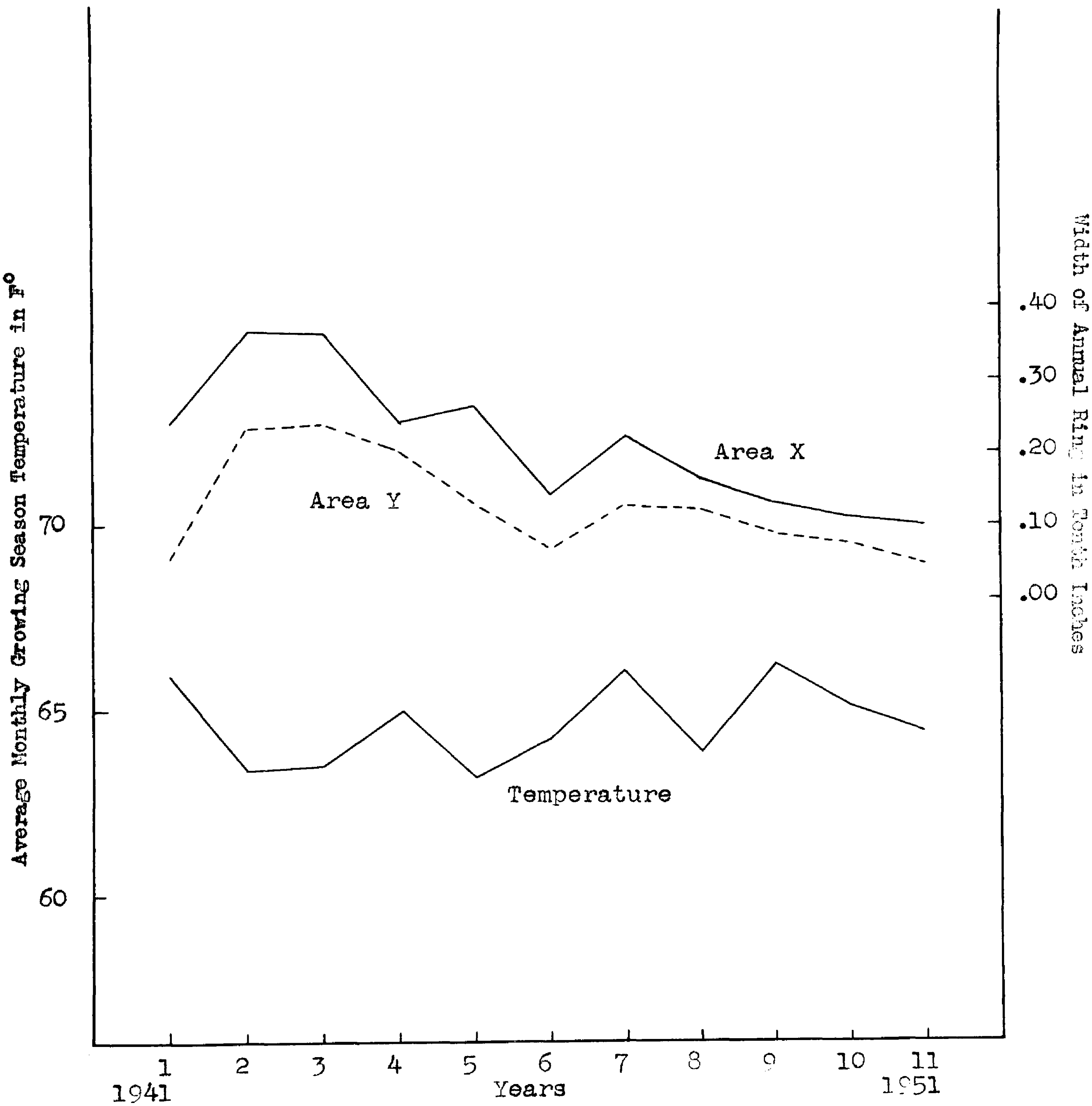
Thus, although both areas are linearly dependent upon growing season temperature in general, the dependency of individual years as expressed by height or diameter growth is less marked. Temperature does not show such wide local variations as are exhibited by precipitation. A regression line of the values in Figure 32 for radial growth and temperature would show a very decided negative correlation between temperature and growth. This reveals that increased temperature augments transpiration and consequently has the same ultimate effect as a decreased water supply. As shown in a study by Diller (1930), high temperature due to its effect upon transpiration would, where the water supply is a limiting factor, intensify the effect of low rainfall and partially nullify the beneficial effect of high rainfall. Thus, a low soil moisture supply coupled with high temperatures during the growing season would become effective in limiting growth as a result of the close relation between turgidity of the tree and growth. These facts would tend to point out that temperature effects are being masked by some other factor, such as growing season precipitation. Further expression of the effects of temperature as shown by seasonal evaporation, relative humidity, and soil-moisture relationships will be considered later.

From the findings above, temperature appears to be affecting the growth of tulip poplar indirectly by its effect on other climatic factors. High temperatures at critical periods of the growing season will affect the relative humidity, soil and air temperatures, and the rate of soil-

Fig. 32.

THE EFFECT OF AVERAGE MONTHLY TEMPERATURE DURING THE GROWING SEASON ON THE RADIAL GROWTH OF TULIP POPLAR

(1941 - 1951)



moisture evaporation. The temperature effects on height growth are probably more closely related to soil drainage and available soil-moisture than to the direct effect of photosynthetic activity upon tulip poplar. However, this assumption can be further demonstrated by the results of data taken daily throughout two growing seasons, 1951 and 1952, which follow.

Thus, it can be concluded that the height and radial growth of tulip poplar in Area X and Area Y seems to be more closely correlated to growing season precipitation and its attendant soil-moisture effects than to variations in temperature of the growing season throughout a 11-year period.

Radial Growth of Trees in the Adjoining Old-Growth Hardwood

Increment borings were taken on tulip poplar and other tree species in an effort to compare the radial growth of the experimental plantation with the radial growth of trees in old-growth associations. Ring width calculations were made on these cores for the same period 1941-1951 as for the plantation-grown tulip poplar. In selecting these trees for increment borings, several trees were bored which were similar in age and diameter to the experimental tulip poplar. By comparing the radial growth of the plantation tulip poplar with trees in the old-growth woods, some estimation of the effects of precipitation upon radial growth could be obtained. Since growing season precipitation has thus far been shown to be closely correlated to radial and height growth of tulip poplar in the experimental area, an investigation was made to find out if similar correlations existed in the adjoining old-growth woods. Radial growth in relation to growing season precipitation was the only correlation attempted; this approach would try to substantiate the effects of precipitation in plantation-grown tulip poplar as compared to forest-grown trees.

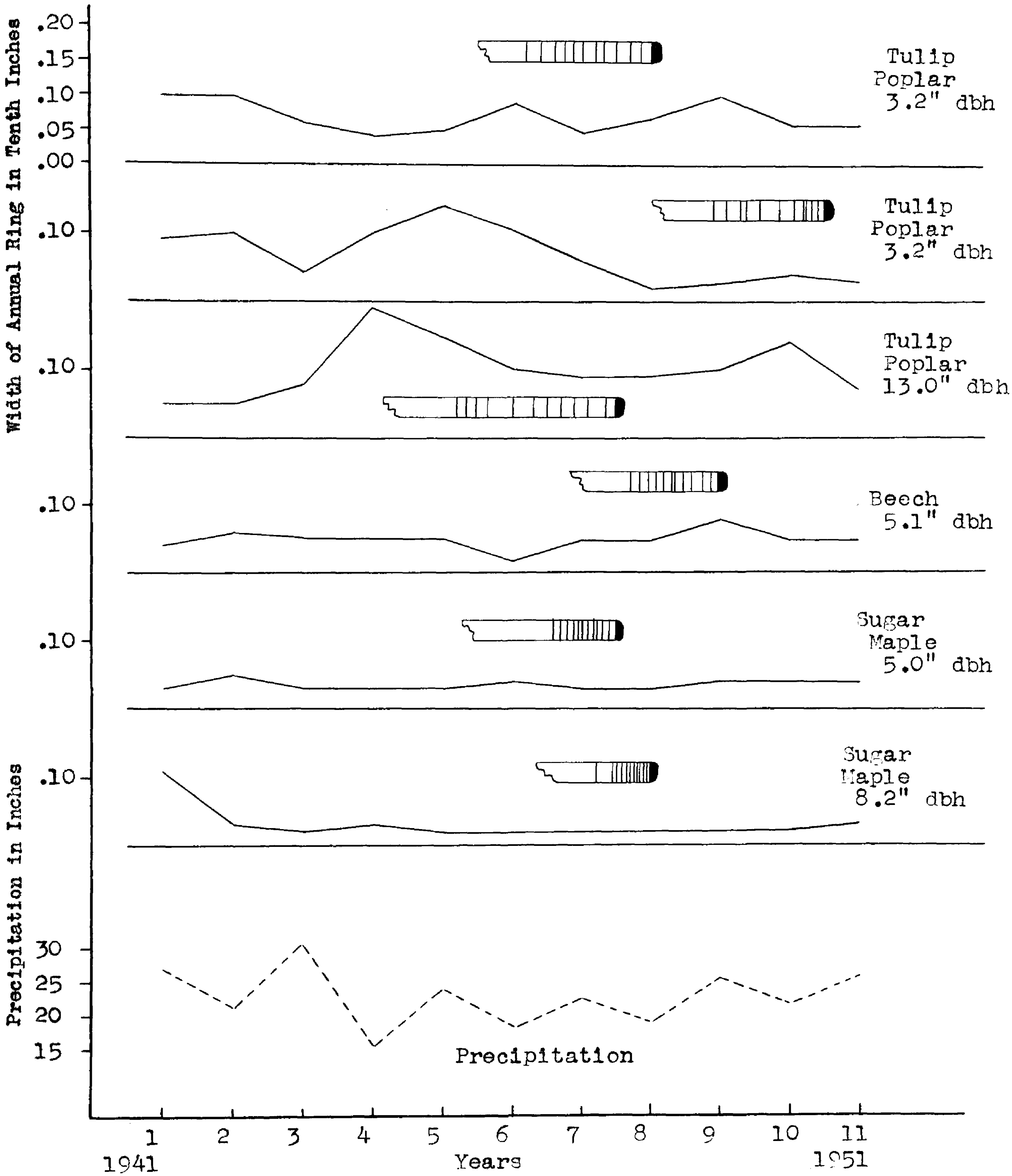
Results

From the results of curves constructed from increment cores as shown in Figure 33, the relationship of radial growth to precipitation can be observed throughout an 11-year period. These increment borings were taken on trees whose associates included beech, sugar maple, black cherry, red oak, white oak, black oak, and dogwood. By contrasting precipitation with the curves of the six trees measured, it is interesting

Fig. 33.

RADIAL GROWTH IN RELATION TO GROWING SEASON PRECIPITATION FOR TREES IN OLD-GROWTH HARDWOODS

(1941 - 1951)



to note that none of the curves correlate closely with precipitation. This result is in contrast to the markedly close correlation of plantation-grown tulip poplar and growing season precipitation. The following statements can be made concerning these relationships:

1. Tulip poplar, beech, and sugar maple growing in old-growth forest associations adjoining the plantation do not exhibit a close relationship to growing season precipitation as shown by increment cores throughout a 11-year period (Figure 33).
2. The width of annual ring of the above three species is evidence that other factors are masking the effect of precipitation, as expressed in ring width.
3. Tulip poplar found growing in old-growth forest associations is less closely dependent upon precipitation for its diameter growth than tulip poplar grown in plantations of the type here investigated.
4. It is surmised that diameter growth of tulip poplar in old-growth forests is greatly affected by the density and age of the stand, whereas tulip poplar in plantation-grown sites (where age and density are constant) shows a close correlation to diameter and the growing season precipitation.

The Effect of Sunscald in Relation to Height Growth

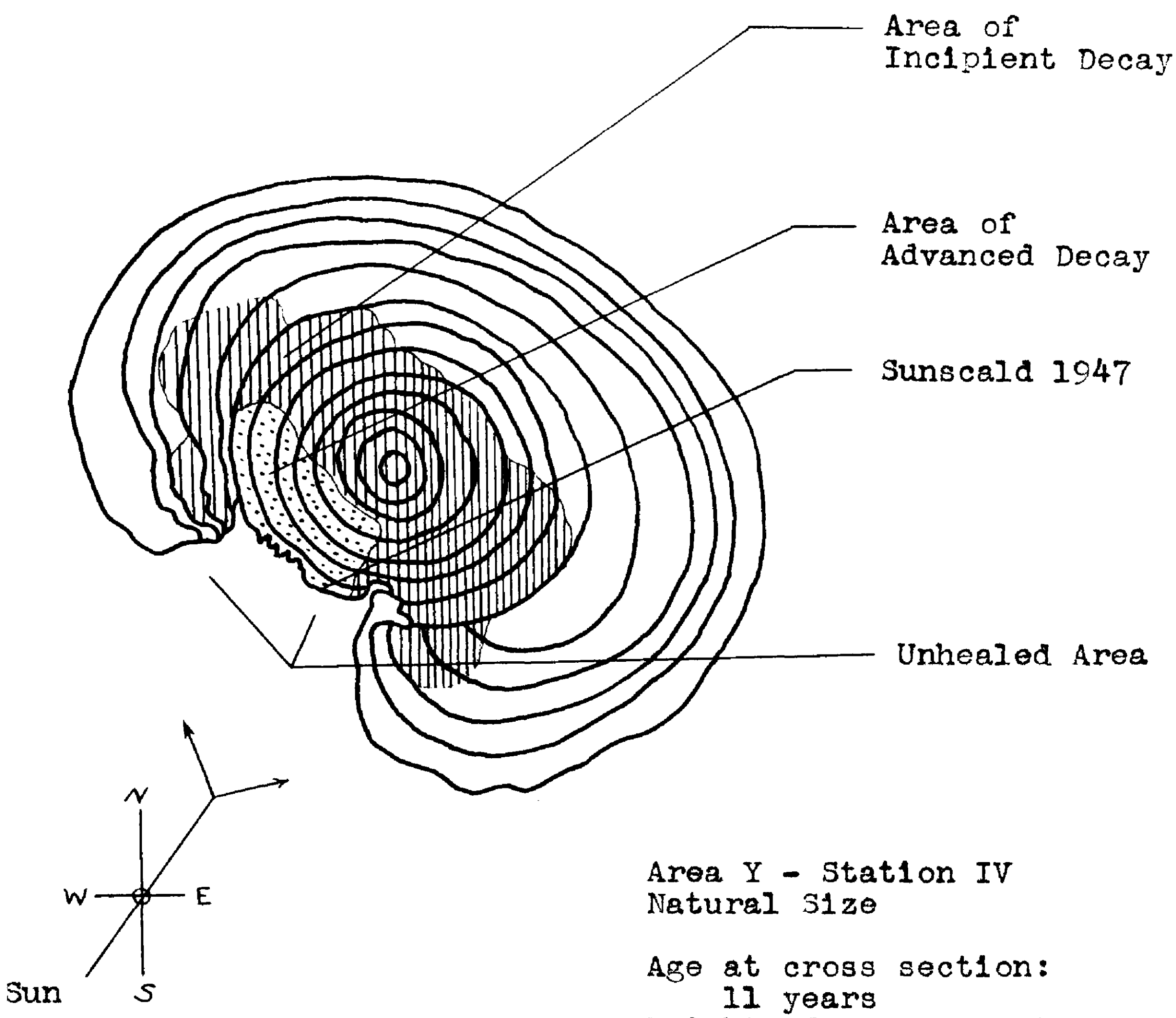
Observation of tulip poplar trees growing in Area Y (poor height growth) shows that these trees are damaged by extreme sunscald (Figures 34 and 36). Since it is possible that the casual observer might interpret this damage in terms of reduced height growth for Area Y, a study was carried out to determine what effect sunscald might have upon height growth. Trees located on the southern and western sides of the "influence line" are virtually free from sunscald damage. In practically every case, the sunscald is the result of incidence from a southwest direction (Figure 35). It is not the object of this study to investigate the cause or set of circumstances which contributed to the damage. Although a number of hypotheses have been conjectured as a reason for this sunscald, it is sufficient to interpret the results in terms of height growth, since this is the prime objective of the dissertation.

Direct Effects

Several trees were felled and sectioned in Area Y where the damage is extreme. Macroscopic examination of the annual rings, plus evidence received by local residents, discloses that the damage occurred in 1947, Figure 35. With the year of occurrence having thus been established, the height growth curves (Figures 23 and 24) were examined. The curve of annual height against growth rate for 1947 and 1948 indicates no variation whatsoever from the normal uniform rate of growth for Area Y. If the sunscald damage had been contributing directly to height growth rate, then one might expect a deviation or fluctuation in the growth rate curve. No extreme break or dip in the growth curve is noted in Area Y for 1947 or

Fig. 34.

A closeup view of sunscald damage occurring in Area Y. The tree shown above is 4.2 inches in diameter (d.b.h.). Extensive sprouting has occurred at the base of the tree as a result of sunscald and tree cricket activity; note the extreme taper from base of the tree to d.b.h. Fungi have attacked the cambium and bark on the southwest side of the bole. Evidence indicates no direct correlation of sunscald to the rate of height growth.



Area Y - Station IV
Natural Size

Age at cross section:
11 years
Height of cross section
above ground level:
16 inches

DIAGRAMMATIC REPRESENTATION OF STEM CROSS SECTION
SHOWING DATE OF SUNSCALD IN RELATION
TO DIRECTION OF INCIDENCE

Fig. 35.

1948. Data based upon the growth curve shows that the average annual height growth for 1947 and 1948 was 1.5 and 1.5 feet respectively. This rate of growth for these years is in line with the continuous and uniform rate of growth preceding and following 1947. Thus, evidence based upon growth rate and actual height measurement clearly reveals that sunscald had no direct effect upon the rate of height growth in the area where damage occurred.

The bark and cambium on the southwest side of tulip poplar trees in Area Y have been seriously damaged in many instances (Figure 34). Damage to these trees has resulted in profuse sprouting at the base of the trees, a result of sunscald and tree cricket activity.

Indirect Effects

In terms of indirect effects of sunscald, certain fungi have invaded the sapwood through cracks in the bark which develop after the stems are damaged. Two main fungi have been identified as *Polyporus tulipiferus* and *Pleurotus ostreatus*.[12] The first of these fungi is by far the more prevalent of the two. As a result of the action of these fungi, fairly extensive wind breakage has occurred (Figure 36) in portions of Area Y.

Since sunscald failed to occur in Area X, south and west of the "influence line," it is obvious that the shadow effect caused by the presence of the old growth hardwoods must have contributed in some manner

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12. Identified by Professor Forrest Strong, Botany and Plant Pathology Department, Michigan State College, East Lansing, Michigan.

Fig. 36.

A view taken in Area Y showing the indirect effect of sunscald, with subsequent wind breakage caused by fungi weakening the stems. Extensive basal sprouting has occurred in virtually all trees exhibiting sunscald damage. This basal sprouting is the result of sunscald and tree cricket activity, either in combination or singly.

to the complete absence of sunscald in this area. However, the sunscald damage in Area Y can be interpreted as an indirect index of the effect upon height growth. Thus, Area Y has greater exposure from incident sources of heat and light, higher soil evaporation rates, higher air temperatures and lower relative humidity, and higher wind velocities than Area X. These indirect effects, or factors of site, in relation to height growth will be taken up under microclimatic investigations and further substantiated. Although rather extreme damage has been caused by the sunscald in Area Y, nevertheless the damage has revealed a clue to other indirect important climatic and edaphic considerations of the site.

The Herbaceous Vegetation as Related to Soil Moisture in Area X and Area Y

Throughout the growing season of 1952, a systematic tally of herbaceous species was taken in both areas of good and poor height growth. Photographs of the ground vegetation were obtained throughout the growing season in order to observe the kind of vegetation present in successional stages. Many classifications of forest sites on the basis of indicator plants appear to be highly subjective, but in a general way it is recognized that relationships exist between ground vegetation and soil moisture. Thus, rather than being used as an indication of site quality, indicator plants are most useful in this study as an expression of soil moisture conditions in two adjoining areas. Also, plant indicator species are best used when dealing with natural-grown, mature forests; the present study deals with plantation-grown tree species. Indicator vegetation has been used to a limited extent in evaluating planting sites. In this study, no attempt is being made to group classes of sites on the basis of composition of the herbaceous vegetation. The main objective of the herbaceous vegetational analysis is to show how the succession of species throughout the growing season relate to soil moisture conditions.

Results

The presence of herbaceous species now apparent after a 15-year successional period in Area X and Y is a useful criterion as to soil moisture relations in each area. Tables 49-51 give a listing of species according to plentifulness throughout the growing season of 1952. It is possible to follow the succession of an individual species or genus throughout the entire growing season, thus achieving some indication of

TABLE 49.

THE GROWING SEASON SUCCESSION OF HERBACEOUS SPECIES IN AREA X AND AREA Y

Plentifulness Criteria:

VA - Very abundant
A - Abundant
O - Occasional
R - Rare

VERNAL ASPECT (MAY 20 - JUNE 20)

Area X (Good height growth) Species	Area Y (Poor height growth) Species
VA - Very abundant	
Acer saccharum Marsh *	Trifolium pratense L.
Viola spp.	Trifolium repens L.
Potentilla norvegica L.	Rumex acetosella L.
Potentilla recta L.	Potentilla norvegica L.
Rubus idaeus L.	Potentilla recta L.
	Daucus carota L.
	Hieracium aurantiacum L.
	Achillea millefolium L.
	Cerastium vulgatum L.
	Poa compressa L.
A - Abundant	
Daucus carota L.	Chrysanthemum leucanthemum L.
Galium spp.	Danthonia spicata L.
Impatiens pallida Nutt.	Antennaria spp.
Parthenocissus quinquefolia L.	
O - Occasional	
Ulmus fulva Michx. *	Erigeron ramosus Walt.
Trifolium pratense L.	Sonchus arvensis L.
Trifolium repens L.	Taraxacum officinale Weber.
Taraxacum officinale Weber.	Verbascum thapsus L.
Rhus toxicodendron L.	Aster spp.
Plantago major L.	Polytrichum commune Hedw.
Asclepias syriaca L.	Lactuca canadensis L.
Geum canadense Jacq.	
Rumex acetosella L.	
Achillea millefolium L.	
Fragaria virginiana Duchesne.	
Poa compressa L.	
Lepidium campestre L.	
Laportea canadensis L.	
Hydrophyllum appendiculatum Michx.	
Cornus florida L.	
Rhus typhina L.	
Carex spp.	
R - Rare	
Prunus serotina Ehrh. *	Prunus serotina Ehrh. *
Fagus grandifolia Ehrh. *	Acer saccharum Marsh. *
Barbarea vulgaris R. Br.	Ulmus fulva Michx. *
Dryopteris marginalis L.	Fragaria virginiana Duchesne.
Hypericum perforatum L.	Senecio aureus L.

* Seedlings

TABLE 50.

THE GROWING SEASON SUCCESSION OF HERBACEOUS SPECIES IN AREA X AND AREA Y

EARLY ESTIVAL ASPECT (JUNE 20 - JULY 21)

Area X (Good height growth) Species		Area Y (Poor height growth) Species
	VA - Very abundant	
Acer saccharum Marsh. *		Daucus carota L.
Rubus idaeus L.		Potentilla norvegica L.
Parthenocissus quinquefolia L.		Trifolium pratense L.
		Trifolium repens L.
		Poa compressa L.
		Chrysanthemum leucanthemum L.
		Danthonia spicata L.
	A - Abundant	
Daucus carota L.		Erigeron ramosus Walt.
Impatiens pallida Nutt.		Hieracium aurantiacum L.
Potentilla norvegica L.		Achillea millefolium L.
Potentilla recta L.		
Viola spp.		
Laportea canadensis L.		
Galium spp.		
	O - Occasional	
Aster spp.		Polytrichum commune Hedw.
Cryptotaenia canadensis L.		Taraxacum officinale Weber.
Erigeron ramosus Walt.		Verbascum thapsus L.
Trifolium pratense L.		Lactuca canadensis L.
Plantago major L.		Rumex acetosella L.
Ulmus fulva Michx. *		Solidago nemoralis Ait.
Geum canadense Jacq.		Circaea latifolia Hill.
Sanicula trifoliata Bickn.		Cornus florida L.
Solidago nemoralis Ait.		
Taraxacum officinale Weber.		
Rhus typhina L.		
Achillea millefolium L.		
Lactuca canadensis L.		
Chrysanthemum leucanthemum L.		
Rudbeckia hirta L.		
Rhus toxicodendron L.		
Poa compressa L.		
	R - Rare	
Hypericum perforatum L.		Rhus typhina L. *
Fragaria virginiana Duchesne.		Juglans cinerea L. *
Prunus serotina Ehrh. *		Carya ovata Mill. *
Carex spp.		Quercus velutina Lam. *
Quercus velutina Lam. *		
Juglans cinerea L. *		
Carya ovata Mill. *		
Lepidium campestre L. *		

* Seedlings

TABLE 51.

THE GROWING SEASON SUCCESSION OF HERBACEOUS SPECIES IN AREA X AND AREA Y

MID - ESTIVAL ASPECT (JULY 31 - AUG.20)

Area X (Good height growth) Species	Area Y (Poor height growth) Species
VA - Very abundant	
Parthenocissus quinquefolia L.	Daucus carota L.
A - Abundant	
Rubus canadensis L.	Achillea millefolium L.
Laportea canadensis L.	Hieracium aurantiacum L.
Acer saccharum Marsh. *	Potentilla norvegica L.
Impatiens pallida Nutt.	Potentilla recta L.
Aster spp.	Poa compressa L.
Potentilla norvegica L.	Danthonia spicata L.
Potentilla recta L.	Hypericum perforatum L.
Circaea latifolia Hill.	Aster spp.
O - Occasional	
Prunus serotina Ehrh. *	Quercus velutina Lam. *
Ulmus fulva Michx. *	Polytrichum commune Hedw.
Plantago major L.	Taraxacum officinale Weber.
Ambrosia trifida L.	Ulmus fulva Michx. *
Daucus carota L.	Erigeron ramosus Walt.
Geum canadensis Jacq.	Rhus typhina L.
Prunella vulgaris L.	Lactuca canadensis L.
Carya ovata Mill. *	Prunus serotina Ehrh. *
Viola spp.	Prunella vulgaris L.
Lactuca canadensis L.	Solidago nemoralis Ait.
Rhus typhina L. *	
Hypericum perforatum L.	
Oenothera biennis L.	
Rudbeckia hirta L.	
Fagus grandifolia Ehrh. *	
Trifolium pratense L.	
Erigeron ramosus Walt.	
Asclepiodora viridis Walt.	
Quercus velutina Lam. *	
R - Rare	
Ribes cynosbati L.	Rudbeckia hirta L.
Cornus florida L.	

* Seedlings

its moisture requirements for a specific environment. Further evidence of the species present at a particular stage of succession is shown by means of quadrat photographs taken at the same position throughout the growing season.

The most striking evidence of the difference in available soil moisture between Area X and Area Y is shown in Figures 37 and 38. Area Y possesses a dominantly grass-weed aspect throughout the entire growing season. Although weed species occur in Area X, these species are much less abundant than in Area Y. Such genera as Viola, Impatiens, Parthenocissus, Galium, Circaea, and Acer (seedlings) are completely absent in Area Y. These genera are usually indicative of moist habitats. Instead, in Area Y are found such dominant genera as Achillea, Hieracium, Poa, Danthonia, and Polytrichum. The latter genera are indigenous to drier sites, or old-field associations. It is noteworthy that all of the above named genera are not transients, but persist in these two areas throughout the growing season succession. Further evidence of the contrast in available soil-moisture between Area X and Area Y, as supplemented by the presence of herbaceous vegetation, is found under climatic data of this thesis. A definite correlation appears to exist between the kind of herbaceous vegetation present throughout the growing season, and the percent of available soil moisture at a depth of six inches as evidenced by readings on Bouyoucos blocks taken throughout a similar period.

Thus, the presence of herbaceous vegetation associated with a specific area is further supplemental evidence that available soil moisture is a factor of primary importance in the differential height growth of plantation-grown tulip poplar.

I

II

Fig. 37. The vernal aspect in Area X (good height growth).

III

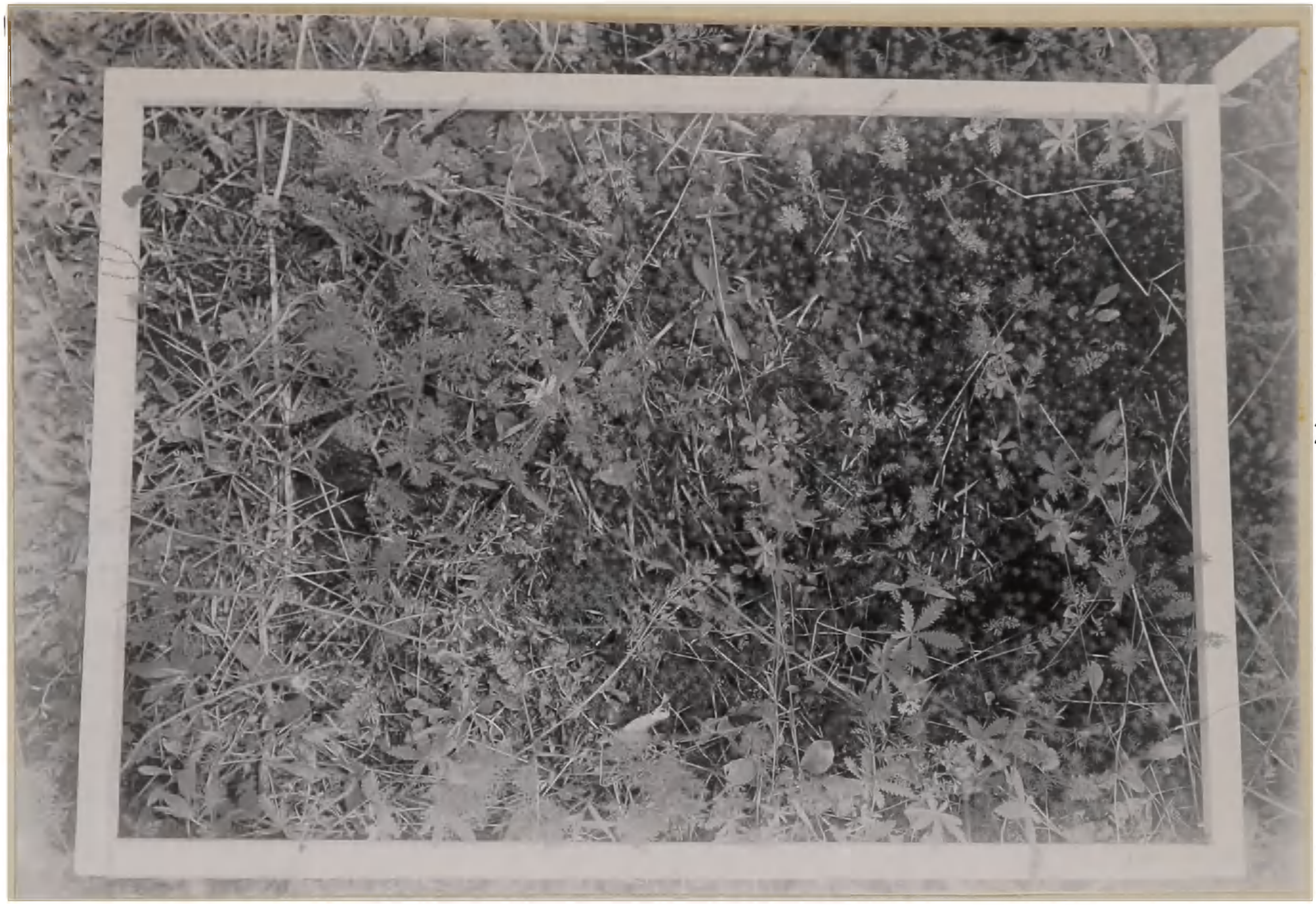
IV

Fig. 38. The vernal aspect in Area Y (poor height growth).

I

II

Fig. 39. The early estival aspect in the area of good height growth (Area X).



III

IV

Fig. 40. The early estival aspect in the area of poor height growth (Area Y).

III

IV

Fig. 41. The mid - estival aspect in Area Y

II

Fig. 42.

III

Fig. 43.

The early autumnal aspect in Area X (above) and Area Y (below).

Microclimatic Factors in Relation to Height Growth of Tulip Poplar in Area X and Area Y

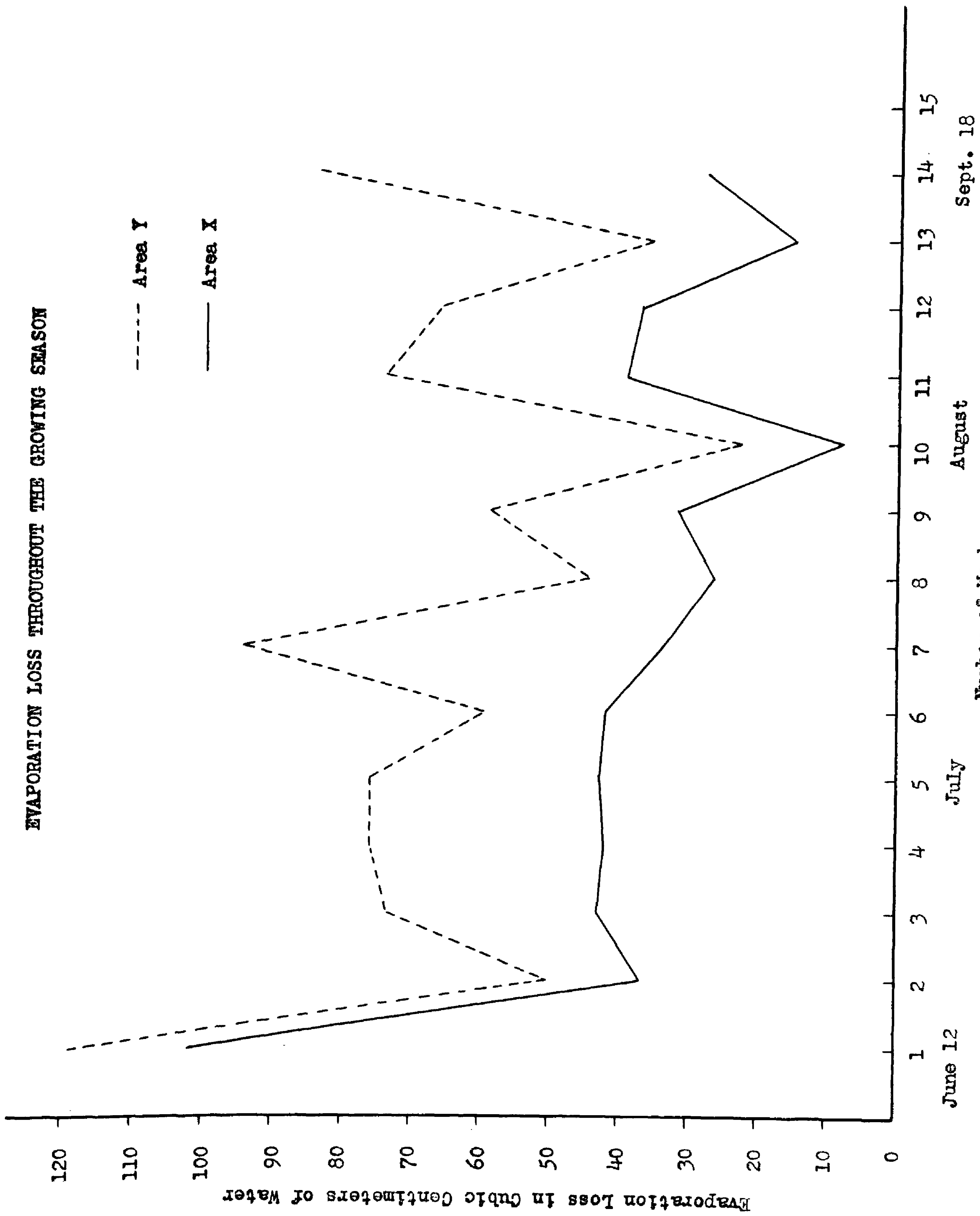
During the growing seasons of 1951 and 1952 several microclimatic factors were recorded at climatic stations in the areas of good and poor height growth of tulip poplar. Two stations were set up close to the old-growth hardwood stand and two stations were established farther out in the plantation where the height growth is poor. Readings on air temperature, evaporation loss, percent available soil moisture, soil surface temperature, and relative humidity were taken daily throughout the growing seasons. These data were then plotted for both areas for the years 1951 and 1952; the results of this microclimatic study are here recorded for the 1951 growing season only.

Since the water economy of young forest plantations is directly related to the photosynthetic activity of individual trees, it is clearly a factor of importance in governing the rate of height growth of tulip poplar under the climatic conditions of southwestern Michigan. Thus, from the results obtained here, it appears that height growth of the trees on two contrasted areas is conditioned by factors which are obviously associated with water utilization of the tree. Any of these factors which affect the soil-moisture regime are reflected in height growth and over a period of time will define the site quality. Fortunately, in this investigation, the area of good height growth represents a "natural laboratory" with the presence of old growth woods on the south and west acting as a control in which certain variables have operated throughout a 15-year period. Since height growth varies with the climatic conditions of the growing season, assuming other factors are comparable, it is possible to correlate rather closely the growth of tulip poplar and the microclimatic factors acting upon this growth. Again, the spacing and age of the tulip trees in both Area X and Area Y is constant, adding validity to the investigation of those factors which are suspected of being limiting. The microclimatic data presented here are aggregate verification of the fact that available moisture is the primary limiting factor in producing a differential height growth of plantation-grown tulip poplar. This is not to imply that the tulip trees in the area of good height growth are necessarily receiving greater amounts of moisture, but rather that the trees in this area are able to utilize the moisture more effectively due to a set of interrelated site conditions not found in Area Y. Six microclimatic factors are here presented graphically in order to contrast the climatic conditions of two opposing sites of plantation-grown tulip poplar. Since only the microclimatic data for 1951 are included, it was deemed advisable to delay the complete statistical analysis of these data until the termination of two growing seasons. A complete analysis of the microclimatic data will be published at a later date. Nevertheless, enough data have been compiled to indicate the trend of climate in the experimental area; data for the early growing season of 1952 indicate trends similar to those of 1951.

Evaporation

The rate of evaporation was taken daily throughout the growing season in both Area X and Area Y utilizing the now well-known Livingston atmometer bulb. This device was used to show in an indirect manner the relative rates and integrated effect of wind movement, humidity and air temperature

Fig. 44.


EVAPORATION LOSS THROUGHOUT THE GROWING SEASON
Area Y
Area X
Evaporation Loss in Cubic Centimeters of Water
0
10
20
30
40
50
60
70
80
90
100
110
120
Number of Weeks
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
June 12
July
August
Sept. 18

in each area. The evaporation stress of the atmosphere as affected by the above factors is of great importance to growth of plants. The atmometers were placed on the forest floor in order to ascertain the evaporation loss at this level. In this study, the loss of water from the soil surface is of prime importance as an index to soil moisture evaporation and determines the efficiency of rainfall to a great degree.

The evaporation loss for Area X and Area Y is shown in Figure 44. It is apparent from the results obtained here that throughout the entire growing season, the water loss is greatest in Area Y. The greatest loss difference between the two areas occurs at the most critical height growth period (July) for this area. Thus, at a time when tulip poplar is at the peak of its height growth, Area Y has the greatest evaporation loss. The microclimatic environment for Area X, with regard to evaporation, is obviously one more suitable to the better height growth of tulip poplar.

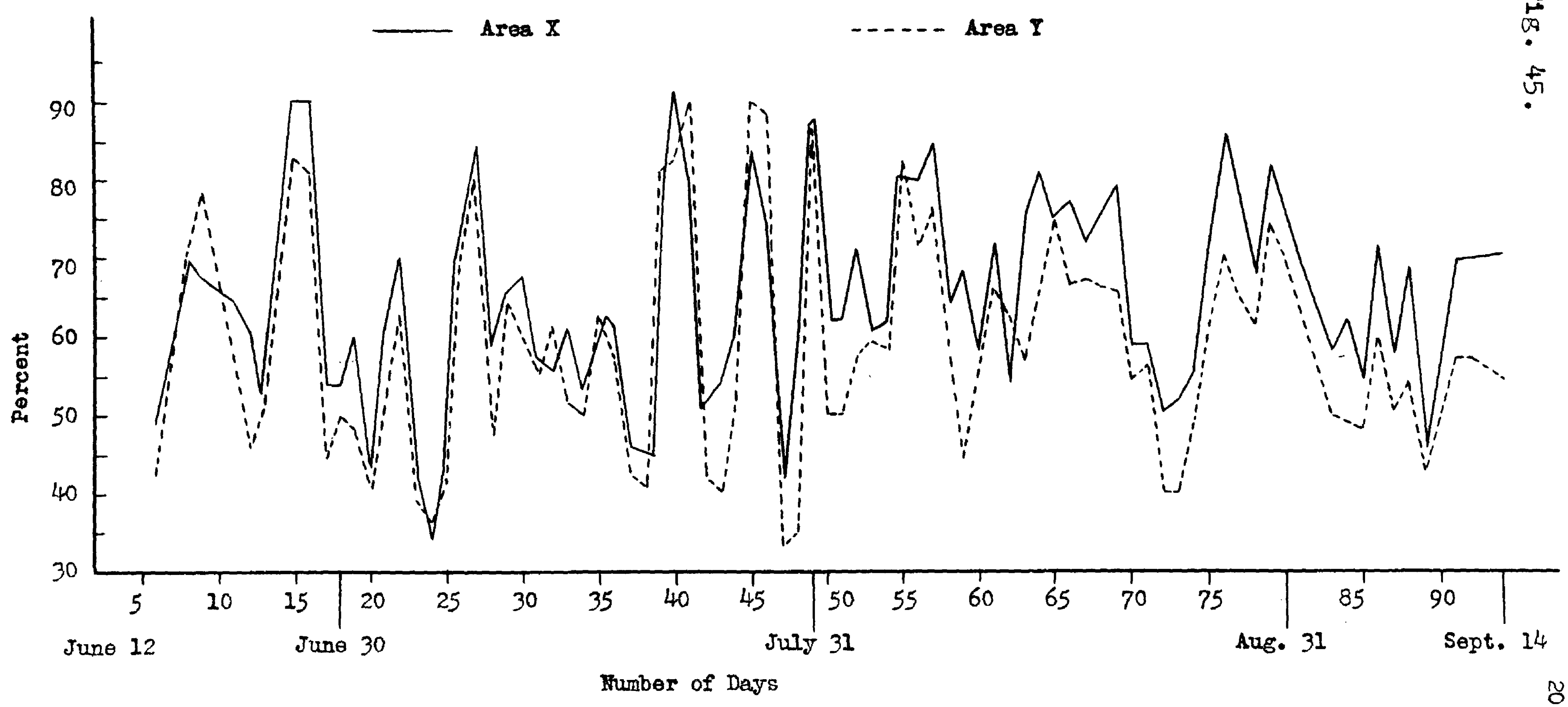
Relative Humidity

The relative humidity was measured daily throughout the growing season in both areas. Humidity readings were taken by means of a hand-aspirated psychrometer. These values are shown in Figure 45.

The relative humidity is closely related to the rate of water loss from a free water surface or from a plant. It is dependent upon temperature and the amount of moisture present. Thus, every change in temperature results in a change in relative humidity and a consequent alteration of evaporation or transpiration. The results of the present study show lower relative humidities throughout the growing season in the area of poor height growth. Indirectly, this indicates higher temperatures in Area Y,

Fig. 45.

RELATIVE HUMIDITY THROUGHOUT THE GROWING SEASON



so that water exposed quickly evaporates and the more rapidly the air will take up water from transpiring leaves or from a moist soil surface. These results are correlated with the high evaporation rate, higher soil surface temperatures and high air temperatures of the poor height growth area. The higher temperature of Area Y increases the capacity of the air for moisture and consequently lowers the relative humidity; the opposite situation exists in Area X.

Air Temperature

Air temperatures were recorded daily throughout the growing season by means of a sling psychrometer. The values obtained for both areas are shown in Figure 46.

The results show higher temperatures in Area Y throughout the entire growing season. This clearly shows the more exposed position, higher evaporation rate, lower relative humidity, and higher surface temperature of the poor height growth area. The graph of air temperature clearly indicates the higher air temperature of Area Y in the critical period of growth for tulip poplar. The increased temperature of Area Y thus promotes greater transpiration and evaporation at a time when tulip poplar requires more reduced temperatures.

Surface Soil Temperature

The temperature of the soil surface was taken daily throughout the growing season by means of a soil thermometer. The striking results are given for both Area X and Area Y in Figure 47.

A markedly higher growing season soil surface temperature is revealed in Area Y than in Area X. This high surface temperature exerts an indirect

Fig. 46.

AIR TEMPERATURE THROUGHOUT THE GROWING SEASON

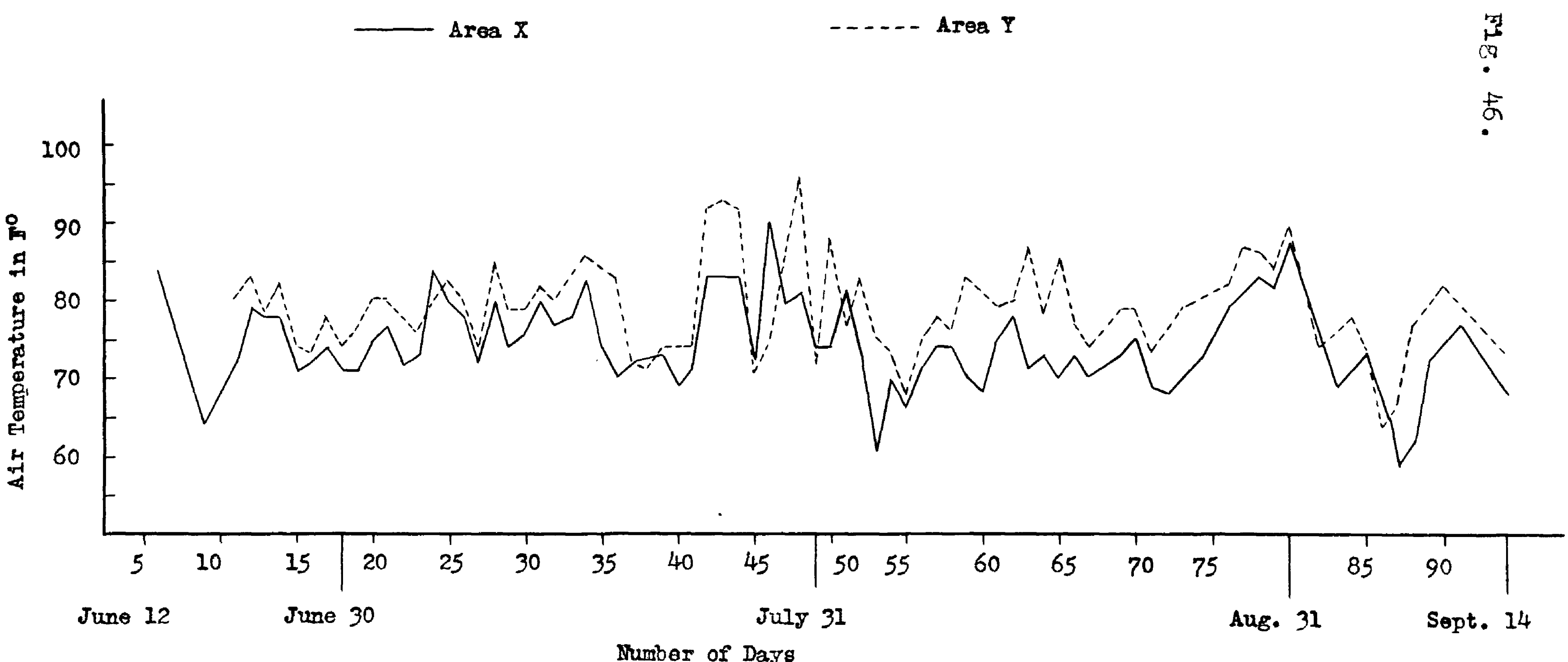
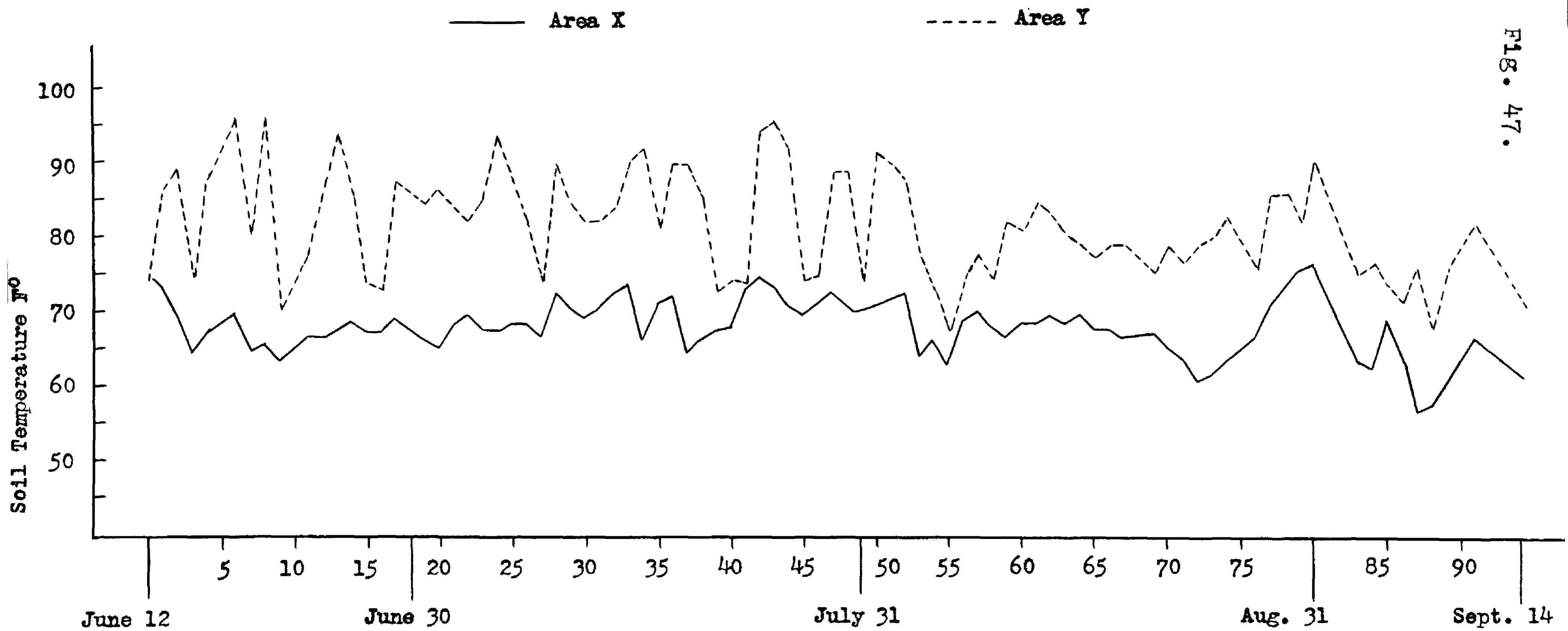


Fig. 47.

SURFACE SOIL TEMPERATURE THROUGHOUT THE GROWING SEASON



effect by increasing evaporation loss from the soil. A correlation appears to exist in this study between the herbaceous vegetation type and the surface soil temperature, with its subsequent rapid surface soil moisture loss. It is apparent that the more exposed situation of Area Y results in greater evaporation loss and drier conditions throughout the period of growth than Area X. Again, the greatest difference in soil surface temperature between both areas occurs at the critical height growth period of tulip poplar.

Percent Available Moisture

Throughout the growing season, daily soil moisture measurements were taken by means of Bouyoucos blocks at depths of six and eighteen inches respectively. The results of these findings are shown in Figures 48 and 49. At a depth of six inches, Area Y shows a markedly lower available moisture content throughout the growing season than in Area X. This result is of prime importance, since it has been shown previously that soils in Area Y possess higher water-holding capacities and clay content than Area X. Thus, despite a significant textural soil difference between the two areas, the percent of available soil moisture at the effective root zone depth is greater in Area X. This is further validation of the fact that soils in Area Y have a higher water-holding capacity based upon mechanical analysis, yet lose water at a faster rate than Area X. It is apparent from these findings that the effective utilization of a continuous water supply is greatest in the area of good height growth.

At a depth of eighteen inches, Area Y has a greater available moisture content in the early spring and early autumn than does Area X. This result

Fig. 48.

PERCENT OF AVAILABLE MOISTURE THROUGHOUT THE GROWING SEASON AT A SOIL DEPTH OF SIX INCHES

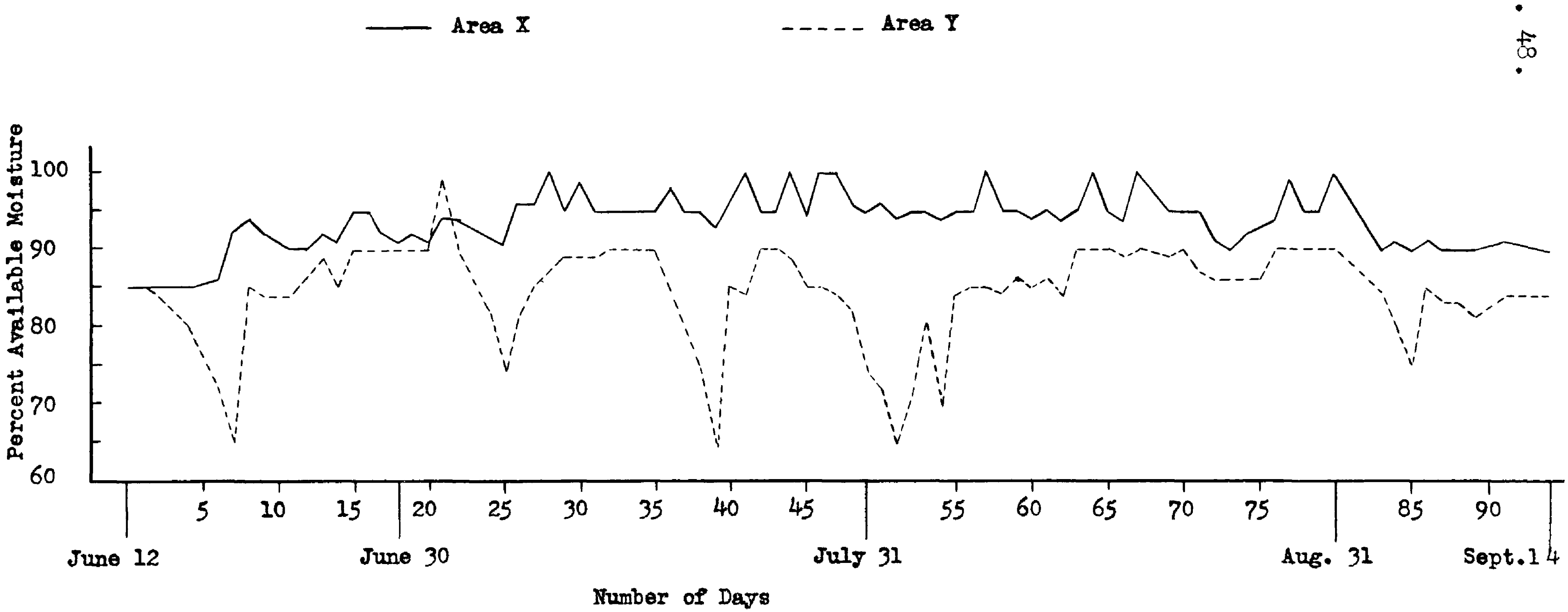
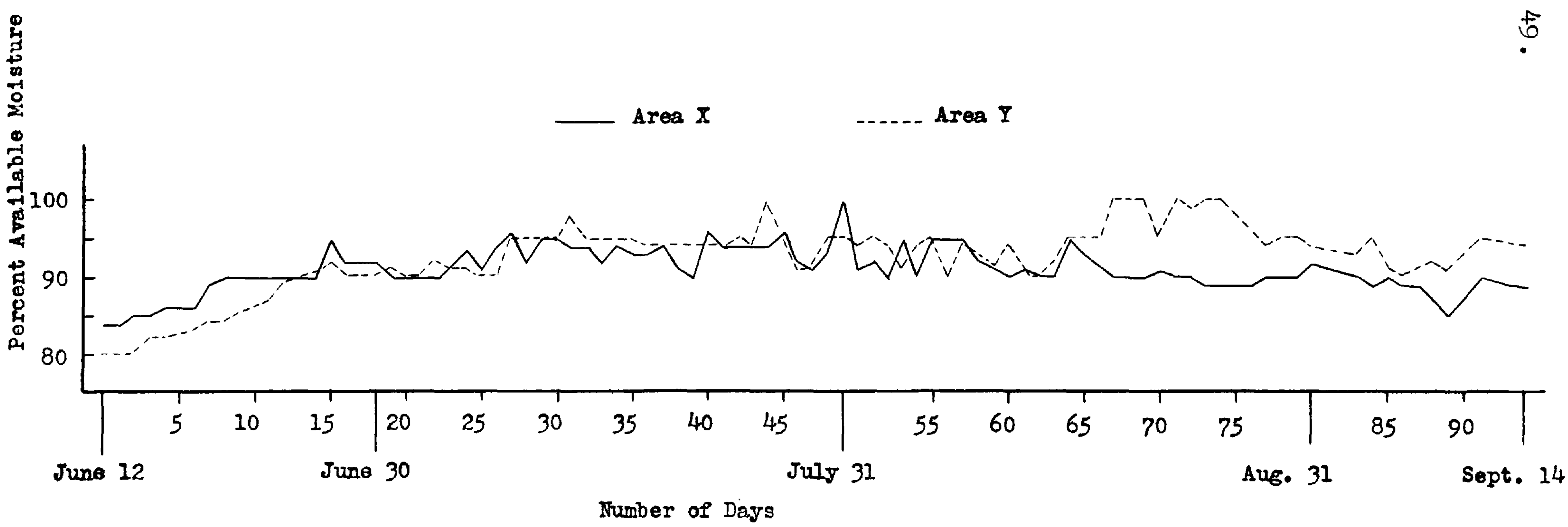


Fig. 49.

PERCENT OF AVAILABLE MOISTURE THROUGHOUT THE GROWING SEASON AT A SOIL DEPTH OF EIGHTEEN INCHES



is apparently due to the fact that the water table level is closer to the surface in Area Y at these periods. However, the results indicate no material difference in available water between the two areas during the critical period of growth (July, August).

Light Intensity

At various intervals throughout the growing season, light intensity measurements were taken in both Area X and Area Y. These readings were recorded with a photoelectric cell utilizing the intensity of reflected light expressed in terms of a percent of full sunlight. Since no record of the light intensity was made at any time prior to the present readings, the numerical results are not included here. However, the results of the present study reveal that the average light intensities in Area Y are considerably greater than in Area X. This result was anticipated due to the more shaded and less exposed site conditions of Area X.

With the limited data available it is difficult to determine what effect light intensity plays in the role of a separate climatic factor. Furthermore, it is difficult to express quantitatively which portion of the solar radiation exists as light intensity, light quality, or as heat. Since no light readings have been taken during the 15-year interval previous to the establishment of this plantation, it is virtually impossible to establish any concrete evidence as to the direct effect of light upon height growth, with the exception of the external evidence of sunscald. The role of light in both areas in this study is therefore based upon the indirect observational <u>results</u> of solar radiation rather than a <u>cause</u> of height differentiation.

Certain anatomical features of tulip trees in Area X suggest a response to lower light intensities. Such features as natural pruning of the lower branches in this area indicate the effect of the presence of the old growth hardwood and the greater height growth of these trees. Gross observation on the thickness of leaves, leaf color, and general leaf succulence does not reveal any marked difference in the two habitats. At the time of establishment of this plantation and for many years following this initial growth, it is presumed that all trees in the plantation were receiving approximately the same light intensity, and that differentiation in height growth based upon light conditions *per se* is not tenable.

Thus, with the limited data available, it appears that light is complexly associated with the other integrated site factors in this study. For example, in Area Y, the greater light intensity is associated with the drier habitat and higher transpiration rates as shown by supplemental evidence. Most of the evidence in this thesis points to the fact that light is integrated with the other site factors but is being masked by other more limiting factors with reference to the height growth differential.

Discussion of Results

A growing season study of seven microclimatic factors in Area X and Area Y shows in virtually every case that these integrated factors, supplemented by edaphic and biological factors, are associated with a marked differential height growth for plantation-grown tulip poplar. All of these microclimatic factors indicate that the moisture regimen, either directly or indirectly, is most likely the major function resulting in the differential height growth of the experimental plantation. The presence of an old-growth hardwood stand adjacent to Area X has altered the microclimate in this area and reveals rather clearly some of the silvical features to be considered in growing plantation tulip poplar. The microclimatic features of Area X and Area Y have previously been validated statistically with reference to precipitation and temperature.

SOIL MICROBIOLOGICAL EXPERIMENTS (QUANTITATIVE)

The Relation Between Numbers of Soil Organisms and the Edaphic and Microclimatic Factors of Area X and Area Y

Field Experimental Method:

During the growing season of 1951, soil samples for microbiological studies were taken from Area X and Area Y. These samples were collected and preserved by a method originated by the present investigator. At appropriate intervals throughout the growing season the soils were sampled for numbers of fungi, bacteria, and actinomycetes existing in four separate soil horizons in each experimental area (Figures 50-53). A revised method of collecting microbial soil samples was carried out as follows:

1. Glass containers of 65 milliliter capacity were sterilized in an oven at 105° C for a period of one hour. Sterile lids were then screwed tightly to the empty glass containers and taken directly into the field.
2. By means of a post-hole digger, soil profiles were exposed to an appropriate depth. Using an ordinary sterile, wooden ice-cream spoon, enough soil was taken at definite soil horizon depths to fill each container. After each individual soil sampling, the wooden spoon was discarded. This method eliminates the usual tedious and cumbersome procedure of igniting alcohol on a trowel prior to each sampling in order to prevent contamination.

3. After the samples were taken at each natural soil horizon, a beaker of paraffin wax was melted and the sample containers emersed, thus sealing them from air and contamination. This wax-sealing process enables the investigator to keep the samples indefinitely until the soils are ready to be sampled for microbes. In addition, the soils can be run at the same pH and moisture content as originally sampled.

The microbial soil samples were taken at approximately the same area location as the microclimatic data. Uniformity in the correlation of edaphic and climatic data with the microbiological changes was thus obtained.

Laboratory Experimental Method:

The laboratory procedure used in isolating the desired organisms from each soil sample divides itself into two parts:

1. From the soil samples taken at Stations I and II, a composite sample was made to represent each horizon in Area X; similarly, composite samples were made for each horizon in Area Y.

   Soil dilutions of each composite soil were prepared as follows: The addition of 10 grams of soil to 1000 cc. of sterile distilled water giving a dilution of 1:100. After the coarse particles had settled out after shaking, 10 cc. of the 1:100 dilution was pipetted into 90 cc. of sterile distilled water. Successive transfers were made resulting in a series of dilutions. These were 1:100, 1:1000, 1:10,000, and 1:1,000,000. All work was done aseptically.

2. Selection of media and culturing procedure for bacteria, actinomycetes and fungi:

From the above dilutions, 1 cc. of each was dispensed by sterile pipettes into a selective media and poured aseptically into sterile petri dishes. This mixture of agar and soil dilution was allowed to harden and the cultures were placed in a culture room at 28° C. The bacteria and actinomycetes were permitted to grow one week or less before observations were made and the fungi were allowed four days before observing. The medium used for bacteria was Nutrose agar; for fungi; a Peptone-glucose acid agar used with a pH between 3.8 and 4.0 so that bacteria would not develop. The media used were as follows:

Bacteria and Actinomycetes - Nutrose agar

Agar	12.5 grams
Nutrose	2.0
Glucose	1.0
K_2HPO_4	0.2
$MgSO_4 \cdot 7H_2O$	0.2
$FeSO_4 \cdot 7H_2O$	trace
Tap Water	1.0 liter
Reaction pH	6.8 (no adjustment)

Fungi - Peptone glucose acid agar

Agar	25.0 grams
KH_2PO_4	1.0
$MgSO_4 \cdot 7H_2O$	0.5
Peptone	5.0
Glucose	10.0
Distilled Water	1.0 liter
Reaction pH	3.8 to 4.0 (adjusted)

In all cases where inoculations were made, glassware was thoroughly sterilized and the media used were autoclaved prior to each soil "run" in order to prevent contamination. Each dilution was run in duplicate both for bacteria and fungi, in addition to controls. The number of organisms computed from the plates represent the average values of three dilutions, or the average value of six individual plates for each soil horizon. Moisture contents were obtained for each horizon immediately before the isolations were made. This was done by heating the composite samples at 90° C until all water was lost; the percentage figures obtained were indicative of the amount of water lost in each sample, and the number of organisms present per gram dry weight of soil was computed from these results, using the plate method for counting microbes. For each soil horizon, the acidity (pH) was obtained by the glass-electrode pH meter.

Several exemplary photographs of the plate count were made in order to illustrate the principles involved (Figures 54-56). The number of organisms on each plate was counted by means of a microscope and counting plate. Only the 1:100 and 1:1000 dilutions were used for statistical presentation of numbers of organisms appearing on the plates. After correction for moisture content, the numbers of organisms were plotted in order to compare quantitatively the difference in microbial counts between Area X and Area Y.

Objectives

The present microbiological investigations were concerned with the soil as a mass of living debris, including certain bacteria, actinomycetes, fungi, algae and protozoa. These living microbes are not a complete list of the soil flora and fauna. However, the bacteria, fungi and actinomycetes exert a profound influence upon the genetical development of soil profiles as well as an indirect effect upon forest trees. This study is strictly quantitative in its approach. In most soils the qualitative distribution of organisms remains much the same, but there are very marked differences in the quantitative relationships. Biological transformations brought about by soil organisms are extremely complex, and it is assumed that the forester possesses a general background in the implications of this study. No attempt has been made to enable the reader to analyze the results of these experiments by means of a strict index that will hold true in all cases. Nevertheless, the results are a function of two independent bodies, the soil and the forest, each of which are acted upon by climatic influences, all of which are integrated parts of the same dynamic system influencing the growth of tulip poplar. In all comparative studies certain variables and incidental factors enter in; no direct or indirect correlation between the soil and the growth of the forest stands described can be expected to hold true in all situations. Since no identical studies like the one presented here have been made, interpretation of data is only indicative of principles and trends supplemental to other factors. Practically no silvical studies have specifically shown the relationship of organisms to a set of integrated site factors throught a growing season. This portion of the dissertation has the following specific objectives:

1. To present quantitative data concerning bacteria, fungi, and actinomycetes in two contrasting sites of the same age and density. These two sites represent an area of good height growth and an area of poor height growth of plantation-grown tulip poplar.
2. To show the fluctuation in the population of organisms throughout the growing season on compared tulip poplar sites, by utilizing soil horizons as the differentiating criterion.

3. To correlate the fluctuation in population of organisms throughout the growing season with the following major microclimatic and edaphic factors in each area:
   (1) soil-surface temperature
   (2) moisture content of soil to a depth of six inches
   (3) rate of evaporation and air temperature
   (4) soil organic matter
   (5) soil acidity (pH)

In interpreting the results of a quantitative microbial study it should be constantly kept in mind that the numbers of organisms referred to are only relative figures. They should not be interpreted as representing a constant number of organisms in a particular soil; the counts refer only to the relative abundance of certain types of microbial cells at the time that the determination was made. Great changes occur when certain environmental conditions are modified. The manner in which these organisms vary with a set of integrated site factors throughout an entire growing season in two contrasting tulip poplar habitats is the objective of this microbiological study. In essence, the findings of this biological investigation merely attempt to corroborate and validate the microclimatic and edaphic studies. The role of microorganisms as to their function, activities, and transformations are not included here. This investigation is designed to demonstrate how microbial studies can be incorporated into the forester's concept of site quality by integrating the soil flora with other site factors. Since the surface soil horizons reflect the external effects of the immediate environment, the quantitative correlation of organisms to soil and climate is interpreted and plotted by soil horizons, A_0 and A_1.

Fig. 50.

VERTICAL DISTRIBUTION OF SOIL MICROBES IN AREA X AND AREA Y DURING THE SPRING

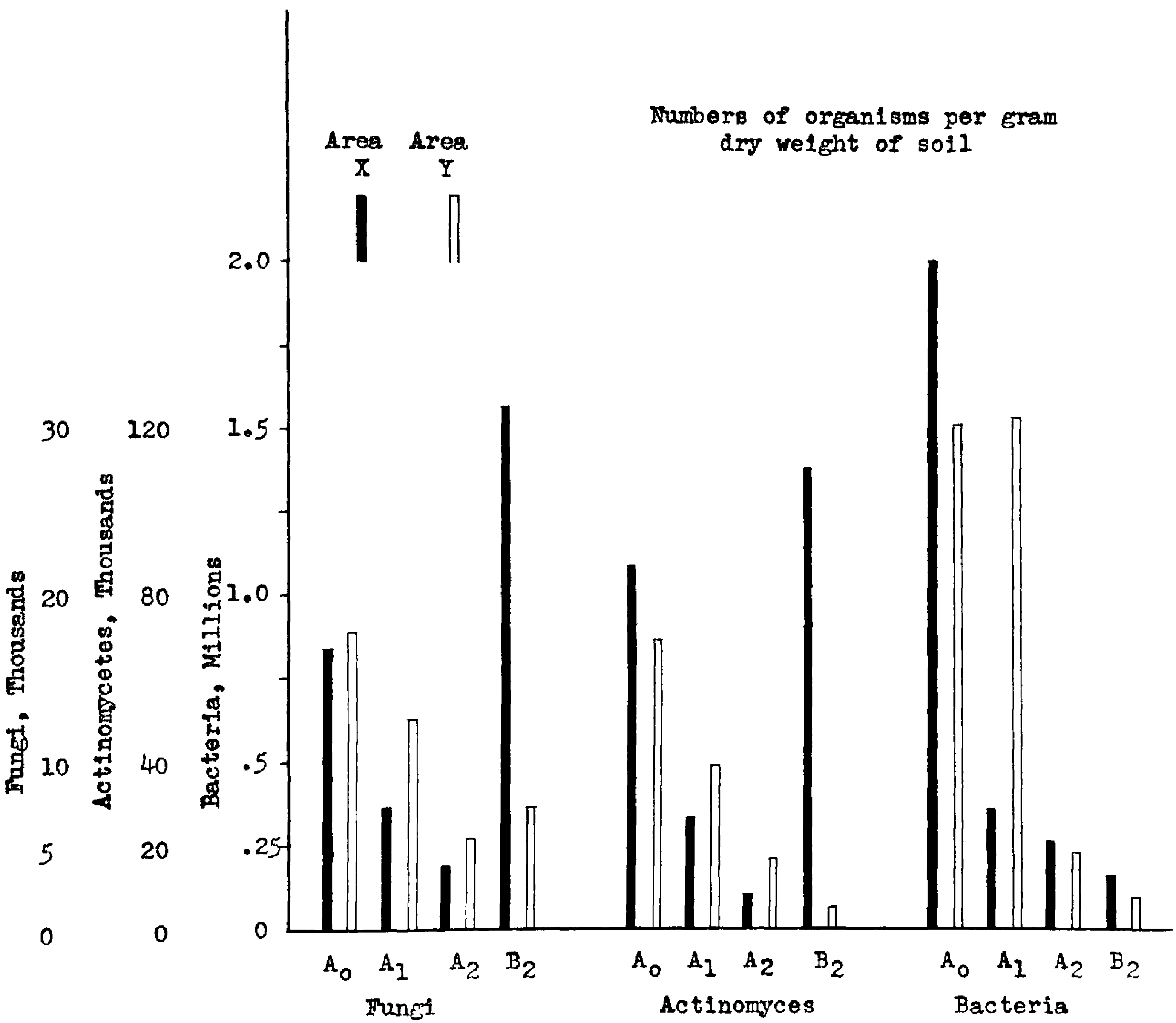


Fig. 51.

VERTICAL DISTRIBUTION OF SOIL MICROBES IN AREA X

AND AREA Y DURING EARLY SUMMER

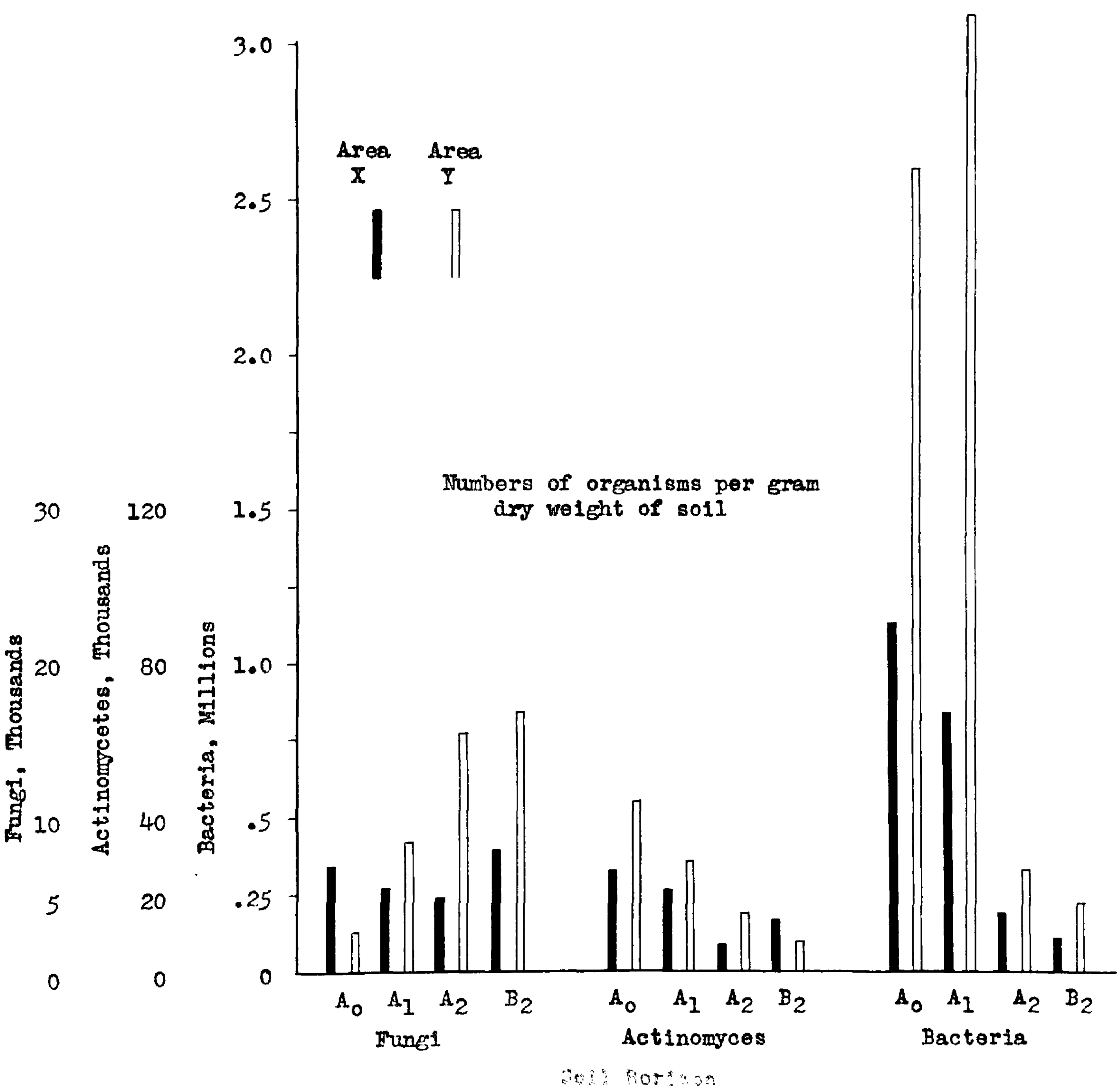


Fig. 52.

VERTICAL DISTRIBUTION OF SOIL MICROBES IN AREA X AND AREA Y DURING MID-SUMMER

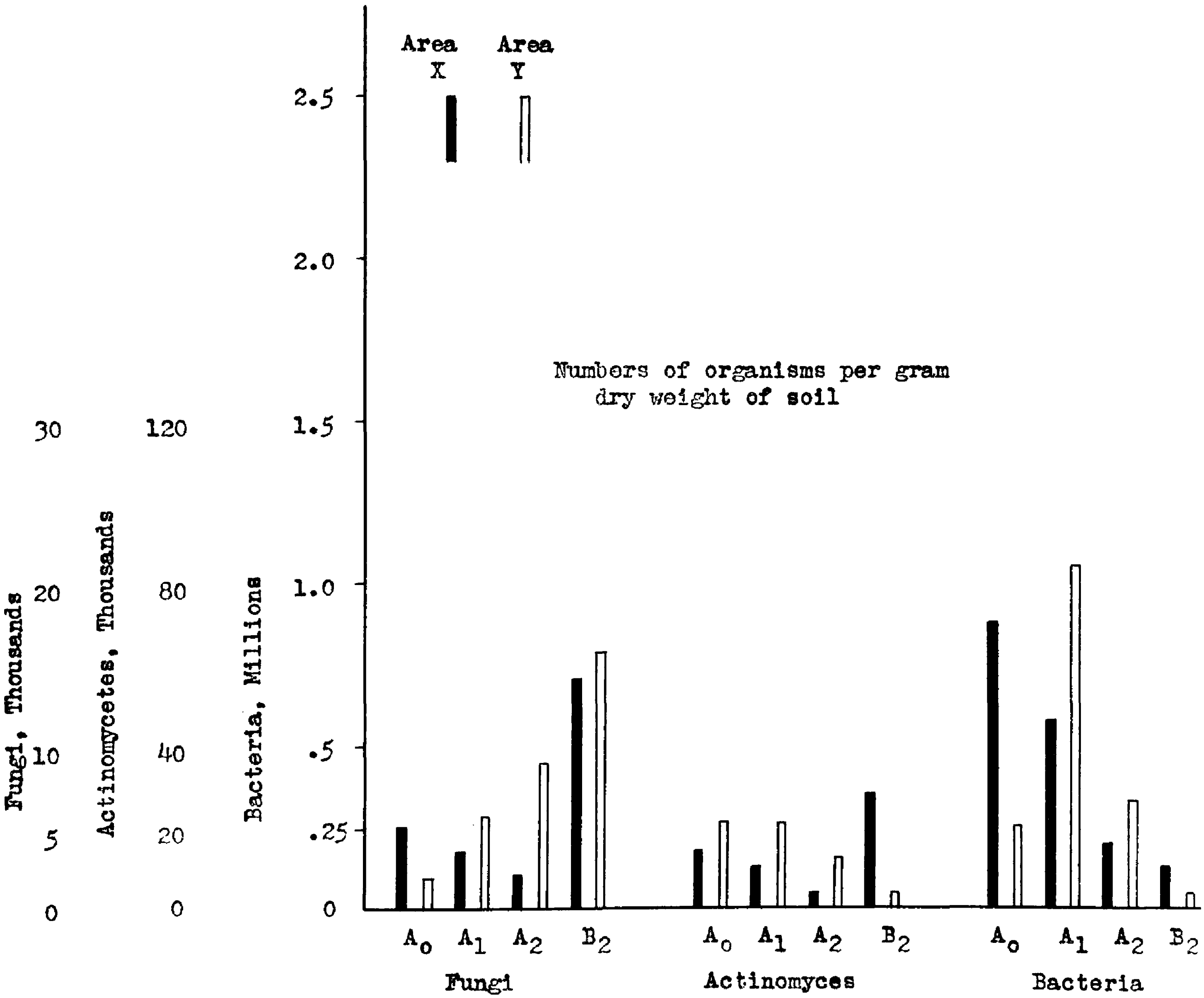
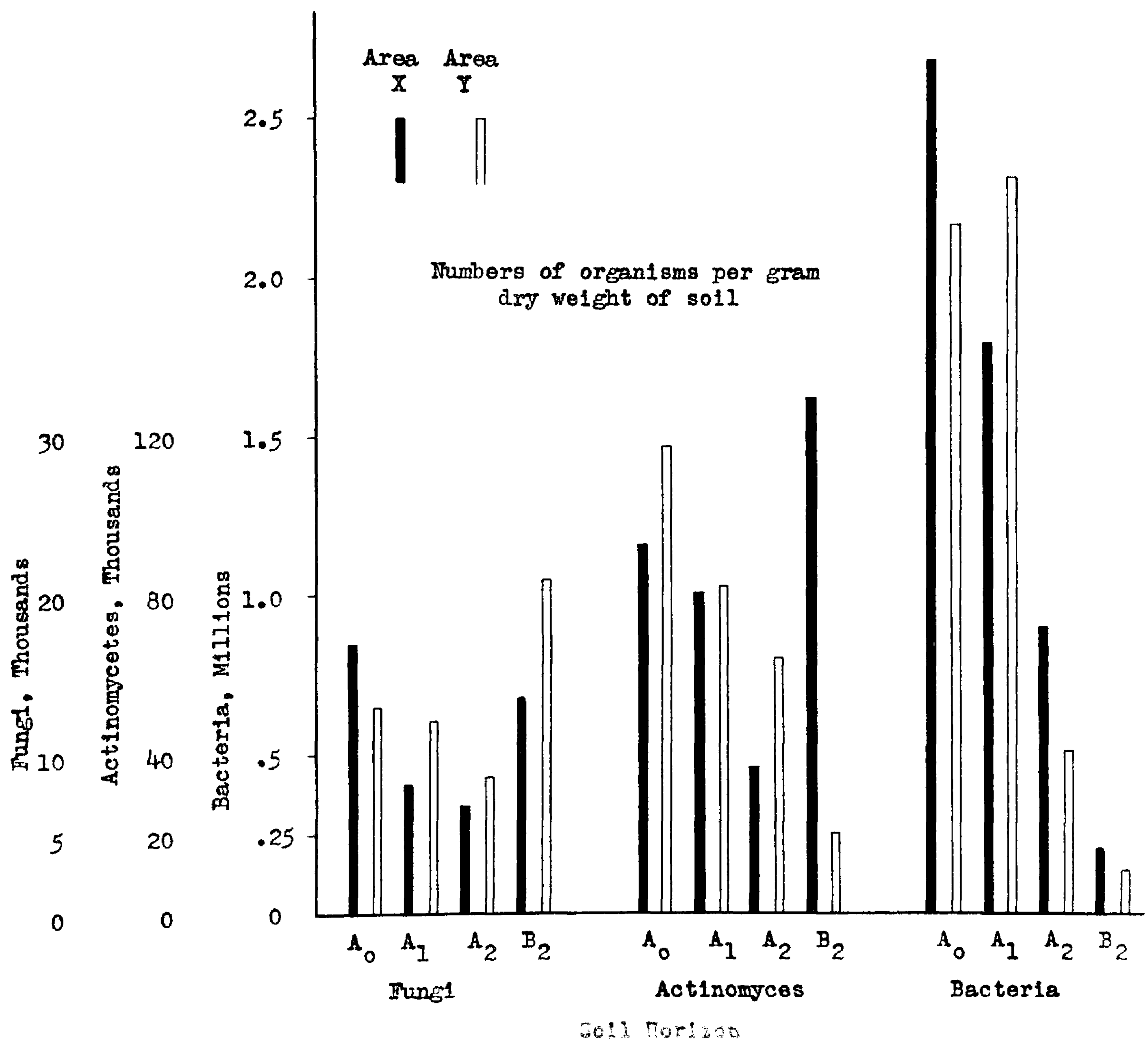


Fig. 53.

VERTICAL DISTRIBUTION OF SOIL MICROBES IN AREA X AND AREA Y DURING EARLY AUTUMN



Results

Total Abundance of Organisms:

The relative numbers of all three classes of organisms investigated in Area X and Area Y ranged from a minimum of 1000 fungi per gram to a maximum of 3,100,000 bacteria per gram throughout the course of the growing season. Of the three classes of organisms, the bacteria were found in greatest numbers followed by the actinomycetes and fungi (Figures 50-53). Although the numbers of organisms fluctuated with the season, the greatest total numbers of bacteria and fungi occurred in Area Y throughout the growing season. Area X exhibited greater total populations of actinomycetes than Area Y. The greatest differences in numbers of organisms between Area X and Area Y occurred with the bacteria; differences for the fungi and actinomycetes were not extreme with the exception of the B_2 horizon. The seasonal change in numbers of organisms showed a maximum count in spring, a minimum during mid-summer, and a secondary maximum in early autumn. This cyclic fluctuation throughout the growing season occurred with all three classes of organisms studied. The greatest numbers of fungi, as determined by plate count, were found in the B_2 horizon for both Area X and Y for all periods of the growing season. In contrast to the fungal population, the bacterial numbers were greatest in the A_0 and A_1 horizons throughout the season. Actinomycete numbers were highest in the B_2 horizon for Area X. The total abundance of organisms in both areas was not high in relation to numbers of organisms found in similar soil types by various investigators. The highest individual bacterial count for any one horizon occurred in Area Y at the A_1 horizon.

Approach to Interpretation of Results:

Fungi: The results presented are primarily quantitative. For each dilution, the numbers shown in Figures 54 and 55 represent the number of colonies in composite samples throughout the growing season. Assuming that each colony developed from a single spore or hypha, the number per gram can be computed by multiplying the number on the plate by the dilution. Adjustment with reference to moisture content of the soil must be made so that the number of organisms present is based upon dry weight of the soil.

Bacteria and Actinomycetes: The results are entirely quantitative since no effort was made to identify the colonies . Actinomycete numbers are computed per gram based upon dry weight of the soil the same way as the bacterial and fungal numbers.

Interpretation of Results

In order to show a relationship between the soil organisms of two contrasting tulip poplar sites, an overall explanation of the role of fungi, bacteria, and actinomycetes in reference to what they do is necessary. A relationship exists between the soil and forest growth and is quite variable and complex. The part that each group of organisms plays in this study is presented, following a brief description of their role in general.

Number of Fungi in Forest Soils:

Fungi are free of chlorophyll and derive their energy from the decomposition of dead or living matter, organic in character. Their prevalence in the soil is closely tied up with the presence or absence of decomposing organic matter. They occur in soils either as free molds or as symbiotic fungi forming mycorrhizae with the roots of higher plants as shown by Wilde (1946). The forms with which the present study is concerned are the ordinary filamentous fungi (Phycomycetes, Ascomycetes and the Fungi Imperfecti) which occur as free molds. Fungi generally occur abundantly in the soil, particularly in soils of high organic content where the acidity is high. This means that the fungi can withstand greater acidities than the bacteria and actinomycetes. Numbers of fungi will increase with moisture content provided there is good aeration, and a supply of organic matter with the proper soil reaction as pointed out by Waksman (1927). The greatest numbers of fungi are found in the upper few inches of soil but will occur to a depth of at least four or five feet. It is evident that the role of fungi in forest soils cannot be over-emphasized, as they decompose proteins, cellulose, hemicellulose, and most other carbohydrates. The composition of the fungus flora of the soil changes with a corresponding change in the nature of the soil. It is important to note that numerically, as determined by the number of single cells, the fungi are fewer in the soil than the bacteria although their actual abundance, as measured by the amount of cell substance produced, may be considerably greater than that of bacterial growth. This residue of mycelia adds to the nitrogenous content of the soil complex. As a rule, most fungi grow under aerobic conditions where most of the cell substance is produced.

Significant Results on Fungi: (Refer to graphs, photographs, and numerical data)

1. The total relative numbers of fungi occurring in both plantation sites, Area X and Area Y, were markedly similar for an

entire growing season in the four soil horizons investigated. This lack of a significant difference can be seen by reference to Figures 54 and 55, and in Tables 52 and 53.

2. A slightly greater total number of fungi occurred in Area Y for the total soil profile throughout the growing season.
3. Fungi occurred in least total numbers of organisms than any of the three groups of organisms studied. This was true for both Area X and Area Y.
4. The greatest number of fungi per gram of soil for both areas occurred in the B_2 horizon, where the number of colonies rises to 16,700 per gram based on dry weight of the soil.
5. In both areas, the fungal population in the A_0 and A_1 horizons was highest in the spring, dropped to a minimum in mid-summer, and reached a secondary maximum in early autumn.

Conclusions Regarding Fungus Results:

Since there is no useful method yet devised to determine how much of the fungus material exists in the soil as mycelium or as spores by this isolation method, there is no concrete way of determining what percentage of the colonies is due to spores and what percentage is due to pieces of mycelia. With this limitation in mind, the fact remains that the greatest number of fungi (spores and mycelia) were found at the B_2 horizon in both plantation sites. Thus, no direct correlation between these numbers and the potential activity of this horizon can be made, unless it can be determined what percentage of these colonies are spores and mycelium respectively. Since the total number of fungi is greatest at the B_2 horizon in both areas it is possible to interpret this result in terms of

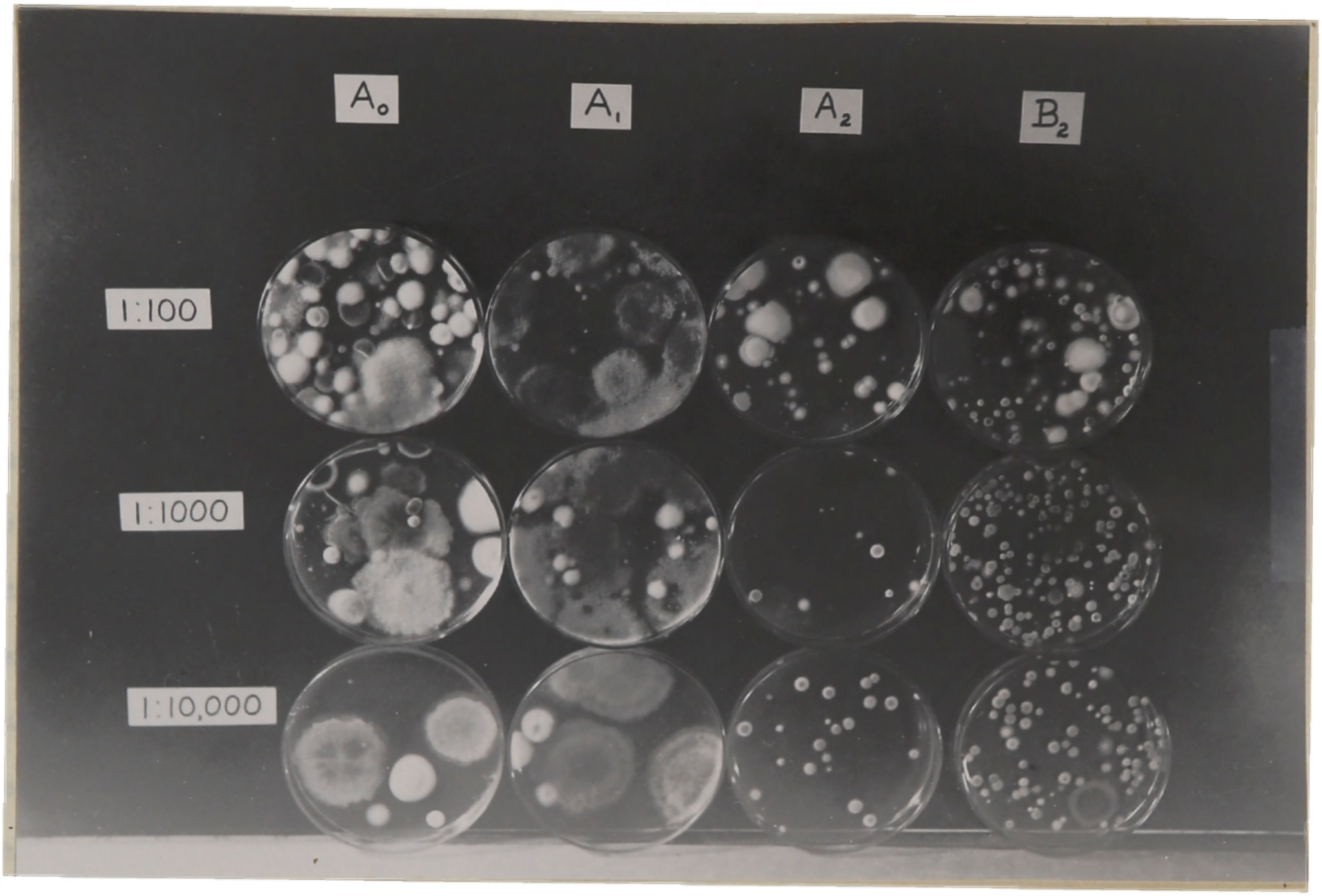


Fig. 54.

A photograph of the relative numbers of fungal colonies occurring by soil horizon in the area of good height growth. The number of colonies on each plate represents soil samples extracted in the Spring (May 20, 1951). Note the diminution in number of colonies with the increased depth of the horizon until the B_2 horizon is reached. The larger number of colonies occurring in the latter horizon is a function of decrease in pH at a soil depth of 20 inches. All of the dilutions show the same relationship with reference to the number of colonies.

factors which limit the vertical distribution of fungi. The results of Tables 52 and 53 reveals in both areas that the most alkaline conditions occur at the surface, and also the greatest content of organic matter, highest moisture content, greater nitrogen content and porosity occur at the same horizon. However, the greatest fungal population occurs at the lower horizon. This result reveals rather clearly that the fungal population in this plantation is a function of the acidity or pH of the horizon concerned. The more acid conditions at lower depths is apparently masking the effect of other factors. This conclusion regarding the fungi points out biologically that the soils are strongly acid and also discloses the "immaturity" of the forest insofar as organic decomposition is concerned. Also, the slightly higher total concentration of fungi in Area Y suggests that the soils in this area are at a generally higher fertility level insofar as soil type is involved. These facts tend to corroborate the evidence that the soil moisture regimen is masking the effects of soil texture as determined microbiologically. Thus, the poor height growth of tulip poplar in Area Y cannot be explained on the basis of low soil biological counts, since just the reverse situation is indicated by these results.

The reflection of microclimate upon the seasonal fluctuation of fungi in the surface horizons of both areas was not so marked as with the bacterial population. However, the lower counts for fungi in midsummer for Area Y at the surface horizon were definitely associated with the higher evaporation rate, less available soil moisture, higher air temperature, greater light intensity, and higher surface soil temperatures of this habitat. The failure of the fungal counts to correlate directly

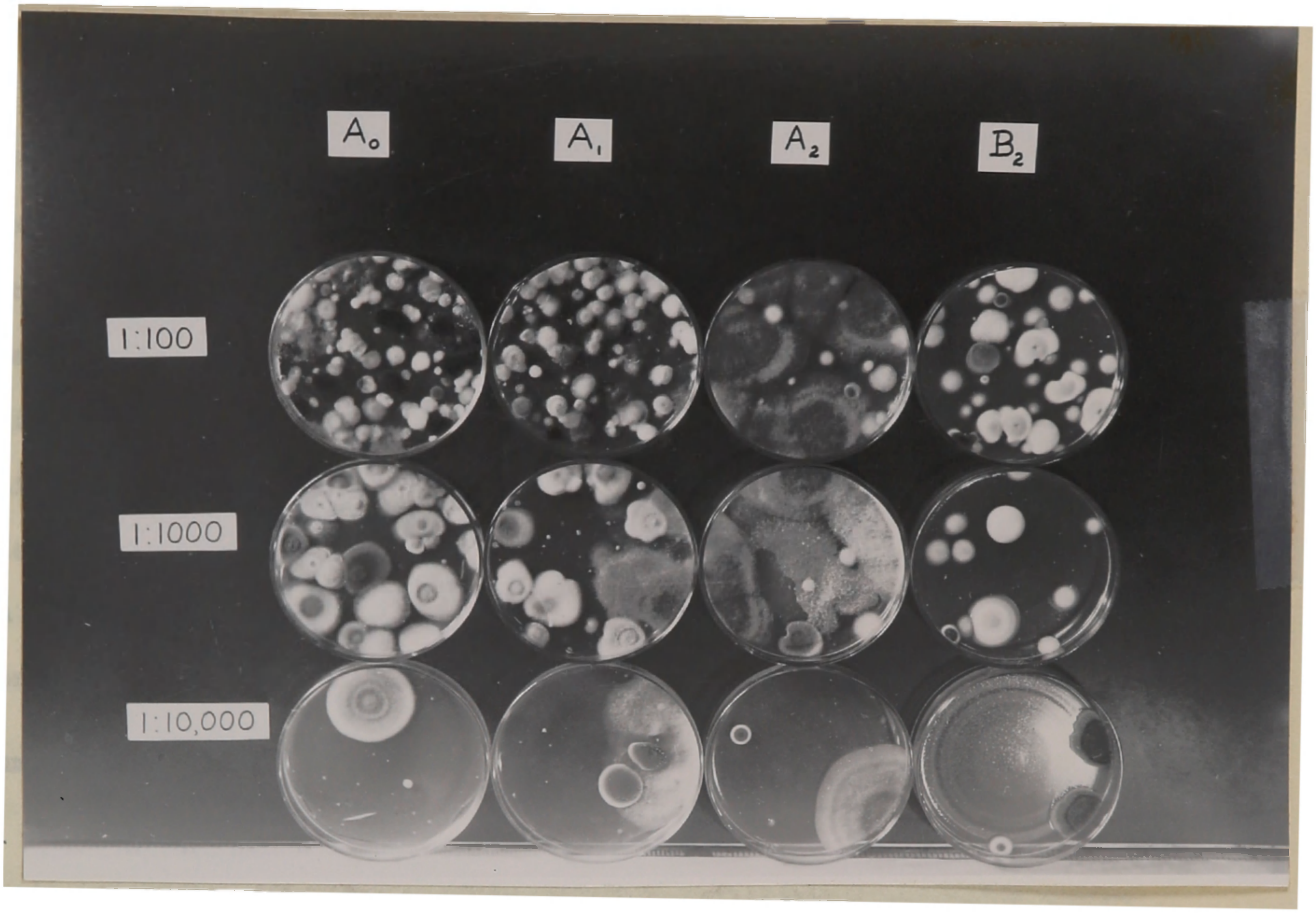


Fig. 55.

A photograph of the relative numbers of fungal colonies occurring by soil horizon in the area of poor height growth. The number of colonies on each plate decreases with depth for all the individual A horizons, and then increases slightly for all dilutions until the B_2 horizon is reached. As with Area X, the numbers of colonies in the B_2 horizon is a function of decrease in pH concentration at a lower depth.

In contrast to Fig. 54 (Area X), there is a greater number of colonies in Area Y with the exception of the B_2 horizon. Area Y, as illustrated microbiologically above, has slightly greater content of organic matter, greater porosity, higher water-holding capacity, greater acidity, and a narrower C/N ratio than Area X.

with the organic matter content of the surface horizons was supposedly due to the immaturity of the plantation; a period of fifteen years is not long with respect to the decay of resistant tree products deposited on the forest floor. The lesser sensitivity of fungal populations at the surface horizons to microclimatic factors is suggested in this study, since the quantitative counts fluctuate less responsively than the bacteria and actinomycetes. Thus, the fluctuation in the fungal population can be utilized to supplement the effect of acidity (pH) and microclimatic elements in soils of plantation-grown tulip poplar. These findings are in accord with the forester's concept of site quality in relation to forest growth.

Numbers of Bacteria and Actinomycetes in Forest Soils:

Bacteria as a group are the most abundant organisms in the soil. In their activities and numbers they exceed all other soil organisms except in the bulk of organic cell substance found in the soil as living and dead microbes. It is not exceptional to find hundreds of millions of bacterial cells in a gram of soil, particularly where the organic substances are present according to Waksman and Starkey (1931).

In this study the bacteria were isolated with the actinomycetes and it is appropriate to present them together since microscopically the spores of the actinomycetes appear much like bacterial cells. However, as a group, the actinomycetes may be considered distinct because they have characteristics that resemble both fungi and bacteria. No attempt is made here to segregate the autotrophic and heterotrophic bacteria as to their physiology and morphology. Most of the bacteria developing on the plates are heterotrophic forms, requiring combined nitrogen, although still larger numbers may develop slowly or not at all.

Lohnis (1886) came to the conclusion that a determination of bacterial numbers in the soil is worthless as an attempt in interpreting soil phenomena. However, later studies have clearly proven that studies on the numbers of organisms are important and indicative when used in conjunction with other edaphic and climatic considerations. In comparing numbers of bacteria, no single variable such as season of the year can be considered alone without reference to moisture content, acidity, and other factors as shown by Waksman (1927). Studies of soil organisms in natural and planted forest stands by Shipman (1947) have shown that site quality is definitely related to soil organism populations. Most of the bacteria in the soil develop best at reactions of acidity close to neutrality (pH7.0) The amount of free air with possible access to bacteria may determine the type of heterotrophic bacteria that develop, either aerobic or anaerobic. As far as moisture content is concerned, all bacteria require a considerable supply of water for active development and is often a limiting factor in the numbers of bacteria present.

Since the actinomycetes are next to the bacteria in number of forms developing on the plates, they are important in the addition of mycelia to the soil. Here again, large numbers do not necessarily indicate more abundant growth, but a result of a greater abundance of conidia. It is well to remember that greater abundance represents a greater potential activity of organisms. The percentage of actinomycetes in forest soils in relation to the number of bacteria is important insofar as decomposition of organic matter in the soil is concerned. Actinomycetes are very sensitive to acidity and to an excess of moisture and the numbers decrease in soils devoid of decomposed material, in comparison with the bacteria.

As a general rule, the less acid the soil the higher is the relative abundance of actinomycetes. Most of the actinomycetes are aerobic and as a rule are more sensitive to changes in reaction and live over a narrower range of acidity and alkalinity than the bacteria as shown by Waksman and Starkey (1931).

Significant Results on Bacteria and Actinomycetes:

1. The total relative numbers of bacteria and actinomycetes occurring in two plantation sites, Area X and Area Y, were not significantly different for an entire growing season, in four soil horizons investigated. This similarity in quantity of organisms can be seen in Tables 52 and 53 and Figures 50-53.
2. A slightly greater total number of bacteria occurred in Area Y for the entire soil profile throughout the growing season. The total actinomycete population was greatest in Area X.
3. Bacteria occurred in the greatest total numbers of organisms than any of the three groups of organisms studied. This was true for both Area X and Area Y.
4. The greatest number of bacteria per gram of soil for Area X occurred in the A_0 horizon, where the count rises to 1,741,620 per gram of soil. For Area Y, the greatest bacteria count was found in the A_1 horizon, where the count rises to 2,043,750 per gram of soil.
5. The greatest number of actinomycetes for Area X occurred in the B_2 horizon, where the count was 71,820 per gram of soil.

TABLE 52.

INFLUENCE OF CERTAIN PHYSICAL AND CHEMICAL EDAPHIC FACTORS UPON THE NUMBERS OF ORGANISMS IN SOILS OF PLANTATION-GROWN TULIP POPLAR

AREA X (Good Height Growth)

Soil Horizon	Soil Treatment Last 15 Years	Soil Reaction pH	Moisture Percent	Soil Texture	Organic Matter Percent	Nitrogen Percent	C/N Ratio	Porosity Percent	Bacteria*	Fungi*	Actinomyces*
A_0	Injudicious cropping and no fertiliz-ation	5.9	21.9	Mixed Hardwood leaf litter and sandy loam	--	--	--	--	1,741,620	11,390	55,150
A_1	Injudicious cropping and no fertiliz-ation	5.4	15.3	Sandy loam	2.03	.119	20:1	46.8	887,000	5,970	34,280
A_2	Injudicious cropping and no fertiliz-ation	5.2	14.7	Sandy loam	.83	.045	21:1	37.8	1,305,500	4,430	13,870
B_2	None	5.3	12.2	Sandy loam to sandy clay loam	.68	.044	18:1	--	113,080	16,710	71,820

* Each value represents the average product of four seasonal isolations times six duplicate plates, or the average of forty-eight plates per soil horizon taken periodically throughout the growing season.

TABLE 53.

INFLUENCE OF CERTAIN PHYSICAL AND CHEMICAL FACTORS UPON THE NUMBERS OF ORGANISMS IN SOILS OF PLANTATION-GROWN TULIP POPLAR

AREA Y (Poor Height Growth)

Soil Horizon	Soil Treatment Last 15 Years	Soil Reaction pH	Moisture Percent	Soil Texture	Organic Matter Percent	Nitrogen Percent	C/N Ratio	Porosity Percent	Bacteria*	Fungi*	Actinomyces*
A_0	Injudicious cropping and no fertilization	5.7	20.3	Mixed grass litter and sandy loam	--	--	--	--	1,695,640	8,810	62,120
A_1	Injudicious cropping and no fertilization	5.3	14.5	Loam to sandy loam	2.16	.127	19:1	48.9	2,043,750	9,630	41,370
A_2	Injudicious cropping and no fertilization	5.0	16.6	Loam to sandy loam	1.04	.063	19:1	42.5	1,451,000	9,510	26,890
B_2	None	4.8	12.0	Clay loam to sandy clay loam	.79	.057	16:1	--	120,100	15,140	8,990

* Each value represents the average product of four seasonal isolations times six duplicate plates, or the average of forty-eight plates per soil horizon taken periodically throughout the growing season.

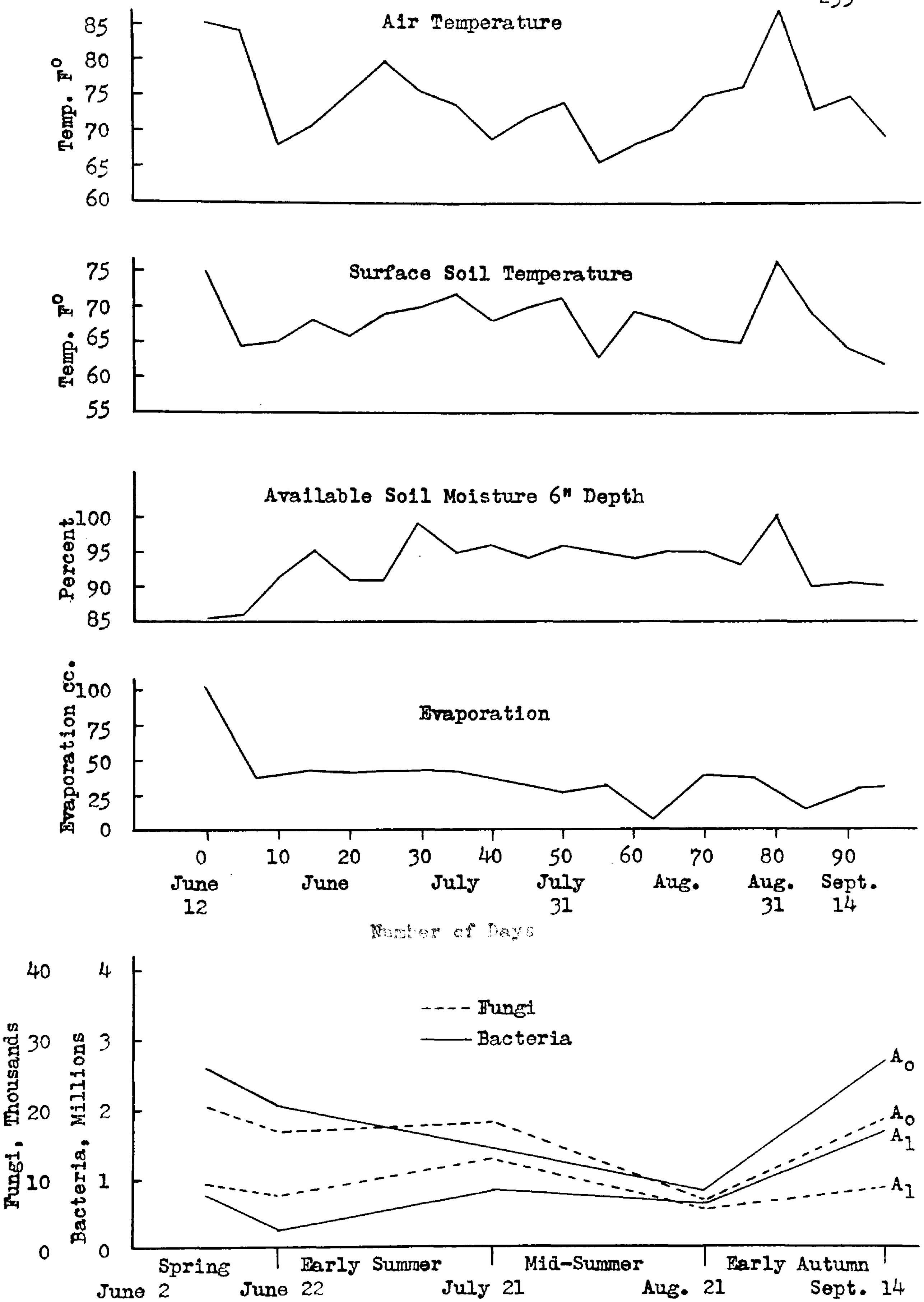
For Area Y, the greatest actinomycete population was found in the A_0 horizon, where the count rises to 62,120 per gram.

6. In Area X, the bacterial population in the surface horizons, A_0 and A_1, was greatest in the spring, dropped to a minimum in mid-summer, and reached a secondary maximum in early autumn. In Area Y, however, the bacteria reached a maximum in early summer, a minimum in mid-summer, and a secondary maximum in early autumn. In both Area X and Y, the actinomycetes followed much the same seasonal fluctuation as the fungi.

Conclusions Regarding Bacteria and Actinomycete Results:

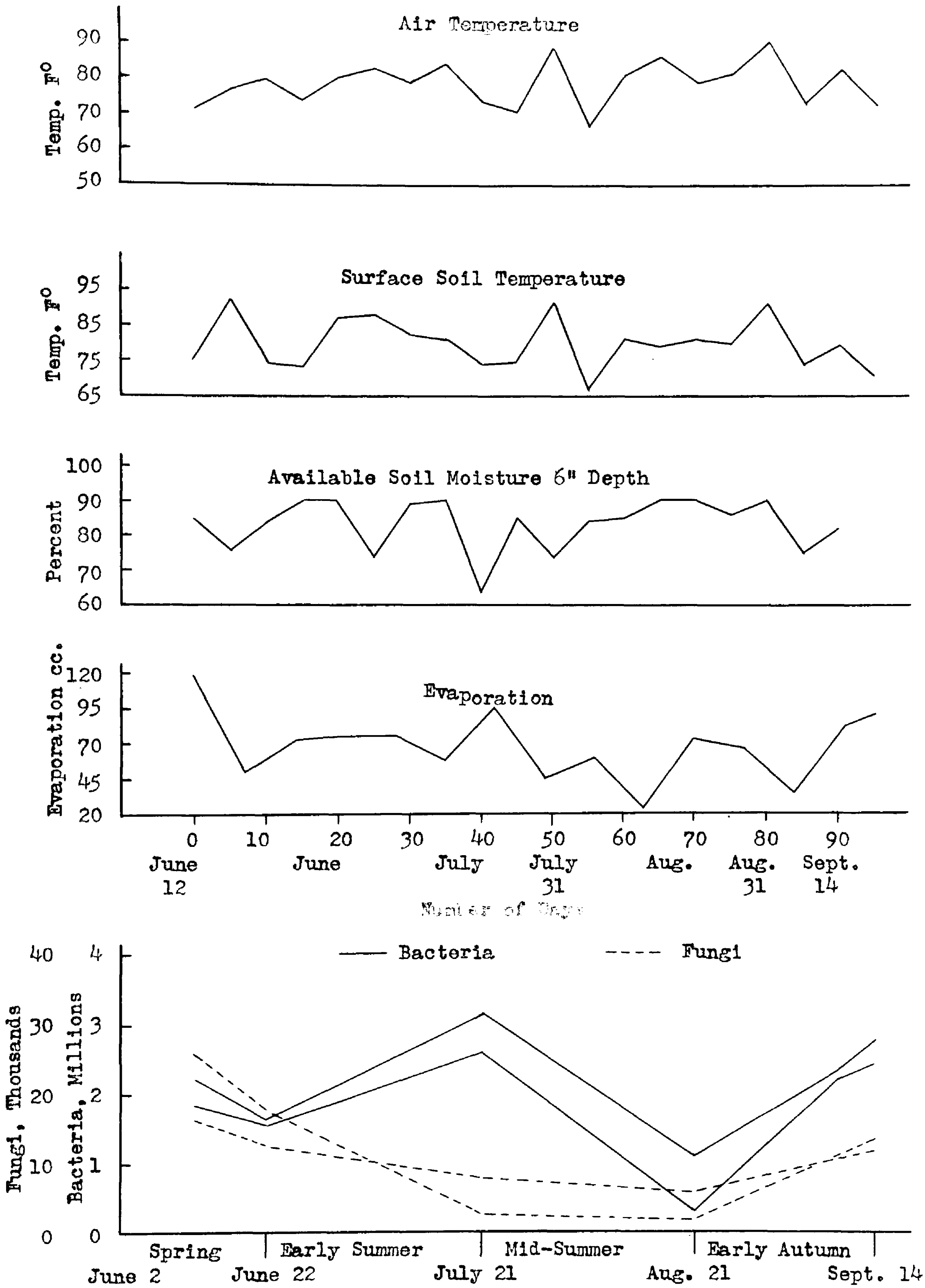
The effects of years of injudicious cropping without fertilization of any kind is strikingly portrayed by the relatively low bacterial counts of this study, taken throughout the growing season. The similarity in total numbers of bacteria and actinomycetes for both Area X and Area Y tends to point out (as with the fungal population) that these two sites are essentially microbiologically similar and that total organism equilibrium is being established at a low quantitative level in both sites. As with the fungi, the total bacterial population is slightly higher in Area Y than in Area X. The correlation of microclimatic factors for the A_0 and A_1 is markedly shown by comparing these two horizions in each area. In Area X, the greatest bacterial population is found in the A_0 horizon, with a very low count in the A_1; in Area Y, the greatest bacterial count is found in the A_1 horizon. This result is clearly a function of the greater available soil moisture, lower evaporation rate, lower soil surface temperatures and higher relative humidity of Area X. The canopy of the tree crowns in Area X is a potent factor in preventing the effect of the

Fig. 56.



THE RELATION BETWEEN NUMBERS OF ORGANISMS AND MICROCLIMATE IN THE AREA OF GOOD HEIGHT GROWTH OF TULIP POPLAR

Fig. 57.



THE RELATION BETWEEN NUMBERS OF ORGANISMS AND MICROCLIMATE IN THE AREA OF POOR HEIGHT GROWTH OF TULIP POPLAR sun's rays from evaporating soil moisture durectly at the surface. In the more arid soil of Area Y, lacking such a protective layer, the number of bacteria at the surface is less, due to desiccation effects. In addition to moisture content of the surface horizons, the soils of Area X more closely approach a neutral or less acid condition than the surface soils of Area Y. A near perfect correlation with increased depth of horizon in Area X is illustrated in Figure 58. These two factors, moisture content and soil acidity, are thus in close relationship to the other microclimatic factors of the individual areas. Here again, by using a microbial factor (bacteria) it is possible to point out that the soil moisture regimen, as a function of external edaphic and climatic factors, is limiting with respect to these tulip poplar sites. As with the fungal results, the greater bacterial population of Area Y cannot be associated quantitatively with the poor height growth of tulip poplar, since Area X possesses a lower microbiological count.

In regard to the actinomycetes, the larger total number found in the surface horizons of Area Y suggests the close relationship to the fungi with respect to organic matter, available oxygen, and soil acidity. The decrease in numbers of actinomycetes with depth until the B_2 horizon is reached, in Area X, is associated rather closely with the more acid conditions at greater depths, to the possible washing down of the conidia or to the greater resistance of these organisms to a lack of oxygen.

The quantitative results obtained here for three distinct groups of soil organisms show that the bacteria are most sensitive to microclimatic factors for use as supplemental evidence in evaluating plantation site quality. This evidence is based upon the plate count method of isolating

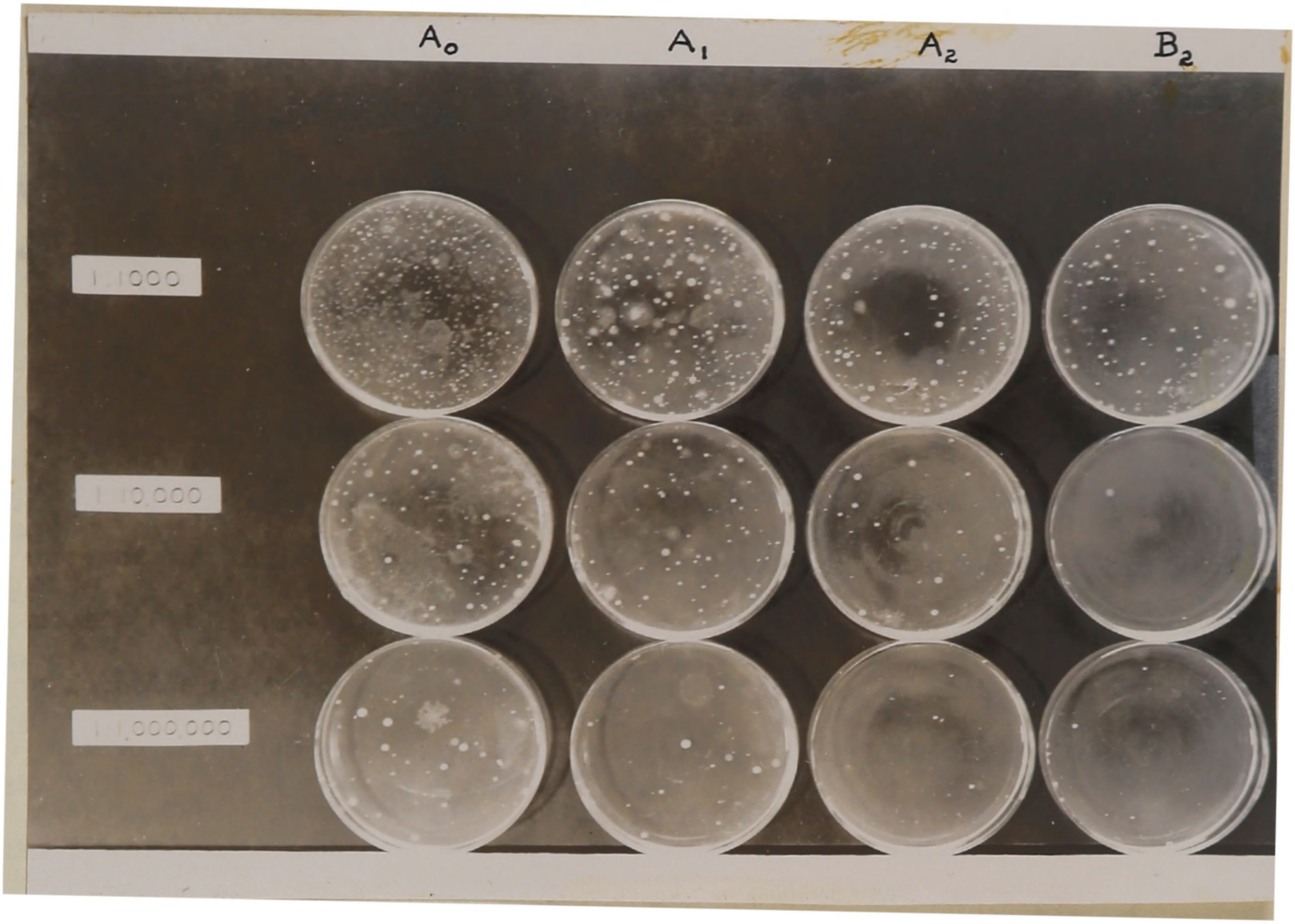


Fig. 58.

Bacteria and actinomycete colonies showing the relative density of organisms by soil horizon for the area of good height growth (Area X). These soil microbial isolations were made in the Spring (May 20, 1951). A nearly perfect correlation with increased depth of horizon is illustrated by this plate count; the numbers of bacteria decrease with increased depth in all three dilutions. The actinomycete counts decrease with depth until the B_2 horizon is reached, illustrating their tendency to follow the trend of fungi for similar horizons. The higher bacterial count of the A_0 and A_1 horizons as shown above is closely related to the more alkaline conditions of the surface soil as contrasted to the more acid conditions at greater depths in this area.

organisms, as used in this study. The counts made for each group of organisms are based upon the average value of six duplicate plates for each soil horizon taken four times throughout the growing season, or the average of forty-eight counts.

SUMMARY AND CONCLUSIONS

A comprehensive investigation of the edaphic, microclimatic, and microbiological factors contributing to the differential height growth of plantation-grown tulip poplar (Liriodendron tulipifera L.) was undertaken. This silvical study was conducted at the Fred Russ Experimental Forest in Cass County, Michigan, during the growing seasons of 1951 and 1952. The investigation includes the results of studies made both in the field and in the laboratory in an effort to determine the silvical requirements of plantation-grown tulip poplar. Since a large acreage of Russ Forest is planted to tulip poplar in various mixtures, a knowledge of the growth habits of this species under the climatic conditions of southwestern Michigan seemed advisable. In addition, this locality of Michigan possesses a large number of farmers and private owners who are interested in converting abandoned farm land into tree farms as a continued investment. The present study was initiated to determine the feasibility of recommending tulip poplar plantings for such enterprises.

The research work was carried out on a 15 year old-20 acre tulip poplar-catalpa plantation. Observation of the tulip trees in this particular plantation show marked differential rates of height growth on trees of the same age and density. This difference in the height growth is associated with the presence of an old-growth hardwood stand adjoining the plantation on the south and west. Trees located next to these woods are one and one-half to two times the height of trees north of the woods. The plantation was thus conveniently divided into two separate areas for research purposes. The area exhibiting good height growth was designated as Area X; the area of poor height growth was designated as Area Y. All edaphic, microclimatic, and microbiological data were obtained at the same stations established in both areas. Maps, photographs, and straight-line transects were made in the plantation showing the climatic stations, boundaries, and soils of the experimental areas. A statistical analysis of variance was applied to the results of the physical and chemical soil factors.

The laboratory experiments on the physical-edaphic factors on the two sites, Area X and Area Y, revealed only two properties of an actual and statistically significant difference between the two areas. These two factors, the amount of fine clay and the water-holding capacity, were the only two variables which differed significantly between Area X and Area Y. Ten physical-edaphic properties were studied in detail and treated statistically. The physical soil factors investigated were soil texture, specific gravity, volume weight, porosity, hygroscopic coefficient, water-holding capacity, moisture equivalent, soil evaporation loss, depth of root penetration, and the water-table fluctuation.

Laboratory experiments on the chemical-edaphic factors of the soils in each area were treated statistically in the same manner as the physical factors. A summation of six rather important major chemical soil properties such as soil acidity, organic matter content, total nitrogen, cation-exchange capacity, total bases, and base saturation, indicated no outstanding real or statistically significant difference between the areas of good and poor height growth of tulip poplar. Further verification of the lack of any outstanding chemical difference was substantiated by a study of seven individual major nutrient elements.

The field experiments concerned with microclimate, growth rates, sunscald, bark thickness, and plant succession were found to be more closely associated with the growth differential than either the physical or chemical edaphic factors. A complete stem analysis of individual trees in both areas revealed the external effects of site upon radial and height growth rates. The physiological "dryness" of the site in Area Y is rather clearly disclosed by the structural variation of the bark of trees in this area.

The effect of the growing season precipitation and temperature on the height and diameter growth of tulip poplar for a 11-year period was undertaken. By use of the correlation coefficient and past records of the U. S. Weather Bureau, it was possible to show the effect of accumulative growing season precipitation and temperature upon the height growth of tulip poplar for both Area X and Area Y. Although both areas were linearly dependent upon growing season precipitation, Area Y was found to be less effective in its utilization of rainfall throughout the growing season. A supplemental study on the radial growth of trees in the adjoining old-growth hardwoods showed no close correlation to growing season precipitation throughout a similar period. The extreme sunscald exhibited by trees in Area Y was investigated and the results reveal the indirect effects of exposure, evaporation, air temperatures and wind velocity upon the height growth of tulip poplar. A study of the herbaceous vegetation in relation to the soil moisture conditions of each area was carried out to correlate the type or kind of vegetation associated with a particular habitat. The results tend to show a correlation between soil moisture conditions of each area and the kind of herbaceous vegetation indigenous to the site.

The growing season study of seven microclimatic factors in Area X and Area Y indicated in virtually every case that the integrated factors of evaporation, relative humidity, air temperature, surface soil temperature, percent available moisture, and light intensity are closely related to the marked differential height growth of tulip poplar. The above factors were measured daily throughout the growing season, with the exception of light intensity.

As a means of further corroborating the findings of the climatic and edaphic factors, a quantitative soil microbiological study was undertaken. The results of this investigation show how numbers of certain groups of soil organisms can be utilized to supplement and verify other site quality factors. Results on the relative numbers of organisms found in each area point out the manner in which one site variable can be masking the effect of another with regard to possible limiting factors. Area Y was found to be microbiologically more suitable to the growth of tulip poplar in terms of organism numbers, and yet this area is producing the poorest trees. The manner in which the moisture regimen is overriding the effects of soil fertility and improved soil texture is clearly revealed by this study. Also, it was possible to show how the microbial population fluctuates throughout the growing season under a set of simultaneously investigated variables. Soil organism numbers were shown to be supplemental indices to the forester's concept of site quality in terms of tree growth.

Thus, evidence based upon a comprehensive study of the silvical requirements of plantation-grown tulip poplar shows that the continuous soil-moisture regimen throughout the growing season is the principal limiting factor contributing to the marked differential height growth of this species.

The presence of an old-growth hardwood stand adjoining the south and west sides of the experimental plantation alters the soil-moisture regimen under a set of integrated edaphic, microclimatic, and biological conditions. This influence of the old-growth hardwoods serves to disclose the ecological contrast between good and poor sites of tulip poplar.

The silvical characteristics of young plantation-grown tulip poplar, as shown by this study, indicates this species as being critical, sensitive, and exacting with regard to its site requirements at the fringe of its geographical range.

In the establishment of plantation-grown tulip poplar under the edaphic and climatic conditions of southwestern Michigan, the forester should give primary consideration to the soil-moisture regimen of this species. The results of this investigation emphasizes the importance of soil moisture in relation to border plantings, drainage, and exposure for proposed tulip poplar plantations.

For maximum development, this species requires side-shading and protection in its early plantation establishment. Based upon these silvical findings, it is recommended that tulip poplar be interplanted with a previously established species, such as white pine, red pine, or other species. Tulip poplar should be interplanted only when the "nurse trees" are of sufficient size to give maximum side protection to this species. As the tulip trees reach a size when side-shading is no longer required, the "nurse trees" can be removed if pure tulip is desired.

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