

NUTRITIONAL-ECOLOGICAL RELATIONSHIPS  
AFFECTING HEIGHT GROWTH OF PLANTED  
YELLOW-POPLAR (LIRIODENDRON TULIPIFERA L.)  
IN SOUTHWESTERN MICHIGAN

Thesis for the Degree of Ph. D.  
MICHIGAN STATE UNIVERSITY  
Charles Edward Schomaker  
1962

This is to certify that the

thesis entitled

NUTRITIONAL-ECOLOGICAL RELATIONSHIPS  
AFFECTING HEIGHT GROWTH OF PLANTED  
YELLOW-POPLAR (LIRIODENDRON TULIPIFERA  
L.) IN SOUTHWESTERN MICHIGAN

presented by

Charles Edward Schomaker

has been accepted towards fulfillment  
of the requirements for

Ph. D. degree in Forestry

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Major professor

Date Feb. 16, 1962

Q-169





## ABSTRACT

# NUTRITIONAL-ECOLOGICAL RELATIONSHIPS AFFECTING HEIGHT GROWTH OF PLANTED YELLOW-POPLAR (*LIRIODENDRON* *TULIPIFERA* L.) IN SOUTHWESTERN MICHIGAN

by Charles E. Schomaker

Two parts of a yellow-poplar (*Liriodendron tulipifera* L.) plantation in the Fred Russ Forest in southwestern Michigan, show a striking difference in height and diameter growth. Twenty-two years after planting, trees in the better area are approximately double the size of the trees in the poorer area. Since yellow-poplar is a highly desirable hardwood species for reforestation, a study was made to determine the reasons for this growth differential.

The plantation is located on an abandoned agricultural field with similar topography and soils throughout. There is no evidence of variation in past land-use practices between the two growth areas. The better growing trees are within an area influenced by an old-growth stand of mixed hardwoods which lies immediately to the south and west of the plantation.

In 1951 and 1952, R. D. Shipman made a microclimatic and edaphic study of the plantation. His study showed that there are significant microclimatic differences between the two areas, but he did not report any important soil nutrient differences between the areas of good and poor growth. He



concluded that the growth differences between the two growth areas are the result of microclimatic variation that produced a more favorable soil moisture regime in the area of good growth.

The foliage and general appearance of the trees in the poor growth area suggest nutrient deficiencies not evident in the good growth area. Besides the size difference, the poorer trees have smaller leaves that show chlorosis and bronzing, suggestive of nitrogen and phosphorus deficiency. In contrast, the leaves of the better trees are larger and exhibit a healthy green color. In addition, the leaves of the poor growth trees turn to autumn colors and abscise several weeks earlier in the fall than the good growth trees. This is also an indication of nitrogen deficiency. Following these observations, the nutrient regime of both areas was examined, using both foliar analysis and a chemical soil examination.

A statistical comparison of the foliar analysis data revealed that there are significantly greater concentrations of nitrogen and phosphorus in the leaves from the good growth area as compared with the poor growth area. Comparing these results with other studies strongly indicate that a severe nitrogen and phosphorus deficiency exists in the poor growth area but not in the good growth area. This conclusion is strengthened by the highly statistically significant correlation between both tree height and diameter, and the concentration of both nitrogen and phosphorus in the leaves.

The chemical soil analysis did not show statistical

difference for any of the factors tested in the A horizon. In the B horizon, however, the concentrations of total nitrogen and available phosphorus were highly significantly different between areas. The nitrogen difference was in favor of the poor growth area and the phosphorus difference in favor of the good growth area. Other investigators have shown that soil analysis is an unreliable means of determining the amount of nitrogen available to plants. There has been little correlation between total nitrogen as determined by soil tests and the growth of trees or other plants. On the other hand, phosphorus content as determined by soil tests has been found to be positively correlated with tree growth.

The results of the foliar analysis indicate that the good growth area has a more favorable soil nutrient regime than the poor growth area. To find the source of the additional nutrients in the better growth area, the annual deposit of litter in both areas was examined. Over two and one-half times as much litter was deposited on the good growth area as the poor growth area, also the litter on the good growth area was richer in many of the essential nutrients. A sizeable portion of the additional litter comes from the adjoining old-growth hardwood stand.

It is concluded from the present study that the growth differential between the two portions of the plantation is due largely to more nutrients being available to the trees in the good growth area as a result of the larger annual deposits of litter. The poor growth area is severely

deficient in available nitrogen and phosphorus, and this has limited the growth and vigor of the trees on that area. In addition, the microclimatic differences found by Shipman result in a more favorable transpiration-water absorption ratio in the good growth area.

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By

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A THESIS

Submitted to  
Michigan State University  
in partial fulfillment of the requirements  
for the degree of

DOCTOR OF PHILOSOPHY

Department of Forestry

1962

### ACKNOWLEDGEMENTS

The author expresses his sincere gratitude to the many persons who aided him in various ways in this study. These include Dr. Terrill D. Stevens, Head of the Department of Forestry, Michigan State University, and Drs. Donald P. White and Jonathan W. Wright, faculty members of that department. Also included are Mr. Raymond F. Finn, Project Leader, Central States Forest Experiment Station; Dr. Henry D. Foth and Mr. A. S. Islam, Professor and Graduate Student respectively, of the Department of Soil Science, Michigan State University; and to Mr. S. W. McCullough, former Resident Forester of the Fred Russ Forest, Cass County, Michigan.

Particular thanks are due to the author's faculty advisor, Dr. Victor J. Rudolph, Associate Professor of the Department of Forestry, Michigan State University, for suggesting this study and for giving generously of his time whenever help was needed. Dr. Rudolph's constant encouragement and advice is deeply appreciated.

To these and to all others who have not been mentioned, my thanks are gratefully acknowledged.

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## CHAPTER I

### INTRODUCTION

Growth is the foundation upon which good timber management is built. The most profitable return from investments in forest land for timber production is realized by growing trees to merchantable size in the shortest possible time. Matthews (1935) states that, "the whole aim in forest management is to get the greatest possible growth from our forest and at the same time leave the smallest amount of timber on the ground as a permanent capital investment." To accomplish this objective, the forest manager must have basic knowledge of the commercial tree-species best suited for each site condition he encounters, and information on practical means of improving site to promote faster growth of quality trees. More information is needed in regard to the soil, water, nutrient, and microclimatic requirements of important tree species.

Tree growth is a result of all the combined influences of environment acting on the genetic characteristics of individual trees. The comparative growth rate will vary with the balance of the environmental factors to the optimum demanded by the inherited physiological capabilities of each tree.

This study covers certain phases of the environment as related to the growth variation of yellow-poplar (Liriodendron tulipifera L.) in two portions of a plantation established in 1938. This twenty-acre plantation, located on former

agricultural land, is unusual because of the extreme differential height and diameter growth exhibited by trees planted at the same spacing in a relatively restricted area. An investigation to determine the reason for this difference in growth is the object of this study. Since these trees came randomly from the same nursery stock, the effect of genetic variation on growth does not enter into the average difference between the two portions of the plantation studied, and is not within the scope of this study. Hence, differences in form, vigor, and especially size of these trees most likely result from variations in the environmental complex between the sites on which they are found.

Although it is practicable to investigate only separate phases of the environment, it should be recognized that any one factor does not affect tree growth as a single entity in itself but only as a part of a vast interrelated and interacting complex of factors. Temperature affects water availability and use. Soil moisture influences nutrient element absorption, and soil nutrients may in turn affect the absorption of water. The interaction of the many factors may be almost infinite and in many cases are unknown or unrecognized. With this in mind, the present study is confined to a few more obvious factors that may be seriously limiting.

Yellow-poplar (tulip-tree) is an important timber species and more information is needed concerning its silvical characteristics and the site conditions best suited for its best growth. On the basis of its individual merits, this tree can be considered one of the more valuable hardwoods in

the United States (Harlow and Harrar, 1941; Smith, 1961). It is relatively free from attacks of insects and disease pathogens, and under forest conditions develops a tall, straight trunk, free of side branches for a considerable distance from the ground. On good sites, growth is relatively rapid and trees will attain heights of well over 100 feet (198 feet, maximum recorded) and diameters up to 12 feet.

Yellow-poplar grows best on moist, friable soils of moderate depth, where drainage is good. Although it will do well on a wide variety of soils, it is not usually found on either relatively wet or dry sites. Fertility appears to be an important factor in the growth of this tree, and Mitchell and Chandler (1939) classify yellow-poplar as a "nitrogen-demanding" species. The root system is normally deep and widespreading, and its crown is often small, oblong, and rather open under forest conditions.

Yellow-poplar is intolerant of overhead shade, and is normally not abundant in old stands. Large crops of seeds are produced at irregular intervals, but germination is usually low, averaging about 5 percent and rarely over 14 percent (U. S. Forest Service, 1949). It usually seeds in open fields or large clearings when the mineral soil has been exposed. Because of its many desirable qualities, yellow-poplar is widely planted throughout its range.

The wood of this species is moderately soft and weak, straight-grained, light, and even-textured. It is easily worked without tendency to split, and is well suited to rotary cut veneer used for the interior finish of furniture

and cabinet work. The sapwood is whitish in color and the heart-wood yellow to pinkish-brown. The wood has a wide variety of uses, the most important being for furniture, doors, sashes, and musical instruments (Brown and Panshin, 1940).

## CHAPTER II

### STATEMENT AND SCOPE OF THE PROBLEM

The problem of site requirements for planting commercially valuable forest trees is an extremely important one. Large expenditures of time and money have been wasted by planting species on sites for which they were not adapted. Such attempts result in either low survival, or equally important, in such low growth rates and poor form that the land itself can usually be considered wasted. However, once the site requirements are well known for all important species, each site can be fully evaluated and the best species for those conditions can be planted. As is often the case, areas in need of planting can be reclaimed, at least to some extent, by a program of site improvement through the judicious use of fertilizers, weed control, deep plowing, cover crops, or other means of site preparation.

Yellow-poplar is a favored species for hardwood planting. The value of this highly desirable tree is limited only by its relative scarcity in natural stands. Attempts to plant yellow-poplar sometimes meet with failure because of its rather exacting site requirements. Even areas which once were good natural yellow-poplar sites may not be adaptable for planting because of deterioration from past poor land practices or through changes in microclimate. On one such area in Cass County, Michigan, yellow-poplar was planted in a field abandoned for agricultural use. There, the success of the planting over most of the area was spectacularly poor,

not through lack of establishment, but because site conditions resulted in poor growth and form of the trees. Near the southern and part of the western boundary of the plantation, however, an exception to the generally poor condition of the trees is found. There, the yellow-poplar has made acceptable growth, and exhibits the tall, straight, clean form that makes it such a desirable tree.

The difference between the areas of good and poor growth was outstanding from the early years of the planting. Shipman (1952) studied soil and microclimatic conditions in both parts of the stand. Data from the study failed to reveal any important soil differences. Some significant microclimatic variations were observed between the two areas, but not of a magnitude to account fully for the large apparent site variation.

The persistent, striking difference in the appearance of the trees in the two portions of the stand with respect to color, leaf size, and density of the foliage coupled with obvious differences in tree size and vigor strongly suggest site variation related to soil fertility. In addition, history of past agricultural practices on this area indicates that the soil was badly depleted of nutrient elements.

This study evaluates soil fertility factors by using foliar analysis to measure the nutrient availability in the two parts of the plantation. A more precise resampling and analysis of the soil using advanced methods is also included.

### CHAPTER III

#### REVIEW OF LITERATURE

The relationships between environment and tree growth have long been an important consideration in management of forest land. In forestry, these considerations are expressed by the concept of site, and the study of site factors and their measurement has occupied the attention of many investigators.

Site is defined by the Society of American Foresters (1958) as "an area, considered as to its ecological factors with reference to capacity to produce forests or other vegetation; the combination of biotic, climatic, and soil conditions of an area." It might also be expressed as a specific (but dynamic) combination of many interrelated biotic, climatic, and edaphic factors found on a particular area, which in their total effect, regulate the growth of trees (or other vegetation) within the boundaries of the plant's genetic capabilities. This combination of factors, acting together, regulate the supply and distribution of the basic necessities for vegetative growth; space, moisture, light, a desirable temperature range, oxygen, carbon dioxide, and the essential plant nutrients (Kramer and Kozlowski, 1960).

Heiberg and White (1956) point out that site is a complex composed of many factors influencing the development of a forest, and that a forester must be aware of all the effective factors that contribute to this development.



They say, further, that it is especially important that the forester sift out the most important factors that dominate growth, health, or form of the vegetation on a particular site. Husch (1959) observes that the relationship of growth to environment is difficult to measure. The factors of site and the plants themselves are interacting and interdependent, making it difficult to assign cause and effect relationships. Like Heiberg and White (1956), he emphasizes that one factor must not be isolated and studied alone, lest the influence of other factors be masked and consequently not recognized.

Although it is important to recognize that all site factors affect growth, certain of them frequently dominate the productivity of an area (Heiberg and White, 1956; Kramer and Kozlowski, 1960). Once these dominant site factors have been determined, the forest manager is better able to plan his operation. Some factors such as macroclimate, physiography, and certain soil conditions cannot be easily manipulated, and species or forest types must be sought that are best adapted to these confines. Others can be altered by judicious use of silvicultural and site improvement techniques to provide better tree growth (Kramer and Kozlowski, 1960; Rudolph, 1958).

In nature, growth of trees probably never reaches its genetic potential. One or more of the basic necessities are usually limiting to some extent. The principle of limiting factors was first proposed by Liebig in 1843 in his "law of the minimum", and was later modified by Blackman and by Mitscherlich (Kramer and Kozlowski, 1960; Meyer and Anderson,

1952).

Blackman's application of Liebig's "law of the minimum" was subject to some question, and in 1909 Mitscherlich modified this concept to state that "the increase in any crop produced by a unit increment of a deficient factor is proportioned to the decrement of that factor from the maximum" (Bray, 1954). This interpretation of the principle of limiting factors is probably more in accord with actual conditions.

Available water is frequently the factor most limiting to tree growth on most forest land. White (1958a) states that "taking the temperate forest regions as a whole, the supply of water from all sources available for plant growth is usually less than optimum and therefore limiting." Kozlowski (1958) reports that soil moisture deficits often occur at the time of year when other factors are often the most favorable for growth and that water undoubtedly controls growth more than any other factor in many areas.

Working in the south, Zahner (1956) found that a water deficiency occurred as early as May in some years, on sites with limited storage capacity. In most years, water deficits that limited growth had occurred by June on nearly every site evaluated. In New Hampshire, Husch (1959), working with four different site conditions, found that cessation of growth of white pine could be attributed to an interaction between photoperiod and soil moisture.

A study in North Alabama (Schomaker, 1958) found that early survival of planted yellow-poplar decreased with

decreasing soil moisture, and that there was a strong positive correlation between height growth and percentage of soil moisture for the first two years after planting.

Available moisture holding capacity of the soil was found to be highly and positively correlated with jack pine growth (Pawlick and Arneman, 1961). White (1958a) points out that "most workable (site) classification schemes are, in effect, an attempt to estimate indirectly the soil moisture regimes and specifically, 'available water' for tree growth."

"Except in situations of acute nutrient shortage, a scheme which would estimate the amount and distribution of available water during the growing season would most probably most accurately evaluate site."

The importance of available water as the most limiting factor on many sites has often led foresters into the error that other factors are not important. On the other hand, Wilde (1958b) emphasizes that in spite of the far-reaching influence of soil moisture, it cannot be singled out as the most important ecological factor as is so often expressed in forest literature, but that the development of any plant depends upon the satisfactory level of all soil factors.

Plant nutrients have been receiving increasing attention as an important site factor. These essential elements for plant growth, long ignored or depreciated by many American foresters, are now coming into their own. Wilde (1958b) notes that early students of environment were inclined to overemphasize the role of water in plant growth and pay little attention to nutrients. Voigt (1958) states, "while

no one can deny the sometimes paramount importance of soil moisture in tree growth, it should be appreciated that the level of available nutrient elements also exert a very positive influence." On old fields, depleted of soil nutrient elements from years of destructive agriculture, and on uncultivated but naturally infertile soils, deficient nutrients may be a more seriously limiting factor than soil moisture. Even when soil moisture has been seriously deficient, judicious applications of nutrient elements have resulted in increased yields and a better utilization of water for growth (White, 1958a).

Many foresters formerly believed that all forest sites had a sufficient supply of nutrients for tree growth, and that plant nutrients are not as important for forest trees as they are for agricultural crops. Certain fundamental differences do exist between nutrient utilization by forest and farm crops, but an adequate supply of nutrients is as essential for one as for the other. Deeply penetrating and widespreading root systems enable forest trees to more efficiently exploit less fertile soils for nutrients. In addition, annual removal of large volumes of plant materials in agriculture has a greater tendency to deplete the soil of nutrients than routine forest practices.

Mitchell and Finn (1935) state that the net loss of plant food elements from forest soils is almost negligible, even though a timber crop is harvested periodically. Cycling of plant nutrients through deep root feeding by trees, and annual leaf fall, maintain the fertility of a forest site

(Mitchell and Finn, 1935; Wilde, 1958b). In addition, the litter cover on the forest floor, plus the lack of annual cultivation provide a more favorable habitat for soil micro-organisms, which in turn results in a more rapid release of nutrient elements from soil minerals and organic matter. Mycorrhizal associations of tree roots also are a factor in the better utilization of relatively infertile sites.

The importance to soil fertility of annual additions of organic matter and of the plant nutrients it contains, is well established. Ovington (1956) states that a well stocked forest stand produces approximately 3,000 pounds of dry leaf matter per acre. Scott (1955) reported that a mixed hardwood stand in the Appalachians produced an estimated 4,000 pounds of litter per acre per year, a 50 year-old birch stand produced 2,970 pounds, and the hardwood type in general produced an average annual quantity of 1,842 pounds of litter per acre. A hardwood stand producing 1,572 pounds of litter per acre provides 11.9 pounds of nitrogen, 7.7 pounds of potassium, 2.3 pounds of phosphorus, 12.5 pounds of calcium, and 6.4 pounds of magnesium per acre. Yellow-poplar litter was reported to contain 0.51 percent nitrogen, 0.11 percent phosphorus, 0.956 percent potassium, 0.21 percent magnesium, and 2.56 percent calcium.

Despite the ability of forest trees to occupy infertile sites more efficiently than agricultural crops, tree nutrients may be seriously limiting on some areas and should not be ignored. Carried to the extreme, a marked deficiency may occur, resulting in low-vigor, slow growing trees showing

obvious deficiency symptoms. Even where no clear visual deficiency symptoms are exhibited, trees may have "hidden hunger" resulting in a significant depression of growth over what is possible if soil nutrients were at an optimum level. Leyton (1957b) states that substantial increases in tree growth have been reported in many countries following applications of mineral fertilizers, and it is generally recognized that many soils under forest cover or available for reforestation are deficient in nutrient elements. In his own work in England (Leyton, 1956), he found a marked response in the growth of sitka spruce when the nutrient status of the trees was improved by fertilization.

Fertilization of yellow-poplar seedlings on a low-nutrient site resulted in a significant increase of height growth the first year after planting as compared to trees without fertilization (McAlpine, 1959).

Many examples of increased growth resulting from improved soil fertility due to fertilization are cited by White and Leaf (1956). Stone (1958) reports that foliar tests from 70 localities plus similar results from other work, indicate that inadequate nitrogen limits growth in many northeastern forests. Substantial increases in height and diameter growth and in the nitrogen content of the leaves of yellow-poplar and other species were found, when planted in a mixture with the nitrogen-fixing legume, black locust, over that of the same species planted on the same site in pure stands or in mixtures with non-legumes (Finn, 1953a).

Swan (1960) believes that growth in many Canadian nurs-

eries, plantations, and natural stands is being seriously retarded by nutrient deficiencies. The importance of soil fertility is well recognized in Australia (Moulds and Applequist, 1957), where it is standard practice to analyze the soil for total phosphate prior to plantation establishment. Deficient areas are brought up to an established minimum level by additions of super-phosphate. Corrections for zinc deficiencies are also necessary in certain instances in Australia (Kessell and Stoate, 1938). Thus it becomes increasingly clear that attention should be given to the nutrient regime of forest sites.

An early and thorough study of the nitrogen nutrition of deciduous trees by Mitchell and Chandler (1939) showed that the range from 2.15 to about 3.00 percent of dry leaf weight of nitrogen is needed for optimum growth of yellow-poplar. Leaf analysis of yellow-poplar growing naturally on a variety of sites in northeastern United States had nitrogen concentrations of from 1.70 to 2.33 percent of dry leaf weight (Table 1), with an average of 2.04 percent. Applications of fertilizer using 60 pounds, 120 pounds, and 180 pounds of nitrogen per acre on the poorest site (1.70 percent leaf nitrogen) resulted in annual diameter increments of .166 inches, .258 inches, and .280 inches, respectively, as compared to .119 inches on the control plot (no fertilizer). In the southeast, Wells (1961) states that leaf concentrations of 1.08 percent nitrogen is considered deficient for yellow-poplar.

On nine sites where Mitchell and Chandler (1939) analyzed

Table 1. - Nitrogen, phosphorus, and potassium concentrations reported for yellow-poplar foliage by previous investigators

Tree classification	Nutrient concentration			Investigator(s)
	N	P	K	
	percent dry leaf weight			
Natural, mature	1.93	0.21	1.46	Mitchell and Chandler (1939)
	2.07	0.31	1.61	
	2.33	0.15	1.33	
	2.22	0.19	1.56	
	1.70	0.14	-	
	2.28	0.28	-	
	2.06	0.15	-	
	1.82	0.20	-	
	1.93	0.26	2.05	
Planted, immature, old-field site	1.85	-	-	Finn (1953a)
	2.54	-	-	
	2.29	-	-	
	1.41	-	-	
	2.32	-	-	
Planted, mature	1.50	0.30	1.30	Bard (1946)
Planted, immature, infertile old- field site	1.54	0.11	0.51	White and Finn (1961) <sup>1/</sup> unpublished data
	1.46	0.11	0.95	
	1.37	0.22	0.67	
	1.52	0.12	0.68	
Planted, immature, infertile old- field, fertilized 2,400 lbs. 14-7-7 fertilizer per A.	2.29	0.15	0.54	White and Finn <sup>1/</sup> (1961) unpublished data
	2.37	0.17	0.69	
	2.00	0.24	0.45	
	2.12	0.25	0.72	

the leaves of deciduous trees for nutrient elements, yellow-poplar leaf tissue had phosphorus concentrations from 0.14 to 0.31 percent of dry leaf weight with an average of 0.21 percent (Table 1). Potassium analyses were reported on five

<sup>1/</sup> White, D. P. and R. F. Finn 1961. Unpublished data.  
Dept. of Forestry, Mich. State Univ.



of these sites, and levels ranged from 1.33 to 2.05 percent of dry leaf weight, with an average of 1.60 percent.

In addition to the work of Mitchell and Chandler (1939), table 1 presents results on nutrient concentration of yellow-poplar leaves obtained by Bard (1946), Finn (1953a), and unpublished data supplied by White and Finn (1961)<sup>1/</sup>.

In a study relating mineral composition of white oak leaves to site quality, Finn (1953b) found nitrogen contents ranging from 1.62 to 2.57 percent of dry leaf weight, with an average of 1.92 percent. Site index was found to be correlated with nitrogen concentration. Potassium concentrations averaged 1.42 percent dry leaf weight and ranged from 1.01 to 1.76 percent. Leaf concentration of phosphorus varied from 0.12 to 0.27 percent and averaged 0.17 percent of dry leaf weight. In that study, neither potassium or phosphorus content was found to be related to site quality.

Walker (1953) reported potassium concentration in the leaves from the middle of the crown of various tree species in connection with the exchangeable potassium content of glacial outwash soil in New York State. Potassium concentrations of leaves collected in August, averaged 0.74 percent for American beech, 0.67 percent for red maple, 1.26 percent for black cherry, and 1.08 percent for gray birch. Leaves from these trees showed no visible deficiency symptoms. leaves from black cherry, red maple, and gray birch showing potassium-deficiency averaged 0.55, 0.50, and 0.71 percent potassium respectively.

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<sup>1/</sup> White, D. P., and R. F. Finn 1961. op. cit.

Leaves of unfertilized, healthy pin oak trees collected on the Ohio State University campus had average phosphorus concentrations of 0.126 percent and potassium concentrations of 0.92 percent of dry leaf weight (Cannon et al., 1960). Chapman (1960) lists values of 0.50 to 1.00 percent potassium and 0.12 percent phosphorus on a dry leaf basis to be consistent with the top performance of citrus orchards in California.

The deficiency of any one of the fifteen essential nutrient elements will result in reduced or abnormal growth, or in the death of the tree as a result of the interference with its normal physiological processes (Kramer and Kozlowski, 1960). Deficiency symptoms of the essential nutrients and the functions of these nutrients in the metabolism of the tree are described in such texts as Kramer and Kozlowski's Physiology of Trees (1960) or Wilde's Forest Soils (1958b).

Unfavorable nutrient regimes on forest sites are often difficult to detect and are sometimes masked by other limiting factors, especially soil moisture. Where a nutrient deficiency is suspected without easily visible symptoms, two methods of nutrient analysis may be employed; soil testing, and tissue analysis of existing vegetation.

Soil testing is widely used in agriculture as a means of estimating fertilizer needs. Because of the value and general acceptance of this technique in agriculture, attempts have been made to use or at least adapt this method for forest lands. These attempts have met with varied but often limited success and have fostered the belief that soil

fertility is relatively unimportant in forest practices.

The lack of success of soil testing in determining the true available nutrient levels on forest sites is due both to certain inherent differences between forest and agricultural crops, and to certain weaknesses in the method itself. Even in agriculture, soil testing is being more and more regarded as only a general method for assessing fertilizer needs rather than an exact means for determining the nutrient regime of an area.

Hoagland (1949) states that soil analysis cannot be relied on (except for unusual cases) to tell a farmer the best fertilizer for his soil condition. It is especially poor for evaluating nitrogen. Goodall and Gregory (1947) say that, "the progress made with chemical soil analysis ... has not led agricultural chemists to become less aware that attempts to imitate the action of plant roots by chemical extractants can never hope to meet with full success, and that workable approximations are the most that can be expected." Developments in soil testing have evolved determinations for phosphorus and potassium which give results in tolerable agreement with field trials. However, methods for determining "available" nitrogen in the soil have never met with general acceptance, due to its transient nature in the soil.

In forestry, soil testing seems to have less application than in agriculture, at least at the present level of knowledge. Gessel and Walker (1958) believe that soil testing is beset with many difficulties, and that foresters are not in a position to correctly diagnose forest nutrient needs on

the basis of a simple soil test. They support this view by pointing out that soil tests do not show how trees absorb and utilize nutrients according to the basic nutrient requirements of each species. That differences in the availability (or feeding power) of nutrients do exist between species is shown by Mitchell and Finn (1935). They found that red maple accumulated approximately twice the amount of phosphorus in its leaves as did red oak when growing on the same site with the same fertilizer treatment.

Gessel and Walker (1958) state that the type and method of soil testing used by agriculture is not applicable in the same manner to forest crops, and that field tests are needed in conjunction with available testing methods. The use of foliar analysis as the best means of evaluating forest nutrient needs is advocated. This view is shared by Leyton and Armson (1955) who state that soil analysis has not proved as reliable in the assessment of site fertility for forest trees as for agricultural crops.

York (1958), an agronomist, observes that while soil analysis can serve a useful purpose in forestry, its application will undoubtedly be more limited than in agriculture due to difficulties in sampling and correlation. Voigt (1958) makes the point that the methods for chemical soil analysis were developed for agricultural crops, and the nutrients extracted by the reagents in current use may bear little relationship to the true situation in forest soils. Mitchell (1935) believes that the ordinary methods of direct chemical soil analysis are not completely satisfactory because no

distinction is made between available and non-available nutrients. Certain of the so-called extractive methods in which "available" nutrients are leached from the soil with various solvents are preferable, but it is doubtful if any solvent exactly duplicates the nutrient extractive and absorptive powers of plants growing in a natural environment.

The reliability of chemical soil tests probably varies with the nutrient for which the test is being made. Pawlick and Arneman (1961) found that total nitrogen content of the A<sub>2</sub> horizon of the soil was negatively correlated with jack pine growth. However, available phosphorus in the A<sub>2</sub> horizon and exchangeable potassium in the B horizon were significantly and positively correlated with the growth of jack pine. Baur (1959) found a correlation between the amount of phosphorus in the soil and in the leaves of slash pine in Australia. Walker (1956) also found a relationship between soil potassium and percent potassium in the leaves of several tree species.

Foliar or tissue analysis is favored by many forest research workers as a more reliable method of determining nutrient needs (Heiberg and White, 1956; Mitchell, 1936; Swan, 1960). Fowells and Krauss (1959) agree that the analysis of the foliage of plants is widely accepted as an indication of nutrient levels of the soil. Ovington (1956) believes that foliar analysis may be useful in interpreting the general availability of plant nutrients in a forest soil. In England, much attention has been paid to foliar diagnosis because of the well-known limitations of soil analysis

(Goodall and Gregory, 1947; Leyton, 1957a). This approach has been widely applied to agricultural and horticultural crops, and investigations have confirmed the potential value of foliar analysis in the study of the mineral requirements of forest trees.

From the diagnostic point of view, Leyton (1957a) reports that a stage has now been reached where foliar analysis, carried out with the necessary precautions as to sampling, would appear to provide a reasonably consistent guide not only to the nature and extent of particular mineral deficiencies limiting tree growth, but also to the interpretation of field observations. Foliar analysis is more straight-forward to test and more subject to direct interpretation (Gessel and Walker, 1958).

According to White (1958c), analysis of the current year's foliage from the top of the crown during the dormant period for conifers, or before autumn leaf coloration in hardwoods, most closely approximates an expression of soil fertility levels or correlates with the growth response of individuals to site or treatment. For major elements in the range of greatest interest, relationships between supply, tissue content, and growth are sometimes remarkably straight-forward (Stone, 1958). Kramer and Kozlowski (1960) say that with proper safeguards and within certain limits, analysis of plant tissue are good indicators of the nutrient status of plants. The leaves of trees are particularly sensitive indicators of nutrient supply.

The chief advantage of tissue analysis over soil analysis

as a diagnostic technique, is that the nutrient content of the tissue reflects the actual availability of the soil nutrients to the plant, since the elements have actually been absorbed by and translocated from the roots (Mitchell, 1936). The tree acts both as the extracting and sampling agent insofar as the soil nutrients are concerned. Such items as root extension and penetration, the relative concentration of the available forms of the nutrients, soil properties, and root competition are taken care of automatically.

Some objections to, or disadvantages of foliar analysis have been noted by Kramer and Kozlowski (1960) and more particularly by Wilde (1958a). Kramer and Kozlowski (1960) point out that foliar analysis faces two difficulties; one, the problem of deciding what constitutes an adequate amount of an element; and two, that the presence of a certain amount of an element in plant tissue does not guarantee its availability for physiological processes. They cite the example of plants showing symptoms of iron-induced chlorosis with as much iron in the leaves as normal plants. Apparently some of the iron was tied up in an unavailable form in the tissues themselves.

Wilde (1958a) points out that foliar analysis cannot be used to determine the nutrient status of cutover or denuded land where there are no trees to be analyzed. Foliar analysis of young plantations on depleted former agricultural land may not give reliable information on potential fertility because the root systems have not had time to penetrate to

possibly more fertile layers. Sampling for foliar analysis of hardwoods must be restricted to a relatively short period of time after the leaves have matured, but before translocation has occurred from the leaves back into the stem. The relative concentration of nutrients in the leaves may reflect outside environmental influence that does not reflect the true fertility of the area, or the concentration may be greater due to luxury consumption. However, most of Wilde's objections are to special conditions that can be taken into consideration without affecting the validity of the method.

Certain considerations must be taken into account to make the sampling of foliage for analysis both standard and valid. For instance, concentration of the nutrients in the leaves varies according to the location of the leaves on the tree and to their morphological development (season of sampling)(White, 1954). Leyton and Armonson (1955) found that the leaves at the top of the trees had a higher concentration of nutrients than those further down. White (1954) found that potassium content in white pine needles decreased from the top toward the bottom of the crown. The age of the leaves affects the nutrient concentration. Period of rapid growth are characterized by rapid accumulations of minerals. After maturation but before senescence, the level of the nutrient elements remains relatively stable. However, after senescence, there is some translocation of the nutrients back into the stem, and losses often occur at that time due to leaching by rain (Kramer and Kozlowski, 1960).

The optimum concentration of nutrients in the leaves



differ with different species, reflecting possibly a variation in the physiological requirements of the species in question. losses of nutrients may also occur with improper handling of the leaf samples due to metabolic activity in the leaves after their removal from the tree (Kramer and Kozlowski, 1960). Disease or insect attacks affect the concentration of nutrients in the leaves and such leaves should not be sampled (Goodall and Gregory, 1947). Environmental conditions such as light or water supply may possibly affect the nutrient concentration either up or down (Goodall and Gregory, 1947) although Mitchell (1934) maintains that the total quantity of nutrients absorbed by the tree varies with the external supply and is relatively independent of other environmental factors, at least as far as nitrogen is concerned.

Careful standardization of sampling procedure plus field tests and greenhouse experiments to determine optimum nutrient concentrations in the leaves of all important species should resolve most difficulties experienced with tissue analysis (Gessel and Walker, 1958).

An optimum quantity of each essential nutrient is necessary to achieve the best possible tree growth. The three major elements; nitrogen, phosphorus, and potassium are however the most often limiting. It is not to be inferred that the other nutrients should be forgotten when considering a forest site where a deficiency is suspected. Marked magnesium deficiencies have been noted in New York State (Stone, 1953), and zinc, copper, and boron deficiencies

elsewhere (Benzian and Warren, 1956; Smith, 1943; Smith and Bayless, 1942).

In summary, it should be emphasized that in evaluating a forest site to determine the conditions that are limiting growth, no one factor should be considered to the exclusion of all others. One or several of the many interrelated factors that affect growth may be limiting. However, in most situations, a relatively few of the factors are frequently dominant. Of these factors, soil moisture is most often in short supply, although deficient nutrients are an often overlooked situation.

## CHAPTER IV

### DESCRIPTION OF THE STUDY AREA

The area studied in this investigation is a portion of a 20-acre mixed yellow-poplar - catalpa plantation established in 1938 (Fig. 1). The plantation is one of several found in the Fred Russ Forest located in Volina Township, Cass County, in southwestern Michigan. Originally a part of the Newton Farm, this 580-acre area was donated in 1942 to Michigan State University by the late Fred Russ of Cassopolis, Michigan, and has since been managed by the Department of Forestry for experimental and instructional purposes.

The Newton Farm was an early government land grant that remained under family ownership for 99 years. Cultivation was intensive without regard to better agricultural practices such as fertilization or crop rotation. As a result, the soil on the area, became so badly depleted and unproductive that the owners were unable to produce paying crops of corn and wheat.

In June 1935, 580 acres of the Newton properties were acquired by Mr. Russ. Of that area, 240 acres were in woodlands, 160 acres of which were relatively undisturbed old-growth mixed hardwoods. By 1951, 320 acres of the former fields had been planted with either coniferous or hardwood trees.

The study area is located near the southern boundary of the forest and has almost level terrain punctuated by occasional shallow depressions. Drainage is good to moderately

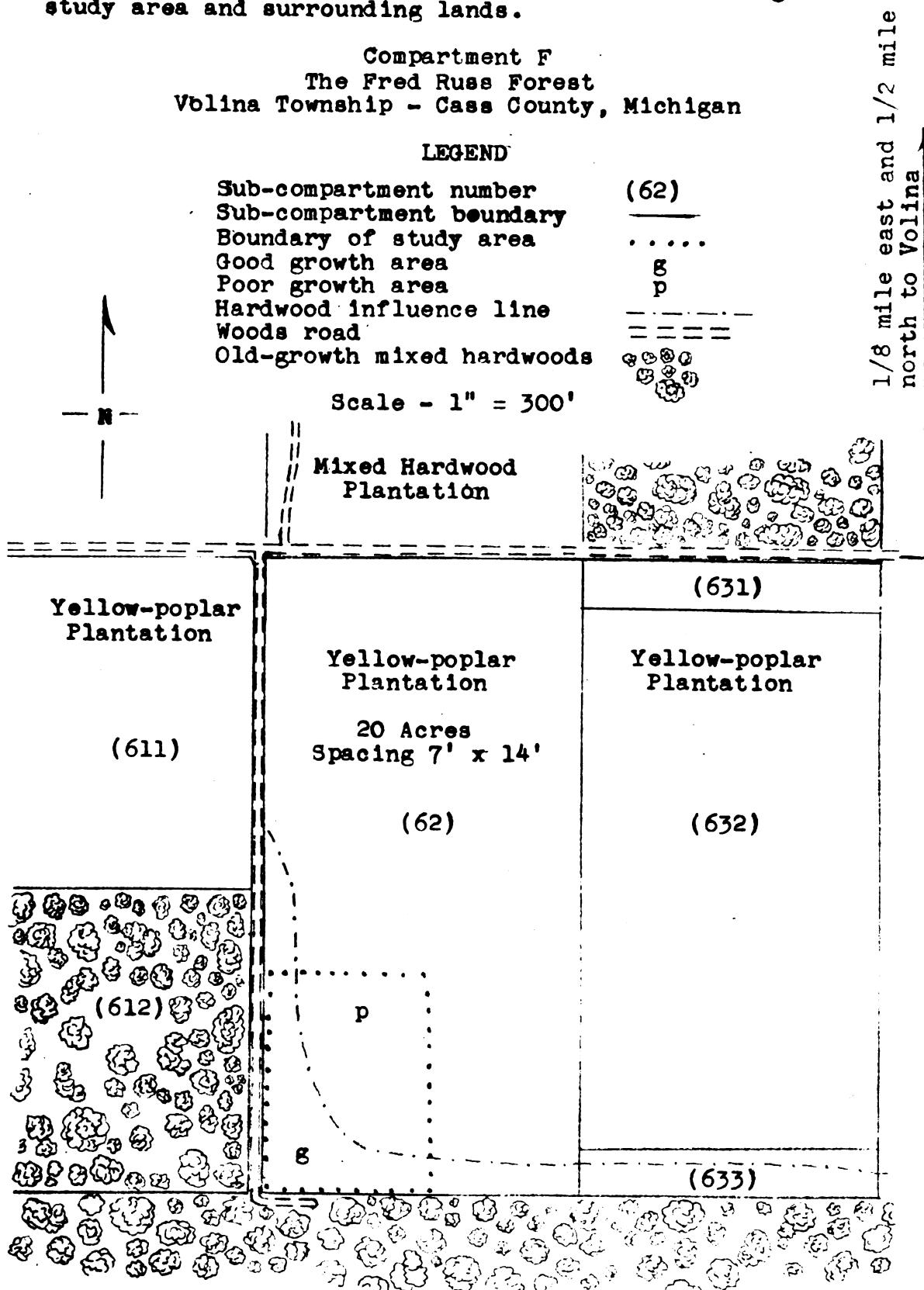
Figure 1. - Map of yellow-poplar plantation showing the study area and surrounding lands.

Compartment F  
The Fred Russ Forest  
Volina Township - Cass County, Michigan

LEGEND

Sub-compartment number	(62)
Sub-compartment boundary	—
Boundary of study area	.....
Good growth area	g
Poor growth area	p
Hardwood influence line	---
Woods road	==
Old-growth mixed hardwoods	⊗⊗⊗⊗⊗⊗

Scale - 1" = 300'



good with the possible exception of slightly poorer drainage in the depressions.

The soils are of glacial origin, formed from sandy drift deposited in an outwash plain between the inner and outer ridges of the Kalamazoo Moraine. They are included in the Gray-brown Podzolic soil group, and in this area are generally free from large boulders or stones. In the plantation itself, the soils have been classified as acid variants of Fox sandy loam and Warsaw sandy loam (Fig. 2). Although these soils are closely related structural types, the Warsaw was originally a prairie soil while the Fox series supported a hardwood forest cover. A complete description of these two soil series appears in the appendix.

The climate of southwestern Michigan is moderate with an average annual temperature of approximately 50° F., and an average annual rainfall of approximately 35 inches. The growing season has an average of 162 frost free days, extending from May to mid-October. Mean temperature during this period is about 65° F.

The study area is approximately 100 miles south of the northern limit of the yellow-poplar range. Yellow-poplar is found as a small but important component of natural stands in the vicinity of the study area, with individual trees having achieved excellent development.

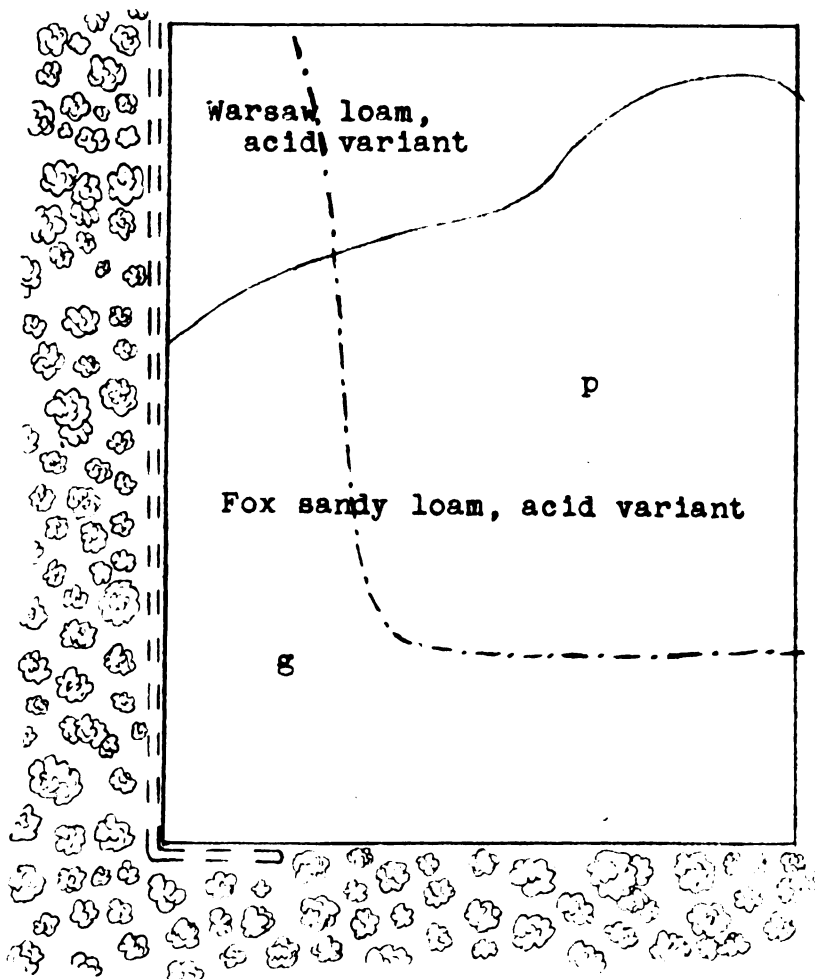
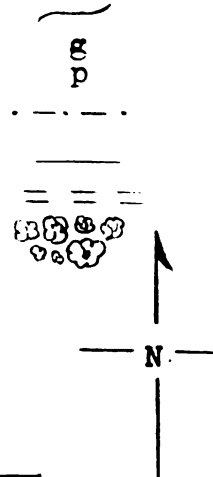
In the spring of 1938, home-grown yellow-poplar seedlings of local seed origin were planted 14 feet apart in rows 7 feet apart on the study area. The plantation was cultivated during the first summer. A year later, catalpa trees were

Figure 2. - Soil map of the study area, located in a yellow-poplar plantation, Compartment F, Fred Russ Forest, Cass County, Michigan.

# LEGEND

Soil type line  
 Good growth area g  
 Poor growth area p  
 Hardwood influence line separating the two growth areas . . . . .  
 Study area boundary  
 Woods road  
 Old-growth mixed hardwoods

Scale  
 1" = 100'



planted between the yellow-poplar within the rows. No cultivation was done during the summer of 1939. The rows were staggered in such a fashion that a catalpa was located on either side of a yellow-poplar tree. After four growing seasons, the bulk of the yellow-poplar were four to eight feet tall with some reaching twelve feet. Survival of the catalpa was poor, and by the time of the present study, nearly all of it had disappeared from the plantation.

On the south and part of the west sides of the plantation is an old-growth stand of mixed hardwoods (Fig. 3). By 1950, the yellow-poplar immediately adjacent to the hardwood stand and within the range of its influence was noticeably better in form, size, and vigor than the trees in the interior of the plantation (Figs. 4 and 5). Average height of the better growing trees is now over twice the average height of the poorer growing trees, and average diameter is approximately one and one-half time larger. The trees closest to the hardwood stand showed the greatest growth, and size decreased row by row until uniformly poor trees are found approximately eight to nine rows north and nine to ten rows east of the woods (Fig. 6). The actual study area consists of an approximately 4-acre rectangular block in the southwest corner of the 20-acre plantation (Fig. 1). This block includes a little less than two-thirds of the good growth area, and a representative portion of the poor growth area.



Figure 3. - Part of the old-growth, mixed hardwood stand that lies to the south and west of the study area. This stand adds considerable deposits of litter each year to the good growth area.





Figure 4. - Winter aspect of the southern edge of the good growth area showing the excellent form of the yellow-poplar trees, typical of that area.



Figure 5. - Winter aspect of a typical portion of the poor growth area showing the relatively small size and poor form of the yellow-poplar trees.



Figure 6. - An oblique view through the study area showing the decreasing total heights of the yellow-poplars, from the good growth area in the foreground to the poor growth area in the background.

## CHAPTER V

### PREVIOUS EXPERIMENTAL WORK ON THE STUDY AREA

In June 1951, a study was instituted by the Department of Forestry to determine the reason for the markedly differential height and diameter growth of yellow-poplar trees between two parts of this 20-acre plantation. Both parts of the area had been planted in the same year, at the same spacing, with seedlings from the same stock, and apparently had identical previous treatment of the land. The work was undertaken by R. D. Shipman and the results used for a Ph.D. dissertation (Shipman, 1952) and later for a technical bulletin (Shipman and Rudolph, 1954).

Shipman made a detailed ecological investigation of the edaphic and microclimatic factors present in both parts of the plantation. Evaporation rates, air temperature, and relative humidity were measured at each of four climatic stations, two in the portion of the plantation that exhibited relatively good growth and two in the portion showing poor growth. In addition, soil moisture was measured at depths of six and eighteen inches by means of Bouyocous soil moisture blocks, and soil temperature was taken at a depth of one inch near each of the above four stations. Besides the above factors, a number of soil determinations both physical, chemical, and microbiological, and several ecological determinations, were made over the study area. The physical soil data included total, capillary, and non-capillary porosity; volume weight, maximum water-holding capacity, specific grav-

ity, hygroscopic coefficient, soil moisture evaporation, and mechanical analysis. Chemical soil determinations included organic matter content, exchangeable hydrogen, total bases, pH, total nitrogen, carbon-nitrogen ratio, base exchange capacity, and the nutrient element content of the individual soil horizons. Soil microorganisms were cultured to show seasonal variation, populations by soil horizons, relation to pH, relation to moisture content, and numbers of fungi, bacteria, and actinomycetes as related to the ecology of each area. Finally, depth to the water table throughout the season, kind and extent of forest litter, concentration and position of roots in the surface soil horizons, light intensity, the effect and extent of sun scald injury, and a tally of the ground vegetation were measured.

Shipman's analysis of the physical soil characteristics showed that very little difference exists between the two areas in that respect. Statistical tests showed no significant difference between the specific gravity, hygroscopic coefficient, capillary porosity, non-capillary porosity, total porosity, volume weight, or moisture equivalent for any of the soil horizons of the two areas. The mechanical analysis revealed a difference in the amount of fine clay present in the  $A_1$  and  $A_2$  horizons, with the soils in the area of poor growth having a slightly higher amount. The difference was statistically significant at the one percent level. A difference was also found in the maximum water-holding capacity between the  $A_2$  horizons of the area of good growth and the area of poor growth. Both sieved, air-dried soil samples and soil

cores ("undisturbed" samples) were used in this determination. The area of poor growth showed a significantly higher maximum water-holding capacity, at the one percent level for the sieved samples and at the five percent level using the soil cores, than the area of good growth. The higher maximum water-holding capacity may be linked to the higher fine clay content found on the area of poor growth.

Shipman points out that on the basis of the significant differences in physical properties that he found, and on the basis of some non-significant differences, the area of poor growth has slightly better physical soil properties than the area of good growth. Therefore, if the physical aspects of the soil were the limiting factors, then the better growth should exist on the area of actually poor growth. Since this is not the case, he stated that those physical soil properties tested are not limiting to growth.

Soil profiles were dug near each climatic station, five times during the growing season, beginning April 18 and ending August 31, and lateral root penetration was examined. Lateral root penetration averaged 13.4 and 11.8 inches at the two stations in the good growth area, and 12.4 and 17.2 inches at the two stations in the poor growth area. Average depths of lateral root penetration did not differ appreciably between areas. The station with the deepest root penetration was also reported as the driest portion of the site, and the place where the water table is closest to the surface. Quantities of roots at various depths were not reported.

The water table showed a continuous drop from April to August. This is, however, a normal condition during the summer when evapotranspiration losses are the heaviest and recharge from summer showers is usually not sufficient to replenish the losses. Shipman found that the average depth to the water table was three feet in the area of poor growth, as opposed to six feet in the area of good growth. He attributed that difference to the heavier drain from the larger trees in the area of good growth.

Of the various chemical soil determinations, Shipman found no difference in pH, percent organic matter, total nitrogen, nitrogen-carbon ratio, cation exchange capacity, total bases, and exchangeable hydrogen. In addition, the soil tests failed to reveal any difference in the amount of available calcium, magnesium, iron, and manganese or exchangeable sodium between the two areas. Three significant differences did exist in the chemical soil properties, however. The percent base saturation of the C horizon in the area of good growth was somewhat higher, and the difference was statistically significant at the one percent level. This difference may be of somewhat doubtful value in explaining growth differences since the C horizon is probably beyond the level of significant root penetration.

Possibly of greater importance was the significantly greater quantity of phosphorus in the B<sub>2</sub> horizon of the good growth area as compared to the poor growth area. Potassium was also present in greater amounts in the A and B horizons of the area of good growth. Since both of these

elements are major essential nutrients, the differences in the amount present between the two areas of the plantation may have had an important effect on the growth differential found there.

The difference in phosphorus content of the soil is especially noteworthy. Shipman's results showed that in the upper three horizons ( $A_1$  through the  $B_2$ ) in which the bulk of the tree roots are located, the soil had nearly twice as much "available" phosphorus in the good growth area as in the poor growth area. This averaged out to be .07 millequivalents per 100 grams of soil as opposed to .04 millequivalents per 100 grams of soil. While it is not currently known if this difference is actually significant in terms of better tree growth, the possibility does exist that phosphorus may be a strong factor in the growth difference of the two areas. This is particularly true if phosphorus becomes limiting somewhere between the above two values.

A stem analysis of selected trees from both areas showed a strong positive correlation between annual precipitation and annual height growth for both areas for the 1941-1951 period. A similar correlation between diameter growth and precipitation was found although it was not as strong.

An examination of the sunscald damage in the area of poor growth showed that it had no effect on the height growth of the trees.

During the 1952 growing season, Shipman made a survey of the ground vegetation to determine if some relationship to the soil moisture regime could be found. A correlation



between species present and the available soil moisture in the surface six inches was established.

Air temperatures were consistently higher in the area of poor growth, varying from a matter of 2 or 3° F. to nearly 15° F. However, air temperatures in either case were not in the range that could be considered damaging, although they would have the effect of increasing transpiration rates in the area of poor growth as opposed to the area of good growth.

Surface soil temperatures showed even more variation between areas. Temperatures were as much as 20° F. higher in the area of poor growth. Again, temperatures did not reach a lethal level but were probably important in increasing soil moisture evaporation from the surface soil. Relative humidity was generally somewhat lower in the area of poor growth which would tend to increase transpiration in this part of the plantation. Evaporation from the soil surface was also consistently higher in the area of poor growth.

Finally, soil moisture levels varied at both the 6- and 18-inch depths between areas. The greatest difference occurred at the 6-inch depth where soil moisture levels were significantly lower in the area of poor growth. However, there were extended periods during which little or no difference occurred, and moisture levels did not fall below 70 percent in either area during the 1951 season. At the 18-inch depth, the actual differences were not as great, although the variation was statistically significant between areas.

Highly significant (at the one percent level) differences were found for all the microclimatic measurements between the

areas of good and poor growth, with the exception of the percent available moisture at the 18-inch depth for the 1952 season. This latter measurement showed a significant difference at the 5 percent level and was in favor of the area of poor growth. Measurements of light intensity were inconclusive, although average light intensities were considerably greater in the area of poor growth.

From these data, Shipman concluded that the difference in height growth between the two areas was a function of an improved moisture regime in the area of good growth resulting from the more extreme microclimatic conditions of the area of poor growth. He stated that "the height growth of the trees in the two contrasted areas is conditioned by factors which are obviously associated with the 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 site quality." He continues, "the microclimatic data presented here are aggregate verification of the fact that available moisture is the limiting factor in producing a differential height growth of plantation-grown tulip-poplar" (yellow-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 the area of poor growth."

## CHAPTER VI

### METHODS AND PROCEDURES

Observations of certain tree characteristics in the poor growth portion of the study area indicate that a severe nutrient deficiency may exist there. Leaves tend to be small and in many cases were definitely chlorotic, suggesting a nitrogen deficiency. Bronzing of some leaves was also noted, which is a phosphorus deficiency symptom. In contrast, the leaves in the area of good growth were consistently larger, with a healthy-looking medium to dark green color. In addition, it was observed that the leaves in the poor growth area changed to autumn colors and abscised from the trees two to four weeks earlier than in the good growth area. This phenomenon also suggests a nitrogen deficiency.

Because of these nutrient deficiencies symptoms, this study was initiated to evaluate the nutrient regime by both foliar and chemical soil analyses. In addition, the litter deposit on both areas was sampled and the nutrient content determined to measure the annual nutrient contribution from this source.

#### Foliar Analysis

Foliar analysis has been generally accepted as a reliable method of determining the available nutrient status of a forest site. The methods of sampling and analysis were standardized according to accepted analytical procedures, so that the trees in the present study could be compared to each other, and to the normal or optimum concentration of

nutrient elements established for yellow-poplar leaves in other studies.

Chemical composition of tree leaves varies according to their position in the crown, physiological age of the leaves, and the effect of insect and disease incidence, as well as by species and the concentration and availability of nutrients in the soil (Leyton and Armson, 1955; White, 1954). The technique of sampling fully mature leaves from the south side of the tree near the top of the crown, as advocated by Mitchell (1936), was used in this study.

In mid-September, 63 trees were systematically sampled in a grid-like fashion covering the areas of good and poor growth over the 4-acre study area, plus the intermediate area between the two. The topmost branch on the south side of the tree below the terminal was clipped off with a pole pruner. Thirty mature leaves that did not show signs of any abnormalities due to insects or diseases were stripped off the branch and put in a numbered kraft paper bag.

The leaves were oven-dried at 70° C., the petioles removed, and the leaves ground in an intermediate Wiley mill until the material could pass through a 20-mesh screen. The ground leaf material was placed in clean two-ounce jars and again dried at 70° C. in an electric oven for 36 hours. The samples were analyzed for total nitrogen by the micro-kjeldahl method; for potassium using a Coleman model 21 flame photometer; and for phosphorus, calcium, magnesium, manganese, iron, copper, boron, zinc, molybdenum, and aluminum using a Quantograph photoelectric spectrometer. De-

scriptions of the analytical procedures are included in the appendix.

### Litter Analysis

Since the area of good growth was suspected of having a more favorable nutrient regime than the area of poor growth, the source and magnitude of the additional nutrients on the good growth area were investigated. Soils on both areas appear to be essentially similar, and there is no evidence of a variation in past land practices. It was hypothesized, therefore, that the greater annual deposit of litter on the good growth area from the adjacent old-growth hardwoods contributed to the improved nutrient regime of that portion of the plantation.

To determine the quantity and chemical composition of the litter deposited on both parts of the study area, samples of the current year's leaf fall were collected in late October from points six feet due east of each sample tree. A metal sampling quadrat covering an area of 2.124 square feet (1/20,000 of an acre) was placed on the litter surface at each sampling point and all of the current year's litter deposit was collected. Where the edge of the quadrat cut across individual leaves, these leaves were divided with a sharp knife and only the part inside the sampling device was taken.

In this method of sampling, some nutrients were probable lost by leaching, and some decomposition of the litter may have occurred before sampling. This would result in a

slightly lower estimate in the total quantity of litter in both areas. However, the proportion between the two areas should have remained the same. Little addition to the litter deposit occurred after the sampling date, because an ice storm had removed even the most persistent leaves from the surrounding trees a few days before.

The litter samples were oven-dried at 70° C. and weighed to the nearest 0.1 gram. The samples were then ground in an intermediate Wiley mill, again oven-dried at 70° C., and subjected to the same analytical procedure as the fresh leaf samples (see appendix).

#### Soil Sampling and Analysis

Sixty soil samples were taken on the study area to determine if differences in the nutrient regime could be found between the area of good and poor growth. A different sampling procedure from that previously used by Shipman (1952) was applied. Each of the two contrasting growth areas was divided into three equal parts, and five sampling locations were randomly spotted in each part. At each location, the soil was sampled at a depth of 2 to 5 inches, and a depth of 18 to 21 inches. The 2- to 5-inch depth sampled the middle of the A horizon, and the 18- to 21-inch depth sampled the middle of the B horizon. The soil was placed in a standard soil sampling bag, and then thoroughly air-dried. To prepare the sample for analysis, the air-dried soil was passed through a 2-millimeter screen to remove the gravel.

Total nitrogen determinations were made using the standard Kjeldahl procedure. Phosphorus, potassium, calcium, and

magnesium were determined by the Michigan State University Soil Science Department's soil testing laboratory. In their procedures, phosphorus was extracted with Bray's number one solution (ammonium fluoride-hydrochloric acid mixture). F-S powder and ammonium molybdate were added to the extract to bring out the color, and the color of the solution was read on a Bausch and Lomb colorimeter.

Potassium, calcium, and magnesium were extracted with 1.0 normal, neutral ammonium acetate, which replaced the reserve method (0.13 normal hydrochloric acid) formerly used by the soil testing laboratory. The potassium and calcium extracts were determined on a Coleman flame photometer and the magnesium extract analyzed with a Beckman D-V flame photometer.

A 1:1 ratio of soil to water was used to determine pH using a Beckman pH meter. Base exchange capacity was calculated from the sum of the bases plus hydrogen.

### Statistical Analysis

Differences in the nutrient content of the leaves, height, and diameter of the sample trees, quantity and chemical composition of the litter, and the chemical soil analysis between the area of good growth and the area of poor growth were tested by the analysis of variance method.

The following design was used in testing the nutrient content of the tree leaves and the quantity and chemical composition of the litter.

<u>Source of Variation</u>	<u>Degrees of Freedom</u>
Total variation	49
Between areas	1
Error	48

The following design was used in testing differences between areas for the chemical soil analysis.

<u>Source of Variation</u>	<u>Degrees of Freedom</u>
Total variation	29
Between blocks	5
Between areas	1
Error	23

A correlation analysis was made between both heights and diameters of the sample trees and each of the determinations of the 12 nutrient elements. The data were processed by the "Mystic" analytical computer, owned by Michigan State University and operated by the Department of Electrical Engineering. This computer determined the correlation between height, diameter and each of the 12 nutrient elements, and also between each of the nutrient elements themselves. Data from 63 sample trees were used.



## CHAPTER VII

### RESULTS AND DISCUSSION

#### Leaf analysis

Analysis of the yellow-poplar foliage revealed a highly statistically significant (at the one percent level) difference between the nutrient element concentration of the leaves of the trees in the area of good growth and the area of poor growth (Table 2). This difference was found for every nutrient analyzed, except boron and magnesium. In every case where a significant difference did occur, the level of concentration was higher in the leaves from the area of good growth. Aluminum, a non-nutrient element, did not differ significantly.

The most outstanding differences, both statistically and in actual nutrient levels, were found for nitrogen and phosphorus concentrations. Both nutrients had nearly twice as high a quantity in the leaves in the area of good growth as in the area of poor growth.

Heights of the sample trees in the good growth area averaged over twice those in the poor growth area, and nutrient concentrations were positively correlated with this difference. Nitrogen and phosphorus showed the strongest correlations with tree heights.

Similar correlations between tree diameter and nutrient concentrations were found for all elements that showed significant differences between areas, except potassium (Table 3). Again, nitrogen and phosphorus showed the

Table 2. - Analysis of differences\* in height, diameter, and leaf nutrient levels of yellow-poplar trees in southwestern Michigan

Tree characteristic	Tree location		"F" value
	Area of good growth	Area of poor growth	
Height	57.5	26.6	125.11**
Diameter	7.38	3.99	47.32**
Leaf nutrient level <sup>+</sup>	percent of oven-dry leaf weight		
Nitrogen	1.75	0.95	122.72**
Potassium	0.890	0.672	17.62**
Phosphorus	0.196	0.101	68.62**
Calcium	3.18	2.76	7.52**
Magnesium	0.318	0.291	2.37
	ppm - oven-dry leaf weight		
Manganese	471	345	7.99**
Iron	122	87	63.61**
Copper	10.3	7.7	64.62**
Boron	72.2	72.6	0.00
Zinc	32	27	30.37**
Molybdenum	12.0	10.5	8.83**
Aluminum	402	437	2.96

\* Based on 25 trees sampled in each area of growth.

\*\* Significant difference at the one percent level.

+ Nitrogen determined by the microkjeldahl method, potassium determined by the flame photometer, and the remainder of the elements were determined using a photoelectric spectrometer.

strongest correlations, although all correlations with diameter were less than between nutrients and height.

Table 3. - Correlation coefficients between height and diameter of yellow-poplar and the level of leaf nutrient concentrations

Tree size	Leaf nutrient level					
	P	N	"Major elements"			
			Ca	K	Mg	
Height	+.764**	+.748**	+.466**	+.297**	+.263**	
Diameter	+.684**	+.647**	+.433**	+.150	+.193	
	Fe	Cu	"Micro-elements"			B
			Mn	Zn	Mo	
Height	+.551**	+.546**	+.472**	+.477**	+.371**	+.065
Diameter	+.342**	+.413**	+.418**	+.275**	+.336**	+.107

\*\* Significant at the one percent level.

\* Significant at the five percent level.

Based on the leaf analysis of the yellow-poplar trees on the study area, there appears to be a definite and highly significant difference in the soil nutrient regime between the area of good growth and the area of poor growth. Of the twelve elements tested, only magnesium, boron, and aluminum did not differ significantly between areas. Aluminum is not considered an essential nutrient element and was routinely included in the spectographic analysis by the

Department of Horticulture because it is sometimes found in highly toxic quantities in fruit trees. Both boron and magnesium are essential elements which are sometimes limiting (Smith, 1943; Stone, 1953) but since the concentrations do not differ appreciably between the two growth areas, it is doubtful that either element could be considered limiting in this instance. Actually leaf concentrations of both elements are relatively high (Kramer and Kozlowski, 1960).

For the major nutrient elements, nitrogen and phosphorus, the situation is very clear. Not only was there a highly statistically significant difference in the leaf composition for these nutrients between the trees of the good and poor growth areas, but the concentrations in the leaves from the poor area were found to be severely limiting. This is especially noticeable in the case of nitrogen, and only slightly less so for phosphorus. Many of the trees in the area of poor growth exhibit chlorosis and small leaf sizes typical of a nitrogen deficiency. A bronzing of some leaves was also noted which is typical of phosphorus deficiency in citrus trees (Camp et al., 1941). Phosphorus-deficient yellow-poplar seedlings in a recent greenhouse study, also exhibited this condition <sup>1</sup>/<sub>.</sub>

Nitrogen composition of the leaves from sample trees on the area of good growth ranged from a low of 1.35 to a high of 2.21 percent, with an average of 1.75 percent. On the area of poor growth, leaf compositions ranged from a

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<sup>1</sup>/ <sub>Finn, R. F. 1961. Project Leader, Central States For. Expt. Sta., Ames, Iowa. personal communication.</sub>

low of 0.54 percent to a high of 1.41 percent, with an average of 0.95 percent nitrogen.

Mitchell and Chandler (1939) consider a range from 2.15 to 3.00 percent nitrogen in yellow-poplar leaves as optimum for growth. Normal trees growing naturally on a variety of sites had leaf concentrations of 1.70 to 2.33 percent nitrogen with an average of 2.04 percent (Table 1, p. 15). In the southeast, nitrogen concentration of 1.08 percent in yellow-poplar leaves is considered deficient by Wells (1961). Other studies that analyzed yellow-poplar leaves from trees with normal growth, showed nitrogen composition levels of 1.50, 1.85, 1.40, 2.54, 2.29, 2.32, and 1.31 percent of dry leaf weight (Bard, 1946; Finn, 1953). It is obvious that the good growth area may be somewhat below optimum in nitrogen level and the poor growth area is severely deficient in that nutrient.

Phosphorus content of the yellow-poplar leaves in this study averaged 0.196 percent of dry leaf weight in the good growth area and 0.101 percent in the poor growth area (Table 2). Deficiency levels for phosphorus in yellow-poplar have not been as clearly defined as for nitrogen. Past work has shown concentrations of this element in the leaves of yellow-poplar without indicating either optimum or deficient levels (Table 1). Phosphorus leaf concentrations for trees other than yellow-poplar have, however, been determined for both normal-appearing and deficient specimens. Based on this information, Phosphorus concentrations in the neighborhood of 0.20 percent dry leaf weight may be considered

adequate for normal if not optimum growth. On this basis, the poor growth area with its 0.101 percent concentration, is deficient in phosphorus.

Results of the leaf analysis are corroborated by unpublished data<sup>1/</sup> from a fertilizer experiment on a nearby yellow-poplar plantation on the Russ Forest where trees show a marked response to applications of a complete fertilizer. Three-year height growth of the trees averaged over two and one-half times as much on plots fertilized with 336 pounds of nitrogen, 168 pounds of potash ( $K_2O$ ), and 168 pounds of phosphate ( $P_2O_5$ ) per acre as compared to the unfertilized controls. Diameter growth averaged three times as much on the fertilized plots compared to the control plots.

Leaf nutrient concentrations averaged 1.90 percent nitrogen, 0.186 percent phosphorus, and 0.78 percent potassium on the complete fertilizer plots, on a three-year basis, as compared to three-year averages of 1.46 percent nitrogen, 0.150 percent phosphorus, and 0.86 percent potassium on the control plots. The trees on this area had shown the same nutrient deficiency symptoms as the trees in the poor growth portion of the present study area, but to a lesser degree. After fertilization, leaf sizes increased noticeably, and the leaves became a healthy, darker green color. Autumn coloration and leaf fall were also found to be delayed for the trees on the fertilized plots as compared to the un-

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<sup>1/</sup> White, D. P., and R. F. Finn 1961. op. cit.

fertilized controls.

Differences in leaf concentration of potassium, although highly statistically significant between the good and poor growth areas, are not as great as they are for phosphorus and nitrogen. Potassium averaged 0.890 percent dry leaf weight in the area of good growth, and 0.672 percent in the area of poor growth. The deficiency level for this element has not been clearly defined for yellow-poplar. However, on the basis of information available for other species, potassium concentrations of approximately 0.80 percent of dry leaf weight are considered sufficient for normal growth.

White and Finn's<sup>1/</sup> fertilizer study of yellow-poplar, showed potassium concentrations of 0.86 percent in the leaves of trees on the control plots, based on a three-year average. Additions of 168 pounds of potash ( $K_2O$ ) per acre resulted in only a small increase in leaf concentration (0.03 percent) and no significant increase in height and diameter growth. Application of fertilizer with 336 pounds of nitrogen and 168 pounds of potash ( $K_2O$ ) per acre did not result in a significantly greater increase in three-year height and diameter growth than an equal nitrogen application alone. These results indicate that potassium is probably not seriously deficient on either the good or poor growth area in the present study.

The strong, positive correlation of both nitrogen and

<sup>1/</sup> White, D. P., and R. F. Finn 1961. op. cit.

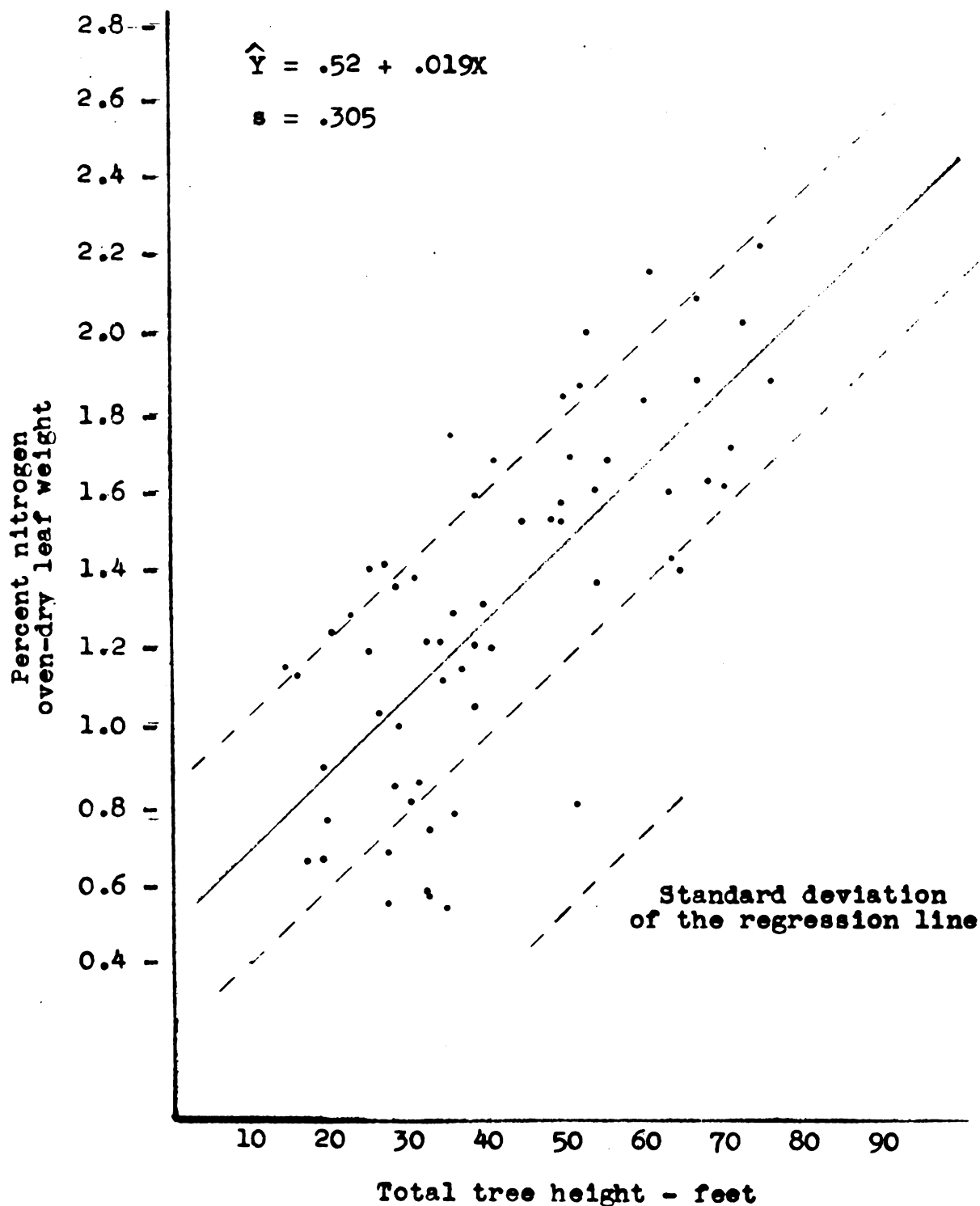
phosphorus to tree height is shown by their respective high correlation coefficients of  $+0.748$  and  $+0.764$  (Table 3; Figs. 7 and 8). A coefficient above  $+0.320$  is highly statistically significant (at the one percent level) for 62 degrees of freedom; the higher the correlation coefficient, the stronger the correlation. Potassium had a coefficient of  $+0.297$ , significant at the five percent level, when correlated with height. These results indicate that differences in nitrogen and phosphorus levels are highly important in accounting for the difference in growth between the two areas of the plantation. Potassium, by reason of its much lower correlation with height growth and the smaller differences in concentration between areas, is less important.

On the basis of work done in determining foliage nutrient concentrations in fruit and ornamental trees, manganese, zinc, molybdenum, calcium, magnesium, boron, iron, and copper are probably not limiting for the trees in either part of the study area (Bard, 1946; Cannon et al., 1960; Chapman, 1960, Davidson, 1960; Goodall and Gregory, 1947). Although optimum or non-limiting levels of these nutrients vary with tree species, the concentrations of these nutrients in the leaves of the yellow-poplar for both the good and poor areas are well above the concentrations generally believed to be limiting for most species.

The significantly higher concentrations of most of these elements in the leaves from the good growth area as compared to the poor growth area probably reflect luxury consumption by the more vigorous trees in the former area.

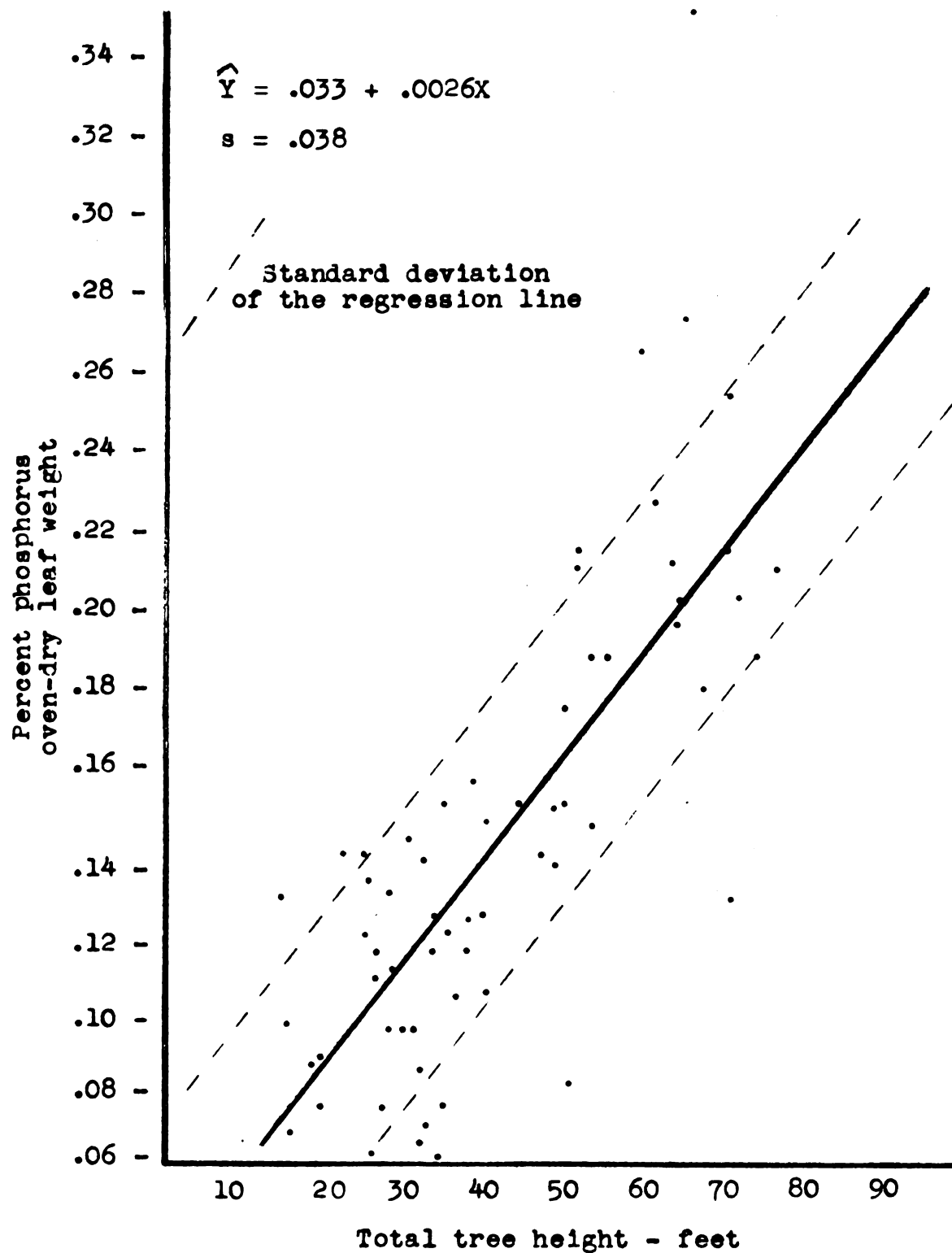


Figure 7. - Linear regression of percent concentration of nitrogen in the leaves over the total height of plantation grown yellow-poplar (Liriodendron tulipifera L.) <sup>1/</sup>.



<sup>1/</sup> Based on a sample of 63 trees

Figure 8. - Linear regression of percent concentration of phosphorus in the leaves over total height of plantation grown yellow-poplar (Liriodendron tulipifera L.)<sup>1/</sup>.



<sup>1/</sup> Based on a sample of 63 trees

This is definitely not the case with respect to nitrogen, phosphorus, and possibly not for potassium. As stated previously, nitrogen and phosphorus leaf concentrations in the poor growth area are below the level considered to be deficient, while leaf concentrations from the good area are well above that level. The situation in regards to potassium is not clear. The difference in potassium leaf concentration between areas is not as great as it is in the cases of nitrogen and phosphorus. In addition, potassium concentration in either area is within a range where it is not possible to evaluate a deficiency difference at the present level of knowledge.

#### Litter analysis

Over two and one half times as much litter is deposited annually on the good growth area as compared to the poor growth area (Table 4). This annual deposit amounts to approximately 3,000 pounds of organic material per acre on the good growth area, as against approximately 1,200 pounds per acre in the poor growth area.

Table 4. - Quantity and nutrient composition of litter on two parts of a yellow-poplar plantation in southwestern Michigan

Area sampled	Litter weight	Quantity of nutrient elements					
		N	P	K	Ca	Mg	
pounds per acre							
Good area	2,913.6 ±421.0	28.2	3.6	5.8	57.4	5.2	
Poor area	1,155.6 ±121.4	10.4	1.0	1.4	24.0	2.0	

This large difference in the quantity of litter deposited on the two areas reflects not only the greater volume of leaf tissue produced by the denser foliage of the trees on the good growth area, but also the considerable leaf fall from the adjoining hardwood stand (Fig. 3) to the west and south. Prevailing winds in this region are southwesterly. Only an occasional leaf other than yellow-poplar was observed in the litter deposit on the area of poor growth, while the litter from the area of good growth contained numerous leaves of other species from the adjacent hardwood stand (Fig. 9).

Not only was the quantity of litter on the good growth area larger, but in many instances its percentage composition of nutrient elements was slightly higher (Table 5). Nitrogen, potassium, phosphorus, manganese, iron, and boron were found in higher concentrations in the litter on the good growth area. Conversely, calcium was present at higher concentrations in the poor growth area. This latter situation is probably due to a reduced cell size in the smaller leaves on the poor growth trees, resulting in a higher proportion of cell wall material to cell contents. Calcium is predominantly found in the cell wall, while the other nutrient elements predominate in the protoplasm.

All these differences, although actually small in some cases, were statistically significant at the one percent level (Table 5). There were no real differences between areas in the levels of magnesium, copper, zinc, or molybdenum.



Figure 9. - Considerable organic material from the preceding year still remains on the ground surface of the good growth area by late summer. This material adds to the nutrient regime of that area each year.

Table 5. - Nutrient composition of the litter from two parts of a yellow-poplar plantation in southwestern Michigan

Nutrient element	Sample location		"F" value
	Area of good growth	Area of poor growth	
	percent dry leaf weight		
Nitrogen	0.97	0.90	10.03**
Potassium	0.197	0.127	102.89**
Phosphorus	0.126	0.095	89.81**
Calcium	1.97	2.11	7.11**
Magnesium	0.177	0.169	3.62
	ppm - dry leaf weight		
Manganese	922	480	48.11**
Iron	432	268	8.72**
Copper	17.9	18.8	0.54
Boron	50.3	36.2	54.24**
Zinc	56	56	0.08
Molybdenum	7.7	7.9	1.04

\*\* Significant difference at the one percent level

It is a well known fact that the annual addition of organic matter in the form of litter is an important means of maintaining and improving a forest site. These additions of organic material not only improve the physical condition of the soil, but they are also an important source of nutrient elements.

Nitrogen and phosphorus are the two nutrients most significantly affected by the higher annual additions of

litter in the area of good growth. Since practically no nitrogen occurs in soil minerals, all nitrogen must come from the atmosphere through additions of nitrates in rain-water and from nitrogen fixation by microorganisms. Most of this nitrogen is eventually incorporated in organic matter, and through decomposition, it finally becomes available to plants. Thompson (1957) states that about 99 percent of the soil nitrogen is in organic form at any one time.

Organic matter is also a very important source of the phosphorus that is available to plants. According to Black (1957), anywhere from 3 to 75 percent of the soil phosphorus may be in organic form. For most soils, organic phosphorus averages about 30 to 50 percent of the total (Buckman and Brady, 1960). This organic phosphorus is released to the soil solution through organic matter decomposition, and becomes immediately available for root absorption. Black (1957) states that organic phosphorus act as a reservoir of this element, and the return of inorganic phosphorus from plant residues constitutes the primary means by which phosphorus availability is increased under natural conditions.

On the study area, the adjacent stand of old-growth hardwoods has acted as a source of nutrient-rich litter for the good growth area for many years. This factor has contributed to the better nutrient regime in this section of the plantation. The effect has been cumulative, since the better nutrient status has resulted in faster growing, healthier trees which themselves now produce more leaf

material, richer in nutrient elements, than the trees in the poor growth area.

Because of its relatively poor condition, the area of poor growth produces far less litter than a normal hardwood stand. Ovington (1956) estimates that a well stocked forest stand should produce approximately 3,000 pounds of litter per acre per year. Other stands have been reported as producing annually from approximately 1,600 to 4,000 pounds per acre.

#### Chemical soil analysis

Reappraisal of soil fertility levels based on chemical analysis revealed little difference in the soil between the two areas (Table 6). The data showed no statistically significant difference for any chemical soil characteristic of the A horizon. For the B horizon, however, both total nitrogen and available phosphorus content was significantly different between areas of growth. The difference in nitrogen was in favor of the poor growth area and in phosphorus in favor of the good growth area.

The real difference in nitrogen was not large, .039 percent in the area of good growth as opposed to .050 percent in the area of poor growth. Phosphorus averages .0581 millequivalents per 100 grams of soil in the B horizon of the good growth area and .0419 millequivalents per 100 grams in the poor growth area.

The real importance of the total soil nitrogen differences found in this study is doubtful. Soil analysis is



Table 6. - Analysis of chemical soil differences between two parts of a yellow-poplar plantation in southwestern Michigan

Soil characteristic	Sample location		"F" value
	Area of good growth	Area of poor growth	
A horizon			
pH	5.2	5.2	0.000
	percent by weight		
Nitrogen	.093	.092	0.006
	millequivalents per 100 grams of soil		
Phosphorus	.0532	.0467	1.66
Potassium	.0974	.0923	0.35
Calcium	2.240	2.195	0.001
Magnesium	2.145	2.265	0.034
Exchange capacity	11.3	11.8	2.26
B horizon			
pH	4.9	4.9	0.006
	percent by weight		
Nitrogen	.039	.050	9.796**
	millequivalents per 100 grams of soil		
Phosphorus	.0581	.0419	10.59**
Potassium	.1320	.1512	2.43
Calcium	2.815	2.748	0.001
Magnesium	2.298	2.099	0.806
Exchange capacity	14.1	15.4	2.53

\*\* Significant at the one percent level

considered an unreliable method of determining the amount of nitrogen available for plant absorption and use during the growing season. There has been little correlation between the amount of total nitrogen in the soil and that absorbed by plants (Bard, 1946; Mitchell, 1934) or between total soil nitrogen and tree growth (Pawlick and Arneman, 1961).

Nitrogen relationships in the soil are very complex and are constantly changing. In the surface 6 inches of virgin forest soils, total nitrogen content ranges between 0.1 and 0.3 percent (Wilde, 1958b), and in the plow layer of cultivated soils, the total nitrogen content varies between 0.02 to 0.4 percent (Black, 1957). Usually less than two percent of this nitrogen will be in the available ionic forms at any one time, the rest being in organic forms (Black, 1957).

The readily available forms of nitrogen are very transient, varying from a relatively abundant supply one day to relatively little or none the next (Thompson, 1957). Much of this readily available nitrogen is in a very water-soluble form and is either easily leached from the soil or rapidly absorbed by plants (Mitchell and Chandler, 1939). In addition, the most soluble and available form of nitrogen (nitrate) is an anion which is not absorbed by the negatively charged clay particles of the exchange complex. Thus it is highly mobile and easily lost. Ammonium nitrogen, on the other hand, is positively charged and is absorbed by the soil exchange complex. Ammonium, however, is usually

soon changed to nitrate by microbial activity.

Microorganisms affect the supply of available nitrogen by decomposing fresh organic matter, releasing some of the nitrogen in less complex forms and temporarily fixing the rest in their own protoplasm. The proportion of nitrogen released to that fixed is dependent upon the carbon-nitrogen ratio of the substrate. A high carbon-nitrogen ratio will result in the release of little or no nitrogen available to plants and may even tie up some of the inorganic nitrogen present.

In addition to their role in constantly changing the form of soil nitrogen, soil microorganisms are instrumental in adding nitrogen to the soil through the ability of some of them to fix atmospheric nitrogen.

All these factors make it extremely difficult to assess the nitrogen content of the soil by a chemical analysis (Hunter, 1958). Low total soil nitrogen on a high yielding site may only reflect a quicker release of organic nitrogen to a more available form and its consequently more rapid absorption by the plants.

Nitrogen is an important factor in the availability of phosphorus. Even though the nitrate anion competes with the phosphate anion in the uptake of nutrients by plant roots, sufficient nitrogen must be present in the soil for microbial use, in order for the organic phosphorus to be released from the plant residues. In the present study, there is a very strong correlation between nitrogen and phosphorus in the tree leaves as shown by a correlation

coefficient of .851. It is probable that the better uptake of phosphorus by the trees in the area of good growth and the greater amount of available phosphorus in the soil may be due, at least in part, to the greater amount of available nitrogen in that area as indicated by its higher concentration in the good growth area leaves.

In contrast to total soil nitrogen, phosphorus level in the soil has sometimes been found to be correlated with tree absorption and tree growth (Baur, 1959; Pawlick and Arneman, 1961). On this basis, the higher soil phosphorus in the area of good growth is related to the better tree growth in that area.

The influence of a lower available water supply in the area of poor growth as determined by Shipman (1952), on the uptake of nutrients must be considered. In general, it is believed that there is an increase in the absorption of nitrogen with a decrease in soil moisture and there is a decrease in the absorption of phosphorus and potassium with decreasing soil moisture (Hibbard and Nour, 1959). Using sand cultures, Kramer and Pharis (1960) found that decreasing moisture resulted in an increase of nitrogen in the leaves. Lundegardh (1945) observed that nutrient concentration in leaves varied according to total precipitation, and was generally higher in drier years. Acting on these observations, he initiated a fertilizer and watering experiment and found that nitrogen concentration in the leaves of test plants was higher at the lower moisture levels.

Leyton (1957a) states that if growth is reduced by moisture deficiencies and if the deficiency does not interfere with uptake, leaf concentrations of nutrients should automatically rise. On the basis of these findings, the greater nitrogen concentration in the leaves of the good growth area compared to the poor growth area is not related to the soil moisture supply but is a result of more available nitrogen in the soil.

The increase of nitrogen absorption by roots to decreasing soil moisture is due to the high solubility of available nitrogen ions. As the quantity of the soil solution decreases, the concentration of the available nitrogen increases, resulting in greater absorption due to mass action. On the other hand, phosphorus is relatively insoluble. Decreasing soil moisture causes little or no rise in the concentration of this element and a portion of the total phosphorus is lost from the soil solution by precipitation. Therefore, there is proportionately less of this nutrient available in the soil solution for root absorption.

A dense stand of poverty grass and annual weeds is found in the area of poor growth due to the lack of crown closure by the trees (Figs. 5 and 10). These plants may compete for nutrients and moisture with the trees and may be a factor in the poor growth in that area. Aird (1956) concluded from a fertilizer study that weed and grass competition seriously inhibited the growth of hybrid poplar. Elimination of the grass and weeds by tillage resulted in



Figure 10. - The soil surface of the poor growth area shows a dense cover of grasses and herbs with very little organic debris from the tree cover.

significantly better growth both with and without fertilization. Chlorotic leaves of fertilized trees, where the competing grasses and weeds had not been eliminated, indicate the intense competition of those plants for nutrients.

It is not known whether there was a difference in the ground cover between the good and poor growth areas at the time of planting. If the grass and herb cover on the poor growth area was significantly more dense at that time, then that may have been an important factor accounting for the present size difference of the trees in the two areas. At the present time, the grasses and herbs are probably removing sizable portions of the water and nutrients that would otherwise be available for the trees. However, it is not known whether they compete to a greater or lesser extent than the dense undercover of sugar maples and other sapling-sized trees in the area of good growth.

## CHAPTER VIII

### CONCLUSIONS

Foliar analysis of yellow-poplar Trees in two parts of a plantation in southwestern Michigan, indicates that the growth differential between the two areas is due in part to differences in nutrient regimes. Significant differences in nutrient concentration of the leaves between the two areas of growth suggest that a severe nutrient deficiency is limiting growth in the poor area.

Tree growth is, to a large extent, a result of the relative production of photosynthate. Nutrient deficiencies seriously limit photosynthesis indirectly through reduction of leaf size and chlorophyll content (Kramer, 1958). Formation of chlorophyll is dependent on adequate supplies of nitrogen, magnesium, iron, copper, and zinc. Deficiencies of any of these nutrients will decrease growth. Kramer (1958) reports that adding nitrogen to apple trees in the autumn resulted in better retention of chlorophyll and higher photosynthetic activity in late autumn. In the present study area, not only are the leaves in the good growth area noticeably larger and of a darker green color, but autumn coloration and leaf fall are delayed several weeks as compared to the poor growth area. This in itself is an indication of a more adequate supply of nitrogen in the better growing area and results in a longer period of photosynthetic activity.

Besides reducing photosynthetic activity per unit area



of leaf surface, deficiency of nitrogen reduces the total leaf surface area, and the combined effect of this is a serious reduction in the amount of carbohydrates available for growth. In the area of good growth, not only are the leaf areas on the average greater than in the area of poor growth, but the tree canopies are more dense, providing more leaves for photosynthetic activity.

Of the nine nutrients found in significantly smaller quantities in the leaves of the poor growth area, it appears that nitrogen and phosphorus are the two most responsible for limiting growth in that area. The micro-elements and calcium appear to be present in sufficient concentrations in the leaves of both areas so that they cannot be considered deficient. The weaker correlation of potassium concentration in the leaves to height and diameter growth indicates that this element is probably not a primary reason for the growth differential found in the plantation. This is corroborated by the lack of response to potassium fertilization on a nearby yellow-poplar plantation<sup>1/</sup>. On the other hand, both nitrogen and phosphorus leaf concentration were strongly correlated with height and diameter growth of the yellow-poplar trees. Comparison with other studies (Mitchell and Chandler, 1939; Wells, 1961) indicates that nitrogen is severely deficient in the poor growth area. The lack of correlation that was found between nitrogen concentration in the leaves and total soil nitrogen is not uncommon (Bard,

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<sup>1/</sup> White, D. P., and R. F. Finn 1961. op. cit.

1946; Mitchell, 1934). Possible reasons for this have been discussed previously. However, soil analysis did show significantly higher quantities of available phosphorus in the soil of the good growth area, which agrees with the higher concentrations of leaf phosphorus found in the trees from that area. Again, these results are in accord with other work (Bard, 1946; Baur, 1959).

Findings of White and Finn's experiment<sup>1/</sup>, reported earlier, corroborates the conclusions from the present study, that the depressed growth and vigor of the yellow-poplar trees on the poor growth area primarily result from a nutrient deficiency in that area. The correlation between the increased growth and higher leaf nutrient concentration of the fertilized trees in the fertilizer study can also be compared to the larger trees and higher leaf nutrient concentration in the good growth area of the present study. It is apparent that the better growth in each instance is a result of an improved nutrient regime.

In the present study, the question arises as to the reason for the difference in the nutrient regime of the two growth areas which have very similar soils and apparently identical past treatment. The answer lies, at least in part, in the annual additions of organic matter deposited in the area of good growth (Fig. 9) from the adjacent hardwood stand. Mitchell and Finn (1935) point out that the principal means by which trees may improve the chemical

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<sup>1/</sup> White, D. P., and R. F. Finn 1961. op. cit.

fertility of the soil is through the annual addition of mineral nutrients and nitrogenous material contained in the leaves.

Data gathered here show that the yearly deposit of tree litter in the area of good growth is far greater than that deposited in the area of poor growth. Much of the extra deposit consists of material from outside the plantation. The litter on the good growth area has higher concentrations of nitrogen, phosphorus, and potassium than the litter on the poor growth area. This, coupled with the greater quantity deposited in the good growth area, results in considerably more of these nutrients being added there to the nutrient regime each year. In essence, it amounts to an annual program of fertilizer application for the promotion of better growth.

In the previous examination of the study area, Shipman (1952) found certain microclimatic differences between the two areas of growth that might produce a less favorable water balance between uptake and transpiration losses in the area of poor growth as compared to the area of good growth. These microclimatic differences are the result of the fringe influence of the old-growth hardwood stand at the south and west edges of the good growth area. It resulted in lower air temperatures and higher relative humidities in that area.

Both of these factors result in relatively more rapid transpiration losses in the poor growth area as opposed to the good growth area, causing possibly more frequent and

longer periods of water deficits in the leaves of the poorer trees. This in turn would reduce photosynthesis by restricting the entrance of carbon dioxide into the leaves because of stomate closure. This condition is aggravated by the lower amount of water available on the poor growth area because of weed and grass competition. Kozlowski (1958) points out that water deficits develop regularly in leaves during the middle of the day and cause a decrease in photosynthesis even when the soil is adequately supplied with water. Kramer (1958) also states that bright sunlight and dry air causing excessive transpiration produce water deficits in the leaves of trees growing in moist soil.

Shipman (1952) concluded that available moisture was the primary factor limiting the growth of yellow-poplar due to less favorable microclimatic conditions in the poor growth area. This reasoning was based partially on the significantly shorter supply of water in the soil at 6 and 18 inches on the poor growth area. However, it should be pointed out that the available moisture did not fall below 70 percent at the 6-inch depth or 80 percent at the 18-inch depth during the 1951 season. During the 1952 season, the available moisture in the poor growth area did not fall below 50 percent at the 6-inch depth, except for a 6-day period in early July, and was significantly higher in the poor growth area compared to the good growth area at the 18-inch depth.

Soil moisture is probably about equally available throughout the range from field capacity to wilting point

in a sandy loam soil (Army and Kozlowski, 1951; Kramer, 1949). Certainly there should not be any difficulty in water absorption by the yellow-poplar roots above 50 percent available moisture in the coarse soil of the study area.

The greater amount of nitrogen available for tree growth in the good area is probably a factor in the better uptake of other nutrients. When nitrogen is deficient, the physiological processes of the tree are interrupted, including active nutrient absorption. The greater amount of nitrogen supplied to the good growth area from the litter of the adjacent hardwood stand results in more vigorous root growth. This in turn enables those trees to exploit more of the soil for both moisture and nutrients. Stone et al. (1958) found with red pine in New York State that adequate nutrients may promote root growth in xeric conditions of deep sandy soils so that the trees may exploit greater volumes of the soil for moisture. White (1958a) reports that fertilizer applications resulted in an increase in photosynthetic activity and water economy during a period of moisture stress.

The results of this study and Shipman's (1952) previous work on the same plantation, supported by similar results from other studies, show the growth differential exhibited in two parts of the yellow-poplar plantation is due primarily to two factors. One, the nutrient regime of the good growth area is much more favorable due to annual additions of nutrients from the litter deposited from the adjoining old-growth mixed hardwood stand; two, the less favorable micro-

climate in the area of poor growth may be limiting growth by causing water deficits in the tree leaves from more rapid transpiration losses than the trees are able to overcome by absorption of water from the soil.

Whether these two factors are equal in their effect or one is more dominant cannot be said with certainty at this time. However, the fertilizer study<sup>1/</sup>, previously mentioned, increased growth without changing the microclimate.

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<sup>1/</sup> White, D. P., and R. F. Finn 1961. op. cit.

## CHAPTER IX

### SUMMARY

Yellow-poplar (Liriodendron tulipifera L.) is an important tree in the central hardwood region. This species makes good growth in southwest Michigan, at the northern edge of its natural range. It grows rapidly on good sites, develops very good form, and is relatively free from insect and disease attacks. Normally, it is not abundant in natural stands, but because of its desirable characteristics, it is widely planted throughout its range.

Trees in two parts of a 33-year-old plantation of yellow-poplar in southwestern Michigan show striking differential height and diameter growth. Because of the limited area in which this growth difference occurs, and because the entire plantation was established the same year, from the same planting stock under apparently identical planting conditions, this plantation offers an excellent opportunity to study the site factors which contribute to the growth of this species.

A detailed edaphic, microclimatic, and microbiological investigation of this plantation was initiated by Shipman (1952) in 1951. The conclusions from his study were that the growth differential resulted from a combination of microclimatic conditions that produced a more favorable moisture regime in the area that had the best growth, and that no nutrient differences existed between the two areas.

In the present study, observation of the foliage

suggested that a nutrient difference between the two areas does exist. The leaves on the good growth area are larger and consistantly of a darker, healthier, green color. By contrast, the leaves in the poor growth area show characteristics indicative of a nutrient deficiency. Using modern methods of foliar analysis, including spectroscopy, this study was made to determine if nutrient differences exist between the two areas.

The sample trees in the good growth area averaged 57.5 feet in height as opposed to an average of 26.6 feet in the area of poor growth. Diameters were also larger, averaging 7.38 inches in the better area compared to 3.99 inches in the poorer area. An analysis of the foliage from both areas showed that the area of good growth had significantly higher, at the one percent level, concentrations of all the macro-elements, except magnesium, and most of the micro-elements in the leaf tissue. Nitrogen composition averaged 1.75 percent of dry leaf weight in the good growth area and 0.95 percent in the poor growth area. Phosphorus levels averaged 0.196 percent of dry leaf weight from the better growing trees and 0.101 percent in the leaves of the poorer growing trees. These concentrations show that the yellow-poplar in the poor growth area are severely deficient in nitrogen and phosphorus.

A statistical comparison of both height and diameter growth of the yellow-poplar sample trees and the nutrient composition of their leaves revealed a highly significant correlation between the nutrient concentration of eight of



the elements in the leaves and both height and diameter of the trees. Nitrogen and phosphorus showed particularly strong correlations between nutrient concentration and height growth. From these data, supported by other published studies and corroborated by unpublished data<sup>1/</sup> from a nearby fertilizer study, it is concluded that nitrogen and phosphorus are two of the primary factors contributing to the differential height growth of the planted yellow-poplar.

Foliar analysis of the yellow-poplar trees showed that the soil nutrient regime is more favorable in the area of good growth than in the area of poor growth. Much of this difference can be attributed to the nearly three times as great a quantity of litter being deposited on the area of good growth each year compared to the area of poor growth. Much of this additional litter comes from an adjoining old-growth mixed hardwood stand to the south and west of the good growth area. In addition, the nutrient composition of the litter on the good growth area is in most cases slightly higher, resulting in considerably greater quantities (statistically significant at the one percent level for six nutrients) of plant nutrients being added to that area each year. This litter is probably the primary source of most of the nitrogen and phosphorus available for tree growth.

A factor that may contribute to the growth differences in the two areas, is the dense stand of grasses and herbs found in the poor growth area but not in the good growth

1/ White, D. P., and R. F. Finn 1961. op. cit.

area. This ground cover may compete for soil nutrients and moisture to a great extent. It is not known how serious this competition may be, or whether it is greater or lesser than the competition from the dense undercover of sugar maple and other saplings found in the good growth area, but to a much lesser extent in the poor growth area.

It is concluded from the data collected in this study that the significantly better growth of the trees in the good growth area results in a large part from the better nutrient regime there. Trees from the poor growth area are decidedly deficient in nitrogen and phosphorus. The better nutrient regime of the good growth area stems from deposits of litter from the adjoining old-growth hardwood stand. In addition, Shipman's (1952) study showed that the micro-climatic conditions in the area of poor growth are less favorable, which may result in longer periods in which water deficits in the leaves halt photosynthesis.

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## **APPENDIX**

APPENDIX A  
STUDY AREA SOIL DESCRIPTIONS

**Fox sandy loam (acid variant)**

**Soil profile:**

- Ap 0-8" Dark grayish brown to brown; sandy loam; weak, medium, granular structure; friable; pH = 5.2.
- A<sub>2</sub> 8-12" Brown; sandy loam; weak, coarse, granular structure; friable; medium acid.
- B<sub>1</sub> 12-16" Dark yellowish brown to dark brown; sandy loam to silt loam; moderate, medium, subangular blocky structure; firm; medium acid.
- B<sub>21</sub> 16-32" Dark brown to dark reddish brown; sandy clay loam; moderate, medium, subangular blocky structure; firm to very firm; pH = 4.9.
- B<sub>22</sub> 32-36" Dark brown to dark reddish brown; gravelly clay loam; weak, coarse, subangular blocky structure; firm when moist and slightly plastic when wet; slightly acid.
- D 36"+ Pale brown or brown; stratified gravel and sand; single grain structure; loose; calcareous.

On the study area, the Fox sandy loam is a well-drained Gray-Brown Podzolic soil, occurring on a nearly level outwash plain with numerous shallow depressions. It originally supported a mixed hardwood type of vegetation.

**Warsaw sandy loam (acid variant)**

**Soil profile:**

- Ap 0-8" Dark grayish brown; sandy loam; weak, medium, granular structure; friable; pH = 5.2.
- A<sub>12</sub> 8-12" Dark grayish brown; sandy loam; coarse, granular structure; friable; medium acid.
- B<sub>21</sub> 12-16" Dark brown; sandy loam; moderate, fine, subangular blocky structure; firm; medium acid.
- B<sub>22</sub> 16-32" Dark reddish brown; sandy clay loam; moderate, medium, subangular blocky structure; pH = 4.9.
- B<sub>23</sub> 32-36" Dark reddish brown; sandy clay loam; weak to

Warsaw sandy loam (acid variant) cont.

moderate, coarse, angular to subangular blocky structure; firm when moist, plastic when wet, and hard when dry; slightly acid.

- D 36"+ Light brownish gray or pale brown; gravel and sand; stratified; loose; calcareous.

On the study area, Warsaw sandy loam is a well-drained Brunizem soil, occurring on an outwash plain dotted with shallow depressions. It originally supported a tall prairie grass type of vegetation.

APPENDIX B  
LEAF AND LITTER ANALYSES PROCEDURES

Microkjeldahl procedure

Fifty to 80 milligrams of oven-dried leaf material is weighed to four places of accuracy on a "Mettler" B-5 analytical balance and placed in a microkjeldahl flask. A micro-spatula of dry mixture, consisting of one part of potassium sulphate and three parts of mercuric sulphate, is added to the plant material, along with one cc. of digestion reagent<sup>1/</sup>. The mixture is then digested over heat, under a hood, until a water-clear solution is obtained. The digestion process takes approximately two and one-half hours. A small quantity of distilled water is added to the solution to dissolve the precipitated salts and the material is then ready for distillation.

After the solution is introduced into the distillation apparatus, five cc. of oily lye (concentrated sodium hydroxide) is added and the material distilled into an Erlenmeyer flask containing ten cc. of 1.5 percent boric acid and two drops of brom cresol green-methyl red indicator. The distillate is titrated with standardized .01 normal hydrochloric acid and the quantity of nitrogen calculated.

This process is a wet combustion method of digestion in which the fats and carbohydrates of the leaf material are

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<sup>1/</sup> Prepared by adding 1 gram of salicylic acid to 30 cc. of sulphuric acid.

oxidized into carbon dioxide and then volatilized. The dry mixture added to the plant material is a source of oxygen, acts as an oxidizing agent, and raises the boiling point of the water. The proteins are hydrolyzed into amino acids and the carbon, hydrogen, and oxygen converted into carbon dioxide and water. The nitrogen is liberated as ammonia and immediately converted into ammonium sulphate by the excess of sulphuric acid used in the oxidation. After oxidation, the ammonia is released from its salt by adding an excess of sodium hydroxide and collected in the boric acid solution. The amount of ammonia liberated is determined by titrating the boric acid-ammonia solution with standardized hydrochloric acid and the amount of nitrogen computed from these data.

#### Flame photometer procedure

Approximately 0.2 grams of leaf material is weighed to the nearest milligram and placed in an Erlenmeyer flask. Fifty ml. of 1.0 normal ammonium acetate is added, the mixture is shaken intermittently for thirty minutes, and is then filtered into a clean beaker. The filtrate, containing the extracted potassium, is introduced into the flame photometer and oxidized by means of a high intensity, direct atomizing, oxygen-gas burner. The light from the burning filtrate is picked up by a vacuum phototube after passing through a light filter that removes all of the spectrum except that part from the oxidizing potassium. Electric current generated by the phototube is transmitted to a galvanometer where it is read on a scale from 0 to 100.

Ppm. of potassium is found on a calibration curve previously prepared by oxidizing a range of solutions of known potassium concentrations.

#### Photoelectric spectrometer procedure

Leaf analysis for phosphorus, calcium, magnesium, iron, manganese, copper, boron, zinc, and molybdenum was made by a "Quantograph"<sup>1/</sup> photoelectric spectrometer operated by the Department of Horticulture, Michigan State University. Leaf ash is burned by means of an interrupted electric arc, producing a spark-like condition. The desired wave length of each element is passed through a slit and the light received by a specific phototube positioned behind the slit. The light energy is changed to electric energy by the phototube and recorded on a chart. Readings from the chart are transformed to quantity of the particular element from tables prepared during the calibration of the instrument.

The sample is prepared by ashing a 0.5 gram quantity of oven-dried leaf material for 12 hours at 550 degrees C. The leaf ash is dissolved in the ash crucible with 5.0 ml. of hydrochloric acid-cobalt-lithium-potassium solution. A portion of the dissolved ash is transferred to a porcelain boat and burned in the spectrometer.

<sup>1/</sup> Produced by Applied Research Laboratories, Inc., Glendale, California.

# APPENDIX C

COEFFICIENTS OF CORRELATION FOR COMBINATIONS OF TREE HEIGHT, TREE DIAMETER, AND NUTRIENT ELEMENT COMPOSITION OF LEAVES<sup>1/</sup>.

	<u>Ht.</u>	<u>Dia.</u>	<u>N</u>	<u>K</u>	<u>P</u>	<u>Ca</u>	<u>Mg</u>
Ht.	+1.000	+0.919	+0.758	+0.297	+0.764	+0.466	+0.263
	Dia.	+1.000	+0.647	+0.150	+0.684	+0.433	+0.193
		N	+1.000	+0.492	+0.851	+0.264	+0.123
			K	+1.000	+0.486	-0.045	-0.173
				P	+1.000	+0.404	+0.259
					Ca	+1.000	+0.307
						Mg	+1.000
	<u>Mn</u>	<u>Fe</u>	<u>Cu</u>	<u>B</u>	<u>Zn</u>	<u>Mo</u>	<u>Al</u>
Ht.	+0.472	+0.551	+0.546	+0.066	+0.447	+0.371	-0.125
Dia.	+0.417	+0.342	+0.413	+0.107	+0.275	+0.336	-0.162
N	+0.389	+0.620	+0.717	-0.145	+0.419	+0.256	-0.205
K	+0.084	+0.529	+0.478	-0.426	+0.425	-0.002	-0.142
P	+0.465	+0.561	+0.666	-0.046	+0.419	+0.316	-0.170
Ca	+0.169	+0.264	+0.206	+0.275	+0.335	+0.833	-0.081
Mg	+0.375	+0.092	+0.086	+0.367	+0.196	+0.316	+0.256
Mn	+1.000	+0.312	+0.291	+0.198	+0.218	+0.112	+0.188
	Fe	+1.000	+0.713	-0.051	+0.610	+0.264	+0.058
		Cu	+1.000	-0.080	+0.507	+0.253	-0.102
			B	+1.000	-0.088	+0.231	+0.344
				Zn	+1.000	+0.340	-0.132
					Mo	+1.000	-0.075
						Al	+1.000

<sup>1/</sup> For 62 degrees of freedom; a correlation coefficient of 0.320 or larger is significant at the 1 percent level, 0.246 or larger is significant at the 5 percent level.





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