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ESTABLISHMENT AND EARLY GROWTH OF *POPULUS DELTOIDES* BARTR.

A Dissertation

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ABSTRACT

Planting cuttings 20 inches long at a depth of 16 inches in a thoroughly cultivated soil is the standard technique for establishing cottonwood (Populus deltoides Bartr.) plantations in the southern United States.

There has been no previous study to determine an optimum planting depth in proportion to the above-ground part of a long cutting for achieving the best survival and growth in various soils.

Five experimental cottonwood plantations were established during the 1961-1968 period in the Mississippi River bottomlands in southern Louisiana for evaluation of various methods of planting cottonwood cuttings in comparison with the standard method.

The effects on first-year survival and growth of 20 combinations of five planting depths (1.3 to 5.0 ft) and four lengths of cutting above the ground (0.3 to 5.0 ft) were tested in undisturbed soil during 7 years. The effects of planting depth (1.3 and 3.0 ft), length of cutting above the ground (0.3, 2.0, and 3.6 ft), diameter of planting hole (1, 9, 14, and 18 in.), and fertilizer (P and P+N) were tested on first-year survival and growth in undistrubed soil and in the soil mixed in holes; some of these treatments were tested in combination with bedding the surface soil and with mulch. The effects of clone and cutting diameter were also tested.

Survival depended on the combinations of these treatments and on

the ratio (R_p) of available moisture to large pore space in the soil profile of planting depth. Survival in undisturbed soil was best at $R_p = 7.5$. Survival in soil mixed in the planting hole increased with planting depth, length of cutting above the ground, and diameter of hole. Survival was additionally improved by bedding the surface soil and by mulching with laminated Kraft-paper pads.

The annual variation in first-year survival of cottonwood planted by identical methods was directly related to seasonal precipitation adjusted for evapotranspiration. Incidence of leaf beetles and competition from vines considerably decreased first-year survival.

Tree growth in undisturbed soil depended on the same factors as survival and on nutritional soil properties, e.g. as expressed by the ratio (R_e) of potassium to calcium in the soil profile of planting depth. The best tree growth was obtained from long cuttings planted in the soil with optimal R_p (5 to 9) and R_e (0.03 to 0.05). The optimum pH in such soil varied from 7.43 to 7.67. Growth in height depended on different soil conditions from growth in diameter.

The variation in tree height at different ages depended on tree age and length of live cutting above the ground. The earliest data for projecting 7-year tree height and diameter were 2-year height and diameter measurements.

Planting long cuttings at a depth adjusted for the soil texture (R_p) extended the range of satisfactory conditions to sites which were considered unproductive for planting cottonwood by the standard method.

First-year growth was significantly improved by planting long cuttings in soil mixed in holes. The improvement was proportional

to the volume of mixed soil. An additional increase in first-year height growth was obtained from bedding the surface soil.

First-year growth depended on diameter and vitality of cutting and was directly related to survival by treatment regardless of site.

Root systems of trees planted 3 feet deep, especially in soil mixed in holes, were more abundantly developed than root systems of trees planted by the standard method in undisturbed soil.

It was concluded that the standard method of planting should not be considered as the universal method for establishing cottonwood plantations.

Recommendations were made for selection of cottonwood sites and appropriate planting methods.

INTRODUCTION

Silvicultural and Economic Importance of Cottonwood

There are more than 100 species of poplar (Populus L.) in the world, many of which can be used to meet the increasing demand on forest resources. In the United States, six of the nine native poplars are important in forestry. In particular, the eastern cottonwood (*Populus deltoides* Bartr.) possesses high economical and silvicultural merits, such as wood characteristics suitable for many industrial uses, wide range of natural distribution (Figure 1), fast growth rates, ease of vegetative propagation, genetic variability, and ease of natural and induced hybridization. For many years cottonwood has been an important source of basic raw material for manufacturing boxes, tubs, baskets, shingles, excelsior, cooperage stock, furniture, wall-paneling, veneer for match boxes and sticks, and plywood cores.

The bottomland forests in the lower Mississippi Valley in the states of Arkansas, Missouri, Louisiana and Mississippi have been the major source of cottonwood lumber since the beginning of this century. In 1900, these four states supplied 68.7 percent of the 415 million bd. ft of cottonwood lumber produced in the United States.

About 25 years ago the paper industry found an important use for cottonwood. It is an ideal material for paper production because of its soft texture which requires less power for grinding, its whiteness

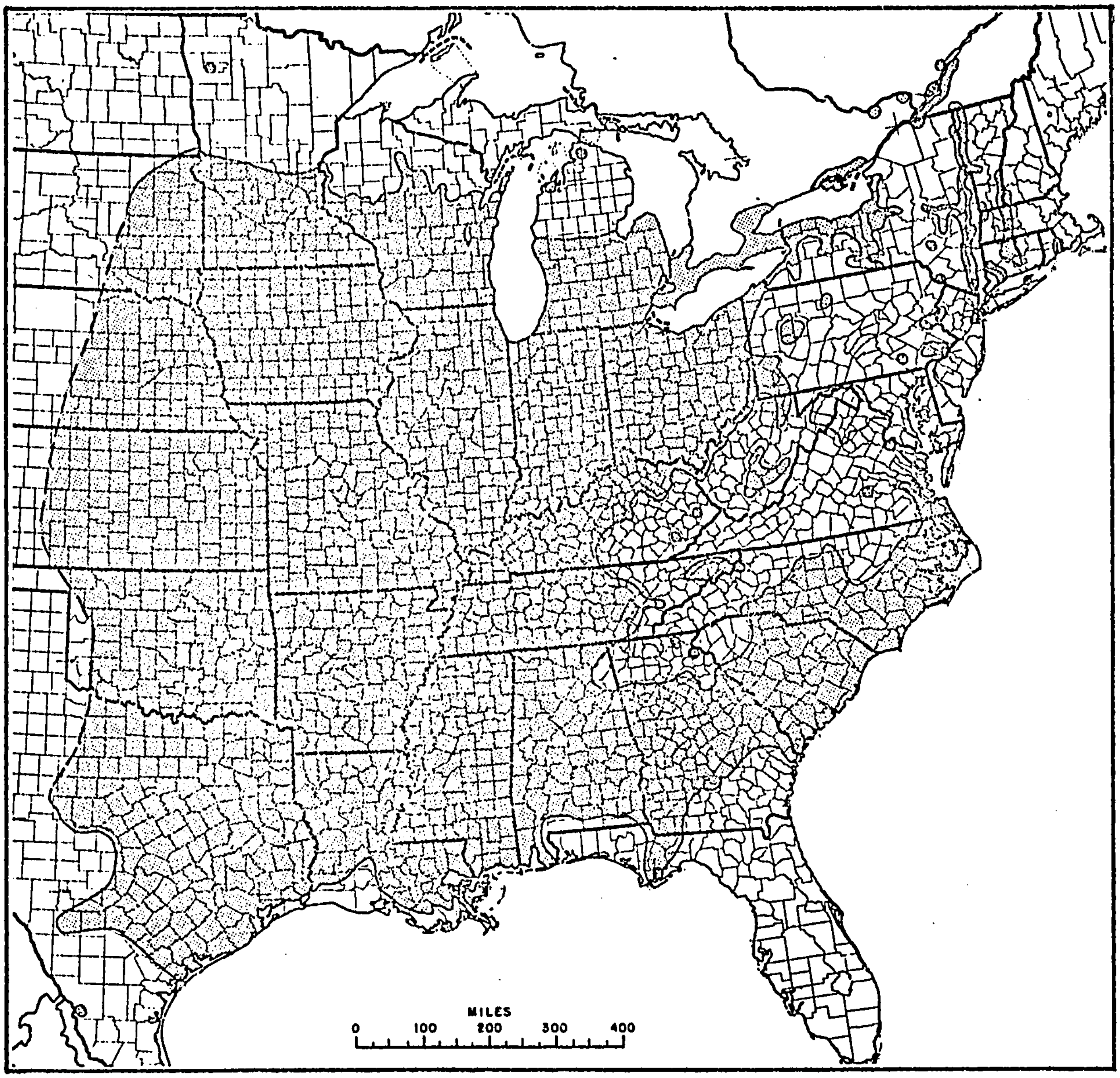


Figure 1. Range of eastern cottonwood (<u>Populus</u> <u>deltoides</u> Bartr.).

which needs almost no bleaching, and its lightness in weight resulting in paper sheets of 25 percent less weight as compared to those produced from the pulp of conifers. Consequently, savings are attained in the processing and shipping costs. The use of conventional groundwood of cottonwood as a filler to the coniferous pulp improves significantly the uniformity, the compressibility, the elasticity, and also the printability characteristics of paper such as smoothness, porosity to ink, brightness and opacity, which are essential for the sharpness of print, illustration, and color (Swartz 1960).

The development of a technique for producing paper from a 50-50 mixture of coniferous and cottonwood fibers has resulted in remarkable improvements in the strength, tear and burst characteristics of the paper sheet, allowing it to run through high-speed presses without web breaks. This development has made cottonwood a most important source of raw material for the production of paper.

In recent years, there has been a decrease in the production of cottonwood lumber, accompanied by a marked increase in the utilization of the species for pulpwood (Van Sickle and Sternitzke 1964), and this trend is expected to continue.

While the demand for cottonwood fiber has increased, the growing stock has decreased at a rather alarming rate due to the conversion of forests to agricultural land. In the mid-1930's, 11.8 million acres of land in the Delta were classified as forest, but by 1970, 3.7 million acres of this had been converted to agricultural and other usage (Sternitzke and Christopher 1970). These authors also anticipate that

the remaining 8 million acres of forest will be subject to a further reduction. However, Harrison (1961) estimated that the acreage will not drop below 5 million.

The best bottomland forest sites have been the choice for clearing and conversion to long-term highly productive farmlands. Consequently, as the acreage of good sites and their quality decline in the South, so does the yield of cottonwood.

All such circumstances dictate that an increase in the production of cottonwood on the available sites in the South can only be achieved by a widespread application of intensive cottonwood culture using genetically improved planting stocks.

Planting Techniques and Their Economics

The research work pertinent to cottonwood culture which was done prior to 1960 can be divided into three broad categories: (1) silvics, management, and the studies of site-species relationships and growth and yield of natural stands, (2) site preparation, planting stock, rooting cuttings, planting technique, survival and early growth and (3) tending and protection of plantations (weeding, fertilizing, pruning, and pests and diseases). The results of about 30 works in category (2) were published during that period of time.

Maisenhelder (1960) summarized the results of 18 years of research with cottonwood culture at Stoneville, Mississippi, and updated all attainments in this field. Planting 20-inch-long cuttings 16 inches deep in well-cultivated bottomland soil was generally accepted as the standard method for establishing cottonwood plantations

in the South. Loamy soil was considered to be the best for cottonwood. However, planting cottonwood on a commercial scale was just beginning in the South. The commercial plantations totaled only 1809 acres by the end of 1961. The large industries were the first to begin cottonwood regeneration programs (Poplar Council 1968).

The standard method for establishing cottonwood plantations requires very laborious and expensive site-preparing operations. A complete clearing, windrowing, and slash burning must be done on cutover forest lands; a cross-subsoiling is necessary to ease placement of cuttings in the ground and to facilitate the infiltration of precipitation in compact soils; and a costly weeding is indispensable. Often, a plantation needs three cultivations during its first season. These operations require heavy equipment, which may be available only to large companies. Small farmers, who generally lack heavy equipment, have limited opportunities to plant cottonwood for profit by using the conventional methods. However, since 35 percent of the commercial forest land in the Mississippi Delta is in small farms, farmers can play an important role in a cottonwood program, if a suitable method for planting is developed.

The success of cottonwood plantations depends to a great extent upon soil characteristics and even more upon the yearly and seasonal rainfall distribution. The survival and growth of cottonwood plantations have varied from excellent to complete failure. The costs of establishing a cottonwood plantation in the late 1950's were $43.80 per acre (Moore 1958). While the anticipated yield averaged about 2.2

cords at that time (King 1962, Capel and Coffman 1966, Henderson 1968), later it did not exceed 3.8 cords per acre per year on good sites (McKnight 1970). The stumpage price for hardwood pulpwood, cottonwood included, was too low ($2 per cord). Consequently, the investment in cottonwood plantations did not secure an early and satisfactory return.

Although the use of planting stock from newly selected Stoneville clones offers a yield increase to about 5 cords per acre per year in a 20-year-rotation on good sites (So. Forest Exp. Sta. 1970), the economics of cottonwood plantations have recently changed for the worse, because the costs of establishing a plantation have risen to $108.00 per acre (McKnight 1970). Meanwhile, the cottonwood pulpwood stumpage price has remained the same ($2 per cord) as it was 10 years ago.

All this leads to the conclusion that the widespread interest in planting cottonwood has declined because of its poor economics. However, the economics of cottonwood plantations may be improved either by an increase in yield through better utilization of the productive capacity of soil, appropriate soil conditioning, and a properly selected planting stock; or by an increased stumpage price for pulpwood; or probably by both. Otherwise, an early and satisfactory return from cottonwood plantations cannot be attained; therefore, cottonwood planting may remain an exclusive enterprise of the cottonwood-using industry. The high returns from soybean crops strengthen such a status.

Italy is an excellent example of high efficiency in intensive poplar culture. The nation-wide Italian interest in planting poplars on a commercial scale dates to the beginning of the 19th century.

Before 1955 there had been 89,000 acres planted, but by 1961 the total area of poplar plantations had reached 385,000 acres. Pulpwood production of 8 cords per acre per year on a 12-year rotation is an average yield on the alluvial soils of the Po' River Valley (Prevosto 1965).

The Experimental Institute for Poplar Culture (Istituto di Sperimentazione per la Pioppicoltura), established in 1937 at Casale Monferrato, Lombardy, has contributed a great deal to the success. The poplar, Populus x euramericana (Dode) Guinier cv. 'I-214', which was selected by the Institute, has been used for many years to establish commercial plantations.

For many years prior to 1960, and even at the present time, the Italians have established commercial poplar plantations by planting poplar trees with 2-year-old stems and 3-year-old root systems in 10-inch-diameter and 3-foot-deep planting holes drilled with a tractor-mounted soil auger. Only healthy trees with straight stems and no injuries are planted; all crooked, curved, and diseased plants are discarded. After lifting, the roots are shortened and the stems pruned. Deep planting is considered to be essential for the fast growth and support of large planting stock. A rigid selection of planting stock has been found to be indispensable for homogenous growth of trees and for the production of high quality timber (Boyce 1963). The planting holes are drilled manually in deep sandy soil, often to a depth of 15 feet, using a 4-inch-diameter spiral soil auger. After ten years, trees planted by this method reached a merchantable height of 50 feet with 4-inch diameter at the top of the trunk and 15 inches at breast height (May 1959).

Planting long cuttings (sets) of poplar and willow was practiced in the Roman Empire (Seidensticker 1886) and later in Italy; this technique was also used in Germany, Austria, France, and the Netherlands for afforestation of flood plains (Zycha et al. 1959).

Objectives of the Study and Hypothesis

No analytical study has been made, either with poplars in Europe or with cottonwood in the United States, to determine the most favorable planting depth in proportion to the above-ground part of a long cutting to achieve the best tree growth in various soils.

A comparison of the yields attained in poplar plantations in Italy with the yields of cottonwood plantations in the southern United States motivated the author to try the deep planting method with cottonwood cuttings in the bottomland soils in Louisiana. The objective of the study was to evaluate the effects of the deep planting method on eastern cottonwood cuttings planted in the alluvial soils of the Lower Mississippi Valley in southern Louisiana in an attempt to develop a technique for cottonwood planting which does not require expensive site preparation, and which at the same time will guarantee a high yield of timber.

A preliminary trial of deep planting cottonwood cuttings was made in 1960 with encouraging results (Kaszkurewicz 1964). As a consequence, a project titled "Deep planting of cottonwood" was initiated in 1961. A series of experimental cottonwood plantations was established in the Mississippi River bottomlands in the vicinity of St. Francisville, Louisiana, during the period 1961 through 1964. This study is a phase

of research project 1055 of the Louisiana Agricultural Experiment Station.

The hypothesis that the effects of different cutting sizes, different planting methods, different silvicultural treatments, and different soil properties are reflected in the survival and in the subsequent growth of trees was investigated. The results of the studies made on the growth of cottonwood trees planted as cuttings of various lengths by different methods and in different soils are presented. A method for determining the productive capacity of site which is related to properties of soil is also presented.

The information obtained as the result of this study will explain some of the factors which were not considered previously but have decisive effects on the shaping and the growth rate of cottonwood trees in a plantation, thus affecting the quality and the yield of timber.

It is hoped that the results of this study will find practical applications beneficial to cottonwood growers and, at the same time, stimulate a widespread cottonwood culture. It is also hoped that this study will generate an impulse towards new studies among research foresters for solving the still numerous vital problems in poplar culture.

Definition of Terms and Symbols

The definition of all technical forestry terms used in this dissertation are given in Terminology of Forest Science, Technology, Practice, and Products (Ford-Robertson 1971). The following two sections give the definitions of soil and genetic terms.

Soil Terms

Bulk density (BD) - Ratio of the weight of oven-dry soil to the volume it occupied in the field, expressed as grams per cubic centimeter; also apparent specific gravity of soil (Baver 1959).

Total pore volume (TP) or soil porosity - percentage of the soil-core volume which is not occupied by solid soil particles. Total pore volume is calculated in percent from bulk density and (real) specific gravity of soil particles (2.62 g per cm^3) for soils with less than 10 percent organic matter.

$$TP = \left(1 - \frac{BD}{2.62}\right) 100$$

Large pores (BP) - Readily drained pores which are filled with air, if the soil is not waterlogged, and are responsible for the air capacity and ready percolation of water through the soil. The volume of these pores is obtained by subtracting the 60-cm water-tension value from the total pore volume of a soil core.

Capillary pores (CP) - The small pores that hold water by capillarity. They are responsible for field capacity. Their volume (CP) is calculated by subtracting the (BP) from (TP).

Field capacity (FC) - Field moisture content of well-drained soils approximately two days after saturation. Moisture content in soil held in equilibrium at a tension of 1/3 atmosphere.

Water-holding capacity (WC) - Moisture content of a soil core or disturbed column of soil after it has drained following saturation. Moisture content in soil held in equilibrium at 60 cm of water tension.

Wilting point (WP) - Moisture content of a soil when plants growing in it wilt permanently. Moisture of a wetted soil after reaching equilibrium at a tension of 15 atmospheres.

Drainage capacity (DC) - That volume of soil voids in a sample calculated by subtracting volume of water held at 1/3 atmosphere tension (FC) from total pore volume (TP).

Available water capacity (AW) - Moisture content available for plants in a well-drained soil, calculated by one of the following methods:

(AW) = (FC) - (WP); (AW) = (TP) - (DC) - (WP).

Genetic Terms

Barbatelle - A young plant grown either from seed or from cutting, prepared for out-planting with the shoot cut back to desired length and roots shortened to fit the size of planting hole.

Clone - All the plants (ramets) reproduced asexually from a common ancestor (ortet) and having identical genetic constitutions (except as changed by bud mutations). Each clone is given a name or identification code, enclosed in single quotation marks, preceded by the abbreviation cl., e.g. *Populus deltoides* cl. 'Tensas-2'.

Clonal test - A field test in which only asexually propagated progenies (ramets) are represented, and which, if replicated, is useful for the demonstration of hereditary differences among clones and, consequently, the ortets.

Cultivar - Abbreviation of "cultivated variety." An assemblage of individuals which is distinctive and promising enough to be given a separate name. Cultivar names are enclosed in single quotation marks, preceded by the abbreviation cv., e.g. Populus cv. 'Roumei.' Most, but not all, cultivars are distinct genetically; some are merely topophysic phenomena.

Variety - The taxon below subspecies; a group which distinctly differs, for various reasons, from other varieties within the same subspecies. Often used loosely in botany and zoology to mean a genetic variation within the species.

Phenotype - A plant with visible characteristics which are the product of the interaction of the plant's genes with the environment. Identical phenotypes do not necessarily breed alike.

Ecotype - A distinct race resulting from the selective action of a particular environment and showing adaptation to that environment. Ecotypes are distinguishable only through uniform environment experiments. Ecotypes include climatic ecotype, geographic ecotype, and edaphic ecotype.

Genotype - This term may be used in a limited sense to describe

the genetic constitution of an individual plant in terms of a few specific genes, or in a general sense to include the entire genetic constitution (expressed or latent) of an individual.

Progeny test - Evaluation of parents by the performance of their sexual progeny. The evaluations include a one-parent progeny test, in which only the female parent is known, and a two-parent progeny test, in which both the seed and pollen parents are known.

Full-sibs - Trees with two parents in common.

Half-sibs - Trees with one parent (usually the female) in common.

Hybrid - The product of a cross between individuals of unlike genetic constitution. When used without qualification this term usually refers to the product of a cross between species.

Definition of Symbols

For the sake of brevity in the text, formulas, diagrams, and tables in this dissertation, symbols are often used. An alphabetical listing with the definition of each symbol is given below.

B -- Cultivation of the surface soil by bedding after planting.

C_d -- Depth (feet) of planting a cutting.

C_h -- Length (feet) of that portion of a cutting which remains above the ground after a cutting has been planted.

C_o -- Length (feet) of live above-ground portion of a planted cutting measured from ground level to the base of the leader shoot.

C_p -- Clay content (percent) in a soil profile of planting depth, as averaged from the samples taken from all strata in the profile.

C_{ϕ} -- Diameter (centimeters, or inches) of a cutting.

$C_{\phi b}$ -- Diameter (centimeters) at the base of a cutting.

$C_{\phi t}$ -- Diameter (centimeters, or inches) at the upper end of a cutting.

C_{θ} -- Cross-sectional area (cm^2) at the middle length of a cutting.

dbh -- Tree diameter (inches) outside bark at 4.5 feet above the ground level.

E -- Fertilizer treatment by application either of one essential element or a combination of elements.

ETa -- Adjusted monthly evapotranspiration (inches).

ETd -- Deviation of monthly adjusted evapotranspiration from that predicted for a month (inches).

ETp -- Evapotranspiration per month predicted by Thornthwaite's method (inches).

ETr -- Evapotranspiration rate per month per $1^{o}F$ (inches).

h -- Total height (feet) of a tree.

h_X -- Tree height (feet) at the age of X years; hence h_6 -- tree height at age six.

H^+ -- Hydrogen ion activity (10^{-8} moles/liter) in soil.

H_d -- Depth (feet) of a planting hole.

H_{ϕ} -- Diameter (inches) of a planting hole.

H_{θ} -- Cross-sectional area (square inches) of a planting hole.

M -- Mulching treatment.

Mb -- Adjusted moisture balance calculated for a given month (inches).

$\sum$Mb -- Adjusted moisture balance (inches) for an entire growing season.

Nd -- Deviation of long-term mean monthly precipitation from evapotranspiration predicted for a month (inches).

P -- Fertilizing treatment by application of 1.5 lb of superphosphate per tree.

P+N -- Fertilizing treatment by application of 1.5 lb of superphosphate and 2 oz of ammonium nitrate per tree.

Pa -- Actual monthly precipitation (inches).

Pd -- Deviation of actual monthly precipitation from long-term mean monthly precipitation (inches).

Pm -- Long-term mean monthly precipitation (inches).

Q -- Deep cultivation by mixing the soil in a planting hole.

R_d -- Ratio of available water (AW) in percent by volume to large pore space (BP) in the deepest 1-foot stratum of a soil profile of planting depth.

R_e -- Ratio of extractable potassium (K) to calcium (Ca) in a soil profile of planting depth.

R_p -- Ratio of available water (AW) in percent by volume to large pore space (BP) in a soil profile of planting depth.

Ta -- Actual mean monthly temperature (^oF).

Td -- Deviation of actual mean monthly temperature from long-term mean monthly temperature (^oF).

T_m -- Tree mortality (percent) by treatment or by type of soil; T_{m2} -- the mortality at the end of second year.

T_s -- Tree survival (percent) by treatment or by type of soil;

T_{s7} -- the mortality at the end of seventh year.

V -- Seven-year tree volume o.b. (cubic feet) as related to certain factors in a plantation.

$\bar{V}$ -- Seven-year average tree volume o.b. (cubic feet) per treatment.

V_t -- Seven-year total volume o.b. (cubic feet) per treatment.

* -- Statistical significance at the 0.05 probability level.

** -- Statistical significance at the 0.01 probability level.

Diagramatic meanings of some of these symbols are shown in Figure 2.

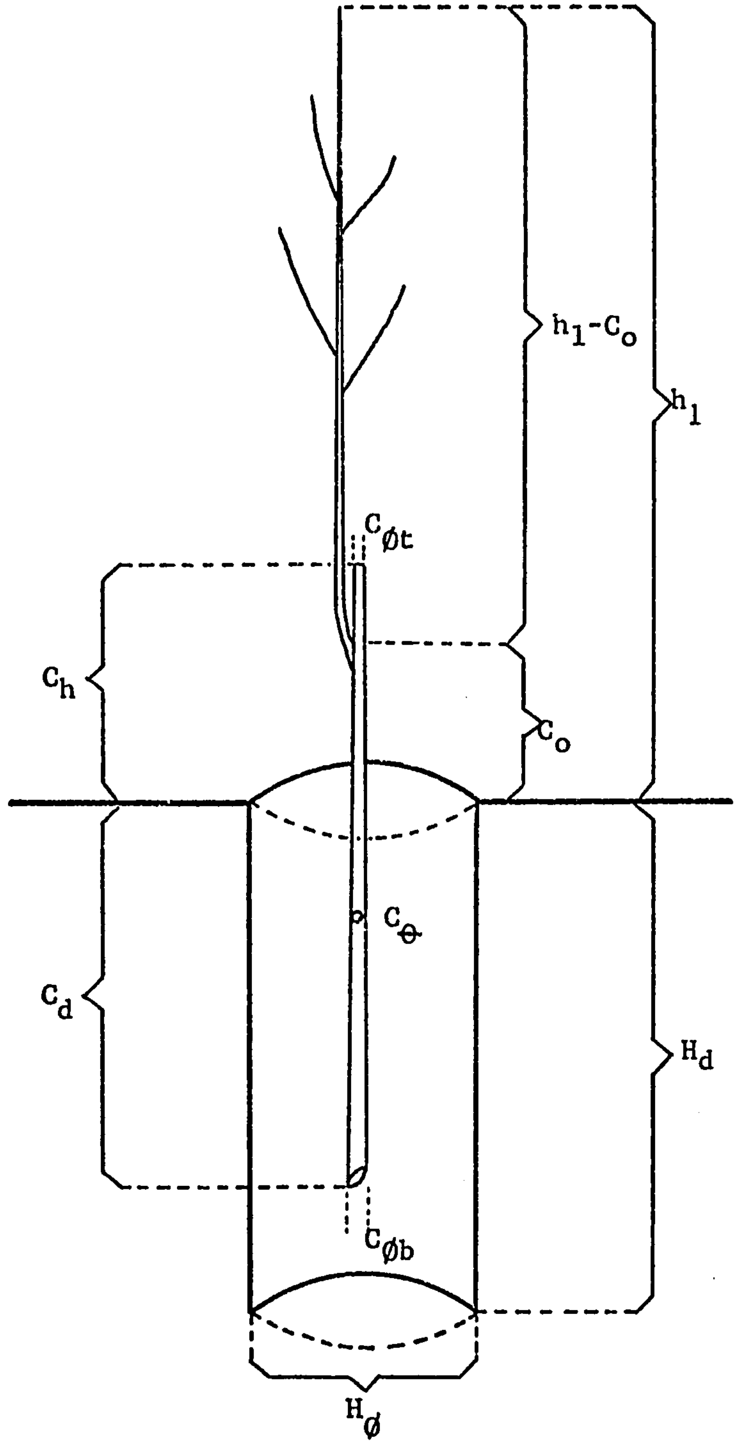


Figure 2. Diagram showing the meanings of some of the symbols used in this report.

REVIEW OF LITERATURE

By 1963, two years after the initiation of this study, the world literature on poplars reached about 1600 references (Farmer and McKnight 1967). At that time in the United States, there were only 80 publications and four theses written about the eastern cottonwood. Among these works, 20 publications were dedicated to the selection of site, planting technique, and cultural treatments; 14 publications were about the production of planting stock; 15 works were about silvicultural characteristics of the species and management of natural stands of the species; and 6 works were about the growth of cottonwood in natural stands and in plantations. The remaining 29 publications dealt with wood properties and pests.

During the following years, new works were reviewed as they were published. The pertinent material is discussed below. Numerous foreign works were reviewed. Particular attention is paid to those on the silviculture of Euramerican poplars because of their many close relationships to our native cottonwood.

In several cases works relating to species of other genera have been included in the review. In addition, many works in other related fields such as soil science, climatology, plant physiology, biochemistry in connection with tree nutrition, and subjects having bearings on a better development of the study were also studied, having in mind "to apply all that is applicable." The review of the

literature is divided into sections in accordance with subject matter and is presented in the following pages.

General

The genus Populus L. is one of the oldest dicotyledonous plants of the world. Geological history counts 125 fossil species found from deposits beginning as early as the closing days of the lower Cretaceous and through Tertiary. The geological epochs of those remote times were represented by various numbers of poplar species, fossils of which were found scattered in the region of high latitudes of the North American and Euro-Asiatic continents. No trace of poplar was found in the Southeastern part of North America as far north as the mouth of the Ohio River. Prior to the Pleistocene, the climate was sub-tropical in this region, and the vegetation consisted of rain trees, bread fruit, nutmegs, date palms, and many other associated plants. The Pleistocene was represented by ten species of poplar, two of which are extinct. Five species found in Europe and three in America were identical with our contemporary species. The ancestor of our cottonwood, the so-called necklace poplar (Populus deltoides) has been found in river terrace deposits in Alabama and Kentucky (Berry 1917, Regnier 1955).

The first written information about black poplar (aigeiros) and white poplar (leuce) appeared in Greek in the 9th Century B.C. in the epic poems of Homer, the Iliad and the Odyssey. The Latin name of poplar (populus), which was used by Linneus in 1753 as the scientific name (Populus L.) for the poplar genus, appeared for the first time in

Roman literature ca. two centuries B.C. in a treatise on agriculture, "De re rustica," written by Marcus Porcius Cato, Censorius. This work was a translation of 28 books written in Phoenician by Mago (6th Century B.C.). Mago was the first to write about the advantage of planting poplars on a farm, especially in the places with moist soil, to provide leaves for sheep and timber for farm needs (Cato ca. 200 B.C.). The earliest information on silvical characteristics, site, propagation, and wood properties of black and white poplars and aspen was published in Greek by Theophrastus in an 18-book series entitled Enquiry into Plants; five books in this series were dedicated to the trees (Theophrastus ca. 300 B.C.).

The ancient forest history provided information on the effects of poplars on the economy of those times. Poplar wood has had several uses such as for rafters in construction, in carving art objects, in making sandals, boxes, tubs, baskets, posts, parts of wheels, and shields of warriors. Sawdust, wood shavings, and chips were used for storing grapes. Poplar trees were highly esteemed in ancient times for their fast growth and also for their light crowns. Intensive poplar plantations were established in the Roman Empire with the main purpose of providing a support for the grape vine, since grapes ripened in dispersed light were considered to be of a higher quality than those which were grown in the open (Seidensticker 1886).

The genus Populus L. constitutes a large, though yet undetermined, number of species. Harlow and Harrar (1941) considered 35 species; Zycha et al. (1959) estimated as many as 150 species; Pravdin and

Filimonova (1960) reported that more than 100 species have been described. However, the list is still not complete. The genus includes cottonwoods, balsam poplars, white poplars, and aspens, which are widely distributed throughout the Northern Hemisphere: from the Atlantic to the Pacific in the New World, northern Africa, the southern slopes of the Himalayas, central China, and Japan in the Old World. Fifteen species of Populus are native to North America, but only six of them occur in commercial size and quantity.

Taxonomically, the genus Populus belongs to the family Salicaceae of the order Salicales and is divided into the following five sections (Fontaine 1958, Zycha et al. 1959, Schreiner 1971):

1) Leuce Duby, which includes white poplars and aspens. Of this section two aspens, P. tremuloides Michx., and P. grandidentata Michx. are native to North America.

2) Aigeiros Duby, to which belong the European black poplars and the eastern cottonwood (P. deltoides Bartr.) of North America.

3) Tacamahaca Spach, which comprises all balsam poplars of the world with P. acuminata Rydb., P. angustifolia James & Gray, P. balsamifera L., and P. trichocarpa Torr. of North America.

4) Leucoides Spach, to which belong large-leaf poplars represented by swamp cottonwood (P. heterophylla L.) in the southeastern part of the United States.

5) Turanga Bunge, the polymorphic-leaf poplars, which are not represented by any species in North America.

Komarov (1936) has divided the genus Populus into three subgenera (Turanga, Leuce, Eupopulus), seven sections, and nine series. According to his classification P. deltoides Bartr. belongs to the subgenus Eupopulus, the section Aigeiros, and the Aigeiros series.

General morphological features and taxonomically useful characters of North American poplars have been described by Harlow and Harrar (1941), Fernald (1950), and Sargent (1961).

The poplars, as the other species of the Salicaceae family, are dioecious; yet several cases of hermaphroditism in a _P_. _deltoides_ Bartr. tree, after self-pollination, produced seed with 65 percent germination capacity. In general, however, the dioecious character of the genus favors cross pollination, which produces viable hybrids, especially among the species of the same section. This ease of intrasectional hybridization resulted in the development of the Euramerican poplars which are the cross-products of _P_. _deltoides_ Bartr. with the European black poplar (_P_. _nigra_ L.) (Campo 1963).

The putative intersectional hybridization and introgression, especially along the extensive western and northern borders of the cottonwood range where it overlaps with the ranges of the other American poplars, are the causes of many _Populus_ populations in this region being taxonomically indistinct. The occurrence of putative natural hybrids of eastern cottonwood with poplars of the sections _Leuce_ and _Tacamahaca_ has been reported by Brayshaw (1965).

On the other hand, the occurrence of considerable phenotypic variation in cottonwood within its range may be attributed to the wide variation in climatic and edaphic conditions in which it grows (Marcet 1961, Farmer 1966 and 1968, Farmer and Wilcox 1966, Wilcox and Farmer 1967 and 1968, Kaszkurewicz and Fogg 1967, Randal and Mohn 1969).

The silvical characteristics of cottonwood have been exhaustively

presented in many works (Williamson 1913, Putnam and Bull 1931, Maisenhelder and Heavrin 1957, Putnam et al. 1960, Fowells 1965, McKnight 1968).

Regeneration by Seeding and Coppicing

Many factors must coincide to create favorable conditions for successful natural reproduction of cottonwood. In the period of seed fall, from the middle of May through the middle of July, it is essential for the bare soil to remain moist (Maisenhelder 1960). Dispersed light rather than bright sunshine is preferable for achieving successful germination and early survival. According to McKnight (1965), "the most favorable temperature range for germination in water is about 80° to 90°F." The author of this dissertation found that air temperature between 70° and 80°F is ideal for the germination of cottonwood seed. Both the temperature of about 65°F and the soil reaction below pH = 5, which are conducive to the development of most fungi, depress germination of the seed (Small 1946). The cotyledon-stage seedlings may be injured by temperatures higher than 80°F, since the upper 1/4-inch of soil will be heated and become dry.

Germination of cottonwood seed is epigeous; therefore, the cotyledons start to grow first, and then three tiny lateral radicles develop on the embryo (Plate 1). Before the radicles have developed, a fringe of cottony hairs, attached on a collar-like ring to the embryo-end of the seed, serves as a substitute for a moisture-absorbing root system (Figure 3).

The seed of cottonwood is very small; 1 pound of cleaned

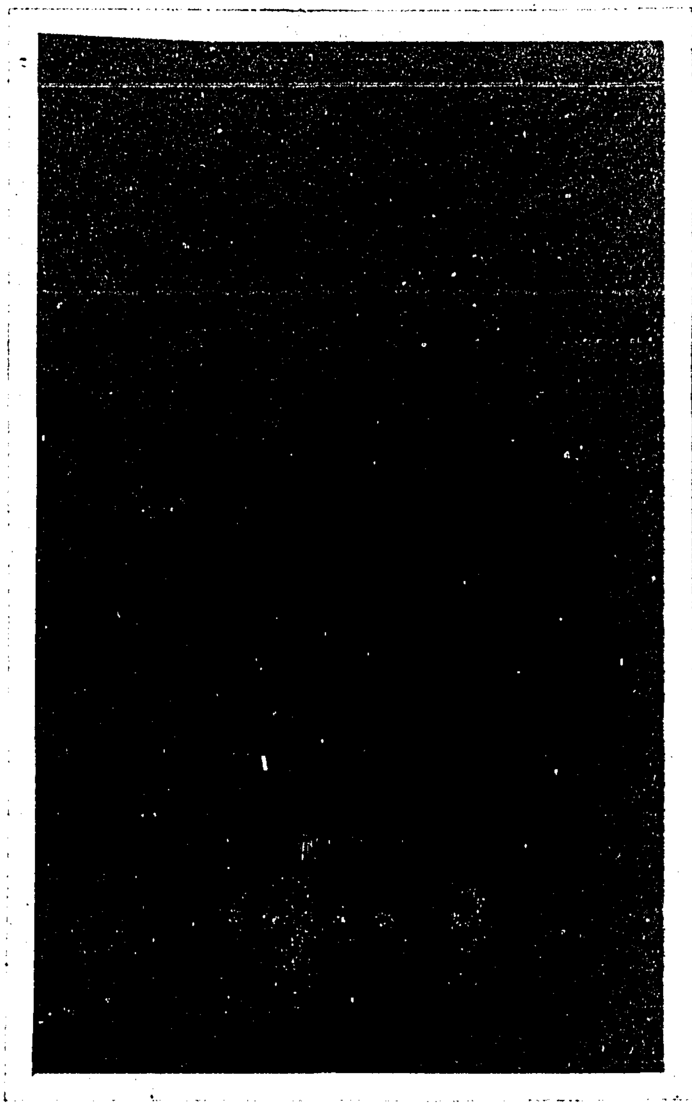
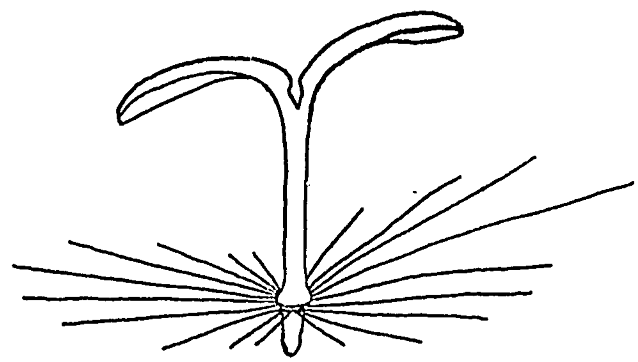
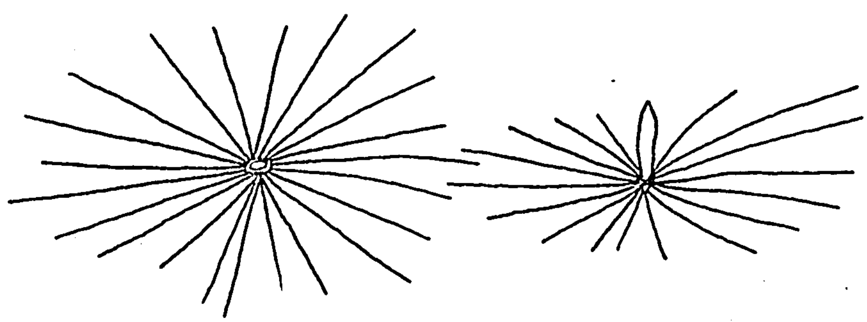


Plate 1. Six-day-old cottonwood seedling (x3).



Cotyledon-stage seedling



Detached parachute | Seed with parachute

Figure 3. Cotyledon-stage cottonwood seedling, and seed (x5).

cottonwood seeds consists of 200,000 to 590,000 seeds (U. S. Forest Service 1948). The average weight of different seed lots varies from 2×10^{-5} to 6×10^{-5} lb, which is a ratio of 1 to 3. However, the relative variation in the weight of a single seed is from 1 to 8. Such a variation in seed size must affect germinative capacity of seed in addition to survival and vitality of seedlings, at least during the first few days of their lives. No study has yet been made to determine the effect of the size of cottonwood seed on germination and growth of seedlings.

A mature cottonwood seed tree of about 30 inches dbh with a well-developed crown is able to produce several thousand necklace-like, fruit-bearing clusters annually (Plate 2). A well-developed cluster can have about 35 fruits. Each fruit, a capsule, contains 20 to 30 viable seeds. Thus, 2 to 5 million seeds, each suspended in the air on a parachute-like cottony fringe, are carried by the wind to an average distance of 200 feet away from the tree. Two seed trees are sufficient to provide good seeding for one acre (Johnson 1965). Not all the seeds will reach the ground; many of them remain anchored to the limbs. Those falling in places covered with vegetation or on bare compacted soil are lost. Often, however, a dense regeneration of cottonwood can be seen growing vigorously on moist sand bars near the water level of larger rivers, in borrow pits, and on spoil banks along drainage ditches (Plate 3).

Johnson (1965) tried to simulate the bare land where cottonwood establishes itself naturally. In a cut-over bottomland forest, all the

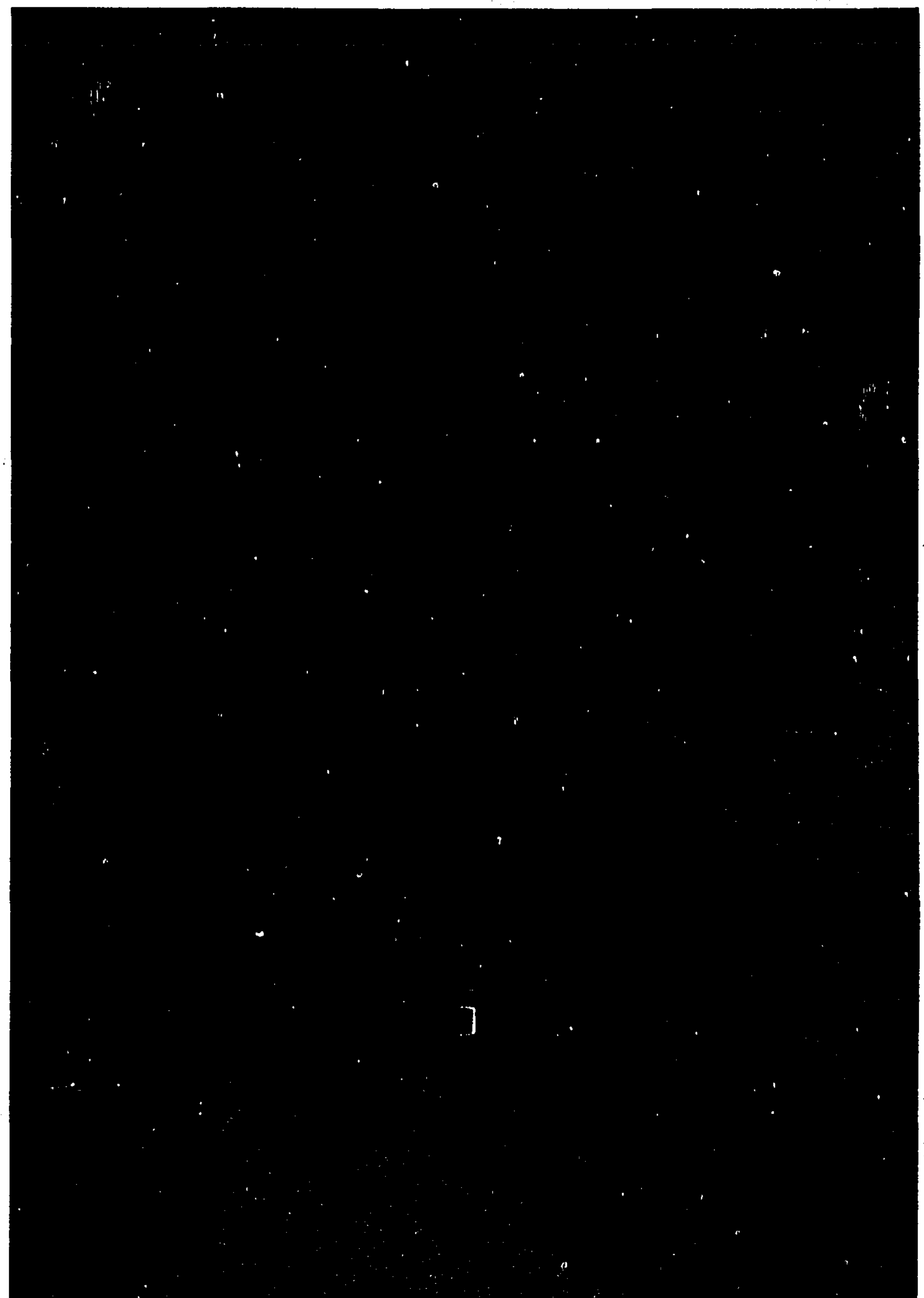


Plate 2. Clusters of cottonwood capsules.

Plate 3. Natural cottonwood regeneration on spoil bank along a road-ditch.

trees except the cottonwoods were either cleared or deadened during April. Beginning in May, a series of 3- to 10-foot-wide strips were prepared by plowing, disking, or bulldozing to depths varying from 5 to 20 inches. During the first season the cottonwood seedlings established themselves on the strips at various densities depending on the type of soil treatment. No regeneration developed on disked strips. Stocking was unsatisfactory on plowed strips. The best stocking was achieved on 10-foot-wide and approximately 10-inch-deep bulldozed strips. After three years, the stocking of seedlings was maintained at about 85 percent and the heights of the dominant seedlings averaged 10 feet. The result was so encouraging that several lumber companies treated about 1,500 acres of understocked forests with bulldozed strips. Each company reported considerable variation between, and even within, treated areas.

McKnight (1968) reported, as experience indicated, there was a bare 50-50 chance of success for regenerating cottonwood from seed by the application of trenching methods.

Regeneration of cottonwood by the coppice method was studied by Hofman (1912) in Minnesota. He found that the number of sprouts from the cambium at the cut surface of a stump increased with an increase in the height of the stump (three sprouts on a 6-inch-high stump and 70 sprouts on a 40-inch-high stump). However, the average height of sprouts decreased with an increase in the height of the stump (9 feet on 5-inch-high stump and 3.5 feet on 40-inch-high stump). He also found that low stumps tend to produce sprouts from the root collar

in addition to the sprouts from the cambium. The largest number (14) of sprouts from the root collar was found on the 4-inch-high stumps; with an increase in the height of the stump, the number of these sprouts decreased. No sprouts were observed on the stumps which were higher than 17 inches.

Hofmann observed that the most reliable sprouts for regeneration of a stand were root suckers--those from root collars and from roots themselves. These sprouts easily developed their own root systems. The sprouts from the cambium of the stumps lower than 6 inches in height grew well. However, their lives were shorter than those growing from the root collar. High stumps did not produce decent trees from sprouts on the cambium ring. Better growth of sprouts from root collar or low stumps resulted if the number of sprouts per stump was reduced to three or less.

Regeneration of cottonwood by the coppice method had not been studied in the South before 1967. At that time, Crown Zellerbach Corporation established a series of plots at the Fitler Plantation, Mississippi, to study regeneration by coppicing. No results have yet been released.

Planting Methods

Regeneration of cottonwood and other poplars by natural seeding is possible only under certain optimal conditions of soil moisture, light, temperature, air humidity, and ground cover. Simulating such conditions presents numerous problems. As yet, satisfactory results have not been produced in the field. Growing cottonwood seedlings in

nursery beds where the conditions can be controlled steadily is sufficiently facile. But these seedlings usually exhibit considerable variation in various aspects due to the origin and the quality of the seed.

Modern silviculture, intended for growing high quality timber, is based on the use of a rigidly selected superior planting stock. This requirement can be met when selected clones are used to establish commercial plantations. Vegetative propagation of clonal material, using dormant or green cuttings, provides the means of producing a large number of plantable materials for commercial plantations in a short period of time. Planting cuttings is a simple operation performed either manually or mechanically. In addition, handling of cuttings in storage, transport, or grading is much easier than of seedlings, thus resulting in favorable cost of planting stock and planting operations. Nevertheless, the establishment of poplar plantations by planting cuttings was not adopted on a world-wide basis for reasons to be discussed later.

Discussions of planting methods in various countries of the world are presented in the following sections.

Italy

In Italy, the development of planting techniques for establishing poplars passed through several stages. Various sizes and ages of planting stock (1-1, 1-2, 2-2, 2-3 and 3-3)[1/] and several spacing

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[1/] 2-3 planting stock means a seedling with a 2-year-old shoot on a 3-year-old root system; this numerical system is employed in Europe.

combinations (from 100 to 266 trees per acre) have been tried during the past 30 years.

The technique now consists of a site preparation (20 to 24 inches deep plowing and disking); planting of 2-2 nursery-grown saplings 25 to 30 feet tall in holes 2 feet in diameter and 27 to 32 inches deep; two annual weedings (or one light cultivation and one weeding); three prunings (in the 2nd, 4th and 7th years); pest control treatments; and at least one yearly irrigation. As a rule, nitrogen-phosphorus-potassium fertilizer is applied at the time of planting and in the third growing season (Fontaine 1958, Ente Nazionale per la Cellulosa e per la Carta 1964).

Prevosto (1965) reported that on all sites the highest constant annual income was derived from poplar plantations with 125 to 142 trees of clone 'I-214' per acre (300 to 345 square feet per tree). These plantations were established based on a rectangular spacing of 16.4 by 19.6 feet, which was considered to be the optimum at that time.

An equilateral triangular spacing, with the distance of 21 feet between the trees, has recently been promoted. It gives the possibility of a better utilization of planting area, and at the same time a single tree retains the same space as in the case of the rectangular spacing. Fifteen percent more trees can be planted on the same area than if rectangular spacings are used.

Yugoslavia

A technique very similar to the one used in Italy is being used in Yugoslavia (Bura 1967). Either 2-3 seedlings or 2-year-old switches

with the diameter not smaller than 1 inch at the height of 3.3 feet above ground are planted 30 to 40 inches deep in holes 26 inches in diameter. The graded seedlings (I-grade 1.6 inches; II-grade 1.4 to 1.6 inches; III-grade 1.0 to 14 inches) are usually planted in separate areas. Seedlings which are smaller than 1 inch in diameter and less than 8 feet tall, crooked, or diseased are discarded. After lifting, the roots are shortened and stems pruned.

In sandy soil with a deep water table, 2- or 3-year-old switches 2 to 3 inches in diameter are planted in holes 6 to 13 feet deep with the purpose of providing desirable moisture conditions, occurring about 2 feet above the water table, at the base of the switch. The taller the switch, the deeper the hole and the smaller its diameter. The optimum depth of water table may range from 3 to 5 feet, depending on the capillary structure of the soil.

Fertilization is recommended at the time of planting. The quantity of the fertilizer depends on the fertility of the soil and on the size of the hole. As a starting fertilizer, Bura (1967) suggested a mixture of 0.516 pounds of nitrate, 0.5 pounds of potassium salt, and 1.0 pound of superphosphate for each 25 cubic feet of the soil from a planting hole. He also recommended the equilateral triangular spacing used in Italy.

England

For out-planting, the use of well-formed and sound 5- to 10-foot-tall 1-2, 2-2, or 2-3 seedlings grown in a nursery has been recommended by foresters of the British Forestry Commission (1948). The smaller

seedlings should be used on drier sites. In lifting the seedlings, their roots should be shortened, upper branches cut back, and the lower half of the stem pruned clean.

Spacings of 21 by 21 feet for narrow-crowned varieties and 24 by 24 feet for broad-crowned varieties are recommended if the trees are to be grown without thinning. Spacings from 18 by 18 feet to 21 by 21 feet may be used if marketable thinnings are planned. Plantations with spacings of 12 by 12 feet are undesirable as they require an early precommercial thinning.

Site preparation is made by either plowing strips or cleaning patches of at least 4 feet in diameter and preparation of planting holes 18 inches deep. While planting seedlings, care must be taken to set the roots below ground level especially on the drier sites. Mounding the soil around the seedlings and mulching with any kind of vegetation is highly recommended.

During the years after planting, undesirable shrubby vegetation, especially that interfering with the crowns of the poplars, must be controlled.

Union of Soviet Socialist Republics

In Byelorussia (BSSR) and in the Ukraine (USSR), site preparation for planting poplars consists of brush clearing and scarification of sod by disking in the early summer, followed by 10- to 14-inch-deep plowing in the autumn and succeeded by cultivation and harrowing in the spring of the next year when planting is made. On poor soils, a seeding of lupine or clover, which should be plowed after blooming, is recommended.

In this case, poplars are planted in the second spring after scarification of the sod, shortly after a preplanting disking.

Planting poplars with cuttings 3/8 to 1/2 inch in diameter and 10 to 14 inches long is a method commonly accepted. Until 1960, a definite opinion regarding optimum spacing was nonexistent in the USSR. However, a trend toward larger spacings was noticeable as a consequence of many experiments with different spacings (square and rectangular spacings with 100 to 680 trees per acre).

In plantations with less than 440 trees per acre, underplanting of slow-growing hardwood species such as maple (Acer pseudoplatanus L.), basswood (Tilia parvifolia Ehrh.), ironwood (Carpinus betulus L.), black alder (Alnus glutinosa Gaertn.), ash (Fraxinus excelsior L.), beech (Fagus silvatica L.), and shrubs such as elder (Sambucus nigra L.), euonymus (Evonymus verrucosa Scop.), filbert (Corylus avellana L.), and currant (Ribes rubrum L.) for soil protection and for speeding of natural pruning of poplars is advised (Bogdanov 1968, Pravdin and Filimonova 1960).

Poland

To establish plantations on sites subject to flooding in Poland, Glyda (1948) recommended planting one-or two-year-old poplar seedlings (4 to 6 feet tall) in holes 16 inches square and 2 feet deep. Three-year-old seedlings (8 to 11 feet tall) should be planted in holes deeper than 2 feet. For out-planting, care must be taken to use only healthy and well-formed seedlings, and their root collars must be set at least 6 inches below the ground surface. The method outlined

results in a high percentage of survival. In addition, the cleaning of sod and other vegetation in a radius of 1.5 to 2 feet around the seedlings is an important treatment which will help the success of plantations.

For commercial plantations in Poland, Glyda (1948) recommended a 16.4 by 16.4-foot spacing. This spacing will be adequate for the development of the trees until the time of the first thinning (at the age of 20). Each alternate diagonal row of trees is then removed and a 23.1 by 23.1-foot spacing is attained. By using the same procedure at the second thinning (at the age of 40), the spacing is enlarged to 32.8 by 32.8 feet.

For protecting the soil and for control of the poplar crown, underplanting of basswood, maple, or ash, and on moist sites, alder and willow (*Salix caprea* L.) is commonly practiced.

Germany

Zycha et al. (1959) reported that in West Germany since 1951 only certified poplar planting stock can be obtained from licensed nurseries. Every year in late summer the nurseries are visited by the representatives of the German Poplar Society, usually one forester, one scientist, and one nursery man. These three men test growing conditions of stock, verify the origin of species and clone, and grade each single seedling in the bed. The seedlings which do not conform to the standards do not receive the certificate label. Seedlings of poor form or diseased and all those which were grown in beds richly treated with nitrogen fertilizer are rejected. In addition, seedlings

which are one year old and smaller than 4 feet and with diameter less than 0.4 inch at 4 inches above the ground, two years old and smaller than 6.5 feet and with diameter less than 0.6 inch at 3.3 feet above the ground, or three years old and smaller than 10 feet and with diameter less than 0.9 inch at 3.3 feet above the ground are also rejected.

In Germany, mostly 1-2 seedlings are used to establish commercial poplar plantations because of their high rate of survival. Unrooted cuttings are very seldom used in commercial plantations because of their relatively low growth potential and consequent difficulty in resisting adverse conditions of environment such as frost, pests, drought, and competition. Though the technique of planting cuttings is simple and initial investment is relatively low, costs of maintenance of such plantations during the first two years (replanting, complete weedings and cultivations, pest control, protection against wildlife, and the tending of the shoot form by pruning the twins and forks) are disproportionately expensive in comparison with the results which can be achieved during the same period of time by planting 1-2 seedlings. The use of 1-1 seedlings is not popular for the same reason. However, planting of cuttings or 1-1 seedlings is recommended in the afforestation of spoil banks or other bare lands.

Site preparation consisting of land clearing, deep plowing, and digging of planting holes is usually done during the growing season preceding planting. Broadcast liming, if needed, is carried out immediately after plowing. In early spring before planting, additional cultivation and harrowing are conducted. The size of the planting

holes depends upon the age of seedlings: 16-by-16-by-16-inch holes for 1-1 seedlings, 24-by-24-by-24-inch holes for 1-2 or 2-2 seedlings, and 28-by-28-by-28-inch holes for 2-3 or 3-3 seedlings. Holes of larger diameter and depth are drilled by a mechanical auger. The excavated soil remains on the ground surface for weathering until the next spring when the planting is made. At the time of planting, the excavated soil is mixed with a so-called starter-fertilizer; i.e., a humus-fertilizer, hyperphosphate, and calcium carbonate at the rate of approximately 4 ounces of each per cubic foot of soil. While planting, the roots are shortened to fit the planting hole and the seedlings are placed in the holes in such a way that root collars remain below the ground surface at least 8, 12 and 16 inches, respectively for one, two- and three-year-old root systems.

Square spacings are preferred in Germany. They vary from 13-by-13 feet to 20-by-20 feet depending on the site; wider spacings are used on poorer sites. The equilateral triangular spacing system used in Italy and in Yugoslavia is not popular there.

The underplanting of a moderate number (150 to 200 per acre) of seedlings of filler trees and shrubs, usually one or two years after planting poplars, is becoming a frequent practice. The choice of species depends upon the site. On soils poor in nitrogen, black locust (*Robinia pseudoacacia* L.) is preferred; on wet soils, black alder is suggested; and on fresh soils, elm (*Ulmus campestris* L.), maple, basswood, and beech are planted. Planting of ash, birch (*Betula verrucosa* Ehrh.), oak (*Quercus pedunculata* Ehrh.), or any type of conifers is not advised.

Argentina

In Argentina (Celulosa Argentina 1965), planting of 2-foot-long cuttings 20 inches deep in cultivated soil is a standard method for establishing poplar plantations. Cuttings are prepared from well-formed and healthy one- or two-year-old poplar shoots grown in a nursery. Spacings of 12-by-12 or 16-by-16 feet were used until 1965. Since then only 16-by-16-foot spacings have been used.

United States of America

Planting of 20-inch-long cuttings at a depth of 16 inches in previously cultivated soil is a commonly used technique for establishing cottonwood plantations in the southeastern part of the United States (Maisenhelder 1960, McKnight 1970). This technique requires very laborious site-preparing operations. A complete land clearing, windrowing, and slash burning must be done on cutover forest lands. In addition cross-subsoiling is necessary on heavy and compact soils. After planting, a costly weeding is indispensable. Often the plantation needs three cultivations during its first season. The above operations require heavy equipment, which may be available only to large companies (King 1962, Capel and Coffman 1966, McKnight 1970). Dannenberg (1970) estimated that for successful establishment of 1,250 acres of cottonwood plantation each year, an investment of 69,000 dollars (in equipment only) is necessary. The cost of site preparation, planting, and weed and insect control during the first year (without the cost of equipment amortization) amounts to $108.00 per acre of plantation. Of this amount, $75.00 is spent for site

preparation (McKnight 1970).

Serious problems are associated with establishing cottonwood plantations on batture land (the land lying between the watercourses and the levees, therefore unprotected from flooding). Cuttings with sections 2 to 4 inches above ground, planted by the standard method, may be buried several inches deep as a result of siltation. Seedlings or cuttings with parts 2 to 3 feet above the ground may have enough time to leaf out, but then they may be covered by rising water and be killed. Planting 10- to 15-foot-tall seedlings also does not produce satisfactory results because of poor resistance to the impact of water. In such cases, McKnight (1970) suggested early fall planting of one- or two-year-old saplings 16 to 20 feet tall with shortened roots and completely pruned branches in 40-inch-deep and 8-inch diameter holes prepared with a mechanical auger when the site is dry.

Selection of Cuttings

Nursery technique for cottonwood cutting production has been discussed in detail by Moore (1958), Maisenhelder (1960) and Turner (1970).

Maisenhelder (1960) recommended that cuttings for the establishment of large plantations be prepared from dormant one-year-old switches grown in a nursery. Cuttings 20 inches long and 3/8 to 3/4 inch in diameter at the small end are most suitable for commercial planting. They should be straight and without any signs of diseases or damage by twig borer (*Gypsonoma haimbachiana* Kearfoot).

Maisenhelder (1960) believed that for small plantations, up to a

few thousand trees, cuttings of uniform size taken from one- or two-year-old wildings, or from sprouts originating within 6 inches of the root collar on stumps of trees not older than five years, can be used successfully. He did not recommend field-planting cuttings taken from one-year-old wood in the crowns of trees older than three years because of their poor survival.

Hofman (1912) found that cuttings taken from the top of the crown of an old tree had low percentage of survival and produced small trees. In his opinion, the best cuttings for establishing cottonwood plantations in Minnesota were those taken either from sprouts or one-year-old branches of vigorous trees not older than three years. The diameter of the cuttings should not be smaller than 1/2 inch and the length of cutting not shorter than 18 inches. In addition, he observed that 24-inch-long cuttings are most suitable for this purpose. However, in rough site conditions, such as with erosion or with strong competition, thicker and longer cuttings are preferable.

Smith et al. (1956) investigated the influence of the position in the crown of poplar trees from which cuttings were taken on growth of ramets. The cuttings which originated from one- or two-year-old leader shoots produced significantly larger ramets than those which grew from cuttings taken from two-year-old branches. Although the cuttings were small (3 to 6 inches long), doubling the lengths of cuttings increased height growth of ramets by 56 percent. The tallest ramets were produced by 6-inch-long cuttings from one-year-old leader shoots.

Briscoe (1963) studied the effects of the position from which cuttings were taken in a cottonwood switch and the date of collection and planting of the cuttings on their rooting ability and growth. He found that both butt-cuttings and second-cut cuttings rooted best when they were collected and planted during the period from October to December. Otherwise, butt-cuttings rooted better than second-cut cuttings.

Alonzo and Sancho (1964) studied the influence of position in the switch from which a cutting was taken on growth of poplar and willow ramets. The purpose of the study was to determine the utilization ratio of switches for production of cuttings which would grow at equal rates. The results of the study showed that 66 to 90 percent of the total length of a poplar switch can be used for such cuttings; the length of this portion depends on species or clone. The top portions (10 to 20 percent of the total switch length), and in some species the base portions (about 20 percent) of a switch, were useless for cuttings because of their poor growth. The effect of cutting diameter on the growth of ramets was not significant. Willow cuttings grew to equal heights regardless of their diameters and the positions in the switch from where they were taken.

Using cuttings of randomly selected cottonwood clones, Wilcox and Farmer (1967 and 1968) have shown that highly significant variations exist among clones in such heritable characteristics as early growth in height and diameter, number of branches, rooting, foliation date, and rust resistance.

Morphology of Root System

Literature related to studies of root systems of cottonwood and poplars is scarce. Some information concerning the root anatomy of poplars can be found in the works of Eames and MacDaniels (1947) and Guttenberg (1960).

Hofman (1912) found that cottonwood seedlings growing in sandy soils having dry surface layers developed deep taproots. This was contrary to the common opinion at the time that the cottonwood root system is widely spread within the surface soil. Yet, it seems that both opinions are correct.

May (1959) made excavations of root systems of three-year-old poplars planted up to 14 feet deep in soil composed of 94 to 99 percent sand. He found that root systems of most trees were developed in two distinct zones. The upper root zone consisted of very long roots with a small number of absorptive rootlets which were spread in the soil 1 to 4 feet below the ground surface, and the lower root zone consisted of numerous short roots with dense rootlets 10 to 15 feet below the ground surface. Some trees had more than two root zones. Trees planted at depths less than 14 feet had developed deep taproots. Only a few roots extended into the upper zone and they were very poorly developed.

Sika and Mraz (1964) made a comparative study of the morphological structures of main root systems and the distribution of lateral roots in soil blocks 6 to 9 feet deep located beneath crown perimeters in even-aged hardwood stands composed of two poplar clones (*P*. x *eurameri-*

cana Dode , Guinier cv. 'marilandica,' and P. x euramericana Dode , Guinier cv. 'robusta'), and other hardwood species. They found significant variations in the distribution patterns in roots of different sizes among the species. The longest lateral roots were in P. cv. 'marilandica' (40 ft ave. from stump) and in P. cv. 'robusta' (25 ft ave.). About 55 percent of lateral roots of P. cv. 'marilandica' and about 40 percent of roots of P. cv. 'robusta' were distributed in the soil from 2 to 18 inches deep. The poplar clones had the smallest concentration of roots less than 1 millimeter in diameter per unit area of surface soil. The P. cv. 'marilandica' clone developed single tap roots about six feet deep. The P. cv. 'robusta' clone had several taproots, and they were the deepest roots (over 7 feet) of all species. The authors concluded that in pure poplar stands the soils are not fully utilized and that poplars are much more sensitive to competition in the crowns than in the rhizosphere.

Rooting of Cuttings

Rooting of stem cuttings is an important means of vegetative propagation practiced in forestry and horticulture for mass production of improved planting stock within a short time.

The rooting ability of stem cuttings varies considerably with individual trees, the position in the crown from which cuttings were taken, and with season. According to Cunnigham (1953), the rooting ability of cottonwood cuttings depends on the clone.

Shapiro (1958) reported that roots in Populus nigra L. appeared

along the entire length of cuttings taken from dormant trees but only at the base of those cuttings taken from active growth in the spring.

Bala et al. (1970) found that seasonal rooting potential of stem cuttings was related to starch content in cuttings. The low rooting was associated with high starch content and prolific rooting with low content of starch. These changes in starch content were due to variation in the activity of hydrolizing enzymes. The rooting process is preceded by a period of high starch content, followed by hydrolysis of the starch, and an increase in the content of soluble carbohydrates and their subsequent decrease during the rooting period. Thus, soluble carbohydrates (saccharides or sugars) appear to be the essential organic compounds utilized during the development of the roots.

Nanda et al. (1969) reported that cuttings of _P. nigra_ L. required at least three 24-hour days of darkness for a satisfactory rate of rooting and that the number of roots increased with increasing number of days of darkness.

Farmer (1966a) tested the effects of tree, sex, collection date, β-indolylbutyric acid (IBA), and presence of flower buds on root formation by dormant cuttings of _P. deltoides_ Bartr. Cuttings were taken from the middle portions of crowns of trees grown in the open. The experiment was conducted in greenhouse conditions which were almost similar to those in the field during the summer time. It was found that untreated cuttings collected in early February rooted better than those taken in December, January, or early March. Flowering and foliation preceded rooting in the March collections and reduced the

rate of rooting. Removal of flower buds increased rooting. Tree-to-tree variation in rooting was highly significant, as was the effect of IBA treatment. The effect of sex was insignificant.

Michniewicz and Kriesel (1970) investigated the dynamics of auxins, gibberellin-like substances, and growth inhibitors in the rooting process of P. nigra L. cuttings. They found that the auxins are effective a' the time of initiation and development of root primordia, but thereafter the gibberellins become responsible for promoting root growth. The ratio of gibberellins (GA) to auxins (Ax) was 2.8 in the cuttings from one-year-old shoots in the period of development of the root primordia and changed to GA:Ax = 737.1 in newly developed adventitious roots. The contents of auxins and gibberellins in the cuttings from 3-year-old shoots were lower than in the cuttings from one-year-old shoots; thus both the number and growth of roots on cuttings taken from shoots older than one year were poor.

Small (1946) reported that treating cuttings with cane sugar, potassium permanganate, and various compounds of manganese, iron, or phosphorus improved root production.

Nanda et al. (1971) found that leafless cuttings of Populus nigra L. do not root whether cultured in pure water, or in solutions of 1.0 mg/l of β-indolylacetic acid (IAA) nor IBA. However, these cuttings rooted when cultured in 1.0 percent glucose with 1.0 mg/l IBA.

The number and the length of roots increase with increase in auxin concentration, especially of IBA. When used alone, a 10^{-5} ppm concentration of IAA promotes rooting, while at 1.0 ppm concentration it

inhibits rooting completely and produces a stimulating effect on stem growth (Audus 1963).

Selection of Site

Cottonwood (P. deltoides Bartr.) thrives in a large variety of climatic and edaphic conditions, such as may be found in the valleys of the Missouri River in North Dakota, the Chattahoochee River in Georgia, the St. Lawrence River in New York, the Brazos River in Texas, and chiefly in the lower valley of the Mississippi River in Missouri, Arkansas, Mississippi, and Louisiana. On the other hand, cottonwood is extremely exacting in its edaphic requirement when a particular ecotype and the various soils within the range of this ecotype are taken into consideration. In spite of such a paradox, a common characteristic in the edaphic requirement can be traced among all ecotypes of cottonwood and among all species of the genus Populus as well. This characteristic is the preference for new alluvial (azonal), medium-textured, and moist soils by black poplars (Aigeiros), American cottonwoods included, and for well-drained glacial outwash and alluvial fans especially along the margins of seepages and bogs by white poplars (Leuce), aspen included.

Foresters of the British Forestry Commission (1948) were of the opinion that poplars can be grown on a wide variety of soils ranging from sands to clays, although on extreme soil types growth is much slower and the trees may never reach large dimensions. Notwithstanding, the ideal site for poplars is loamy soil with the water table

from 2 to 5 feet below the ground surface during the growing season. No success can be expected from plantings on either waterlogged or acid soils.

Pravdin and Filimonova (1960) reported that in Byelorussia (BSSR) and in the Ukraine (USSR) poplars are usually planted on non-forest lands such as brush, poor meadows, and pastures. Planting poplars on waterlogged soils, heavy clay soils, and acid soils is considered prohibitive. A water table ranging from 4 to 6 feet below the surface was found to be optimum for growing poplars. Where the water table is slightly higher than 4 feet, a drainage system is advisable if economically feasible.

Glyda (1948) reported that in Poland it is generally accepted that soil which is friable, neutral, and rich in organic matter and with a water table about 40 inches below the ground surface is the best for growing poplars. Where the water table is nearly 2 feet below the surface, drainage is necessary; and where the soil is moderately acid, 2 pounds of lime mixed in the surface soil around the seedling will provide satisfactory improvement of soil condition. Planting poplars either in dry sandy soil or in compact clay soil is poor practice.

German foresters pay much attention to the selection of a proper site for planting poplars (Zycha et al. 1959). For black poplars alluvial medium-textured soils which are rich in base elements and nearly neutral, usually found in the larger river valleys, are considered the most suitable sites. Those sites where regular sedimentation takes place and with ground water containing at least 50 ppm of

calcium are most favorable. The water table during the growing season should not be higher than 20 inches below the ground surface, and the speed of the water flow should not be slower than 6.5 feet per day. In soils with high content of organic matter, as in low moors, a swifter water flow is required. The soils with very slow lateral movement of ground water are harmful to poplars. Soils containing stagnated water preclude growth entirely, especially during the hot part of the growing season. Among the sites which are not influenced by fluvial water, those with brown soils containing particles formed from granite, basalt, silica sands, and loess, with pH higher than 5, are quite promising for growing poplars. Soils with a high clay content, though rich in base elements, should be excluded from programs for afforestation by black poplars. Clay soils, if moderately moist, should be planted with balsam poplars or with their hybrids. Planting poplars on rendzinas and on soils which exhibit podzolization is not advisable because of their compaction and/or low water-holding capacity. Surprisingly good growth results were observed with black poplars planted on lithosol which received enough moisture from the mountain slope.

In Argentina, the alluvial plains and the coastal marshlands of the River Parana Delta are the sites where the poplars have been planted since the time of their introduction at the beginning of this century. The marshlands with the water table often at 20 inches below the ground surface are drained by a system of canals and ditches before they can be plowed, cultivated, and reclaimed for afforestation with poplars (Celulosa Argentina 1965).

Maisenhelder (1960) considered moist, well-drained, fine sandy loams or silts in the batture of the Mississippi Delta as the best sites for growing cottonwood, although the heavier soils of gentle slopes bordering swamps or sloughs may support satisfactory growth of trees. Poorly drained soils, such as heavy clay "buckshot" which dry out and crack in the late summer, are less favorable. Growth of cottonwood on such soils is two to three times slower than on moist loam soils. Low swampy sites where flood waters cover the small trees completely for several days during the growing season are entirely unsuitable. Ridges of coarse sand (former sandbars) are useless for cottonwood. Cottonwood does not survive nor grow in the small bottoms of upland hardwood or pine areas.

Broadfoot (1960) based his methods for evaluating cottonwood sites on pedogenetic characteristics of locality, soil texture, internal drainage, and inherent moisture conditions. The inherently moist soils of medium texture with good internal drainage were classified as the best site for cottonwood (Site Index 120 at age 30), and the inherently dry soils of fine texture with poor internal drainage as the poorest site (Site Index 90).

Broadfoot (1964) has formulated a classification of suitability of soils for hardwoods in the Mid-South, which he based on the frequency of the occurrence of each single hardwood species on a particular series of soil. He took into consideration the parent material, age, texture, drainage, physiographic position, stratigraphy, moisture

conditions, and pH of soil when determining the degree of soil suitability for a given hardwood species. Although a standard soil-type map may be helpful in making a preliminary selection of the site, the advice of a competent soil scientist would be desirable before a final decision can be made regarding an investment for afforestation of a given locality with a selected species. According to this classification, cottonwood can be favored in management on soil series such as Crevasse, Robinsonville, Commerce, Mhoon, Bowdre, Tunica, Sharkey, and Alligator in the Delta area; Vicksburg, Collins, Falaya, Morganfield, Waverly, Adler, Wakeland, Birds, and Dekoven in the Loess area; Marietta, Verona, Catalpa, West Point, Leeper, and Tuscumbia in the Blackland area; and Yahola and Norwood in the Red area. Broadfoot also listed more than twenty other soil series in the five soil areas on which cottonwood may be promoted. However, its growth should be expected as less satisfactory.

McKnight (1970) has slightly modified the list of soil series listed by Broadfoot (1964) as suitable for cottonwood and has sorted them according to their productivity into three groups: soil series for "the best growth," "good growth," and "mediocre growth." He considered that well-aerated sandy loams and silt loams containing abundant nutrients, moist throughout the growing season especially when subjected to the natural overflow of river waters, and with a water table 3 to 6 feet below the surface are the best sites for growing cottonwood. He stated that ridges with deep layers of sand lacking moisture during rainless periods in the summer, soils derived from the Coastal Plain

limited in their content of nutrients, and dry clay soils with scarce amounts of organic matter, because of their high degree of compaction and poor aeration, are all unsuitable for planting cottonwood. Clays moist and rich in organic matter, however, if their physical structure is maintained by periodic plowing, may support good cottonwood growth.

Soil Factors Affecting Tree Growth

Commonly, when soil productivity is being estimated, four factors are considered: soil texture, availability of water, soil reaction, and fertility of soil.

References on tree growth and soil condition relationships are innumerable. Many aspects of these relationships were discussed exhaustively by Wilde (1958), Daubenmire (1967), Czarnowski (1964), and Kramer (1969).

Texture and Compaction of Soil

As stated earlier, Mainsenhelder (1960) considered moist, well-drained, fine sandy loams or silts as the best soils for growing cottonwood. Poorly drained soils such as heavy clay "buckshot" are less favorable, and coarse sand is useless for cottonwood.

Brendemuehl (1957) found that site index at age 50 for cottonwood was directly related to the silt content in the soil ($r = 0.501^{**}$), to silt plus clay content ($r = 0.499^{**}$), and the depth of soil profile to a layer with more than 50 percent sand.

Broadfoot and Bonner (1966) studied the effects of soil compaction on survival and growth of cottonwood cuttings. Very fine sandy loam

soil was compacted to densities of 1.1, 1.2, and 1.6 g/cc. At each level of soil compaction ten cuttings were grown for a period of three months. The best developed cuttings were those in the soil with a bulk density of 1.4 g/cc. Their shoot heights, shoot dry weights, and root dry weights were significantly greater than those of cuttings grown in soil with 1.6 g/cc bulk density. The differences in the survival among the treatments were not significant. The authors concluded that old fields and other compacted soils with bulk densities above 1.6 g/cc should be deep-plowed well in advance of planting.

Broadfoot (1969) found that, in a multiple regression equation which included clay, silt plus clay, pH, and phosphorus as the independent variables, the site index at age 30 for cottonwood was directly related to the content of silt plus clay, as well as to pH, but it was inversely related to clay and phosphorus contents. All factors in this equation were significant at the 0.01 probability level, and they accounted collectively for 45 percent of the variation in the site index.

Soil Moisture

The amount of soil moisture is controlled by many factors. Both abundance and uniform distribution of precipitation during the growing season are primary conditions for maintaining a satisfactory level of moisture in soil. According to Kozlowski (1961), "Growth of trees probably is controlled more by water availability than by any other environmental factor."

Broadfoot (1969) also arrived at the same conclusion and stated that "available moisture, probably, is the single most important determinant of productivity."

Brendemuehl (1957) found that site index at age 50 for cottonwood is directly related to the amount of available moisture in the first 4 feet of the soil profile (r = 0.603**). However, a poor relationship (r = 0.423**) was found between the site index and the soil moisture storage capacity (FC). Reasons for this given by Brendemuehl were that moisture storage capacity also includes the water of 15-atmosphere tension (WP), which is not available for trees. Moreover, in different soils neither WP nor FC alone are directly related to the values of the available moisture (AW).

Smith (1957) studied the factors indicative of site quality for black cottonwood (_P. trichocarpa_ Torr. & Gray). He felt that physical characteristics of the soil were possibly less important than the moisture and the soil pH. For this species, he stated that an abundance of soil moisture, nutrients, and soil pH of 6 to 7 are the most important factors collectively. Neither one of these factors was decisive individually.

Bowersox and Ward (1969) studied the effects of black polyethylene mulch on the variation of soil moisture at different depths and on survival and growth of poplar cuttings during the first growing season. Both survival and growth of poplars on mulched plots were equal to or better than those of the poplars cultivated mechanically.

However, in a season of prolonged drought, the polyethylene film prevented the recharge of soil moisture and nullified its advantage for tree growth during the previous season.

Reaction of Soil

The reaction of soil is generally considered as a vital factor controlling the survival and growth of plants. There is little agreement among researchers regarding the pH value favorable for best growth of cottonwood and/or other poplars. Some researchers have reported that the favorable pH value is greater than 5.0, others have found the desirable range to be 6.0 to 7.0, and still another group specify ranges as high as 7.0 to 8.5 as the best values for this species. Becker-Dillingen (1939) considered pH of 6 to 8 as the optimum range for the growth of poplars. Hilf (1951) recommended a neutral to alkaline reaction as a prerequisite for satisfactory growth of any poplar species. Brendemuehl (1957) found pH of 7 to 8 as the best reaction for cottonwood. Schreiner (1959) reported that a pH of 6 is required for a maximum growth of European poplars. Capel and Coffman (1966) were of the opinion that a pH of 7 is favored by cottonwood. Bonner and Broadfoot (1967) conducted nutritional experiments with cottonwood using solutions of pH 5.5 to 6.5. Hacskaylo et al. (1969) performed similar experiments at pH = 5.4. McKnight (1965) was of the opinion that a pH of 7 to 8.5 was best; however, in 1970 he stated that a pH between 6 and 7 is required for the best development of cottonwood. Carter and White (1971) recorded the best growth of cottonwood in a

soil with a pH of 6.4 to 6.6 in a profile 3 feet deep and recommended that "soils strongly acid (below pH 5) should not be planted to cottonwood."

Thus, one may summarize that the favorable pH value for cottonwood is greater than 5.0 and it may even be as high as 8.5. This would suggest that cottonwood is appreciably tolerant with respect to the availability of extractable ions and especially to their proportions in the soil.

Soil Fertility and Fertilization

Soil productivity depends upon many factors. According to Aaltonen (1937), "Determination of the productivity of soil on the basis of its properties is one of the most important objectives of forest soils research. At the same time, it is one of the most difficult problems, for it seems that the productivity seldom depends upon a single factor or even a few factors, but it is usually a result of the combined action of several factors." One of these factors is the fertility of the soil. It can be expressed by the amounts of extractable and/or exchangeable ions in the soil.

The content of inorganic nutritional elements in the soil depends upon mineralogical and chemical composition of parent material. The degree of solubility of these nutritional elements is greatly affected by physical soil properties. In alluvial soils of the Red, Ouachita, and Mississippi Rivers the amounts of extractable phosphorus and exchangeable K, Ca, and Mg cations have been found to be related to the

texture of the soil (Peevy 1972).

The intake of nutritional elements by plants depends upon very complex chemical interactions among inorganic and organic components of the soil and the products resulting from activities of micro-organisms and roots. However, according to Grable (1966): "At the present time it is difficult to tell whether nutrient interactions occur inside the plant and are physiological or whether they occur outside the plant and are chemical."

Soil pH, as generally considered, is a key factor in regulating the supply of nutrient for plants. Base saturation percentage (Lyon and Buckman 1952) and oxidation-reduction potential (Wilde 1958) are related to pH of the soil.

Research in forest fertilization started to move with gigantic steps after World War II. The bibliography in this field for the period from 1910 to 1939 includes 177 references, while for the period 1940 to 1964 it contains 1737 references (White and Leaf 1956, Mustanoja and Leaf 1965). Among all the works in the two periods only 49 of them deal with the fertilization of poplars.

Mayer-Krapoll (1956) reported that application of 600 g calcium ammonium nitrate per tree (applied in the first two seasons) improved average height growth of eight different poplar clones by 36 percent and average dbh by 77 percent above the controls. A large variation in the response to the fertilizer was also observed among the clones.

Pravdin and Filimonova (1960) warned users to be cautious when applying nitrogen fertilizers to poplar plantations. Nitrogen makes

trees more susceptible to various diseases, especially in nurseries and in dense plantations.

Aughanbaugh and Mitchell (1963) reported that application of 2 pounds of 8-24-12 fertilizer per tree at the beginning of the fifth year of growth, and 2.5 pounds of 4-16-8 fertilizer per tree in the following spring on the same plots in a plantation of McKee hybrid poplar (*Populus* x *generosa* Henry) on a moist silt loam soil, increased the average tree volume 67.5 percent at the end of the 12th year. However, the incidence of trunk canker on fertilized plots was recorded in 50.4 percent of the trees as against 28.8 percent of the untreated trees.

Bonner and Broadfoot (1967) used the sand culture method for testing the effects of 21 different nutrient solutions on the growth of cottonwood seedlings. The nutrient solutions consisted of 86 ppm of calcium, 104 ppm of magnesium, traces of micronutrients, and N, P, and K elements, each applied at seven different levels. When one element was varied the other two elements were supplied at the rates of 100 ppm for N and K, and 50 ppm for P. The pH of the solution was maintained between 5.5 and 6.5. The growth of seedlings was minute in the solutions where either N, P, or K was missing (0.1 to 1.9 g of dry weight per seedling after 9 weeks). The best growth of seedlings (76 g o.d.w. ave.) was achieved in a nutrient solution with 100 ppm N, 75 ppm P, and 100 ppm K. This corresponds to the 10-7.5-10 commercial fertilizer formula.

Jones and Curlin (1968) observed pronounced differences among nine cottonwood clones in their response to fertilization with 300 lbs./acre of ammonium nitrate. Although these clones showed a highly significant response to nitrogen, it was possible to distinguish three definite classes of responses by ranking the ratios of growth with fertilizer to growth without fertilizer. As a result, A-8 clone was classified as the superior type with or without fertilizer. A-16 clone showed the best response to nitrogen, with a 24-fold volume increase after two years of growth with fertilizer as compared with seedling growth without fertilizer.

Broadfoot and Farmer (1969) studied the effects of clone and moisture supply on the nutrient content of leaves of eastern cottonwood and found that fast-growing clones contained lower proportions of leaf nitrogen than slow-growing clones. The contents of nitrogen, phosphorus, and potassium per gram of dry leaf were significantly higher in seedlings grown under water stress than in those grown in favorable moisture conditions. The authors concluded that nutrient concentrations in leaves are not always good indicators of nutritional conditions of cottonwood trees.

Huebinger (1969) reported on the positive effects of nitrogen and phosphorus on the first-year growth of cottonwood cuttings. The application of 48 g of N and 60 g of P_2O_5 in a 1-foot-radius circular band around the cutting resulted in prolific root branching on the periphery of the fertilized band and in 52 percent increase in the dry

matter of shoots. No significant increase in the nutrient content of the foliage was observed. Foliar analyses averaged 2.19% N, 0.97% P, 2.06% K, 1.33% Ca, and 0.35% Mg.

Poluboyarinov and Moroz (1968) reported on the results of spraying roots of black poplar with a suspension of phosphorobacterin in water. They stated that the method improved the first-year height growth of seedlings by 70 percent and the survival rate by 30 percent. Phosphorobacterin is a preparation of a pure culture of *Bacterium megatherium phosphaticus* with kaolin. These bacteria are capable of breaking down organic phosphorus compounds and transforming them into soluble phosphates, thus increasing the content of available phosphorus in soil. Application of phosphorobacterin is especially recommended in soils with high content of organic matter. This preparation does not produce any effect in acid soils with a low content of organic matter (Asarov 1964).

Fritzsche (1970) studied the effects of different levels of NPK and NPK MgCa fertilizers on the size of leaves, concentrations of nutritional elements in leaves, and tree heights of various black poplar hybrids and balsam poplars. The experiments were conducted in a greenhouse by the method of sand culture and also by field trials in poplar plantations. Variations in leaf size were directly related to variations in tree height. The sizes of leaves and the heights of trees were found to reach their maxima when the nitrogen level in the nutritional medium and its concentration in the leaves reached their

optimum levels. The maxima in leaf size and tree height of balsam poplars were reached at lower levels of fertilization than those of black poplars. An increase in the level of fertilizer beyond its optimum level, which corresponded to an increase in the concentrations of N in the leaves, resulted in a decrease in leaf size and tree height. Under such conditions leaves usually exhibited symptoms of deficiencies mostly in K and in either P and/or Mg. A maximum leaf size was reached when the content of N in the leaf was kept within a range of 2.4 to 2.7 percent.

White and Carter (1970) studied the growth dependence of 6- to 9-year-old cottonwood in pure, natural stands on the properties of alluvial soils. They found that extractable potassium accounted for 94 percent of the variation in the height growth of most of the stands. The 6-year-old tree height of these stands (White and Carter 1970a) was correlated with Ca, K, and P contents in the upper foliage and K in the lower foliage of dominant and codominant trees. The contents of nutritional elements in the foliage, used as independent variables in a multiple regression equation, accounted for 76 percent of the variation in height growth. Average concentrations of nutrient elements in the upper foliage of the trees in the same stands were 2.09% of N, 0.20% of P, 1.30% of K, 2.16% of Ca, and 0.29% of Mg, and in the lower foliage 1.98%, 0.19%, 1.18%, 2.78%, and 0.33%, respectively. Average percentages of K, Ca, and Mg in the foliage of suppressed trees were higher than those in the foliage of dominant trees. Con-

versely, the percentages of N and P were lower in suppressed trees.

A complete fertilizer named "Glueckauf" containing 10% nitrogen, 7% P_2O_5, 20% K_2O, 17% $MgSO_4$, 10% CaO, and micronutrients was tried by Gunther (1957). He applied this fertilizer to a one-year-old poplar plantation on a poor neutral sandy loam soil at the rates of 265, 530, and 795 pounds per acre. The second-year height growth of the fertilized trees exceeded the controls by 36, 69.9, and 81.9 percent, respectively. However, it is not known which of the nutritional elements of this fertilizer was the main cause of such an improvement in height growth.

Hacskaylo et al. (1969) studied the response of four tree species, including cottonwood, to 12 macro- and micronutrients applied to sand cultures as a complete solution (containing all macro- and micronutrients), and as deficient solutions (containing only 11 of the 12 nutritional elements). Application of deficient solutions produced visible deficiency symptoms. The concentrations of nutritional elements in leaves, stems, and roots varied from seedling to seedling grown in different solutions. Growth of cottonwood seedlings in the deficient solutions was generally below the level attained in the complete solution. Shoot growth of seedlings was much lower for the solutions lacking S, B, Ca, or N. Root development was severely limited in the solutions lacking Ca, S, or Mn. Cottonwood seedlings in the complete solution had foliar contents of 2.86 percent nitrogen, 0.83 percent phosphorus, 4.59 percent potassium, 0.95 percent calcium, and 0.49 percent magnesium.

Stone (1968) listed poplars among zinc-accumulating plants. The average content of Zn in cottonwood leaves varies from 81 to 199 ppm of oven-dry matter, as compared with 28 ppm in leaves of sweetgum. However, Zn content in the foliage of European aspen (*Populus tremula* L.) is as high as 451 to 1501 ppm. The content of boron in cottonwood leaves (70 to 90 ppm) is significantly lower than that of Zn; however, this content is much higher than the content of boron (7 to 10 ppm) in the leaves of shortleaf pine (*Pinus echinata* Mill.) or the content (38 ppm) in the leaves of white ash (*Fraxinus americana* L.). Manganese content in the leaves of cottonwood seedlings grown in a complete nutritional solution was 49 ppm as given by Hacskaylo et al. (1969). This is a minute content when compared with 121 to 977 ppm of manganese in the leaves of shortleaf pine (Stone 1968).

Kostychev (1931) stated that the compositions of the ashes of different plants grown in the same soil are not entirely alike and that the proportions of the ash constituents in all plants are very different from those in the soil itself. This is because there is a selective absorption of the various ions of the soil by plants. Selective absorption of ions by plants was also reported by Gerloff et al. (1966); it was observed in trees in the field by Young and Guinn (1966) and Young and Carpenter (1967), and supported by experiments with six tree species (cottonwood included) grown in identical nutrient solutions in sand culture by Hacskaylo (1960), Hacskaylo and Vimmerstedt (1967), and Hacskaylo et al. (1969).

Merrifield (1972) emphasized the need of research for determining

the nutrient requirements of cottonwood under various soil moisture regimes.

Mycorrhizae

The importance of mycotrophy in forestry, especially in afforestation of non-forest lands and in introduction of exotics, has been emphasized by many authors (Hatch 1936, Kelley 1950, Russell 1950, Harley 1959, Lobanow 1960).

No experimental work has been conducted to determine the effect of mycorrhizae on the development of poplar trees. However, there are reports available which deal with the identification of different mycorrhizal fungi associated with various poplar species.

Lobanow (1960) reported that, from 26 root samples of seven poplar species, including P. deltoides, grown in various climatic conditions and on different soils, ectendotrophic mycorrhizae were found in only two samples. This led him to the conclusion that poplars have a weak mycotrophic habit.

Trappe (1962) listed 28 different mycorrhizal fungi which were reported by various workers to be associated with 10 poplar species, including P. deltoides. All these fungi produced ectotrophic mycorrhizae, and one of them, Cenococcum graniforme (Sow) Ferd & Winge (= Mycelium radicis nigrostrigosum Hatch), was common in all ten poplars. There were 135 tree species and shrubs listed which were also associated with C. graniforme.

Vozzo (1969) found endotrophic mycorrhizae produced by Endogone sp. on the roots of a planted cottonwood (P. deltoides) tree growing

on a bottomland site near Stoneville, Mississippi. He observed that vesicles, arbuscules, and brown intracellular hypha-strands, all characteristic for this type of mycorrhiza, were penetrating the cells of the root cortex.

For a better understanding of the biological interaction between a mycorrhizal fungus and a host plant, knowledge of the ranges in variation of environmental factors during the growing season, and of their optima for both the fungus and the host, is of the utmost importance. It is much more likely that the symbiosis may take place when the environmental requirements of the fungus and of the host coincide. Otherwise, either fungus or host may find itself in a critical condition.

Calcareous soils are usually considered unsuitable for mycotrophic plants since mycorrhizal fungi prefer an acid substratum. The optimum pH for the growth of mycelia of most mycorrhizal fungi is between 5 and 6, and some fungi, such as *Amanita* sp. and *Boletus* sp., prefer soils with pH of 3.5 to 5.0 (Kelley 1950, Harley 1959).

Lobanow (1960) assigned the weak mycorrhizal habit of poplars to their pioneering character; however, it is known that pioneering abilities of poplars, at least of the black poplars, and particularly of cottonwood (*P. deltoides*), do not extend to acid soils. It seems that poplars are pioneers at least for one reason: they can grow very well without being associated with mycorrhizal fungi. The requirements of poplars with respect to soil moisture, soil temperature, soil aeration, and light are nearly the same as those of the mycorrhizal fungi. But mycorrhizal fungi cannot survive in alkaline soils, and poplars cannot

grow satisfactorily in acid soils (Eschner 1960, Trimble 1963, Davis 1964). Thus, the association of mycorrhizal fungi with poplars may be considered as an indication of the unsuitability of the soil conditions for poplars. Mycorrhizae appear to be a kind of safeguard for poplars when they are not growing on their optimum site.

Cultural Treatments

The establishment of a plantation of a tree species cannot be confined merely to planting seed, a seedling, or a cutting in the ground. Moreover, a survival rate of over 90 percent in the first year cannot always be regarded as a definitive criterion of the success of a plantation. Variation in planting stock and in numerous environmental factors, such as micro-relief, soil conditions, climatic conditions, competition, and incidence of pest and diseases, are usually the causes of considerable variation in the first-year growth of trees.

If no steps are taken to minimize the effects of adverse environmental conditions, at least for a few years after planting, the variation in growth of trees will increase steadily with the age of the plantation. Consequently, a high mortality of retarded trees will result, and the yield and timber quality will be affected.

Cultural treatments such as control of competition, tending of young trees, and pest control are prerequisites for a satisfactory development of trees in a plantation.

Weed Control

The success of establishing poplar plantations from unrooted cut-

tings depends largely on the control of the competitive vegetation, especially during the period of root initiation and during initial stages of shoot development (Maisenhelder 1960).

Schreiner (1945) has demonstrated the inhibiting effect of sod on the growth of hybrid poplars. Cover crops were found to be unsatisfactory in controlling unwanted vegetation in poplar plantations (Ford et al. 1952).

Krinard (1964) explored the possibility of weed control in cottonwood plantations by applying herbicides and concluded that cultivation is still the best method for controlling weeds during the first growing season. Martin and Carter (1966) made an extensive study of the effects of 14 herbicides, applied at varying rates, on the survival and growth of cottonwood. The experiments were carried out during two seasons on sandy loam soil at the Auburn Forest Nursery in Alabama. Ten of the herbicides appeared to be harmless to cottonwood when applied at certain rates. The authors stated that only Simazine, Diuron, Diphenamid, and Dichlobenil were "probably the most promising herbicides for use in cottonwood plantations because of the broad spectrum of weeds controlled by each of these herbicides." The effects of herbicides on the weed control of cottonwood plantations were also tested by other workers (Kuntz and Riker 1954, Kuntz et al. 1960, Deitshman and Pruett 1960, Pruett and Gatherum 1961, Aird 1962, and White 1962). Maisenhelder (1951) and McKnight (1963, 1970) reported poor results from the application of herbicides for weed control in cottonwood plantations.

The growth-stimulating effect of Amizine was observed by Norwood

(1965) on sweetgum (*Liquidambar styraciflua* L.) and on cottonwood and *Populus* x *Eugenei* Sim. Louis by Merritt and Bramble (1966).

Kaszkurewicz (1967) reported on the application of 1000 g of Amizine per 100 gallons of water, which produced satisfactory weed control in a cottonwood plantation. The application was made in April, May, or in the beginning of June; circular areas 3 feet in radius around each cottonwood tree were sprayed (Plate 4). Broadcast spray of Amizine produced hypertrophy of cottonwood shoot-tips, suggesting a hormone-like action of the chemical compounds (Plate 5). ACP-W-799 at the rate of 800 cc per 100 gallons of water was effective in the control of annual succulent vines (Plate 6). In plantations, Amizine should be applied by directed spray before the vines climb the trees; a heavy broadcast spray may cause curving of the tips of cottonwood shoots.

While broadleaf weeds and grasses compete for soil moisture and soil nutrients with young cottonwood, vines represent a much more serious problem during the entire life of the trees. Many vine species have extensive root systems which spread in the surface soil and penetrate to depths below 5 feet. Young vines form a dense canopy by climbing over seedlings and saplings, causing shoot deformation and often breaking young trees. Vines also twist about the trunks of large trees (Plate 7) reducing the quality of the log, stunting the growth of trees by shading the crowns, and finally, if not controlled at the right time, killing the trees. There are a great number of vine species in the southeastern part of the United

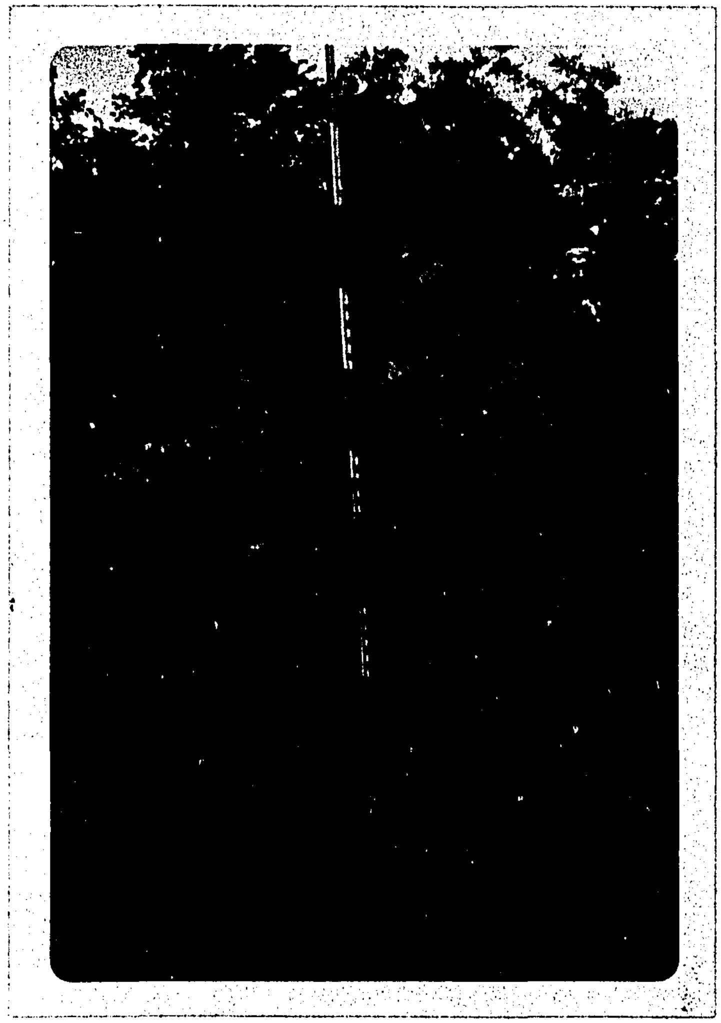

Plate 4. Results of weed control with Amizine four months after application.

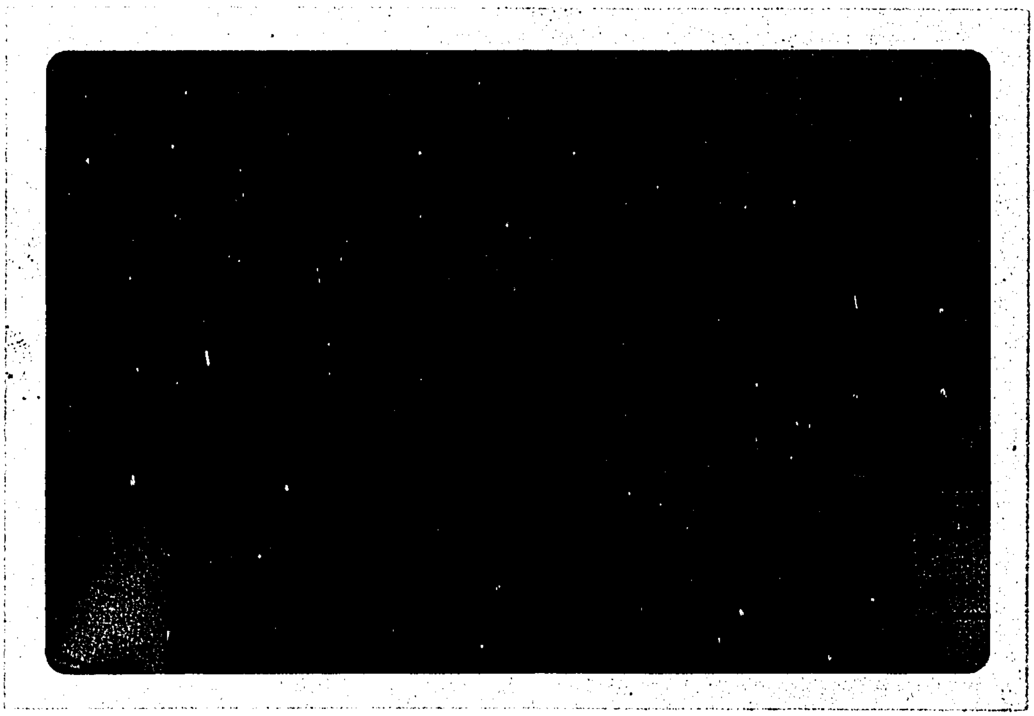

Plate 5. Hypertrophy in the meristematic tissue of a cottonwood shoot caused by a broadcast spray with Amizine.

Plate 6. Control of vines with ACP-W-799 herbicide.

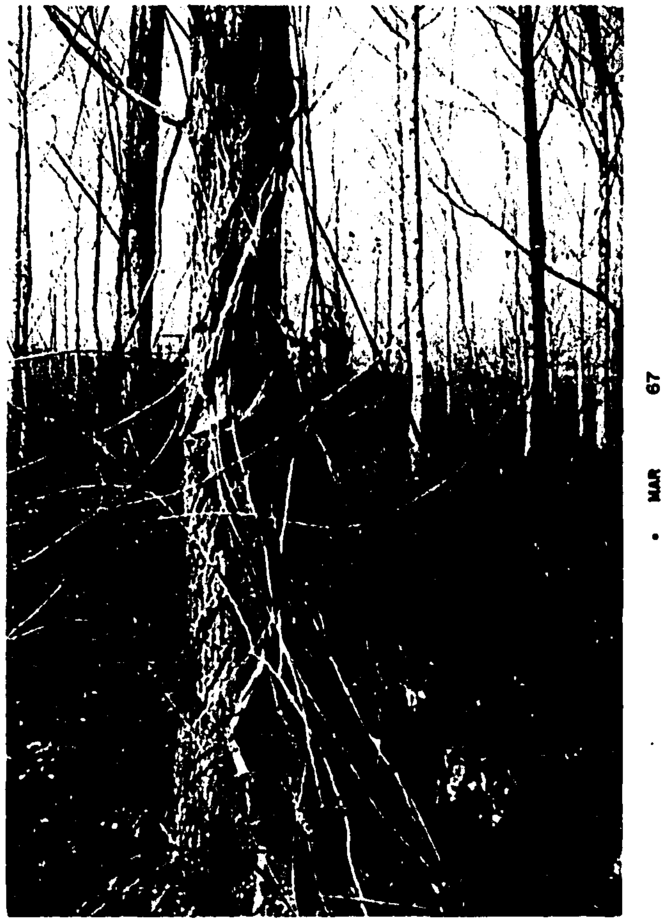

Plate 7. Cottonwood stem overgrown by perennial vines.

States, especially on fertile bottomland soils; such vines are either light-demanding or tolerant and have preference for either light or heavy soil (Maisenhelder 1958). Maisenhelder (1960) and McKnight (1970) included vines among the foremost enemies of cottonwood plantations.

Chemical control of vines appears to be more detrimental to the cottonwood trees than to the vines themselves. The most reliable method of protecting cottonwood trees from vines is by cutting them down once every season on large trees and twice on small trees. For complete weed control in cottonwood plantations Maisenhelder (1960) advised making at least two, and in some conditions even five, cultivations during the first growing season. Cultivations should be timed to eliminate both spring weeds and late summer weeds and must be of such a frequency that the average height of weeds at no time exceeds one-half the height of the trees. Cultivation costs may range from $10 to $15 per acre, depending on the number of cultivations and on the amount of handwork required for weeding the immediate vicinity of the trees (McKnight 1970, Danneberg 1970).

Sites with abundant growth of Johnson grass (Sorghum halepense (L.) Pers.) represent a special case of weed control. Krinard (1964) did not succeed in a satisfactory control of this grass either by frequent disking or by the application of herbicides. McKnight (1970) expressed the opinion that the extermination of Johnson grass must be accomplished one year before planting cottonwood and considered this treatment as a part of site preparation. He explained in detail all

the steps of this costly enterprise.

Pruning

An extensive review of literature (about 60 references) on the subject of forest-tree pruning was presented by Smith (1962); however, only three works dealing with hardwood pruning were included. Some of his basic recommendations on pruning are given below.

An improvement of tree bole quality by "pruning intended for production of clear lumber or veneer, should be limited to trees that are growing rapidly in diameter," since those trees usually are destined to form the final crop. Therefore, trees on good sites should receive preferential consideration. Pruning should commence at an age when the lower branches start to die and should be performed in steps. Pruned bole length should be adjusted to fit whatever bole-length, log-length, or any combination of these lengths is desired. Pruning at high levels can be justified only on a limited number of the best trees, which should be carefully selected. The speed of wound healing depends largely on the rate of diameter growth of the bole, diameter of the pruned branch, and the period of the year when pruning cuts are made.

Nesterov (1933) explained the process of natural pruning as a result of reduction in photosynthesis in leaves on low branches. This reduction is due to low light intensity in this portion of the crown caused by crown closure in the main canopy, especially in the presence of a dense understory. Consequently, potassium, phosphorus, nitrogen, and magnesium, but not calcium and silicon, move from branch to stem. Elimination of dead branches is greatly enhanced by mechanical impact

of understory crowns.

With regard to poplars, Streets (1962) stated that in the production of timber for veneer and matches pruning is essential, and it is intended to confine all knots to a central core of about 3 inches in diameter. The best result from pruning can be achieved when pruning is done in steps. In the first year, bottom sprouts and double leaders should be removed. In the second year, trees can be pruned to a height of about 4 feet. Thereafter pruning can be done as high as practical, up to 25 to 30 feet; but for the purpose of maximum sustained growth, trees should not be pruned to more than two thirds of their total height. Johnson's (1959) opinion was that "the faster the trees grow, the sooner they should be pruned." The live crown should not be reduced below 50 percent of total tree height. His study of cottonwood pruning showed that 44 percent of cuts 1.5 to 2.5 inches in diameter healed by the end of the first year, and the rest of the cuts were closed after two years. Wounds made by the pruning of dead branches healed just as quickly as live-branch wounds. Only two epicormic branches appeared during the first growing season after pruning.

Rettelbach (Zycha et al. 1959) noted that the best time for pruning poplars in Germany is the end of June. Pruning earlier in the growing season provoked epicormic branching. Pruned height of trees younger than 6 years old should not exceed one third of the total tree height. Trees 10 to 25 years old can be pruned up to one half of tree height, and after 25 years crown length may be reduced to

40 percent of tree height.

Eggler (1955) studied the radial growth of several hardwood species in southern Louisiana. He found that the major radial increment of cottonwood (0.18 inch per month) occurs during the period of April through June, as compared to only 0.03 inch, which was the combined growth of March and July. Radial growth ceased at the end of July. This information suggests that in Louisiana the proper period for pruning is from the end of February until mid-March. The crown lost by pruning may be partly replaced before the time of maximum height growth. Fast radial growth will accelerate healing of the wounds of the cut limbs. Pruning should be made a couple of years before the current annual height growth reaches its peak. In this way, the tree will have time to restore the crown and re-establish an optimum root-shoot ratio before the peak of current annual increase in the breast-height diameter occurs.

McKnight (1970) believed that "to avoid canker diseases, wounds should not be created during the winter. The best time to prune appears to be spring or summer."

The Belgian Match Company (Schreiner 1959) prunes poplar trees to one-third of their height at the ages of 8 to 10 years, between 10 and 15 years to half their height, and after 15 years the length of pruned bole is increased to two-thirds of the total tree height.

Pruning of poplars in Yugoslavia (Bura 1967) begins in the third year after planting. Two-year-old unrooted switches or rooted saplings are completely stripped of branches at the time of planting.

During the first and the second year after planting only epicormic branches and branches up to one-third of tree height are removed. Beginning with the fifth year in the field, poplars are pruned stepwise to one-half of tree height, and after the eighth year only one-third of tree height is maintained in live crown.

Early Growth of Cottonwood

The definition of the early growth period is a matter of opinion. This period may be no more than a few weeks if progressive growth of the trees during one growing season is the point of interest. It may be for as long as it is needed for trees to reach a stage when a plantation is ready to furnish some merchantable wood material such as pulpwood, i. e. to an age of the first thinning if the final goal is to produce large timber. This stage also depends upon the initial spacing, survival, and site of the plantation.

For a comparison of the first seven-year growth of the planted cottonwood trees reported in this study, several references containing data for natural and planted stands of corresponding age in the southern and central United States are reviewed below.

Growth in Natural Stands

Williamson (1913) compiled growth and yield data for fully stocked natural cottonwood stands in the Mississippi Valley. Tree heights, dbh, and volumes in cu. feet and bd. feet were presented for stands from 5 to 50 years of age. At 5, 6, and 7 years of age, average tree heights were 22, 29, and 36 feet; dbh values were 2.0,

2.8, and 3.5 inches; and stem-wood volumes per acre were 650, 875, and 1025 cu. feet, respectively. At the age of 7 years there were 1045 trees per acre. According to these data, the current annual volume increment in cu. feet culminated at the age of 12 years. At that time, approximately 450 cu. feet or 3.6 cords of peeled wood was produced per acre. The average annual growth, however, continued to increase until the stand was 16 years old, when 243 trees 85 feet tall and 9.8 inches dbh remained per acre, with a total of 4150 cu. feet of stem wood.

Johnson (1965) reported that the average heights of dominant seedlings established in bulldozed strips on completely cleared plots were 3.8, 7.0, and 10.0 feet at the end of 1, 2, and 3 years, while corresponding heights on plots shaded by deadened trees were 3.0, 6.1, and 9.0 feet. In some favorable locations individual trees attained heights of 23 feet and 2.2 inches dbh after three years of growth.

Maisenhelder (1960) observed that cottonwoods in natural stands on the better sites in the northeastern part of Mississippi grew 0.75 to 1 inch in diameter and 4 to 5 feet in height annually up to the age of 25. Natural stands on good sites yielded about 24 cords of pulpwood at 10 years and 50 cords at 15 years.

Neebe and Fletcher (1960) found that in Missouri, in three natural stands of age 8 with 2160, 1760, and 1160 trees per acre, dbh averaged 2.8, 2.9, and 3.8 inches, respectively. In the first stand, which was not thinned, dbh of 720 trees surviving to the age of 14 averaged 5.7 inches; in the second stand, thinned at age 8 to 420

trees per acre and all surviving to age 14, dbh averaged 6.1 inches; in the third stand, thinned to 600 trees at age 8, the dbh of the 360 trees which survived to age 14 averaged 7.3 inches. The mortality of 80 percent during the first six years in the unthinned stand was among trees of average diameter or smaller. In two other natural stands 8 years old, the average dbh of 2100 trees per acre was 2.4 inches, and that of 1840 trees per acre was 2.5 inches. The first of these two stands remained unthinned and contained 840 trees at the age of 11 with average dbh of 4.1 inches; the second plot was thinned at age 8 to 800 trees, of which 600 trees survived to age 11; their average dbh was 4.5 inches. There was no significant difference between heights and dbh in the natural stands and plantations of the same age.

Walker (1967) found that, in a natural stand on silt loam soil in Oklahoma, 1912 cottonwood trees per acre averaged 1.35 inches in dbh at the age of 3. In the same stand, at ages 6 and 7 with 1320 and 1128 trees per acre, average dbh values were 2.75 and 3.22 inches, and basal areas were 54.6 and 63.9 sq. feet respectively. At the age of 10 in the same stand, there were 664 trees with 79.3 sq. feet of basal area per acre, averaging 4.67 inches in dbh.

White and Carter (1970) used stem analysis for determining 6-year heights of cottonwood trees grown on various sites in natural stands of different densities in southwest Alabama. Average heights of dominant and codominant trees ranged from 32.4 to 55.4 feet depending on growth conditions.

Growth in Plantations

Bull and Putnam (1941) reported that first-year height growth of

20-inch-long cottonwood cuttings planted on a ridge without weed control was 9 inches; the same size cuttings planted in a swamp did not grow at all. Forty-inch-long cuttings grew to 23 inches in height when planted on a ridge and to 56 inches in a swamp. Sixty-inch-long cuttings planted on a ridge reached a height of 30 inches, and when planted in a swamp grew to 57 inches in height. Seedlings with shortened roots and tops cut back to 4 inches (barbatelles) planted on a ridge grew in the first year to a height of 24 inches, and planted in a swamp reached a height of 49 inches. Barbatelles with tops cut back to 18 to 24 inches planted on a ridge averaged 38 inches in height; planted in a swamp they were 61 inches tall. Seedlings with shortened roots and with intact tops grew 44 inches in height when planted on a ridge and reached 78 inches in height when planted in a swamp.

Neebe and Fletcher (1960) reported that in Missouri, for an 8-year-old cottonwood plantation established on silt loam soil at 6-by-10-foot spacing, the average dbh was 5.7 inches in the plot with 375 trees per acre and 6.2 inches in the plot with 385 trees per acre; in the first plot, which was not thinned, the dbh of 232 trees which survived to an age of 14 was 8.9 inches; on the second plot which was thinned to 190 trees at the age of 8, the dbh of 180 trees which survived to the age of 14 was 10.0 inches. The authors found that the rate of growth of dominant trees had not been affected by thinning, but the growth rates of codominant and intermediate trees had been increased by thinning.

Broadfoot (1960a) reported that cottonwood trees planted on

Robinsonville or Forestdale soil series grew nearly twice as fast as on Sharkey series, and on Alligator series growth was intermediate. On Robinsonville series trees at the age of 5 averaged 43 feet in height and 5 inches in dbh, while trees on Sharkey series averaged 38 feet in height and 5 inches in dbh at the age of 11, and trees on Alligator series reached 40 feet in height and 5 inches in dbh at the age of 8.

Maisenhelder (1960) reported that cottonwood trees planted on a good site in northwestern Mississippi averaged 13.5 feet in height at the end of the first growing season; a few trees grew to 19.0 feet. In another plantation on a ridge, 6-year-old trees averaged 22 feet in height and 2.6 inches in dbh. In the same plantation at the foot of the ridge, trees averaged 31 feet in height and 4.1 inches in dbh.

Randall and Mohn (1969) recorded that dbh of 4-year-old trees planted at 10-by-10 foot spacings averaged 5.7 inches on Commerce silt loam (range 4.1 to 7.3) and 2.8 inches on Sharkey clay (range 2.0 to 3.9).

Mohn et al. (1970) calculated growth for randomly obtained cottonwood clones (control) and for 14 select clones. The five-year tree height of control clones on Commerce silt loam averaged 51.2 feet with a dbh of 6.3 inches and on Sharkey clay 28.4 feet and 3.3 inches. The same age trees of select clones on Commerce silt loam averaged 56.8 feet in height (range 53.4 to 61.4) and 7.6 inches in dbh (range 7.0 to 8.5); while on Sharkey clay 31.6 feet of height (range 28.4 to 34.3) and 3.8 inches of dbh (range 3.3 to 4.6) were obtained.

Blackmon (1971) reported that the first-year height growth of 20-inch-long cuttings planted 18 inches deep in Sharkey clay varied from 5 to 8 feet and on Commerce silt loam from 11 to 12 feet, depending on the amount of precipitation during the growing season. Two-year-old trees on these soil series reached 13 and 26 feet, and three-year-old trees were 17 and 34 feet, respectively. Heights of trees from 20-inch and 32-inch-long cuttings planted 18 and 30 inches deep, respectively, in 9-inch-diameter holes did not differ significantly from the heights of trees planted by the standard method.

King (1962) reported that first-year tree height averaged 7 feet in a cottonwood plantation with about 350 trees per acre in southeastern Texas.

The Texas Forest Service (1971) reported that irrigation of cottonwood on a Norwood clay loam improved the two-year height growth to 16 feet as compared to 13 feet on unirrigated plots. Irrigated trees on Miller clay attained an average height of 24 feet because of higher moisture-holding capacity of this soil.

McAlpine (1964) reported that cottonwood trees planted in Georgia with cuttings obtained from the Mississippi Delta grew to an average height of 45 feet and dbh of 5 inches in six years.

Merritt and Bramble (1966) reported that 5-year-old cottonwoods in plantations in Indiana attained average heights of 27.0 to 32.6 feet and dbh of 3.2 to 4.0 inches, depending on the types of cultural treatments.

Farmer (1964) found that male trees were significantly (0.05

probability level) taller than female trees. The dbh difference due to sex was not statistically significant even though dbh of male trees was consistently greater.

Minckler (1970) studied the effects of 5-, 7-, 10-, 14-, and 20-foot square spacings, two thinning methods, and pruning of dead branches on five-year growth of cottonwood trees in Illinois. Trees planted at 14- and 20-foot spacings were not thinned; both mechanical and free thinnings in trees at 5-, 7-, and 10-foot spacings were made in the third and fourth year (25 percent of trees were removed at each time). The five-year basal area in unthinned plantations was related inversely to spacing; it was 69 sq. feet for trees in 5-foot spacings and 21 sq. feet for trees in 20-foot spacings. The effects of thinning became sharply apparent during the fifth year of growth. The fifth-year height and dbh increments of unthinned trees at 20-foot spacings were more than three times higher than those of trees at 5-foot spacings. Increments of trees at other spacings were intermediate. The fifth-year diameter growth of free-thinned trees was about equal to that of wide-spaced trees and much greater than that of mechanically thinned trees. The length of bole with pruned dead branches was inversely related to spacing and ranged from 17 feet for trees at 5-foot spacings to 5 feet for trees at 20-foot spacings. Unpruned trees had only about 2 feet of clear bole; length of clear bole did not vary among spacings.

METHODS AND PROCEDURES

Location of the Experimental Plantations

Five plantations were established to study the effects of different factors on growth of cottonwood trees. Four plantations are located on the east bank of the Mississippi River about 5 miles south-southeast of St. Francisville in West Feliciana Parish, Louisiana (Figure 4). The geographic location of these four plantations is between the 30°42'00" N and 30°42'40" N latitudes and at 91°20'30" W longitude.

The 1961 plantation is located on the St. Francisville Paper Company forest lands in Section 49, Township 4 South, Range 2 West. The 1962, 1963, and 1964 plantations are established on the Crown Zellerbach Corporation forest lands in Section 48, Township 4 South, Range 2 West (Figure 5). The fifth plantation, established in 1968, is located at the Nursery of the School of Forestry and Wildlife Management on the campus of Louisiana State University in Baton Rouge. For the sake of brevity the plantations are named in this report by the year of planting; i.e. "the 1961 plantation," "the 1962 plantation," and so on.

Layout of the 1961 Plantation

The 1961 plantation is the main plantation of this study. The other four plantations were established one at a time to test the hypotheses resulting from preliminary analyses of the data obtained

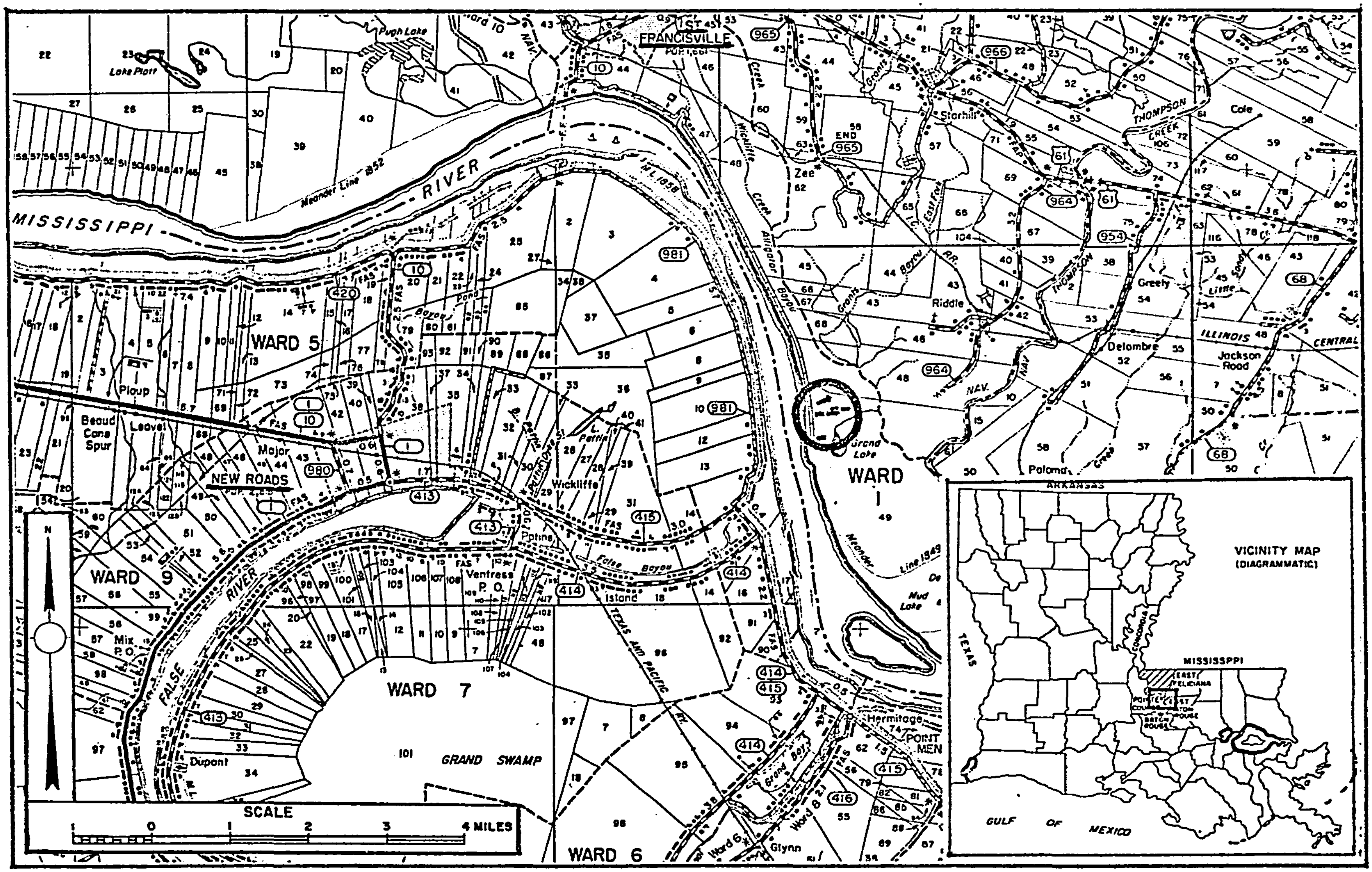

Figure 4. Location of experimental cottonwood plantations (circled).

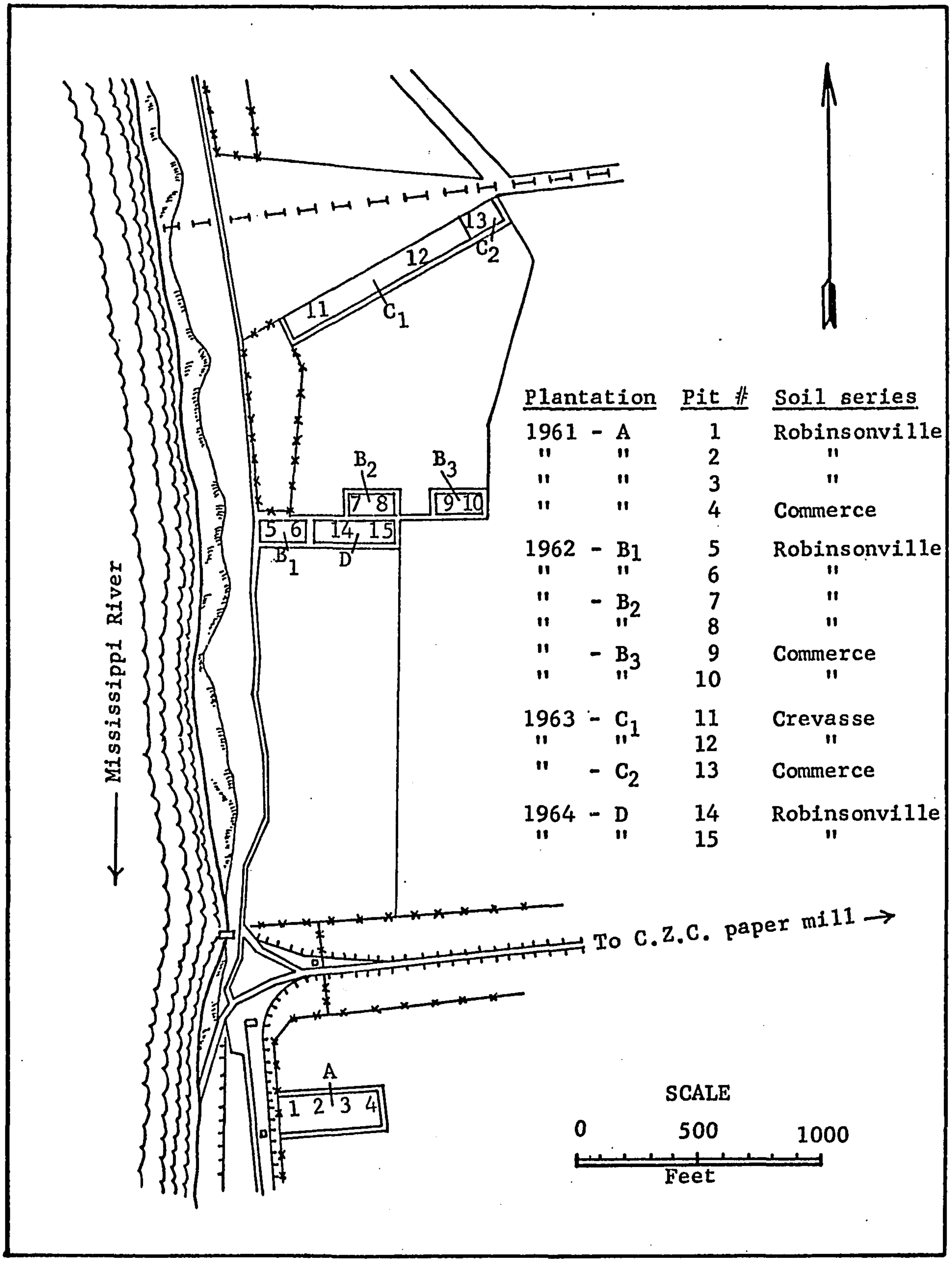

Figure 5. Field layout of the experimental cottonwood plantations near St. Francisville, Louisiana. The numbers 1 to 15 denote locations of soil sampling pits.

from the 1961 plantation.

The 1961 plantation was established in an abandoned cotton field which was cleared of brush vegetation and single trees. Prior to planting, the ground was weeded by a shallow cross-disking. The 1.37-acre ground area, 150 feet wide (north-south) and 400 feet long (east-west), was divided into 24 blocks of 50 by 50 feet. Along three sides (north, east, and south) a 20-foot-wide strip was secured as a divider between the experimental plantation and a commercial cottonwood plantation established the same year. A five-by-four factorial design with single-tree plots randomly located in each of the 24 blocks was used in this experiment. The effects of 20 treatment combinations of five planting depths (1.3, 2.0, 3.0, 4.0, and 5.0 feet) with four lengths of cutting above the ground (0.3, 2.0, 3.5 and 5.0 feet) were tested on survival and growth of trees.

To test variations in survival and growth [C_o, h_1, and (h_1 - C_o)] due to the effects of C_d and C_h, a series of regression analyses and analyses of variance were made.

The model for the analyses of variance is as follows:

Source of variation	Degrees of freedom
Blocks	23
Planting depth (C_d)	4
Error (a)	92
Length of cutting above the ground (C_h)	3
Interaction (C_d) x (C_h)	12
Error (b)	345
Total	479

The cottonwood cuttings for the experimental plantation were obtained from the Louisiana Forestry Commission nursery at Columbia, Louisiana. At that time the Commission's cuttings were grown from wildings which were collected in the Red River Valley. Thus the cuttings did not represent any definite single clone. Only well-formed and sound switches were used for preparation of the experimental cuttings.

After the cuttings were cut to the required sizes they were planted according to the layout presented in Figure 6. For the identification of locations of randomly assigned planting treatments, the following coding system was used.

Code	Description of treatments
10	Planting depth 1.33 ft (16 in.)
20	" " 2.00 "
30	" " 3.00 "
40	" " 4.00 "
50	" " 5.00 "
1	Length of cutting above ground 0.33 ft (4 in.)
2	" " " " " 2.00 "
3	" " " " " 3.50 "
4	" " " " " 5.00 "

As an example, code number 32 refers to a cutting planted 3 feet deep with a 2-foot-long portion above ground.

The cuttings were planted at 10-foot spacing in the north-south direction, and at 12.5 feet in the east-west direction. The planting holes for depths to 3 feet were prepared with a 1-inch-diameter steel bar, and the holes deeper than 3 feet were made with a 2.5-inch-diameter bucket soil auger. Cuttings were inserted in the holes which were then filled in with soil and tamped firmly with a wood pole. No

Block 1	Block 2	Block 3	Block 4	Block 5	Block 6	Block 7	Block 8
23 11 54 34	11 31 21 13	54 11 31 42	34 33 12 41	33 51 44 11	33 52 32 41	11 42 54 12	33 24 11 43
12 43 41 44	12 24 51 22	14 44 32 12	14 43 11 32	21 23 53 42	12 13 23 14	44 33 43 34	32 12 14 13
52 31 51 32	44 23 54 33	34 21 41 13	13 54 42 51	43 34 41 13	31 42 51 21	31 21 51 52	42 51 54 34
53 22 13 24	34 14 43 41	51 43 52 22	23 52 53 44	24 54 22 14	34 53 54 22	53 14 41 23	52 21 23 31
33 14 42 21	53 32 52 42	53 24 33 23	24 21 22 31	52 31 12 32	43 11 24 44	32 24 13 22	41 22 44 53

Block 9		Block 10	Block 11		Block 12	Block 13		Block 14	Block 15		Block 16
42 13 11 53		41 53 31 44	32 33 31 43		13 43 11 21	22 41 44 51		11 32 31 22	54 14 33 53		54 11 41 21
34 22 43 24		52 22 21 32	34 44 12 23		12 32 51 24	42 34 14 13		12 34 23 44	52 34 44 22		44 24 53 13
33 44 41 32	(1)	13 34 51 54	51 13 22 54	(2)	54 22 34 52	53 43 33 23	(3)	13 14 21 24	21 51 11 12	(4)	12 33 42 24
52 12 31 21		42 24 43 23	53 41 21 42		23 44 33 41	11 32 12 31		42 54 53 52	13 43 32 42		51 34 14 52
14 51 54 23		33 12 11 14	52 24 14 11		42 14 53 31	54 24 52 21		43 33 51 41	23 24 31 41		32 22 31 43

Block 17	Block 18	Block 19	Block 20	Block 21	Block 22	Block 23	Block 24
13 51 32 44	53 34 33 12	34 31 14 12	11 33 58 23	52 34 23 24	33 32 22 43	33 12 21 51	12 22 54 23
53 21 34 31	24 54 51 41	54 24 43 33	51 21 32 13	44 53 54 42	13 54 34 11	22 14 52 54	11 41 34 13
41 12 43 52	14 32 52 11	51 11 21 53	54 42 12 41	43 33 21 32	31 23 51 24	44 34 23 41	44 53 51 24
33 14 11 42	21 13 23 22	42 44 13 23	44 34 14 24	31 51 11 14	21 14 44 42	53 32 42 31	21 43 32 14
54 23 24 22	31 44 42 43	22 52 41 32	22 31 52 43	13 41 22 12	12 41 52 53	24 43 11 13	52 42 31 33

Figure 6. Layout of the 1961 plantation. The encircled numbers refer to the locations of soil sampling pits.

insecticide treatments were applied to the cuttings. The planting operations, which lasted three days, were finished on March 9, 1961.

<u>Layout and Design of the 1962 Plantation</u>

The results of a preliminary analysis of the first-year survival and growth data from the 1961 plantation showed that the survival and the shoot elongation (h_1 - C_o) were related to the interaction of soil aeration and available soil moisture. The total tree height was directly related to the length of live cutting above the ground (C_o). This led the author to postulate that significant improvement of tree growth could be obtained through breaking a hardpan and mixing fine-textured soil with coarse-textured soil in deeply cultivated planting holes. The growth improvement was thought to be due to reduced soil compaction and to a homogeneous capillary structure of soil in the vicinity of the entire length of the subterranean part of a cutting.

Theoretically, improved soil structure would favor infiltration of rain water into deeper soil strata and would guarantee a sustained capillary rise of moisture from these strata to the surface soil during a drought period. Reduced soil compaction usually favors the development of roots while a hardpan restricts root growth. A large root system and a sustained availability of soil moisture would reduce the dieback of cuttings and would increase the growth of the shoots. Superphosphate mixed with the soil in the planting holes and a small amount of ammonium nitrate added to the surface soil would also be beneficial in achieving desired growth results.

Based on the above assumptions, the 1962 experimental plantation

was established with the aim of determining the factors that would reduce the dieback of cuttings and improve the growth of shoots.

The 1962 plantation was established in an abandoned cotton field. It was weeded by a shallow cross-disking prior to planting cottonwood cuttings at 10-foot spacings. The experimental plantation consists of three planting areas B_1, B_2, and B_3 (Figure 5). Each area, 120 feet wide (north-south) by 200 feet long (east-west), was divided into 10 blocks of 60 by 40 feet. Each planting area was separated from a commercial plantation by a 20-foot-wide buffer strip. A 2x2x2x3 factorial design was imposed upon each planting area, with the 24 treatment combinations randomly assigned to one-tree plots in each block. The arrangement of the treatments assigned to the plots was identical in each planting area (Figure 7). Thus, the experimental plantation (three areas included) was considered as being of a split-plot design.

For identification of treatments assigned to the plots the following code was used.

Code	Description of treatments
1000	Shallow soil cultivation
2000	Deep cultivation by mixing the soil in planting holes 14 inches in diameter
100	Depth of planting, 1.33 feet (16 inches)
200	" " " 3.00 "
10	Length of cutting above the ground, 0.33 foot (4 inches)
20	" " " " " " 2.00 feet
1	No fertilizer
2	1.5 lbs. of superphosphate (45% P_2O_5) per tree

Block 1				Block 2				Block 3				Block 4				Block 5			
1211	2113	2223	1221	2223	1112	2221	1122	2212	2211	2113	2122	2221	2121	1121	1112	1122	2111	2222	1113
1121	1112	1212	2121	1222	2123	2212	1221	1121	1221	2111	1112	2212	1211	2112	2211	2121	1213	1123	1221
1222	1123	2123	2112	1212	1111	2213	1123	1113	1223	2112	1213	1122	1222	2213	1221	1223	2212	2123	2223
1111	1223	1113	2213	1121	2122	1213	2113	2123	2223	2121	2221	2122	2222	2113	1111	2213	1212	1121	2113
2111	1213	2122	2211	2112	2121	1211	1223	1222	1123	1111	1122	1213	1123	2111	2223	2211	1211	2221	2122
2221	1122	2212	2222	2211	2222	2111	1113	2213	1212	1211	2222	1113	1223	2123	1212	1111	1222	1112	2112
				(5)										(6)					

Block 6				Block 7				Block 8				Block 9				Block 10			
2223	2113	1221	2221	1222	1213	2213	2222	2122	1123	2211	2113	2111	2223	1112	1123	1211	1121	2223	2212
2212	1223	2112	1213	2122	2221	2113	1113	1113	2223	1221	2112	2113	2221	1111	2211	2121	1212	2123	1112
1121	2123	1211	2111	1223	2212	2123	1212	1122	2222	1212	1213	1213	2121	1212	2212	1213	1123	2221	1221
2213	1112	2122	1111	1123	2112	1112	2121	1211	1223	2221	2123	1121	2112	1221	2122	1223	2113	1222	1111
1122	1113	1212	1222	2223	2111	2211	1121	1121	2111	1111	1222	1113	1122	1211	2213	1113	2213	2211	2111
2121	2222	1123	2211	1211	1111	1221	1122	2213	1112	2121	2212	2222	1223	2123	1222	2112	1122	2222	2122

Figure 7. Layout of each planting area of the 1962 plantation. The encircled numbers refer to the locations of the soil sampling pits. The 1962 plantation contains three of these planting areas.

3 1.5 lbs. of 45% superphosphate, and 2 oz. of ammonium nitrate (33.5% N) per tree

As an example, code number 2212 denotes the location of a 40-inch-long cutting planted 3 feet deep in the soil mixed with 1.5 lbs. of superphosphate in a 14-inch-diameter hole.

Deep cultivation of the soil was done by drilling planting holes with a 14-inch-diameter auger using an implement attached to a wheeled tractor (Plate 8). The holes were drilled to a depth equal to the depth of planting as assigned by treatment codes. The soil excavated from the holes was exposed to weathering for a period of about two months (Plate 9). At the time of planting a cutting was placed vertically in the center of each hole. The holes were then refilled with soil thoroughly mixed in order to make its texture as homogeneous as possible. Where superphosphate was assigned, it was mixed with the soil while refilling the holes. During the refilling operation the soil was repeatedly compacted with a wood pole.

The planting holes in undisturbed soil were punched with a steel bar 1.25 inches in diameter. Where superphosphate was applied in undisturbed soil, it was placed in three 1-inch-diameter holes punched with a steel bar at a radial distance of approximately 8 inches from the planted cutting. The ammonium nitrate was placed about 4 inches deep in the soil in two slits which were made with a spade on opposite sides of the cutting and 9 inches from it.

During the planting operations the diameters at both ends of the cuttings were measured with a precision of one millimeter.

Plate 8. Equipment for drilling planting holes.

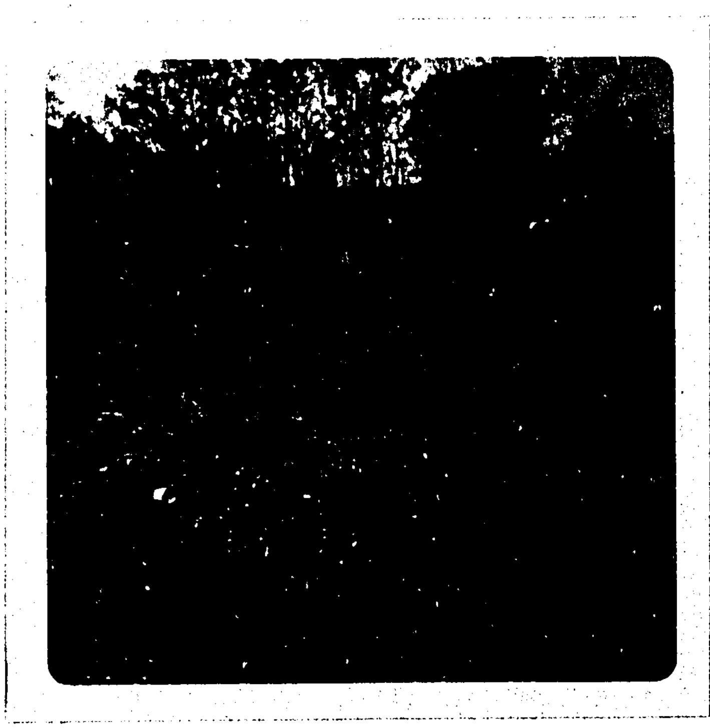

Plate 9. Planting area with prepared holes.

To test the significance of the treatments affecting the survival and growth of the 1962 plantation, regression analyses and analyses of variances were made. The analysis of variance model for a single experimental area is as follows:

Source of variation		Degrees of freedom
Blocks		9
Deep cultivation	Q	1
Depth of planting	C_d	1
Length of cutting above the ground	C_h	1
Fertilizer	E	2
Interaction	$Q \times C_d$	1
"	$Q \times C_h$	1
"	$Q \times E$	2
"	$C_d \times C_h$	1
"	$C_d \times E$	2
"	$C_h \times E$	2
Error		216
Total		239

Layout and Design of the 1963 Plantation

The results of the analysis of the data from the 1962 plantation showed that the application of ammonium nitrate, together with superphosphate, produced a positive effect on tree growth on all three planting areas (sites). However, this treatment resulted in a low survival on planting area B_1, a dry site. This suggested that a satisfactory survival and growth rate on a dry site would require protection of the soil from excessive evaporation. The application of a mulch seemed to be the solution to the problem. The 1963 plantation was designed to test this premise. Since the main purpose of the experiment was to test the effects of the treatments

intended for drought protection, most of the plantation was established in area C_1 (Figure 5), the driest site (Crevasse soil series) on which naturally established cottonwood stands could still be found. The area was originally an abandoned field. In 1962, the area was used for commercial cottonwood planting; however, the plantation failed because of 99 percent mortality. In order to obtain some information concerning the effects of mulches on a relatively moist site (Commerce soil series), area C_2 (Figures 5 and 8) was included in the 1963 plantation. The plantation consisted of 22 blocks: 18 blocks on the dry site and 4 blocks on the moist site. The experimental design was the same for both parts of the plantation, except for the number of replications.

A 2x2x2x2x3 split-plot design with 18 replications on site C_1 and four replications on site C_2 was used for establishing the 1963 plantation.

Although the main purpose of the experiment was to test the mulches, other treatments similar to those applied to the 1962 plantation were also included in the design.

The effects of two levels of bedding, two levels of mulching, two levels of deep cultivation, two depths of planting, and three lengths of cutting above the ground were tested on first-year survival and growth of cottonwood in the plantation.

To identify the 48 factorial treatment combinations assigned in split-plot arrangement to single-tree plots, the following code system was used.

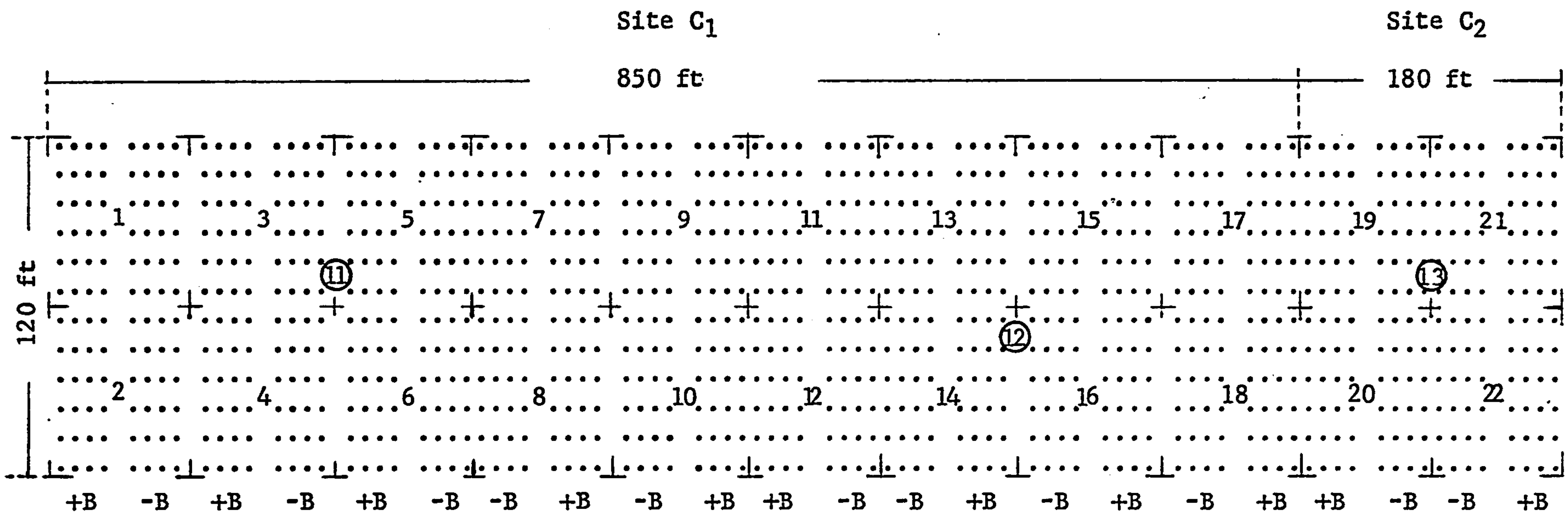

Figure 8. Layout of the 1963 plantation showing blocks, buffer strips, and bedding treatment. No bedding is designated by -B; bedding is designated by +B. The encircled numbers refer to the locations of the soil sampling pits. The other numbers designate blocks.

Code	Description of treatments
10000	No cultivation of the surface soil by bedding
20000	Soil cultivation by bedding after planting
1000	No mulching
2000	Mulching by laminated kraft paper pads 2 feet square
100	Shallow cultivation of the soil
200	Deep cultivation by mixing the soil in planting holes 9 inches in diameter
10	Depth of planting 1.33 feet (16 inches)
20	Depth of planting 3.00 feet
1	Length of cutting above the ground, 0.33 foot (4 inches)
2	" " " " " " 2.00 feet
3	" " " " " " 3.66 "

The cuttings used were obtained from the Louisiana Forestry Commission Nursery, Minden, Louisiana, and were of an unknown genetic origin. About two dozen switches with strikingly different morphological characteristics from those commonly observed in native cottonwood were eliminated from the planting stock (Plate 10). The cuttings were planted at 10-foot spacings, except in the buffer strips between the bedding treatments where 20-foot spacing was used (Figure 9). Deep cultivation was done using the same technique as in the 1962 plantation, except for the diameter of planting holes, which was at this time 9 inches instead of 14 inches. The diameter of the hole was reduced because of a coarse soil texture in site C_1. Asphalt-laminated kraft paper, cut into 2-foot square pads, was used for mulching. In the center of each pad two cross-slits were made with a

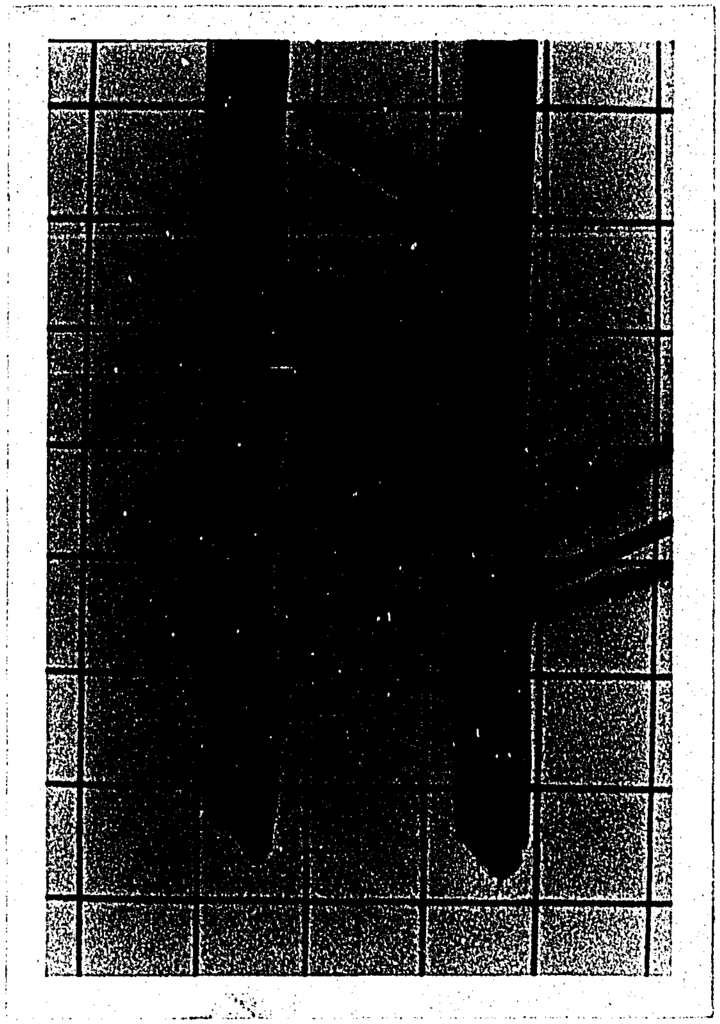

Plate 10. Morphological difference in cottonwood cuttings of two phenotypes. The cutting on the right is typical of native cottonwood; the cutting on the left is atypical, and such cuttings were eliminated from this experiment.

21221	21121	22212	22122		11123	11211	12123	12212
21223	21122	22213	22121		11122	11213	12121	12213
21222	21123	22211	22123	Block 1	11121	11212	12122	12211
21213	21112	22222	22111		11112	11223	12111	12222
21211	21111	22223	22112		11113	11222	12112	12221
21212	21113	22221	22113		11111	11221	12113	12223
22121	22212	21213	21121		12112	12213	11222	11123
22122	22213	21211	21123		12113	12211	11221	11121
22123	22211	21212	21122	Block 2	12111	12212	11223	11122
22112	22223	21221	21111		12113	12221	11213	11113
22111	22221	21222	21113		12111	12223	11212	11111
22113	22222	21223	21112		12112	12222	11211	11112
Bedding					No Bedding			

Figure 9. Arrangement of treatment combinations in the 1963 plantation. The first two blocks are shown above, as an example of treatment arrangements. Each five-digit code number denotes the treatment combination that was applied to a cutting planted at the particular spot.

knife in order to slip the pad over the planted cutting without damaging the buds. After the pad was put on the ground, it was covered with soil to attach it firmly to the ground. Where the bedding treatment was applied, the pads were covered with a soil layer approximately 1 inch thick. Cultivation of the surface soil by bedding (sometimes called a lay-by cultivation) was done with a 20-inch-disc cultivator (four disks) pulled by a tractor between the planting rows. Because the discs were mounted as in a fire plow, the soil was turned over towards the rows of planted cuttings, forming ridges on both sides of the rows.

The benefits of cultivation by bedding are manifold; it increases the effective rooting zone, it protects the original ground surface from drying, and its alternating ditch-ridge system reduces runoff.

To test the significance of the variation in the survival and tree growth in the 1963 plantation, the following model was used for the analysis of variance.

Source of variation		Site C_1 d.f.	Site C_2 d.f.
Total		863	191
Blocks		17	3
Bedding	(B)	1	1
Error (a)		17	3
Mulch	(M)	1	1
Interaction	(B x M)	1	1
Error (b)		34	6
Deep cultivation of soil	(Q)	1	1
Interaction	(B x Q)	1	1
"	(M x Q)	1	1
"	(B x M x Q)	1	1
Error (c)		68	12

Source of variation (continued)		Site C_1 d.f.	Site C_2 d.f.
Depth of planting	(C_d)	1	1
Interaction	(Q x C_d)	1	1
"	(M x C_d)	1	1
"	(M x Q x C_d)	1	1
"	(B x C_d)	1	1
"	(B x Q x C_d)	1	1
"	(B x M x C_d)	1	1
"	(B x M x Q x C_d)	1	1
Error (d)		136	24
Length of cutting above the ground	(C_h)	2	2
Interaction	(C_d x C_h)	2	2
"	(Q x C_h)	2	2
"	(Q x C_d x C_h)	2	2
"	(M x C_h)	2	2
"	(M x C_d x C_h)	2	2
"	(M x Q x C_h)	2	2
"	(M x Q x C_d x C_h)	2	2
"	(B x C_h)	2	2
"	(B x C_d x C_h)	2	2
"	(B x Q x C_h)	2	2
"	(B x Q x C_d x C_h)	2	2
"	(B x M x C_h)	2	2
"	(B x M x C_d x C_h)	2	2
"	(B x M x Q x C_h)	2	2
"	(B x M x Q x C_d x C_h)	2	2
Error (e)		544	96

Layout and Design of the 1964 Plantation

The results of the analysis of the data from the 1963 plantation showed that cultivation of surface soil by bedding (B), deep cultivation by mixing the soil in planting holes 9 inches in diameter and 3 feet deep (Q), the depth of planting the cuttings (C_d), and their interactions (B x Q) and (Q x C_d) were the factors which improved significantly the first-year survival and growth of cottonwood on the dry site (C_1).

Since each of the treatments (B, Q, and C_d) contributed to the

overall results, the author postulated that the volume of cultivated soil in the immediate vicinity of a planted cutting is the most important factor affecting the survival and growth of a plantation.

Treatments Q and C_d are made in a single preplanting operation. Treatment B is a postplanting operation requiring additional investment. If the first-year survival and growth depend only on the volume of cultivated soil around a cutting, a single improved Q treatment (i.e. deep cultivation in much larger diameter holes than were used in the 1963 plantation) should be as efficient as two separate treatments of Q and B. In addition, this new improved treatment might prove to be excellent for improving survival and growth of standard-size cuttings and thus eliminate the need for deep planting of long cuttings. The 1964 plantation was established to test these premises (Figure 5).

A 4x2 split-plot design was used in the layout of treatment combinations in the plantation. The effects of 3-foot-deep cultivations on the survival and growth of cuttings were tested. The soil was mixed in planting holes of 9-, 14-, and 18-inch diameters; the 20-inch-long cuttings were planted 16 inches deep and the 40-inch-long cuttings were planted 36 inches deep. Trees were planted at 10-foot spacings. The area of the plantation, 120 feet wide (north-south) and 360 feet long (east west), was divided into 18 blocks of 60 by 40 feet. Treatment combinations were assigned at random to 3-tree plots in each of the 18 blocks.

The area originally was an abandoned field. In 1962 the field was planted with cottonwood, but most of the trees either died or became severely damaged by various herbicides which were

tried in this part of the plantation during the 1962 growing season. Some scattered trees, mostly of poor form, were rooted out. The area for the 1964 experimental plantation was weeded by cross-disking prior to drilling the planting holes.

For identification of the treatments assigned to each tree in a plot, the following coding system was used (Figure 10).

Code	Description of the treatment
10	Shallow cultivation of the soil; planting holes punched 3 feet deep using a steel bar 1-inch in diameter.
20	Deep cultivation by mixing the soil in 9-in.-diam. and 3-ft-deep holes.
30	Deep cultivation by mixing the soil in 14-in.-diam. and 3-ft-deep holes.
40	Deep cultivation by mixing the soil in 18-in.-diam. and 3-ft-deep holes.
1	20-inch-long cutting planted 16 inches deep.
2	40-inch-long cutting planted 36 inches deep.

The cuttings for the plantation were obtained from the Louisiana Forestry Commission Nursery, Columbia, Louisiana, and they were of undetermined genetic origin. Planting holes of 9, 14, and 18 inches in diameter were drilled on January 21, leaving excavated soil for weathering during a five-week period. The cuttings were planted February 27, 1964. To test the significance of the variation in the survival and tree-growth in the plantation, the following model was used for the analysis of variance.

Source of variation	Degrees of freedom
Blocks	17
Hole diameter (H_{ϕ})	3

Block 1	Block 2	Block 3	Block 4	Block 5	Block 6	Block 7	Block 8	Block 9
42 11 22 31	12 32 41 22	12 41 21 32	22 12 42 31	31 22 41 12	21 31 12 42	11 32 41 22	21 42 12 31	12 31 22 41
42 11 22 31	12 32 41 22	12 41 21 32	22 12 42 31	31 22 41 12	21 31 12 42	11 32 41 22	21 42 12 31	12 31 22 41
42 11 22 31	12 32 41 22	12 41 21 32	22 12 42 31	31 22 41 12	21 31 12 42	11 32 41 22	21 42 12 31	12 31 22 41
41 12 21 32	11 31 42 21	11 42 22 31	21 11 41 32	32 21 42 11	22 32 11 41	12 31 42 21	22 41 11 32	11 32 21 42
41 12 21 32	11 31 42 21	11 42 22 31	21 11 41 32	32 21 42 11	22 32 11 41	12 31 42 21	22 41 11 32	11 32 21 42
41 12 21 32	11 31 42 21	11 42 22 31	21 11 41 32	32 21 42 11	22 32 11 41	12 31 42 21	22 41 11 32	11 32 21 42

(14) (between Block 2 and Block 3) — (15) (between Block 7 and Block 8)

Block 10	Block 11	Block 12	Block 13	Block 14	Block 15	Block 16	Block 17	Block 18
11 32 42 21	41 32 11 22	31 11 42 22	21 41 32 12	11 21 41 32	21 31 12 42	11 32 21 41	21 41 32 12	31 22 12 41
11 32 42 21	41 32 11 22	31 11 42 22	21 41 32 12	11 21 41 32	21 31 12 42	11 32 21 41	21 41 32 12	31 22 12 41
11 32 42 21	41 32 11 22	31 11 42 22	21 41 32 12	11 21 41 32	21 31 12 42	11 32 21 41	21 41 32 12	31 22 12 41
12 31 41 22	42 31 12 21	32 12 41 21	22 42 31 11	12 22 42 31	22 32 11 41	12 31 22 42	22 42 31 11	32 21 11 42
12 31 41 22	42 31 12 21	32 12 41 21	22 42 31 11	12 22 42 31	22 32 11 41	12 31 22 42	22 42 31 11	32 21 11 42
12 31 41 22	42 31 12 21	32 12 41 21	22 42 31 11	12 22 42 31	22 32 11 41	12 31 22 42	22 42 31 11	32 21 11 42

Figure 10. Layout of the 1964 plantation. The encircled numbers refer to the locations of the soil sampling pits.

Source of variation (continued)	Degrees of freedom
Error (a)	51
Total length of cutting (C_t)	1
Interaction (H_ϕ) x (C_t)	3
Error (b)	68
Total	143

Layout and Design of the 1968 Plantation

During four years of experiments, a total of 100 different treatments were tried on the various sites using planting stock of undetermined parentage. Considerable variation in growth of trees within identical treatments and sites was observed consistently. Much of this variation could be attributed to the genotypic, phenotypic, and topophysic variations in planting stock.

The 1968 plantation was established to test the hypothesis that both the genotype and the size of cutting can produce significant effect on the form and growth of trees. Four poplar clones were used for testing this hypothesis: P. deltoides, a clone originating from Mississippi; P. x euramericana cv. 'I-488'; P. x euramericana, a cultivar originating from Belgium; and P. x euramericana cv. 'I-214.' A completely randomized design with five replicated 10-cutting plots of each poplar clone was used in the plantation.

The plantation was located at the nursery of the School of Forestry and Wildlife Management on the campus of Louisiana State University, Baton Rouge. To minimize the effect of site on the tree growth, a

nursery-type plantation was made, i.e. a very close spacing was used. In addition, the planting area was leveled, plowed 1-foot deep, and thoroughly cultivated. Cuttings 20 inches long obtained from a nursery of Delta Match Company at Profit Island, Louisiana, were bar-planted 16 inches deep at 2-foot spacing in five rows 4 feet apart. During the planting the top diameters of cuttings were measured in millimeters with a caliper.

For identification of clone-plots in the plantation the following code was applied:

10 _P_. _deltoides_ cl. 'Mississippi'
20 _P_. x _euramericana_ cv. 'I-488'
30 _P_. x _euramericana_ cv. 'Belgium'
40 _P_. x _euramericana_ cv. 'I-214'

The above code numbers combined with replication numbers (1, 2, 3, 4, and 5) were used for identification of the clone and the replication (Figure 11).

Row 1	....33....	....45....	....44....	....11....
Row 2	....22....	....14....	....13....	....21....
Row 3	....23....	....25....	....35....	....42....
Row 4	....32....	....43....	....12....	....24....
Row 5	....41....	....15....	....34....	....31....

Figure 11. Layout of the 1968 plantation.

Pest Control in the Experimental Plantations

One of the major concerns was the protection of the cottonwood plantations from damage by insects especially during the first-year growth.

The 1961 plantation suffered from two attacks by leaf beetles (Chrisomela scripta Fabr.). The first attack took place during the end of May. It was not observed until after a large number of larvae had begun to feed on the leaves. A spray of Sevin insecticide (a wettable powder of 85 percent 1-methyl, N-methyl carbamate) at the rate of 2 pounds per 100 gallons of water per acre did not control the infestation. The larvae continued to devour the foliage and the meristematic tips of shoots to such an extent that almost 60 percent of the trees in the western six blocks of the plantation became decapitated within a period of one week (Plate 11). As an emergency measure, DDT spray at a rate of 2 pounds of 50 percent wettable powder in 100 gallons of water was applied with a definite effect. The second leaf-beetle attack, which occurred about the end of August, was partially prevented with DDT spray when the larvae were still small. In addition, two applications of DDT at about a one-week interval were needed to control the infestation.

The development of new leader shoots usually took at least four weeks. However, these shoots lost the equivalent of more than four weeks' growth since the vigor of the new shoots was considerably less than that of the original shoots.

An incidence of leaf hopper (Idiocerus sp.) during July was

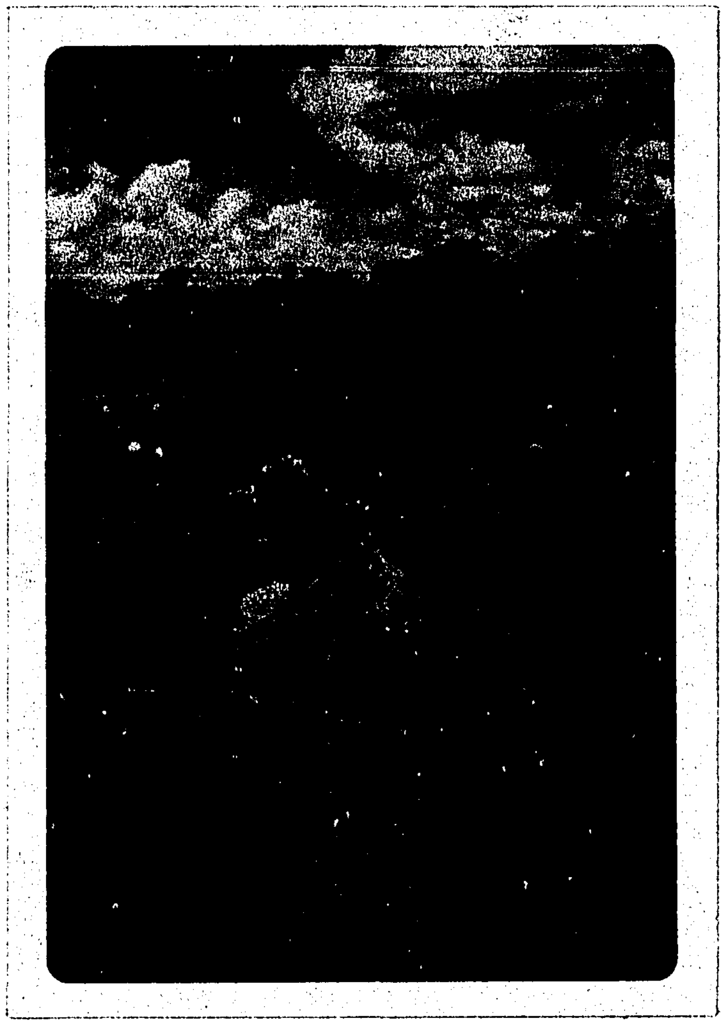

Plate 11. A cottonwood shoot defoliated by leaf beetles.

effectively controlled with a broadcast spray of Sevin at the rate mentioned above. The occurrence of twig borers (Gypsonoma haimbachiana Kearfott. and Saperda concolor Lec.) was rather sporadic. To reduce their number the damaged branches were simply pruned and burned.

The eventual incidence of leaf beetles in the 1962 plantation was successfully prevented with DDT spray as soon as the emergence of the larvae from eggs was observed.

As a measure for pest control, the systemic insecticide Thimet-44 carbon-dust was used for treating the cuttings during the planting operations in the 1962 plantation. Because of high human toxicity, this insecticide was not used in the later plantations.

No insect infestations have been observed in the 1963 and 1964 plantations.

Survival and Growth Data

Tree growth measurements and recording of mortality in the 1961 plantation were made periodically at approximately 30-day intervals during the first growing season. The first measurement was made on April 13 and the last on October 3, when more than 75 percent of the trees had ceased growing. On October 17, an additional check of the trees which had not developed dormant terminal buds by October 3 showed that some of these trees had grown only 0.2 foot. The first measurement of the height (C_o) was made from the ground level to the base of either a leader shoot or an upper opened bud. The height from the ground to the very tip of the leader shoot (h) was also measured. Only

the total tree height was measured subsequently. Measurements were made to the nearest 0.1 foot by use of a graduated pole. A standard IBM code sheet was used as a tally sheet to avoid copying field records. At each measurement the apparent cause of death of each dead tree was also coded on the tally sheet.

Two- and three-year tree heights were measured to the nearest 0.1 foot by use of a telescopic pole. Measurement of the sixth- and seventh-year tree heights was made to the nearest 0.5 foot with a Haga altimeter. Beginning with the second year, tree diameters at breast height, marked with tree treatment tags, were measured to the nearest 0.1 inch with a diameter tape.

The crown heights of 3- and 6-year-old trees were measured to the nearest 0.1 and 0.5 foot, respectively. The diameters at 8.5 feet above ground of 6- and 7-year-old trees and 16.5 feet above ground of 7-year-old trees were measured to the nearest 0.1 inch at points marked with aluminum roofing nails.

First-year survival data and tree height measurements in the 1962, 1963, and 1964 plantations were recorded only at the end of the growing season.

In the 1968 plantation tree height measurements were made periodically at approximately 10-day intervals during the first growing season. At the end of the season tree diameters at 4, 40, and 80 inches above the base were measured in millimeters by use of a caliper.

Total volume (outside bark) in cubic feet was computed for each sample tree in the 1961 plantation at age 7, by use of an equation based on dbh and height, derived from 120 felled cottonwood trees in the

surrounding plantation (Equation 72 in Appendix C, in which all regression equations are listed.

Sampling, Analyses, and Description of Soils

Along with the growth data from the experimental cottonwood plantations, basic data referent to the various soil properties were also collected. These data were used either in a direct or in a modified form (e.g. R_p = AW/BP) in a soil profile instead of AW and BP by soil strata, or H^+ activity instead of pH) as the independent variables in regression analyses used to determine the most significant factors which control the growth of cottonwood trees.

Soil Sampling

During the course of this study, soil was sampled in 15 pits at evenly distributed locations in the 1961, 1962, 1963, and 1964 experimental cottonwood plantations (Figure 5). At each sampling pit approximately 600 grams of loose soil were collected from each 1-foot stratum. In the 1961 plantation the soil was sampled to a depth of 5 feet and in the other plantations only to a depth of 3 feet. To obtain soil samples, a bucket soil auger 2.5 inches in diameter was used. The soil samples were used in determining the soil particle distribution and soil-water constants. In addition, amounts of available phosphorus and extractable calcium, magnesium and potassium, and reaction of the soil were also determined. The same samples were then used for the identification of soil colors and soil series.

In the 1961 plantation, an attempt to take soil samples shortly

after planting failed because of complete saturation of the soil. Because of rising water in the Mississippi River, the area of the plantation remained flooded until the end of June. In late July, in addition to the loose soil samples, cores of undisturbed soil were collected and were used to determine percolation rate, soil porosity, and bulk density. Two superimposed soil cores, 6 centimeters in diameter and 7.1 centimeters in height (i.e. 200 ml of volume) were removed from each 1-foot stratum of 5-foot-deep soil profiles in four sampling pits. A manual soil sampler similar to the one described by Hoover et al. (1954) was used to obtain the soil cores.

Laboratory Analyses

The soil particle distribution (S, Si, C) was determined by mechanical analysis using a modified Bouyoucos method (Patrick 1958).

Soil texture was determined from the standard soil texture triangle (Soil Survey Staff 1951); the percentages of sand, silt, and clay were used as the coordinates (Figure 48 in Appendix A).

Two water constants, field capacity and wilting point, were determined by the tensiometric method by use of a pressure extraction apparatus described by the U. S. Salinity Laboratory Staff (1954). The available moisture constant was calculated by subtracting the wilting point value from the value of the field capacity. The rates of water percolation in the soil cores were determined by the method proposed by the U. S. Salinity Laboratory Staff (1954).

To determine the soil porosity the water-saturated cores were placed on a tension table similar to that developed by Leamer and Shaw

(1941) and described by Hoover et al. (1954). Soil cores were subjected to tensions equivalent to 5, 10, 20, 30, 40, 50, and 60 centimeters of a water column. After being subjected to a specific tension for a period of 24 hours, the cores were weighed before a higher tension was applied. The difference between the weight of the saturated core and the weight of the core after the application of a tension equals the volume of pores which were drained under this particular tension. The volume of drained pores was expressed in percent of the core volume or the volume of the cylinder. The volume of pores drained at the tension of 60 centimeters of water column expressed in percent equals the percentage of large pores (BP) in the soil core. Since two superimposed cores were taken from each 1-foot soil stratum, the figures presented in Table 33 (Appendix A) for percolation, porosity, and bulk density are the mean values of two samples. The percentage of total pore space (TP) in a core was calculated by the formula:

$$TP = \left(1 - \frac{BD}{2.65}\right) 100$$

The percentage of small pore volume was calculated as the difference between the percentages of the total pore space and the large pore space.

To determine bulk density, the cores were oven-dried and weighed. The difference between the weight of the core with cylinder and the weight of the cylinder in grams divided by 200 (i.e. volume of the cylinder in cm^3) equals the bulk density of the soil core.

The results of the analyses referent to the physical properties of the soils are presented in Appendix A (Tables 33 and 34) in which all data are given. Some of these data, such as porosity by soil strata,

wilting point as related to clay content, and soil-water constants as related to textural soil fractions are presented diagramatically in Figures 46, 47, and 48.

Chemical analyses of the soil were made by the staff of the Soils Laboratory at Louisiana State University. Analytical procedures used for determining pH of the soil, amounts of available phosphorus, and extractable calcium, magnesium, and potassium were described by Brupbacher et al. (1968). The data obtained from the chemical analyses of the soil are presented in Tables 35, 36, 37, and 38.

Description of Soil Series

To compare sites in the experimental plantations with those classified by McKnight (1970) as either "good" or "mediocre" based purely on the definition of soil series, a soil series determination was also made for the experimental plantations. The soil cores and loose soil samples arranged by strata and by pits or profiles were used for this purpose. Soil colors were determined from moist soil samples and Munsell's color charts. Identification and description of the most typical soil series in the plantations were made with the assistance of Professor S. A. Lytle, Department of Agronomy, Louisiana State University, Baton Rouge.

The locations in the plantations of soil pits, the soil series associated with each pit, and the series name are shown in Figure 5. The three soil profiles obtained from pits 4, 8, and 12 represent the most typical soil series found in the experimental plantations. Their descriptions are given in Appendix A.

Root Study in the Plantations

In order to gain some knowledge of cottonwood root behavior under different environmental conditions, superficial studies were made of root development in natural conditions and in conditions modified by planting treatments.

Excavations of lateral roots of mature cottonwood trees growing in different-textured soils were made in an attempt to obtain information concerning the patterns of distribution of absorptive roots. Naturally established saplings and one- and two-year-old trees grown from cuttings planted by different methods were excavated for root-system study. Excavated trees were of average size and form for a given site and planting method.

The excavation technique was as follows. The ground was weeded and litter was swept to a radius of 5 to 10 feet around a selected tree, depending on its size. Eight sticks were put in the ground each at a distance of 3 feet from the tree, forming an octagon. The excavation was made using a hoe. At each excavation step a four-inch-thick soil layer was removed. Diagrams of radial distribution of roots within each soil layer were drawn by using the sampled tree as a reference. The single horizontal diagrams were compiled, and the diagrams representing vertical projections of root systems were drawn. Soil textures in the corresponding strata were also recorded.

RESULTS AND DISCUSSION

Effects of Planting Treatments on Survival

A good first-year survival of a plantation is the best indication of successful planting operations. But mortality, even though not signifying a failure of the plantation, is usually a mystery not easily explained. For this reason the mortality in the 1961 plantation was recorded periodically during the first growing season. Notes about apparent causes of mortality were taken simultaneously.

Distribution of mortality by cause and treatment is presented in Table 1. Nine percent of the cuttings (43 out of 480 planted) did not leaf-out for various reasons. The apparent reasons, as indicated in the table, were associated with low viability of the cuttings, since the majority of the cuttings under identical treatments and in identical site conditions leafed-out and survived. The other 94 cuttings (19.5 percent) leafed-out but died later in the season (Figure 12). By the end of the season the overall mortality in the plantation had risen to 28.5 percent.

The distribution of dead cuttings on the plantation area was related to site and to planting treatments. On the dry site at the western part of the plantation (Figure 6) the cuttings which died were either those that did not leaf-out or were shallow-planted cuttings 3.5 and 5.0 feet tall. On the flooded site at the eastern part of the plantation considerable mortality occurred among 2.0- and 3.5-foot-tall cuttings.

Table 1. Distribution of first-year mortality by cause and treatment in the 1961 plantation

Apparent cause of mortality	C_d, feet 1.33				2.00				3.00				4.00				5.00			
	C_h, feet 0.3	2.0	3.5	5.0	0.3	2.0	3.5	5.0	0.3	2.0	3.5	5.0	0.3	2.0	3.5	5.0	0.3	2.0	3.5	5.0
	Number of dead cuttings																			
Dry site	[a] $\underline{2}$	$\underline{3}$	$\underline{2}$	3	$\underline{2}$	1	2	2+$\underline{2}$												
Flood		1	$\underline{2}$		1	$\underline{2}$	$\underline{1}$	1	2	$\underline{1}$			$\underline{2}$	2	$\underline{4}$			2	1+$\underline{1}$	
2-year-old cutting												$\underline{5}$				2	$\underline{3}$		3	$\underline{6}$
Leaf beetles	1	3	4	3			3	4		2	3	5	2	1	3	3	5	2	4	6
Vines	2		1		1							2	4		1	1	1			2
Broken												1								1
Unknown	$\underline{1}$		$\underline{1}$						$\underline{1}$					$\underline{1}$			$\underline{1}$			
Total	6	7	10	6	4	3	6	9	3	3	3	13	8	4	8	6	10	4	9	15
Percent by treatment	25	29	42	25	17	13	25	38	13	13	13	54	33	17	33	25	42	17	38	63

[a] Underlined figures denote the cuttings which did not leaf out.

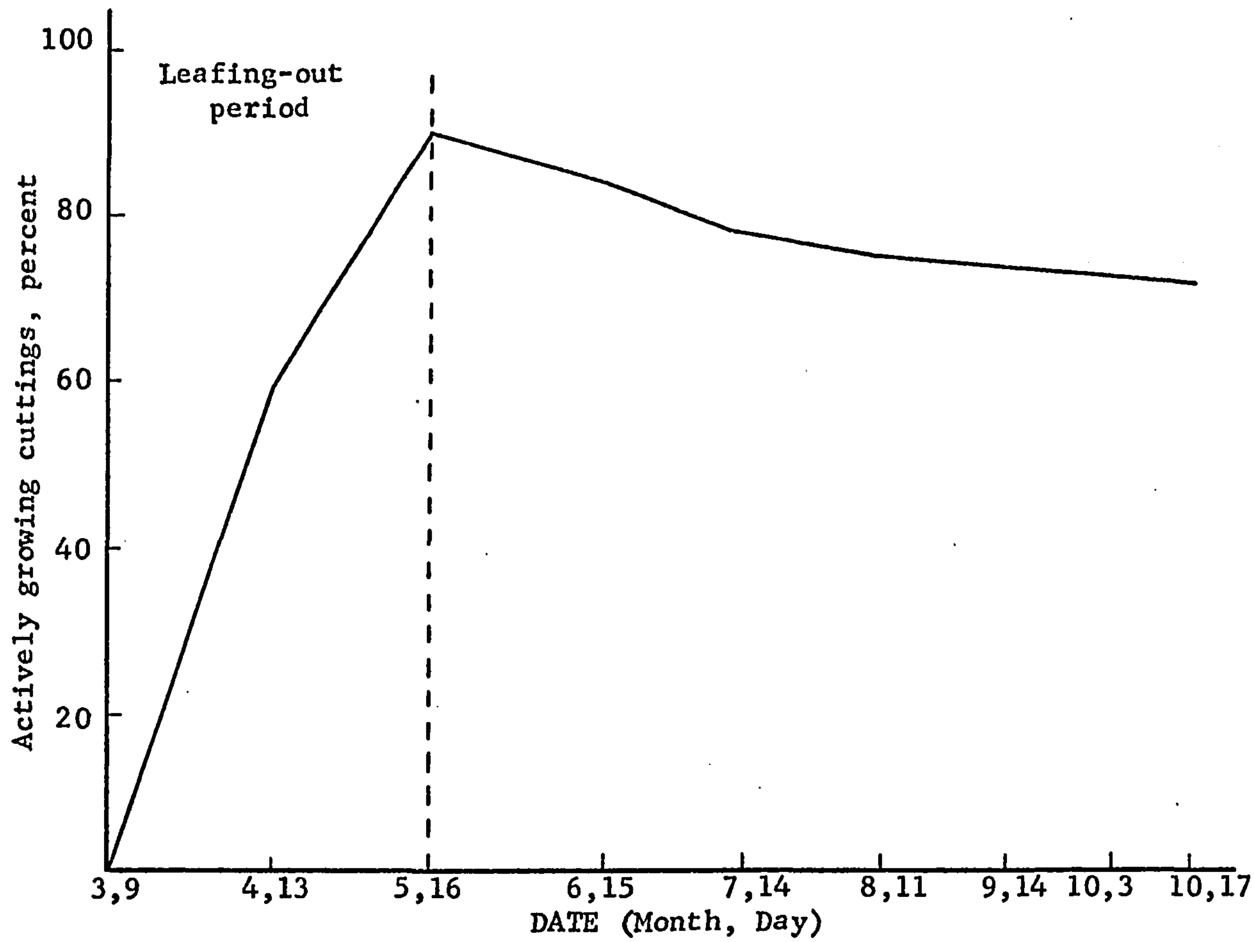

Figure 12. Progress of leafing-out and survival of cuttings during the first growing season in the 1961 plantation.

These cuttings probably leafed out before they became flooded, so the opened buds or young shoots died after being submerged in water for a few weeks. The cuttings with 4-inch tops exposed above the ground were flooded before leafing out and they survived very well. The 5-foot tall cuttings remained with their tops at least 0.5 foot above the highest flood water level. They survived well and there was very little dieback in these cuttings.

Mortality due to leaf-beetle incidence was highest among the cuttings 3.5 and 5.0 feet tall and/or those planted deeper than 3 feet. Tall cuttings were probably affected because they stood above the level of weeds and deep-planted cuttings because of the tenderness of their leaves, since they leafed-out later than shallow-planted cuttings. Most of the cuttings killed by vines were found on the best site.

The results of the analysis of variance of survival in the 1961 plantation plainly supported these observations (Table 39 in Appendix B, which contains all analysis of variance tables). The effects of block, planting depth C_d, and the length of cutting C_h were significant at the 0.01 probability level. The two variables C_d and C_h accounted for 53 percent of the variation in mortality as determined by multiple regression analysis (Equation 1). The percentages of mortality by treatments which were computed from this equation are presented in Table 2 and shown diagrammatically in Figure 13.

The lowest mortality (14 percent), as calculated from the same equation, occurred when $C_d = 2.77$ ft and $C_h = 1.76$ ft. However, the mortality was the result not only of C_d and C_h, but also of the effects of other factors, such as variation in soil conditions by depth and by

Table 2. First-year mortality percentages in the 1961 plantation by treatment

Depth of planting C_d	- - - Height of cutting above the ground C_h, feet - - -			
	0.33	2.00	3.50	5.00
Feet	- - - - - - - - - - Mortality, percent - - - - - - - - -			
1.33	26.2	22.0	28.0	43.2
2.00	20.5	16.3	22.4	37.4
3.00	18.6	14.3	20.4	35.6
4.00	23.7	19.6	25.6	40.8
5.00	36.1	31.9	38.0	53.1

site, incidence of leaf beetle and its control, flood, vines and other weeds, and vigor of cuttings with their physiologic and genetic make-up included. These effects confounded the effects of C_d and C_h.

The coincidence of planting depth (2.77 ft) of cuttings which survived the best (86 percent) with the depth of well-aerated soil layer (Table 33 and Figure 46) suggested that adequate soil aeration was one of the most important factors affecting survival.

The importance of an adequate concentration of O_2 in the soil for development of roots was proved by Cannon (1925) and Patrick (1970). In addition, Cannon (1925) found that a root's requirement for oxygen increases with an increase of soil temperature. Patrick (1970) pointed out the necessity of maintaining soil compaction at a low level to encourage good root growth, especially at high O_2

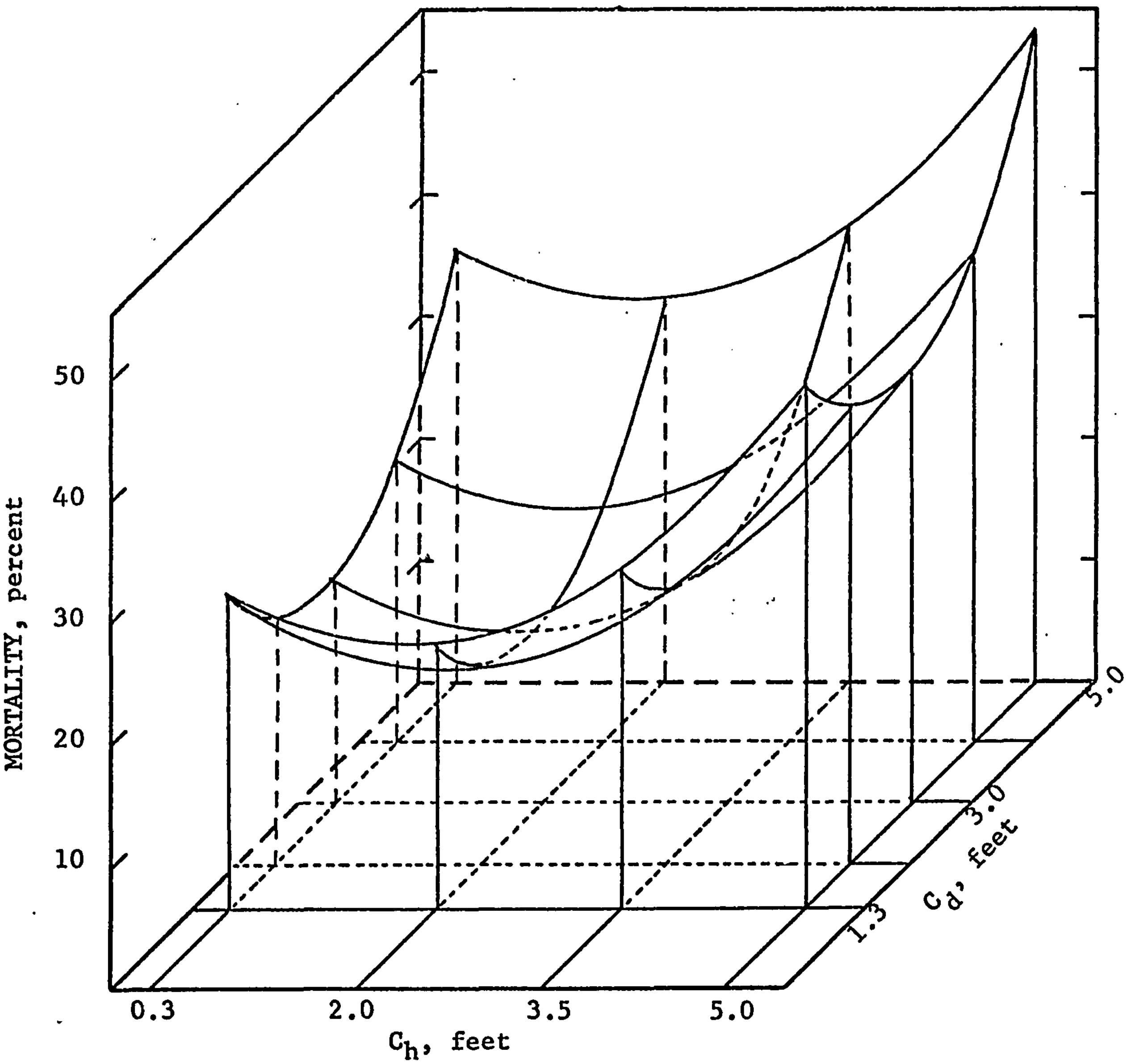

Figure 13. First-year mortality by planting treatments in the 1961 plantation. Mortality percentages were calculated from regression equation 1.

concentrations. Hence, both concentration of O_2 and volume of pores are equally important.

The adverse effect of soil compaction on root development by various plants was observed by many researchers (Hendrickson and Veihmeyer 1931, Doneen and Henderson 1953, Broadfoot and Bonner (1966). As the level of soil compaction increases, root growth is affected through a reduction of soil porosity, by a reduction of capillary voids, and finally by mechanical restriction of root penetration. However, the response of roots to soil compaction at a certain fixed level varies with plant species (Forristall and Gessel 1955).

Patrick (1970) found that the combined effect of O_2 concentration and soil compaction when both are at intermediate levels is greater than the effect of either factor acting alone. This indicates the existence of an interaction between soil compaction and O_2 concentration. A negative effect of low soil compaction apparently connected with an excessive soil porosity and reduced soil moisture content is also indicated.

Maisenhelder (1960) and Broadfoot (1960) found inherent soil moisture and internal soil drainage as the most important factors to be considered while selecting the proper site for cottonwood. According to Schumacher (1864, quoted from Baver 1959), "relative proportion of capillary to non-capillary pores is responsible for optimum soil structural properties." But capillary pores hold both available water and the water of 15-atm tension which is not available for plants. A certain balance between non-capillary pores BP and available water

AW, rather than between BP and CP, is apparently the soil property of biological importance.

After several trials to correlate mortality with various soil properties by plotting data, it was observed that mortality increased with increasing BP or decreasing AW; it also exhibited quadratic relationships with the interactions of (AW X BP) and (AW/BP), showing definite minima at certain values of each interaction.

The interaction AW/BP was chosen to be used as the independent variable because of its meaningful expression of a ratio of soil moisture to soil air (both measurable by volume), whereas AW X BP interaction is practically a meaningless quantity. Since the rooting of cuttings takes place along the entire length of their subterranean part (Shapiro 1958), rooting potential should be due to the compound effects of various soil factors of all strata within the soil profile to planting depth. Therefore, the values of each soil factor were averaged for all strata within the profile depths determined by planting treatments.

The result of the multiple regression analysis of mortality by use of the following equation showed that mortality is significantly dependent on C_d and R_p:

$$T_m = b_o + b_1 C_d + b_2 AW_p + b_3 BP_p + b_4 R_p + b_5 C_d^2 + b_6 R_p^2 + b_7 C_d R_p$$

where: T_m = mortality in percent,

AW_p = available water percentage by volume in the soil profile to C_d depth,

BP_p = percentage of large pores by volume in the same profile, and

$R_p = AW_p/BP_p$.

The variables C_d and R_p accounted for 55.4 percent of the variation in the first-year mortality of cottonwood in the 1961 plantation (Equation 2). Almost 45 percent of the variation remained unexplained. Other factors which without a doubt contributed to the variation in mortality, such as pests, flood, weeds, and vigor of cuttings, were not measurable. Moreover, C_h, which was measured, showed effects which were confounded with unmeasurable factors.

The percentages of predicted mortality computed from Equation 2 are presented in Table 3. The relationship of mortality to depth of planting C_d and physical properties of the soil as expressed by R_p is presented in Figure 14.

For estimating mortality of cottonwood cuttings on a site with clay content not higher than 25 percent, the conversion scale of R_p into clay percentage can be used since they are directly related for the range of R_p from one to twelve units (Figure 15).

A similar conversion scale can also be worked out for R_p and wilting point, since the clay percentage is directly related to wilting point (Figure 47).

Considering these relationships and the nature of R_p, the distribution of mortality by C_d and R_p (Table 3; Figure 14) can be clearly understood. A predicted tolerable mortality up to 15 percent of cuttings with C_h from 0.3 to 5.0 feet is likely to occur within a relatively narrow range of conditions as delineated by the corresponding isopleth in Table 3. Beyond this range the mortality increases sharply with increases of both C_d and R_p, and with an associated

Table 3. First-year mortality in the 1961 plantation predicted from R_p and C_d

R_p	C_d, feet				
	1.3	2.0	3.0	4.0	5.0
Unit	Percent				
1	57.0	45.7	36.6	35.6	42.8
2	44.6	34.6	27.2	28.0	36.9
3	34.1	25.3	19.6	22.2	32.9
4	25.3	17.8	13.9	18.2	30.7
5	18.4	12.1	10.0	16.0	30.3
6	13.3	8.2	7.9	15.7	31.7
7 [a]	10.0	6.2	7.6	17.2	34.9
8	8.5	5.9	9.1	20.4	39.9
9	8.9	7.5	12.5	25.6	46.8
10	11.1	10.9	17.6	32.5	55.5
11	15.1	16.2	24.6	41.2	66.0
12	20.9	23.2	33.4	51.8	78.3

a/Dashed

[a] Dashed curve denotes the isopleth for 15 percent mortality.

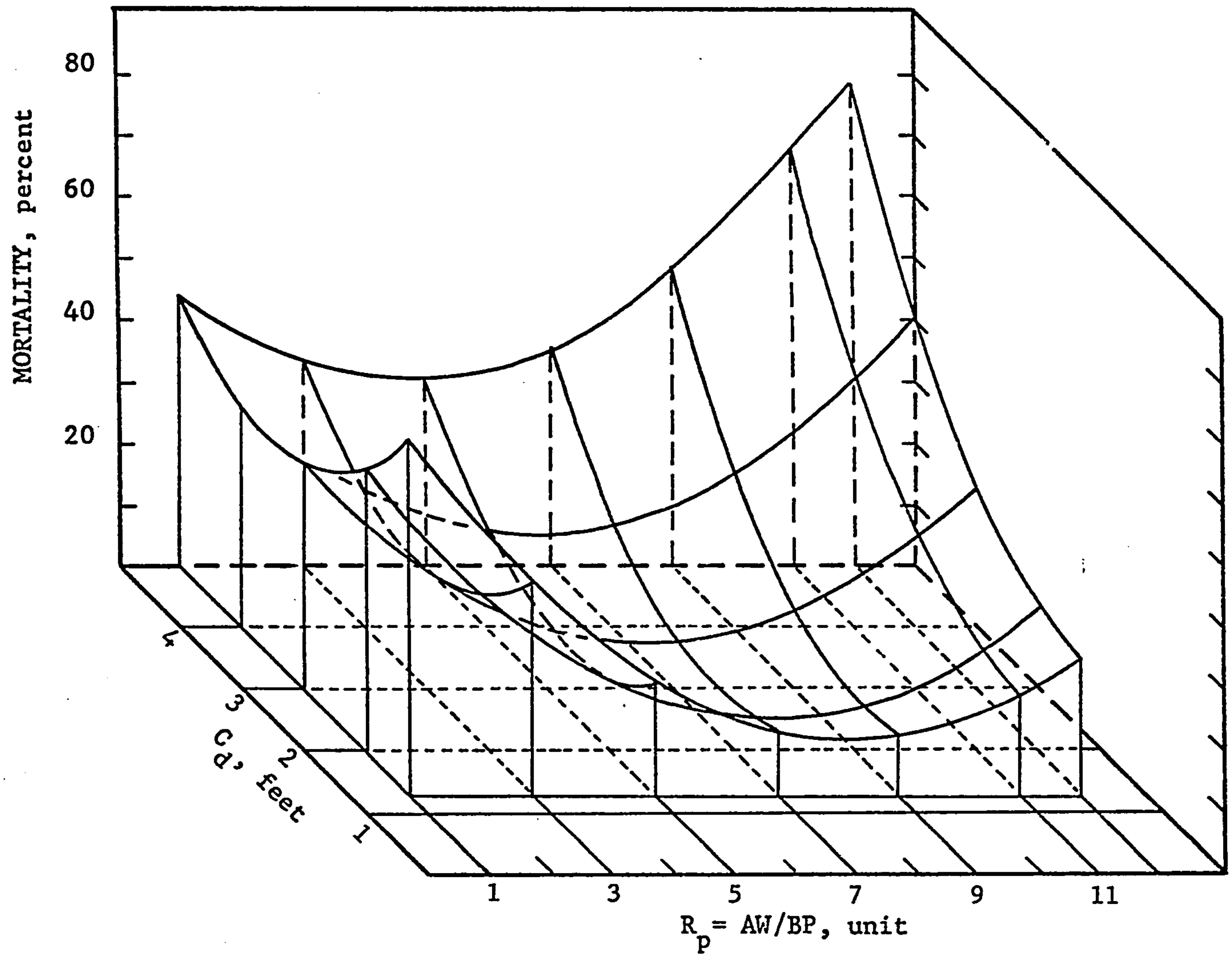

Figure 14. Relationship of first-year mortality to C_d and R_p in the 1961 plantation.

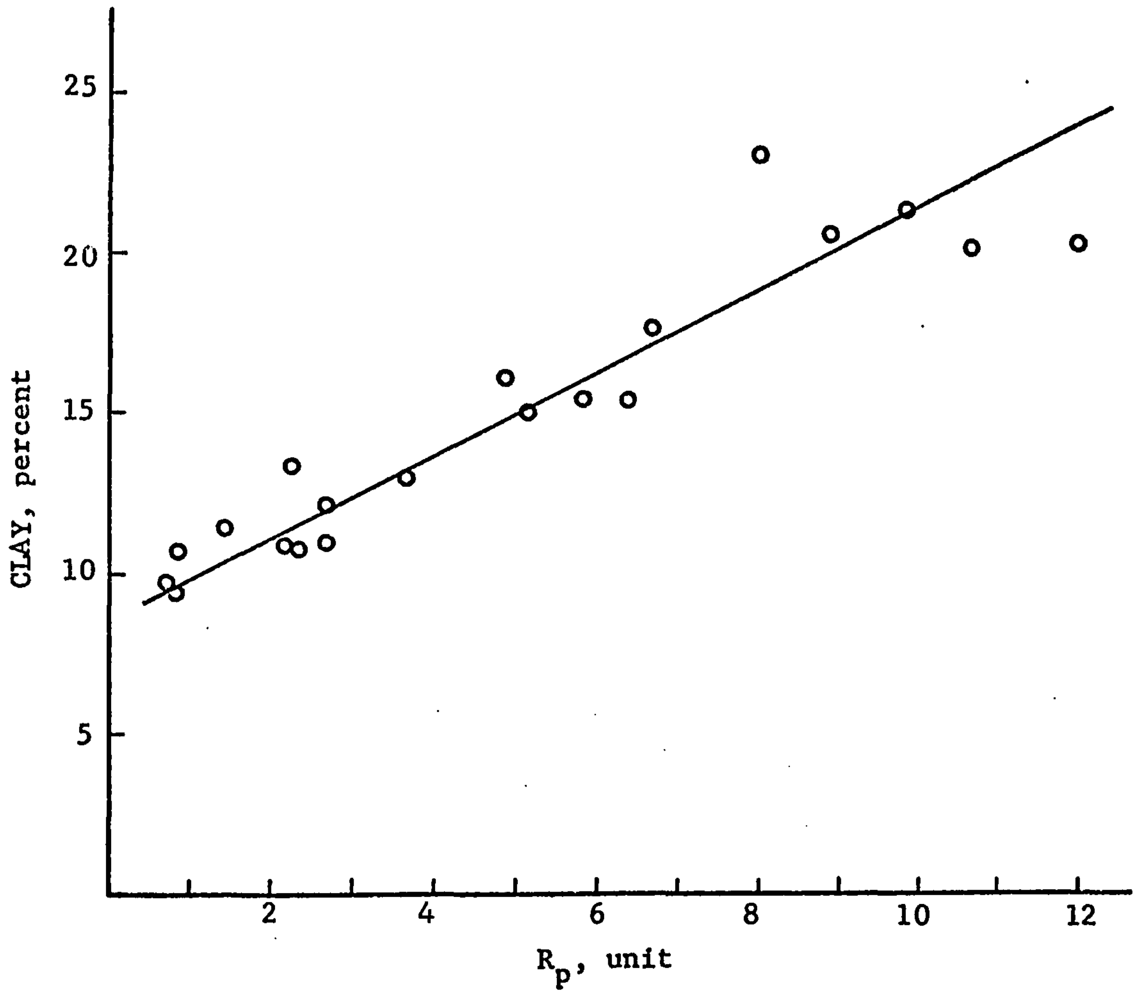

Figure 15. Relationship between R_p unit and percentage of clay in the soil profile to the depth of planting.

decrease in soil aeration. Thus, the mortality reaches a catastrophic level of 78 percent when cuttings are planted 5 ft deep in soil with R_p = 12. On the other hand mortality also increases with decreases of R_p and C_d, which are accompanied by a decrease of available moisture and an increase in large pore space. As a result, mortality of cuttings planted 1.33 ft deep in soil with R_p = 1 reached 57 percent. The variation in percentages of mortality by C_d and R_p follows a definite pattern. Optimum C_d's (i.e. those at which mortality percentage is minimum for a given R_p) increase with decrease in R_p, and optimum R_p's increase with decrease in C_d, although at a different rate. For example, in soil with R_p = 1 the optimum C_d is at 4 feet, and in soil with R_p = 10 it is at 2 feet; but when cuttings are planted 5 feet deep, R_p = 5 is an optimum, and for cuttings planted at C_d = 1.33 feet, R_p optimum is between 8 and 9.

Since there is a significant interaction between C_d and R_p (Equation 2), neither optimum of C_d nor R_p alone was sufficient to produce the best survival of cuttings. The lowest mortality (5.6 percent) in the plantation was achieved only in cuttings which were planted at an optimum C_d = 2.2 feet and in soil with an optimum R_p = 7.4, i.e. in the conditions as determined by the intersection of the lines of C_d and R_p optima. The 5.6 percent mortality, however, was an average mortality for cuttings with C_h from 0.3 to 5.0 feet. Considering this low average and a probable variation (even though very slight) in the percentage of mortality due to a variation in C_h, one should expect that for either C_h 0.3 or 5.0 feet the mortality will be virtually nil.

Unfortunately, it was impossible to determine the distribution of mortality in the presence of R_p, C_d, and C_h together because the effect of C_h on mortality was confounded with other unmeasurable factors.

Nevertheless, one fact appears certain, that in undisturbed soils with R_p lower than 5, cuttings survive better when planted at a depth from 3 to 4 feet, while in soil with R_p above 8 a shallow planting (1.3 to 2.0 feet) is desirable to achieve a satisfactory survival. Since R_p value is directly related to clay content in soil, deep planting in sandy soil and shallow planting in clay soil should be practiced. However, heavy soils with clay content above 22 percent will require an improvement in soil aeration, and in sandy soils with clay content below 15 percent an improvement in moisture status will be imperative. The aeration of clay soil can easily be improved by plowing and bedding or by drainage or by both, depending on soil conditions.

An improvement of moisture status in coarse-textured soils (loamy sands and sandy loams) may be made only to a certain extent if irrigation is to be excluded. The improvement technique depends upon factors which imply depletion of soil moisture as well as factors which inhibit moisture recharge. A low level of available moisture in these soils is due mainly to their inherently excessive internal drainage. The moisture status in such soils is likely to reach wilting point much faster than in a silt loam soil when evapotranspiration exceeds precipitation, especially where recharge of moisture is inhibited by compacted surface soil or by a hardpan.

To improve moisture status in light soils a plowing or rowing in

contour, breaking of the hardpan by subsoiling, and use of organic mulches have been advised by several authors (Zarger 1946, McCormick et al. 1962). However, as a universal method, probably all these treatments together should be used, because it is never known ahead of time which of the moisture-depleting factors will be most critical during the planting season and thereafter.

In order to complete the information on mortality in the 1961 plantation, the progress of the mortality through seven years is given below.

The second-year mortality (33 trees) in the 1961 plantation occurred mostly on a dry site with soil in which R_p varied from 0.8 to 2.4. The distribution by planting depth of 26 trees which actually died on the dry site was 7, 7, 5, 3, and 4 trees planted 1.2, 2.0, 3.0, 4.0, and 5.0 feet deep, respectively. The remaining seven trees which died during the second year were from the wet site (R_p from 9 to 11). Of these trees, four were planted 4 feet deep, one 3 feet deep, and two trees 2 feet deep.

During the third year six trees died, and all of them were suppressed trees which were planted with 0.33 feet of the cuttings above the ground but at various depths.

Thirty trees were uprooted by hurricane Hilda during the fourth growing season, and six trees which were bent from the impact of the falling uprooted trees died during the fifth and sixth year of growth. This mortality was not associated with planting treatments. No mortality occurred during the seventh year of growth.

After seven years only 268 trees survived of the original 480 cuttings planted. This was equivalent to 55.8 percent survival. The progress of change in growing stock in the 1961 plantation during the seven-year period is presented in Figure 16, and distribution of seven-year-old trees by planting treatments is shown in Table 4.

Table 4. Distribution of surviving seven-year-old trees by planting treatments in the 1961 plantation

Depth of planting C_d	C_h, feet				
	0.33	2.00	3.50	5.00	Average
Feet	Percent				
1.33	54	58	37	63	53
2.00	63	58	54	54	57
3.00	63	63	63	58	61
4.00	54	42	63	67	56
5.00	50	75	46	33	51
Average	57	59	53	55	56

The results of analysis of the first-year mortality of cottonwood cuttings in the 1961 plantation have provided information about some major factors which control significantly the survival of cuttings planted in undisturbed soil.

A satisfactory survival of cuttings in the plantation was obtained only by certain treatments and in a very narrow range of soil conditions. Cuttings with C_h over 2.0 feet and/or planted deeper than 3.0 feet survived poorly (Figure 13). Soils with R_p lower than 5 or higher

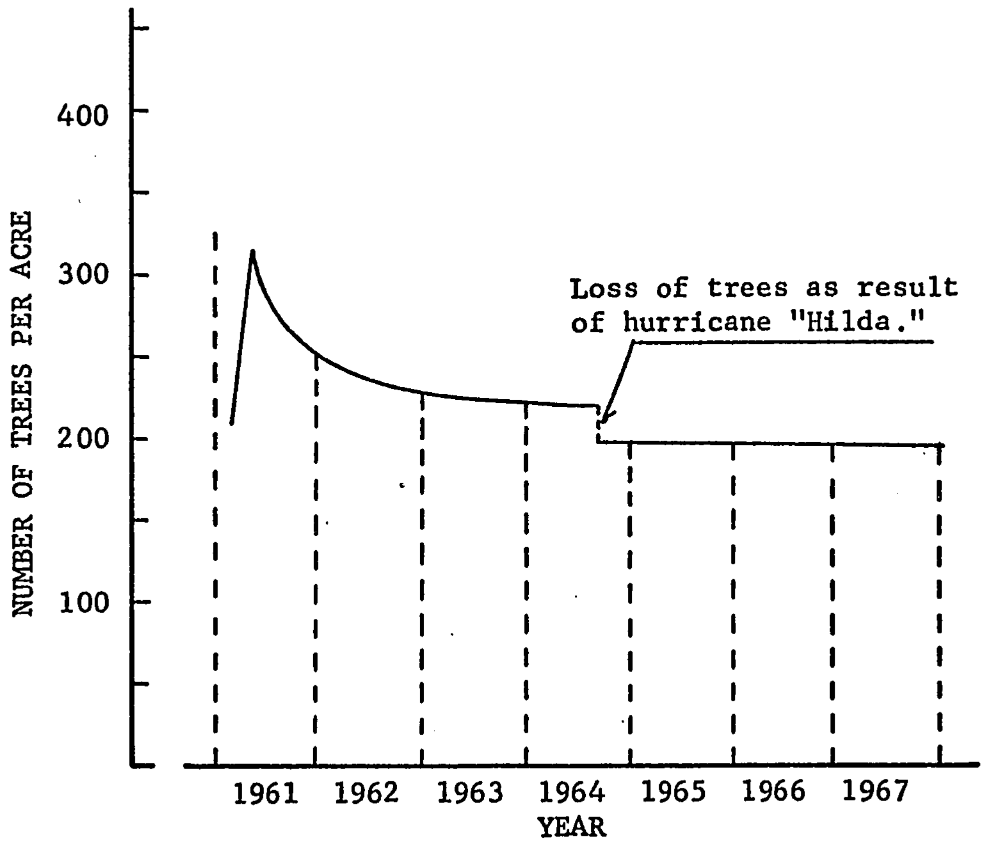

Figure 16. Yearly changes in growing stock in the 1961 plantation.

than 10 (Figure 14) did not favor a satisfactory survival and showed a need for improvement either of moisture status or soil aeration. The tallest trees at the end of the first growing season grew from the cuttings with C_h 3.5 and 5.0 feet, especially of those planted 1.3, 2.0, and 3.0 feet deep. But these treatments are not advised for use in commercial plantations because of poor survival. On the other hand, the cuttings with $C_h = 0.3$ feet planted at the same three depths, although they survived satisfactorily, grew less than cuttings planted by any other treatment which was tried.

The experience obtained in the 1961 plantation led the author to postulate that significant improvement of survival and tree growth would be obtained through mixing the soil of different texture strata within a 3-foot profile by deep cultivation. The author believed that such a treatment would improve the capillary structure and the aeration of soil, as well as the moisture recharge in a rain period, and the capillary raise of moisture during a drought period.

The 1962 plantation was established to test the effect of deep cultivation in 3-foot-deep holes drilled by means of mechanical auger. Three levels of fertilizer were also tested.

The analyses of variance of the first-year survival on three different sites (Tables 40, 41, and 42) proved that deep cultivation Q was effective only on site B_2 with sandy loam soil where clay content in the 3-foot-deep profile varied from 14.4 to 20.3 percent (Table 34; Pits 7 and 8), i.e. in soil similar to that with R_p 5 and 9, in which a satisfactory survival was achieved in the 1961 plantation. The effects

of deep cultivation Q were non-significant either on site B_1 with sandy loam soil where clay content varied from 12.3 to 14.6 percent (Table 34; Pits 5 and 6), or on site B_3 with silt loam to silty clay loam where clay content varied from 23.7 to 30.3 percent (Table 34; Pits 9 and 10). On site B_3 none of the treatments were significant. The effect of planting depth C_d was significant at the 0.01 probability level only on site B_1, where clay content in soil was the lowest of all three sites.

The effect of the (C_d x C_h) interaction, significant at the 0.05 probability level, was on both sites B_1 and B_2, while the effect of C_h was significant only on site B_1. The effects of fertilizer and of the (Q x E) interaction were significant only on site B_2.

The distribution of survival by treatments on each of the three sites separately are shown in Tables 5, 6, and 7.

Large planting areas seldom have a homogeneous site, therefore knowledge of an overall average by treatments may also be of importance. Average survival percentages by treatments for all three sites together in the 1962 plantation are presented in Table 8 and in Figure 17. Average survival of cuttings planted in undisturbed soil without application of fertilizer was the best (60 percent) in cuttings with C_h = 2 feet planted 3 feet deep (Table 8). Average survival percentages for cuttings either with C_h of 0.33 or 2.00 feet planted 1.33 or 3.00 feet deep in the soil mixed with superphosphate were significantly greater than percentages for cuttings

Table 5. First-year survival by treatments on site B_1 in the 1962 plantation

Soil treatment			C_d, feet: 1.33 — C_h, feet: 0.33	C_d, feet: 1.33 — C_h, feet: 2.00	C_d, feet: 3.00 — C_h, feet: 0.33	C_d, feet: 3.00 — C_h, feet: 2.00
			Percent			
-Q	-P	-(P+N)	10	80	70	70
-Q	+P	-(P+N)	20	40	70	70
-Q	+P	+(P+N)	20	50	60	70
+Q	-P	-(P+N)	60	80	80	90
+Q	+P	-(P+N)	40	60	70	70
+Q	+P	+(P+N)	20	40	60	70
-Q			17	57	67	70
+Q			40	60	70	77
	-P	-(P+N)	35	80	75	80
	+P	-(P+N)	30	50	70	70
	+P	+(P+N)	20	45	60	70
Overall			28	59	68	73

Table 6. First-year survival by treatments on site B2 in the 1962 plantation

Soil treatment			C_d, feet: 1.33, C_h, feet: 0.33	1.33, 2.00	3.00, C_h, feet: 0.33	3.00, 2.00
			Percent			
-Q	-P	-(P+N)	40	20	20	30
-Q	+P	-(P+N)	20	30	60	40
-Q	+P	+(P+N)	30	70	60	10
+Q	-P	-(P+N)	50	40	50	50
+Q	+P	-(P+N)	60	60	80	80
+Q	+P	+(P+N)	10	40	80	30
-Q			30	40	47	27
+Q			40	53	70	53
	-P	-(P+N)	45	30	35	40
	+P	-(P+N)	40	45	70	60
	+P	+(P+N)	20	55	70	20
Overall			35	47	58	40

Table 7. First-year survival by treatments on site B_3 in the 1962 plantation

Soil treatment			C_d, feet: 1.33 — C_h, feet: 0.33	C_d, feet: 1.33 — C_h, feet: 2.00	C_d, feet: 3.00 — C_h, feet: 1.33	C_d, feet: 3.00 — C_h, feet: 2.00
			Percent			
-Q	-P	-(P+N)	20	60	60	80
-Q	+P	-(P+N)	60	50	60	50
-Q	+P	+(P+N)	50	70	70	50
+Q	-P	-(P+N)	20	70	60	50
+Q	+P	-(P+N)	80	80	50	60
+Q	+P	+(P+N)	50	60	90	50
-Q			43	60	63	60
+Q			50	70	67	53
	-P	-(P+N)	20	65	60	65
	+P	-(P+N)	70	65	55	55
	+P	+(P+N)	50	65	80	50
Overall			46	65	65	57

Table 8. First-year survival by treatments on all three sites in the 1962 plantation

Soil treatment			C_d, feet: 1.33		3.00	
			C_h, feet: 0.33	2.00	C_h, feet: 0.33	2.00
			Percent			
-Q	-P	-(P+N)	23	53	50	60
-Q	+P	-(P+N)	33	40	63	53
-Q	+P	+(P+N)	33	63	63	43
+Q	-P	-(P+N)	43	63	63	63
+Q	+P	-(P+N)	60	67	67	70
+Q	+P	+(P+N)	27	47	77	50
-Q			30	52	59	52
+Q			43	59	69	61
	-P	-(P+N)	33	58	57	62
	+P	-(P+N)	47	53	65	63
	+P	+(P+N)	30	55	70	47
Overall			36	55	64	57

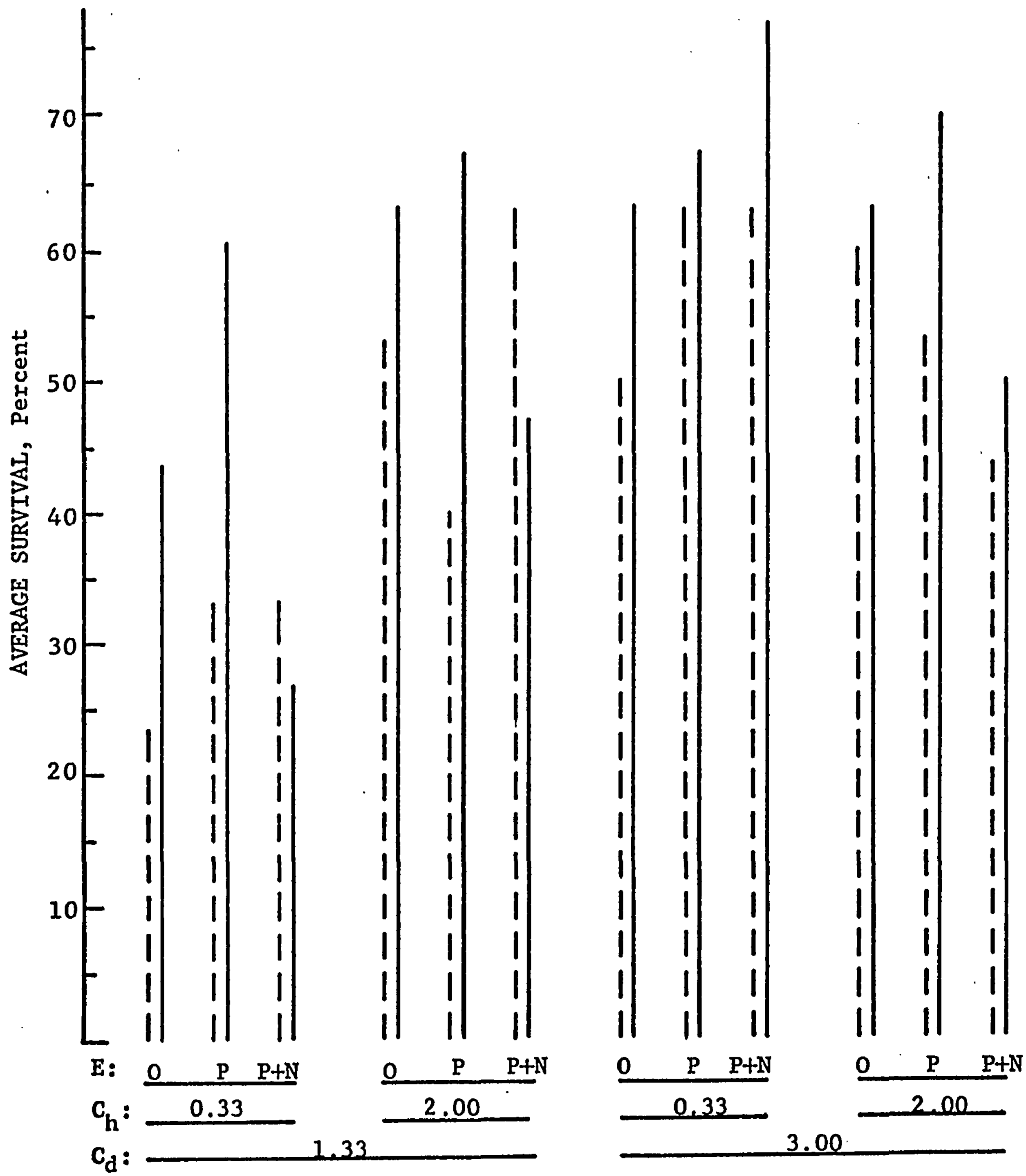

Figure 17. First-year survival by treatments in the 1962 plantation. Dashed lines refer to survival without Q treatment and solid lines with Q treatment.

planted by the same methods in undisturbed soil without fertilizer. Moreover, survival percentage for cuttings with C_h = 2 feet planted 3 feet deep in the soil mixed with superphosphate was three times greater (70 percent) than that for cuttings planted by the standard method (23 percent).

Fertilizing the surface soil with ammonium nitrate produced a suppressing effect on survival of cuttings with either C_h of 0.33 or 2.00 feet planted 1.33 feet deep in soil mixed with superphosphate.

The best average survival (77 percent) in the plantation was achieved in cuttings with C_h = 0.33 feet planted 3.00 feet deep in soil mixed with 1.5 lbs. of superphosphate in holes and with 2 oz. of ammonium nitrate incorporated in the surface soil.

Further tests aimed at improving both survival and growth of cuttings with C_h of 2.00 and 3.66 feet were made on two extreme sites in the 1963 plantation.

The effects of deep cultivation of soil in 9-inch-diameter holes, mulching of soil with 2-foot-square Kraft-paper pads placed around the individual cuttings, and bedding of soil (similar to rowing, or lay-by cultivation) were tested on survival of cuttings with C_h of 0.33, 2.00, and 3.66 feet and planted at two different depths (1.33 and 3.00 feet).

The results of analysis of variance of first-year survival of cuttings on the dry site C_1 (Table 43) showed that main treatments, such as bedding B, deep cultivation Q, depth of planting C_d, length of cutting above the ground C_h, and the interaction (Q x C_d) were

significant at the 0.01 probability level, while mulching M, as well as the interactions (B x Q), (Q x C_h), and (B x Q x C_d x C_h) were significant at the 0.05 probability level. Kraft paper pads decomposed rapidly; therefore the effect of mulch was considerably reduced.

The distribution of survival by treatments on site C_1 in the 1963 plantation is shown in Table 9.

The survival of cuttings planted by the standard treatment was zero. Similar catastrophy occurred with cuttings planted by the other 10 treatment combinations in which either one or two main soil treatments were missing. The cuttings planted 1.33 feet deep were mostly affected.

Application of all soil treatments together (+B, +M, +Q) improved survival of cuttings planted 1.33 feet deep with C_h of 0.33 and 2.00 up to 50 percent and of cuttings with C_h = 3.66 feet to 39 percent. Among 48 treatment combinations tried in the plantation, the best survival on site C_1 reached 61 percent in cuttings with C_h = 3.66 feet planted 3.00 feet deep in soil which received all treatments designed at the highest level (+B, +M, and +Q to 3 foot depth). The straight linear relationship of survival (39, 44, and 61 percent) with corresponding C_h (0.33, 2.00, and 3.66 feet) of the cuttings which received the same soil treatments points to the feasibility of improving the survival of cuttings with C_h longer than 2.00 feet by improving the physical properties of soil.

Table 9. First-year survival by treatments on site C_1 in the 1963 plantation

Soil treatment	C_d, feet 1.33			C_d, feet 3.00		
	C_h, feet			C_h, feet		
	0.33	2.00	3.66	0.33	2.00	3.66
	Percent					
-B -M -Q	0	0	0	6	6	0
-B -M +Q	0	6	0	11	33	28
-B +M -Q	0	11	11	0	6	6
-B +M +Q	6	11	11	17	39	22
+B -M -Q	6	6	6	0	11	11
+B -M +Q	0	22	44	50	50	39
B+ +M -Q	11	11	28	11	17	11
+B +M +Q	0	33	44	39	44	61
+B -M	--a/	14	25	--	30	25
+B +M	--	22	36	--	28	36
+B -Q	--	9	17	--	14	11
+B +Q	--	27	44	--	44	50
+B	--	18	30	--	29	31

a/--denotes no means available because of several treatments with zero survival.

Contrary to the significance of numerous treatment combinations on survival of cuttings on site C_1, survival on site C_2 was significantly dependent (0.01 probability level) only upon the ($Q \times C_d$) interaction (Table 44). The distribution of survival by treatments of cuttings on site C_2 is shown in Table 10. No clear-cut trend attributable to treatment combinations in survival percentages can be seen, probably because of the small number (four) of replications. However, survival percentages by most treatments on cite C_2 are higher than on site C_1.

Survival of 61 percent (the best on site C_1) can hardly be accepted as a satisfactory result. Nevertheless, when weed competition (Plate 12) and conditions of soil on this site (5.8 percent clay and 84.6 percent of sand in 3-foot-deep soil profile; Table 34, Pits 11 and 12) are taken into consideration, such a survival may be viewed as a very encouraging achievement.

In search of a better treatment the 1964 plantation was established. The effects of four different volumes of cultivated soil, produced by four different cross-sections of 3-foot-deep planting holes, were tested on survival of 20-inch-long cuttings planted 16 inches deep and on 40-inch-long cuttings planted 3 feet deep.

The relationship of the first-year survival of these cuttings with size of hole is shown in Figure 18.

The survival of 20-inch-long cuttings increased with increase of hole size and was improved from 37 percent when cuttings were planted by the standard method in undisturbed soil (i.e. in a 1-sq.-inch cross-section hole) to 83 percent when planted in holes with 254 sq. inches of cross section.

Table 10. First-year survival by treatments on site C_2 in the 1963 plantation

Soil treatment			C_d, feet: 1.33			3.00		
			C_h, feet			C_h, feet		
			0.33	2.00	3.66	0.33	2.00	3.66
			Percent					
-B	-M	-Q	0	75	50	50	25	50
-B	-M	+Q	75	50	50	75	50	75
-B	+M	-Q	75	75	75	50	75	50
-B	+M	+Q	75	50	75	75	100	75
+B	-M	-Q	50	25	75	25	75	50
+B	-M	+Q	0	25	100	75	100	75
+B	+M	-Q	75	75	75	50	50	50
+B	+M	+Q	25	25	50	75	50	100
-B	-M		--a/	62	50	62	38	62
-B	+M		--	62	75	62	87	62
+B	-M		--	25	87	50	87	62
+B	+M		--	50	62	62	50	75
-B		-Q	--	75	62	50	50	50
-B		+Q	--	50	62	75	75	75
+B		-Q	--	50	75	38	62	50
+B		+Q	--	25	75	75	75	87
	-M	-Q	--	50	62	38	50	50
	-M	+Q	--	38	75	75	75	75
	+M	-Q	--	75	75	50	62	50
	+M	+Q	--	38	62	75	75	87
-B			--	62	62	62	62	62
+B			--	38	75	56	69	69
	-M		--	44	69	56	62	62
	+M		--	56	69	62	69	69
		-Q	--	62	69	44	56	50
		+Q	--	38	69	75	75	81
Overall			--	50	69	59	66	66

a/--denotes no means available because of two treatments with zero survival.

Plate 12. One-year-old cottonwood in a heavy stand of giant ragweed (Ambrosia trifida L.) in the 1963 plantation.

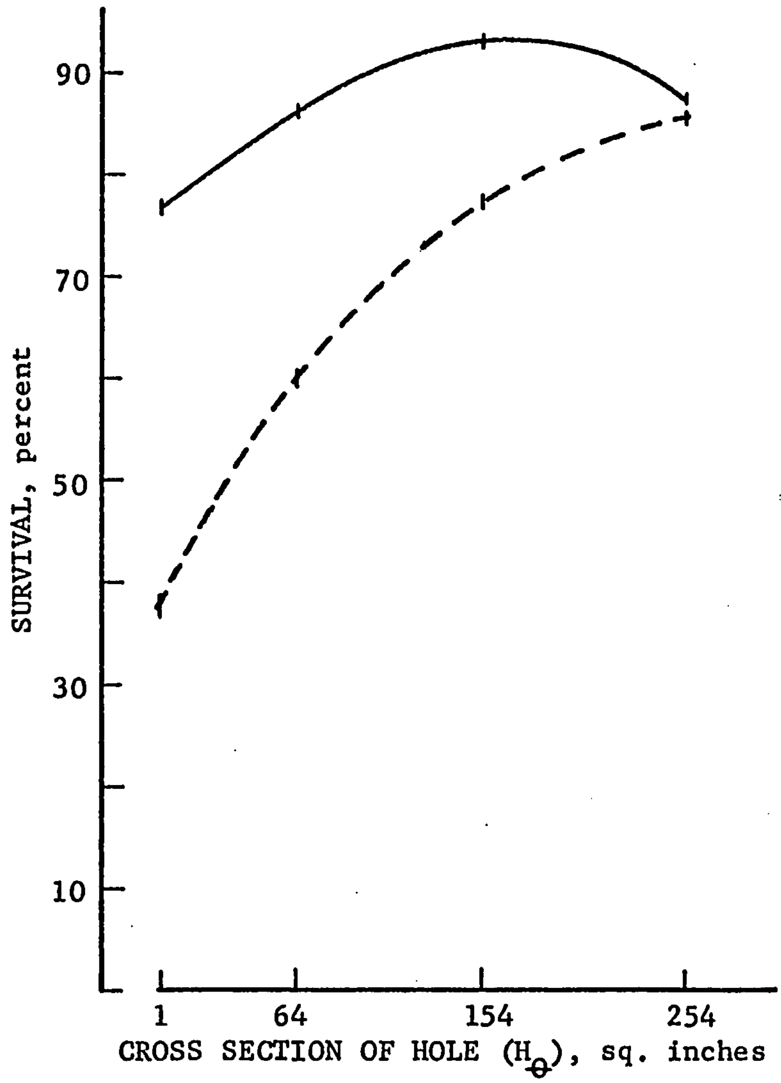

Figure 18. First-year survival in the 1964 plantation as related to cross section (H_θ) of 3-foot-deep planting hole. Solid line is for 40-inch-long cuttings planted 3 feet deep, and dashed line is for 20-inch-long cuttings planted 1.33 feet deep.

The survival of 40-inch-long cuttings reached a maximum of 92 percent when the cuttings were planted in holes with 154-sq.-inch cross section (14-inch diameter). This result indicates that survival of cuttings planted 3 feet deep in the 1963 plantation probably could have been further improved if planting holes had been 14 inches in diameter instead of the 9-inch-diameter holes which were used. On the other hand, the application of bedding treatment might have been beneficial for survival of cuttings in the 1964 plantation.

To summarize the results of the 1961-1964 trials aimed at improving survival of cottonwood cuttings a comparison of efficiencies of treatments (standard vs. poorest vs. best) is presented in Table 11.

The data in this table reveal that survival of cuttings planted by the standard method in none of the trials reached the percentage equal to that produced by the best treatment. However, the standard method was not always the poorest treatment. The survivals produced either by the standard method or by a best treatment varied by site and by year.

As discussed previously, in the 1961 plantation survival of cuttings planted by certain treatments was especially affected either by incidence of leaf beetle or by flood. Nothing similar occurred in the plantations of successive years.

The intensity of weed competition, which varied by site and by year, without doubt contributed to the variation in survival of cuttings planted by any one treatment.

Table 11. Comparison of first-year survival in the 1961, 1962, 1963, and 1964 plantations

Plantation	Site	Standard treatment		Poorest treatment		Best treatment	
		Survival	Code	Survival	Code	Survival	Code
Year		Percent	No.	Percent	No.	Percent	No.
1961	A	75.0	11	37.5	54	87.5	32
1962	B_1	10.0	1111	10.0	1111	90.0	2221
1962	B_2	40.0	1111	10.0	2113	80.0	2222
1962	B_3	20.0	1111	20.0	1111	90.0	2213
1962	Ave.	23.0	1111	23.0	1111	77.0	2213
1963	C_1	0.0	11111	0.0	11111	61.0	22223
1963	C_2	0.0	11111	0.0	11111	100.0	22223
1963	Ave.	0.0	11111	0.0	11111	80.5	22223
1964	D	37.0	11	37.0	11	92.0	23

Moreover, variation in climatic factors such as precipitation and temperature, which influence evapotranspiration, has intensified the variation in survival of cuttings by year, by site, and by treatment.

Survival as Related to Climatic Conditions During the First Growing Season.

Data of average monthly temperature and total monthly precipitation for a ten-year period (1955-1964) at New Roads, Louisiana, (Figure 4) were compiled in order to explain the annual variation in first-year

survival of cottonwood cuttings as the effect of a combined variation in these climatic factors (Tables 12 and 13).

Average monthly temperature, which varied for obvious reasons in a distinctive pattern during the growing season, exhibited an irregular annual variation during the ten-year period (Table 12). The temperatures above the 10-year mean (underlined figures) are likely to occur in any month of the season, and the number of months with such temperature varied greatly from year to year. But the change in the amplitude of this variation displayed an annual cycle with a maximum (15.2°F) in February and a minimum (3.0°F) in August. Its amplitude in March was 12.0°F.

The ten-year mean monthly precipitation (Table 13) did not show a distinct annual pattern. However, the precipitation was highest in July and lowest in October. The greatest difference among ten-year mean precipitations of the growing-season months was only 1.54 inches. Contrary to this, the monthly precipitation during ten growing seasons varied strikingly by month and by year. The largest amplitude of the annual variation in precipitation was in July (15.51 inches) and the smallest in May (3.94 inches). The seasonal precipitation varied very much also. For example, the precipitation in the 1963 growing season was only 51 percent, while in the 1957 season it was 141 percent of the ten-seasons' mean precipitation. The variation in precipitation did not coincide with the variation in temperature either by month or by year. Often (25 cases of 70) when temperature was above average, precipitation was below average.

Table 12. Average monthly temperature during the 1955-1964 growing seasons at New Roads, Louisiana[a/]

Lat. 30°42' N; Long. 91°23' W; Elev. 38 ft.

Month	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	Ten-year Mean	Ten-year Extremes
	Degrees Fahrenheit											
March	[b/] 64.7	58.9	58.5	56.7	57.6	52.7	62.2	56.3	63.5	59.0	59.0	52.7 - 64.7
April	70.7	65.7	68.9	68.0	66.5	68.2	66.1	65.7	72.1	70.5	68.2	65.7 - 72.1
May	76.3	76.6	76.0	75.0	76.4	72.1	73.4	76.0	75.9	76.0	75.4	72.1 - 76.6
June	77.3	78.4	80.3	81.4	80.0	80.7	77.6	79.6	80.6	80.7	79.7	77.3 - 81.4
July	81.3	82.3	83.2	82.7	81.4	84.1	79.7	83.3	81.7	81.3	82.1	79.9 - 84.1
August	81.1	81.8	81.9	81.4	82.0	81.7	79.9	82.9	82.4	82.1	81.7	79.9 - 82.9
September	79.8	76.8	76.7	79.4	78.2	76.8	75.0	77.9	78.2	76.2	77.5	75.0 - 79.8
Average	75.9	74.4	75.1	74.9	74.6	73.7	73.4	74.5	76.3	75.1	74.8	73.4 - 76.3

a/ Compiled from Climatological Data for Louisiana, 1956-1965. Environmental Sci. Serv. Adm., U. S. Dep. Commerce, Washington, D. C.

b/ Underlined figures denote temperature above ten-year mean for the month.

Table 13. Monthly precipitation during the 1955-1964 growing seasons at New Roads, Louisiana a/

Lat. 30°42' N; Long. 91°23' W; Elev. 38 ft.

Month	Year 1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	Ten-year Mean	Ten-year Extremes
	Inches											
March	1.48	4.08	6.40	4.97	2.45	2.54	8.58	2.15	b/ 0.90	9.78	4.33	0.90 - 9.78
April	12.84	4.08	4.87	4.56	3.79	3.03	4.11	8.59	0.49	4.83	5.02	0.49 - 12.84
May	5.56	1.89	4.04	4.31	6.09	4.35	4.39	2.46	3.07	5.83	4.20	1.89 - 5.83
June	2.19	4.33	15.10	8.39	4.05	1.42	5.26	5.49	3.64	3.26	5.31	1.42 - 15.10
July	8.65	2.30	3.56	7.01	6.93	1.20	7.60	0.16	5.32	14.67	5.74	0.16 - 14.67
August	4.90	4.03	2.54	5.01	6.88	8.73	5.55	4.51	1.84	2.52	4.65	1.84 - 8.73
September	3.32	0.70	10.83	4.88	3.19	1.16	8.67	5.52	1.95	2.53	4.29	0.70 - 10.83
Total	38.94	20.41	47.34	39.13	33.38	22.43	44.16	28.88	17.21	43.42	33.53	17.21 - 47.34

a/ Compiled from Climatological Data for Louisiana, 1956-1965. Environmental Sci. Serv. Adm., U. S. Dep. Commerce, Washington, D. C.

b/ Underlined figures denote precipitation below evapotranspiration calculated by Thornthwaite's method.

As a consequence of such variation, moisture deficiency increases according to the increase of the algebraic sum of evapotranspiration and precipitation deviations from their means.

Monthly means and maximum deviations of rainfall and temperature from their 10-year means are shown in Figure 19.

Thornthwaite (1948) has developed a method for calculating potential evapotranspiration from air temperature alone. Using this method he found that evapotranspiration rates in the South vary from 0.01 inch per day for the winter season to about 0.18 inch per day for the summer. According to the method the average monthly potential evapotranspiration for Texas, Louisiana, Mississippi, and Alabama is 6.7 ± 0.4 inches for June, July, and August, 5 inches monthly for May and September, and about 2.5 inches for April or October. These evapotranspiration rates, when plotted with corresponding ten-year mean temperatures, showed that for April through October the monthly evapotranspiration rate increases 0.37 inch with an increase of $1^{o}F$ in monthly temperature.

Zahner (1956) found that the estimates of evapotranspiration in the Gulf South by Thornthwaite's method are about 4 inches too low for June, July, and August, and therefore in calculations of water deficiency for each of these three months he used a rate of 8 inches of evapotranspiration. Zahner's evapotranspiration figures for May, September, April, and October did not differ from those determined by Thornthwaite.

Van Bavel (1959) used Penman's (1948) method for computing monthly maximum evapotranspiration rates for the region of the Lower Mississippi

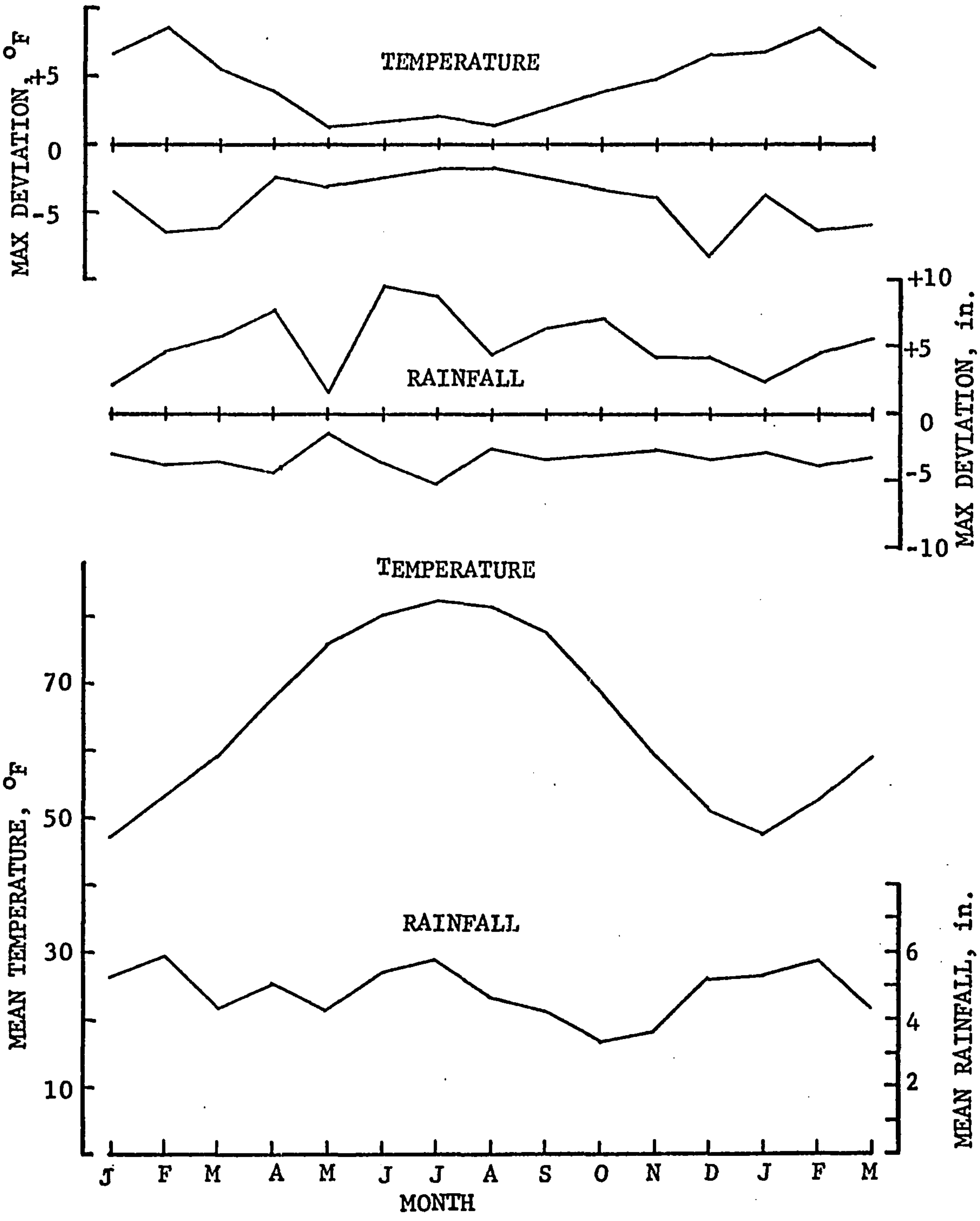

Figure 19. Mean monthly temperature and rainfall for 1955-64 period at New Roads, Louisiana. Maximum deviations of temperature and rainfall are shown at the top.

Valley. The average rates which he obtained for March, April, May, June, July, August, and September for Louisiana and the southern half of Mississippi were 2.8, 3.7, 4.7, 5.4, 5.5, 5.0, and 3.9 inches, respectively.

The comparison of evapotranspiration rates calculated by these three methods (Table 14) showed that the rates calculated by Thornthwaite's method are the closest to the averages; therefore the rates of Thornthwaite were adopted in this dissertation.

Table 14. Evapotranspiration rates calculated by different methods for growing-season months in the Lower Mississippi Valley

	Method of calculation			
Month	Zahner	Penman	Thornthwaite	Average
	Inches			
March	1.5	2.8	1.5	1.93
April	2.5	3.7	2.5	2.90
May	5.0	4.7	5.0	4.90
June	8.0	5.4	6.7	6.70
July	8.0	5.5	7.1	6.87
August	8.0	5.0	6.7	6.57
September	5.0	3.9	5.0	4.63
Total	38.0	31.0	34.5	34.50

A comparison of Thornthwaite's monthly evapotranspiration rates with the monthly precipitation at New Roads (Table 13) leads to the observation that critical rainfall, i.e. below evapotranspiration

(underlined figures), is likely to occur in any month of the growing season, and in the summer this can take place during several consecutive months or in a particular month during many consecutive seasons. However, the deviation of the mean precipitation from the total evapotranspiration for the ten growing seasons was only -0.97 inch.

The number of years with critical rainfall was counted by month and calculated in percent. Plotting these percentages against the probabilities of monthly rainfall being equal to or less than evapotranspiration, as calculated from the tables prepared by Penn et al. (1969), showed a direct relationship. This indicated that the occurrence of critical precipitation at New Roads corresponds to these probabilities.

Use of moisture deficiency as a criterion of critical conditions for plant development is not new.

Variation in moisture deficiencies was applied by Zahner (1956) to explain periodic growth differences among widely distributed pine-hardwood forests in the mid-South. In calculating the deficiencies Zahner used monthly evapotranspiration rates which he estimated for a single large region (Texas, Arkansas, Louisiana, Mississippi, and Alabama) and, depending on site, approximate hypothetical soil-moisture storage capacities (6, 8, 10, or 12 inches) in a 6-foot-deep soil profile, i.e. in the effective root zone, as the basic data, and actually recorded monthly rainfall for a given locality, as the raw data. In other words, rainfall was the only decisive climatic factor considered in the calculations.

Moisture deficiency was also used by van Bavel (1959) to predict drought probabilities for agricultural soils of the Lower Mississippi Valley. For calculating moisture deficiency van Bavel used the daily fractions of monthly evapotranspiration rates determined by him for much smaller regions (six regions within Arkansas, Mississippi, and Louisiana) than those used by Zahner (1956) and daily precipitation averaged for sub-regions (six sub-regions per state). Consequently, the variations in evapotranspiration from day to day within a given month, or between months of different years, were ignored. The variation in rainfall among particular localities within a sub-region was ignored also.

Since the incidence of moisture deficiency was the objective of his study, the amounts of rain in excess of certain hypothetical soil moisture storage capacities were disregarded also.

Both these methods, although serving well their purposes, did not fit sufficiently either the conditions or purpose of the study discussed in this section. However, knowledge of these methods has generated a new idea for a suitable method.

Considering all the variations in precipitation and in evapotranspiration due to the method of its determination and to fluctuations in temperature, the author concluded that determination of moisture deficiency can not be based on data of different rank, i.e. such as daily precipitation at a given locality and monthly evapotranspiration averaged for a large region.

For best results the data used for calculating moisture deficiency

should be adjusted to the conditions of locality and the period of time and be of equal rank.

Since soil moisture storage capacity of the upper 2-foot soil layer (root zone of one-year-old seedlings) is nearly constant, at least for a couple of years, and since according to Zahner (1956) "winter precipitation surpluses do not vary greatly from year to year," the author of this report assumed that, for good survival and satisfactory development of cottonwood cuttings during the first growing season, the moisture content in the soil should remain throughout the whole season equal to that on the planting day.

To support this assumption some information about moisture capacity of the soil in the 1961 plantation is given below.

The average available water capacity in the surface soil (upper 2 feet) in the 1961 plantation is 25 percent (Table 33) by volume, equivalent to approximately 5.6 inches of water.

An excess of precipitation above evapotranspiration, less 1.0 inch of water needed to replenish large pores and saturate the upper foot of soil, usually is lost in runoff.

When monthly evapotranspiration exceeds precipitation by more than 3 inches (the available moisture content in the upper foot of soil), and if capillary rise of moisture from the lower strata is ignored, the wilting point may be reached, resulting in serious moisture stress for shallow-rooted vegetation.

Available moisture rarely drops to the wilting point in the second foot of soil. However, if even one-half of this moisture would be removed

by evapotranspiration, i.e. 4.5 inches of water from the upper 2 feet of soil, it will signify a complete catastrophy for shallow-rooted plants.

According to van Bavel (1959) the minimum number of drought days expected in the region of the experimental cottonwood plantations in the driest five out of ten years during the period March through November for a soil with a moisture storage capacity of 3 inches is 45 days, and for a soil-moisture storage capacity of 5 inches is 25 days.

As a result of the above-discussed analyses a concept of an adjusted moisture balance was developed, with the assumption that the total seasonal difference (-0.97 inch) between predicted evapotranspiration and the 10-year mean precipitation is a constant.

The term "adjusted moisture balance" as used here is the difference between the deviation of the actual precipitation from the adjusted potential evapotranspiration (for a given month or season) and the deviation of long-term mean precipitation from evapotranspiration predicted for the same period of time. When this difference between the two deviations approaches zero, the adjusted moisture balance also is nearly zero.

The variations in temperature, evapotranspiration, and precipitation during the 1961-1964 growing seasons were analyzed in detail in order to determine moisture balance for each month and for each season.

The calculation of a moisture balance requires operations with six variables: actual temperature, long-term mean temperature, actual evapotranspiration, predicted evapotranspiration, actual precipitation,

and long-term mean precipitation.

Because the value of a monthly moisture balance results from interaction of all these variables, and seasonal moisture balance is a cumulative value of seven monthly moisture balances, the necessity of developing a formula for simplification of these calculations was apparent.

In developing the formula, the following terms were used:

Pm -- Long-term mean monthly precipitation (inches).
Pa -- Actual monthly precipitation (inches).
Pd -- Deviation of actual monthly precipitation from long-term mean monthly precipitation (inches); Pd is negative when Pa $<$ Pm.
Tm -- Long-term mean monthly temperature (^{o}F).
Ta -- Actual mean monthly temperature (^{o}F).
Td -- Deviation of actual mean monthly temperature from long-term mean monthly temperature (^{o}F); Td is negative when Ta $<$ Tm.
ETp -- Evapotranspiration predicted by Thornthwaite's method for a month (inches).
ETr -- Evapotranspiration rate per $1^{o}F$ per month (inches).
ETa -- Adjusted monthly evapotranspiration (inches).
ETd -- Deviation of monthly adjusted evapotranspiration from that predicted for a month (inches); ETd is negative when ETa $<$ ETp.
Nd -- Deviation of long-term mean monthly precipitation from evapotranspiration predicted for the month (inches); Nd is negative when Pm $<$ ETp.
Mb -- Adjusted moisture balance calculated for a given month (inches).

As defined above:

$$Mb = (Pa - ETa) - (Pm - ETp)$$

where: $ETa = ETp + ETd$

$$ETd = (Ta - Tm)\ ETr = Td \times ETr, \text{ and}$$

$$Pm - ETp = Nd.$$

Thus, monthly adjusted moisture balance is:

$$Mb = Pa - [ETp + (Td \times ETr)] - (Pm - ETp)$$

$$Mb = Pa - ETp - (Td \times ETr) - Pm + ETp$$

Table 15. Sample calculation table for Mb in the 1963 growing season

Month	Ta	Tm	Td	ETr	ETd	ETp	ETa	Pa	Pm	Pd	Nd	Mb
	^oF	^oF	^oF	In./^oF	Inch	Inch	Inch	Inch	Inch	Inch	Inch	Inch
March	63.5	59.0	5.5	0.15	0.82	1.50	2.32	0.90	4.33	-3.43	2.83	-4.25
April	72.1	68.2	3.9	0.37	1.44	2.50	3.94	0.49	5.02	-4.53	2.52	-5.97
May	75.9	75.4	0.5	0.37	0.18	5.00	5.18	3.07	4.20	-1.13	-0.80	-1.31
June	80.6	79.7	0.9	0.37	0.33	6.70	7.03	3.64	5.31	-1.67	-1.39	-2.00
July	81.7	82.1	-0.3	0.37	-0.11	7.10	6.99	5.32	5.74	-0.42	-1.36	-0.31
August	82.4	81.7	0.7	0.37	0.26	6.70	6.96	1.84	4.65	-2.81	-2.05	-3.07
September	78.2	77.5	0.7	0.37	0.26	5.00	5.26	1.95	4.28	-2.33	-0.72	-2.59
Total					3.18	34.50	37.68	17.21	33.53	-16.32	-0.97	-19.50

$$Mb = Pa - Pm - (Td \times ETr),$$

and seasonal adjusted moisture balance is:

$$\sum_{i=1}^{n} Mb_i = \sum_{i=1}^{n} Pd_i - \sum_{i=1}^{n} (Td \times ETr)_i,$$

where n = number of months in the season.

As an example, a sample calculation of the adjusted moisture balance (Mb) for the first growing season in the 1963 plantation is presented in Table 15 (previous page).

The comparison of adjusted monthly moisture balances during the 1961-1964 growing seasons at New Roads, Louisiana, is shown in Table 16 and also presented diagramatically in Figure 20.

Table 16. Adjusted moisture balances during the 1961-1964 growing seasons at New Roads, Louisiana

Month	Growing season 1961	1962	1963	1964	Mb average	10-yr. mean Nd
	-----	-----	-----	Inches	-----	-----
March	3.77	-1.78	-4.25	5.45	0.80	2.83
April	-0.13	4.49	-5.97	-1.04	-0.66	2.52
May	0.93	-1.96	-1.31	1.41	-0.23	-0.80
June	0.73	0.22	-2.00	-2.42	-0.87	-1.39
July	2.67	-6.02	-0.31	9.23	1.39	-1.36
August	1.57	-0.58	-3.07	-2.28	-1.09	-2.05
September	5.31	1.09	-2.59	-1.27	0.63	-0.72
Total	14.85	-4.54	-19.50	9.08	-0.03	-0.97

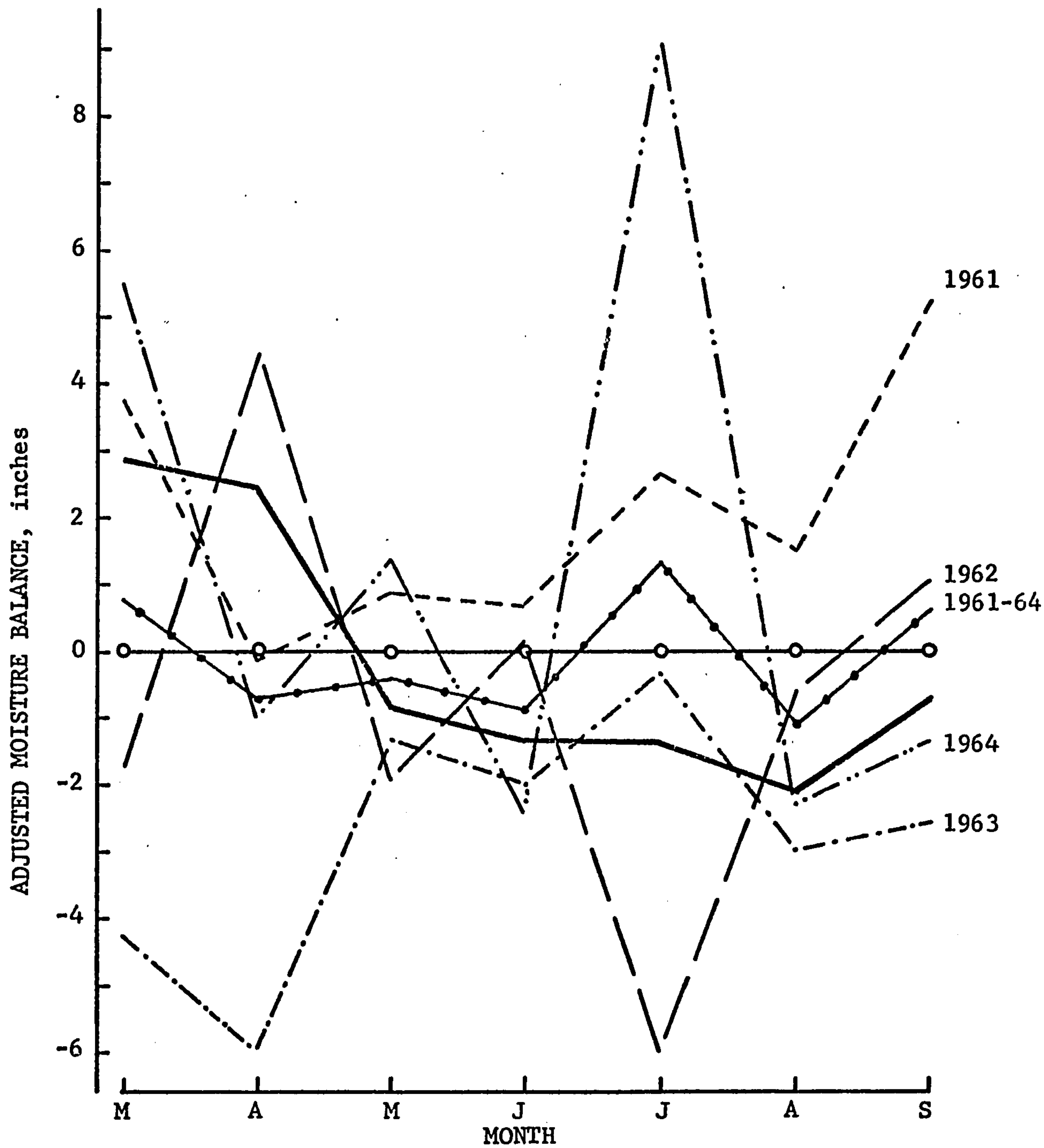

Figure 20. Adjusted moisture balances during the 1961-1964 growing seasons at New Roads, Louisiana. Heavy solid line indicates ten-year mean monthly moisture deficiencies (Nd = Pm - ETp).

The result of regression analysis of first-year survival for cuttings planted 3 feet deep by various improved treatments (at least in two plantations using the same treatment) with $\sum$Mb as the independent variable showed a direct relationship between these two variables (Figure 21).

An increase of 1 inch in $\sum$Mb produced 1.36 percent improvement in survival as proven by the regression equation:

Survival (percent) = 65.4 + 1.36 $\sum$ Mb;
with r = 0.56, and t = 3.318 with 25 degrees of freedom, significant at the 0.01 probability level.

Since 1 inch of seasonal $\sum$ Mb is equivalent to 1/7 inch of monthly Mb, an increase of 1 inch in monthly Mb produced an improvement of 9.52 percent in survival of cuttings planted by the improved methods.

The most extreme values of $\sum$ Mb were -19.50 inches in the 1963 and +14.85 inches in the 1961 growing seasons (Table 16).

The variation in air temperature contributed 21.5 percent to the total difference between these $\sum$ Mb values by increasing the positive balance of the 1961 season by 4.22 inches due to reduced evapotranspiration as a consequence of below normal (10-year mean) air temperature and by increasing negative balance of the 1963 season by -3.18 inches due to increased evapotranspiration as a consequence of above normal temperature.

Since the average temperature in the 1961 growing season was

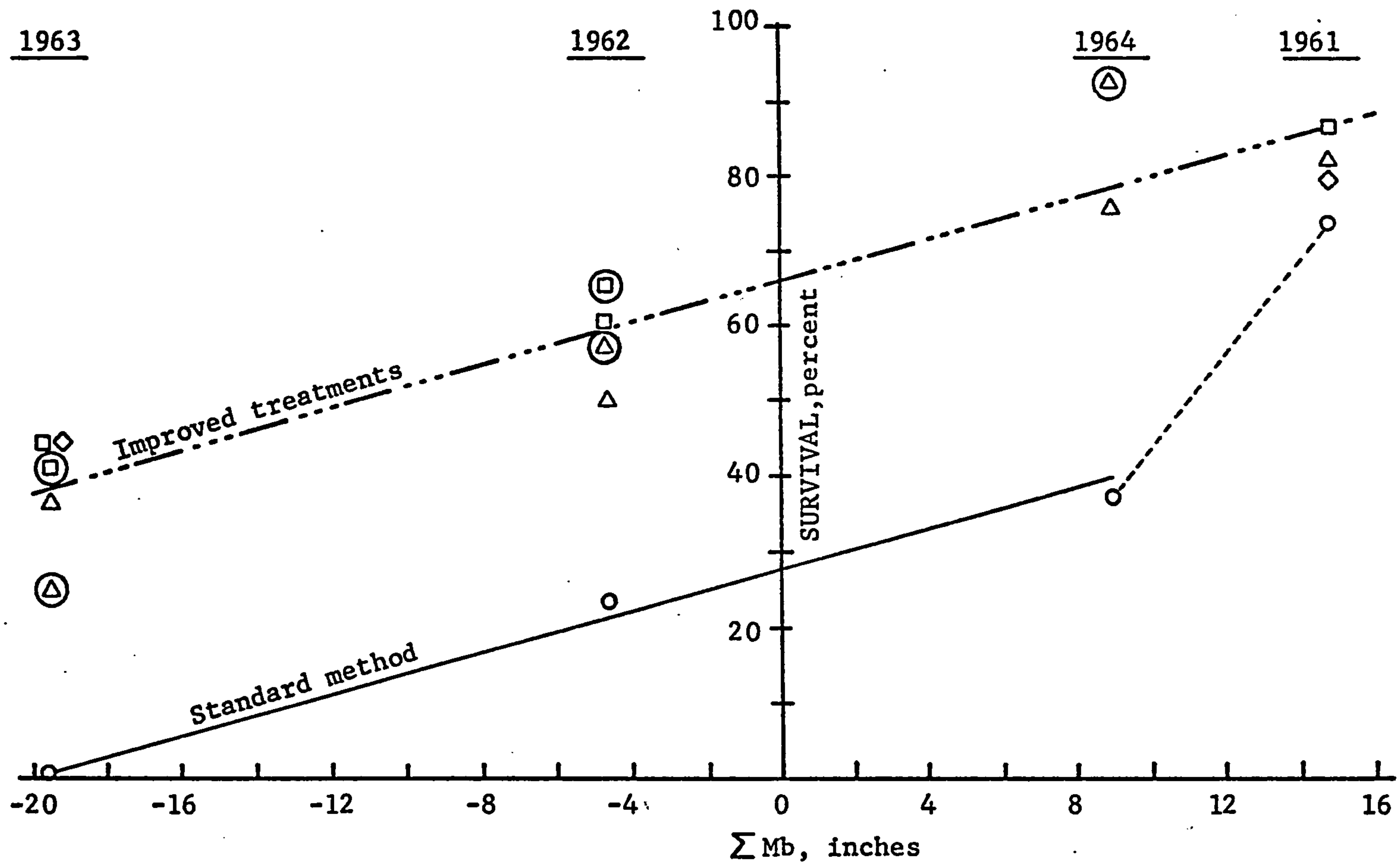

Figure.21. First-year survival by treatment as related to adjusted seasonal moisture balance Σ Mb in the 1961-1964 plantations. The symbols (o, △, □, ◇) denote average survival in cuttings planted by the standard method and cutting with C_h 0.33, 2.00, and 3.66 ft, respectively, planted 3-feet-deep in undisturbed soil. Circled symbols denote cuttings planted in the soil mixed in holes.

1.4°F below and in the 1963 season was 1.5°F above normal (Table 12), the direct effect of temperature on survival was calculated. It was found that 1°F of average seasonal temperature above normal adversely affected survival and 1°F below normal improved survival by approximately 3.5 percent.

As a result of this the survival of improved treatments in the 1961 plantation was 5.74 percent higher and in the 1963 plantation was 4.32 percent lower than it would have been if air temperature in these two seasons had been normal. Consequently, the difference between survival in the 1961 plantation and survival in the 1963 plantation was enlarged by 10.06 percent (equivalent to 21.5 percent of the total difference). The remaining 78.5 percent of this difference in survival was due to the variation in precipitation itself.

The effect of temperature on survival in the 1962 plantation was negligible, and in the 1964 plantation it resulted in -1.1 percent of survival. The difference between survival in these two plantations was practically due to the variation in precipitation only. Hence, the difference between survival in the 1962 and the 1963 plantations was 21.2 percent due to above-normal temperature and 78.8 percent due to difference in precipitation. But the difference between survival in the 1961 and the 1964 plantations was 73.1 percent due to below-normal temperature and 26.9 percent due to difference in precipitation.

While such a relationship was found between the survival of cuttings planted by the improved treatments and the $\sum Mb$, the survival of cuttings planted by the standard method, although satisfactory (73.8

percent) in the 1961 plantation, had decreased to 37 percent in the 1964 plantation because of a decrease in $\sum$Mb by 5.77 inches, i.e. at a rate of 6.37 percent of survival per 1 inch decrease in $\sum$Mb, compared with the rate of 1.36 percent of survival in cuttings planted by the improved treatments (Figure 21).

The author believes that the reason for such a marked decrease in survival of cuttings planted by the standard method was that, when $\sum$Mb decreased by 5.77 inches, soil moisture in the upper 1.3-foot soil layer was reduced to such an extent that some poorly rooted cuttings could not survive, especially when they became oppressed by weed vegetation (Plates 6 and 12).

Contrarily, the combined effect of the same decrease in $\sum$Mb and of equally well-developed weed vegetation resulted in only 7.8 percent decrease in survival of cuttings planted by the improved treatments.

The result of the regression analysis of survival of cuttings planted by the standard method in the 1962-64 plantations with $\sum$Mb as the independent variable showed that the rate of increase in this survival per 1 inch of $\sum$Mb was very similar to that of the survival of cuttings planted by the improved treatments. The regression equation is as follows:

Survival (percent) = 27.6 + 1.34 $\sum$Mb;

with r = 0.83, and t = 2.96, with 4 degrees of freedom, significant at the 0.05 probability level.

Survival of the standard cuttings in the 1962-64 plantations was about 34 percent below the survival of the poorest improved treatment

and about 42 percent below survival of the best improved treatment (cuttings planted in mixed soil in 14-inch-diameter holes).

Survival of cuttings planted by the standard method in the 1964 plantation when $\sum Mb$ was 9.08 inches was approximately the same as survival of cuttings planted by the improved treatments in the 1963 plantation when $\sum Mb$ was -19.50 inches (Figure 21). Such a difference between seasonal moisture balances corresponds to an average difference of 4.1 inches in monthly moisture during the growing season.

Now it is understandable why the cuttings planted by the standard method did not survive on any site in the 1963 plantation. Yet, in the same plantation standard cuttings planted in soil mixed in 9-inch-diameter holes mulched with 2-foot-square laminated Kraft-paper pads and with additional protection for the surface soil against drying-up (bedding the soil) survived 50 percent on a dry site and 75 percent on a moist site. Moreover, in the same plantation, cuttings with C_h = 3.66 feet planted 3 feet deep in mixed soil under similar treatment survived 61 percent on a dry site and 100 percent on a moist site.

As determined by two regression analyses using grouped data (improved treatments), the effect of annual variation in climatic conditions on survival of cottonwood cuttings was significantly modified by planting treatments. However, it was impossible to separate the effect of climatic conditions on survival by site and by treatment because of insufficient degrees of freedom.

Nevertheless, the trends in the data (Tables 5 through 10) indicate the feasibility of selecting a treatment or treatments which can be

efficient in securing the highest survival under any possible climatic and site conditions in the region.

The development of the adjusted moisture balance provides a common-denominator-like device for weighing both the environmental conditions and the efficiency of planting treatments.

Since climatic conditions are subject to a wide variation, which is uncontrollable, new planting treatments should be aimed at diminishing the runoff and the evaporation of moisture from the surface soil, at increasing the availability of moisture from the deeper soil strata, at improving the development of root systems, and at a rigid selection of the planting stock.

The ideal treatment would be one that will yield a high survival over the entire range of possible $\sum Mb$. Such a treatment would have a b_1-coefficient near zero and a b_o-constant near 100 percent. Such a treatment, although desirable, has yet to be found.

Effects of Planting Treatments on Tree Growth

The technique of planting unrooted cuttings is a much simpler operation than planting seedlings. But growing trees from unrooted cuttings presents its own peculiarities, especially when the grading of nursery-run cuttings is based merely on the appearance of the cutting.

A 20-inch-long and from 0.5- to 1.0-inch-diameter cutting free from borer, canker, and mechanical damage has been accepted as the standard planting stock for establishing cottonwood plantations in the South (Maisenhelder 1960, McKnight 1970).

Considering the variation in bottomland soils and the geographic and annual variations of climatic conditions in the South, the author has postulated that the efficiency of a single standard will vary greatly with the ecological conditions of the locality. Consequently, no uniformity in performance of a single standard can be achieved either from year to year or from one locality to another. This was explicitly confirmed in the two preceding sections in regard to first-year survival of cottonwood cuttings planted on different sites during the 1961-1964 growing seasons.

The result of a test of the effects of 20 treatment combinations of four lengths of cutting above the ground (C_h) with five planting depths (C_d) on first-year growth of cottonwood in the 1961 plantation showed that first-year tree height consists of two parts, the height of live portion (C_o) of the above-ground part of the cutting plus the height of first-year shoot (Figure 2). The height of C_o depends on the interaction between C_h and C_d (Equation 3). The shoot height (h_1-C_o) depends on C_h (Table 45), and is slightly related to C_d and C_h (Equation 4) and consequently is related to C_o (Equation 5). Thus, tree height (h_1) is significantly but slightly related to (C_d x C_h) interaction (Table 46 and Equation 6), and consequently h_1 is directly but slightly related to C_o (Equation 7). Heights of C_o and h_1 by treatment in the 1961 plantation are shown in Tables 17 and 18, respectively. The relationships of C_o, (h_1 - C_o), and h_1 with C_d and C_h are presented diagramatically in Figures 22, 23, and 24, respectively. The relationship between h_1 and C_o alone is shown in Figure 25. The relationships

Table 17. Height of C_o by treatment in the 1961 plantation [a]

Depth of planting (C_d)	C_h, feet			
	0.33	2.00	3.50	5.00
Feet	Feet			
1.33	0.13	1.81	3.06	4.07
2.00	0.02	1.54	2.64	3.51
3.00	0.03	1.32	2.22	2.88
4.00	0.14	1.31	2.00	2.46
5.00	0.26	1.49	1.98	2.25

[a] C_o was calculated from regression equation 3.

Table 18. First-year tree height (h_1) by treatment in the 1961 plantation [a]

Depth of planting (C_d)	C_h, feet			
	0.33	2.00	3.50	5.00
Feet	Feet			
1.33	5.77	6.81	7.76	8.67
2.00	5.98	6.84	7.61	8.38
3.00	6.28	6.89	7.42	7.95
4.00	6.59	6.93	7.23	7.53
5.00	6.89	6.97	7.03	7.10

[a] h_1 was calculated from regression equation 6.

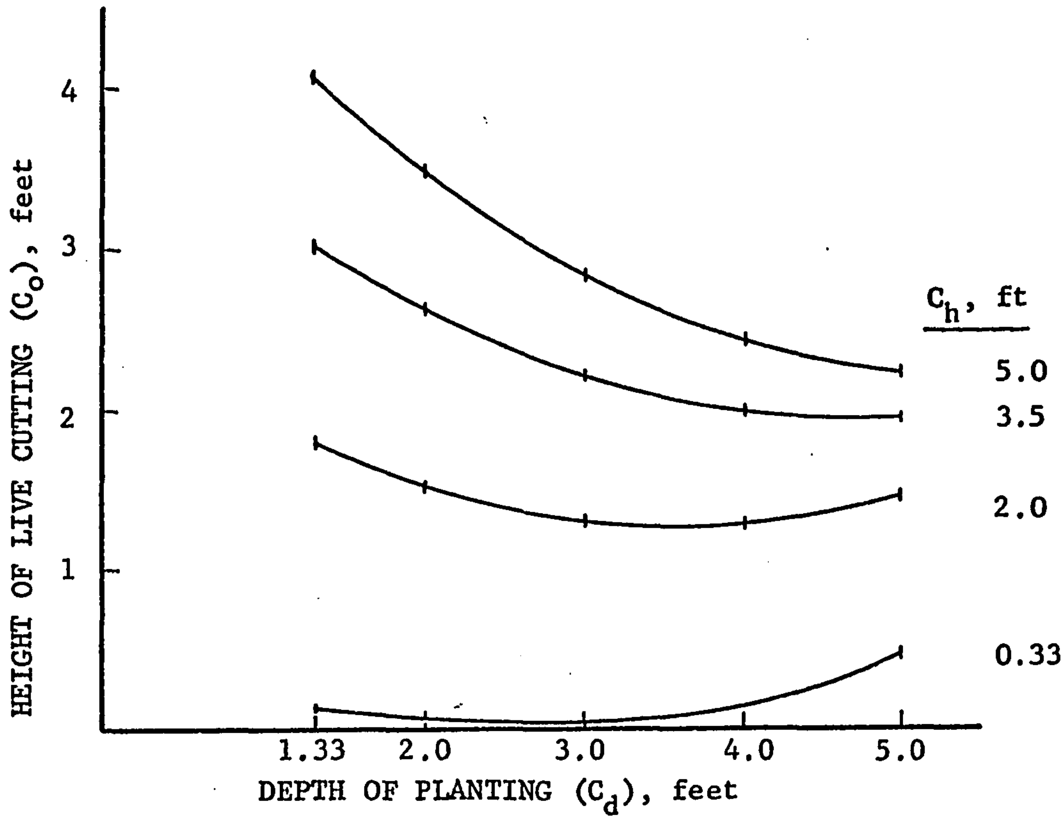

Figure 22. Height of live cutting (C_o) in the 1961 plantation as related to C_d and C_h. C_o was calculated from regression equation 3.

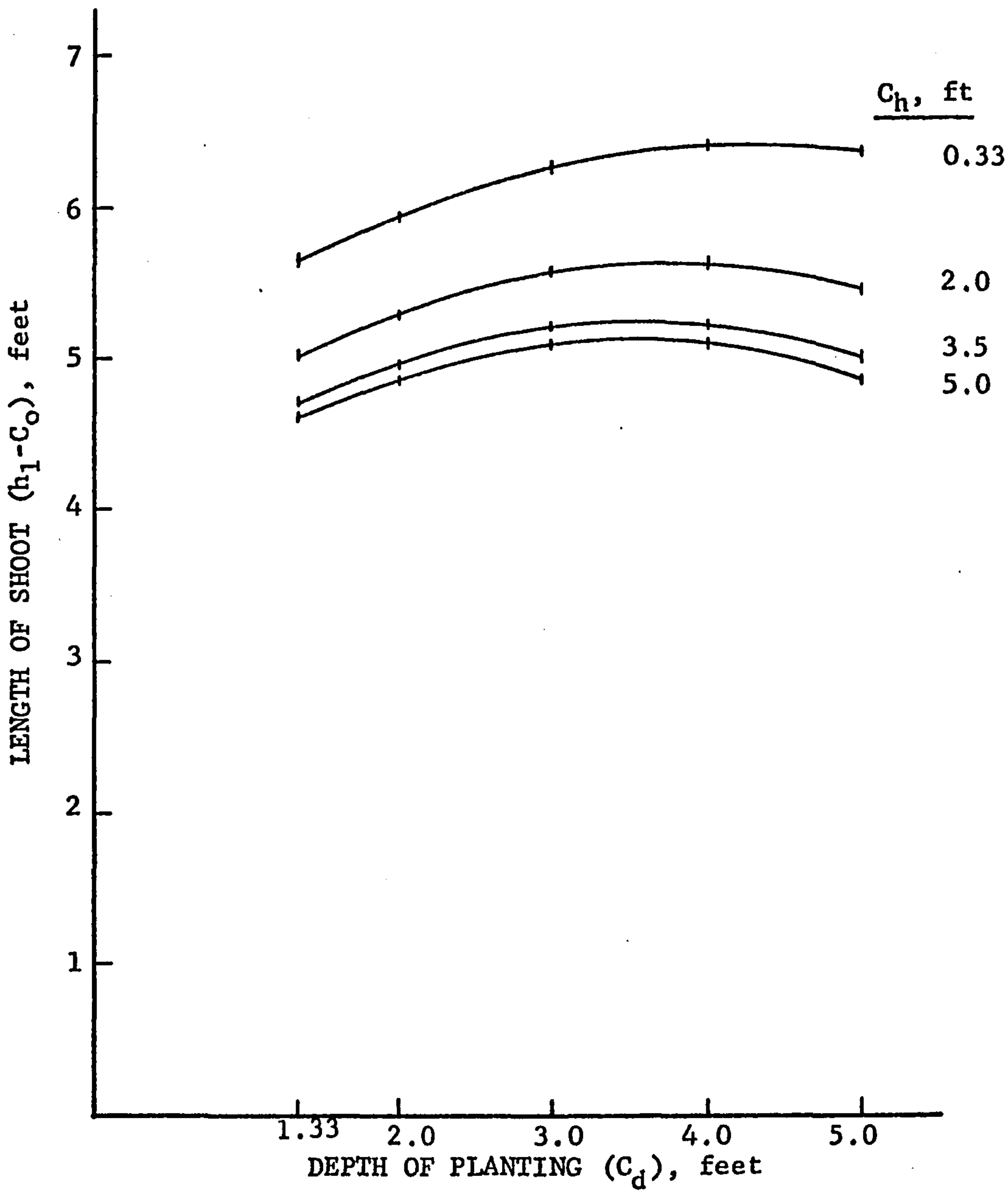

Figure 23. Length of first-year shoot (h_1-C_o) in the 1961 plantation as related to C_d and C_h. Shoot height was calculated from regression equation 4.

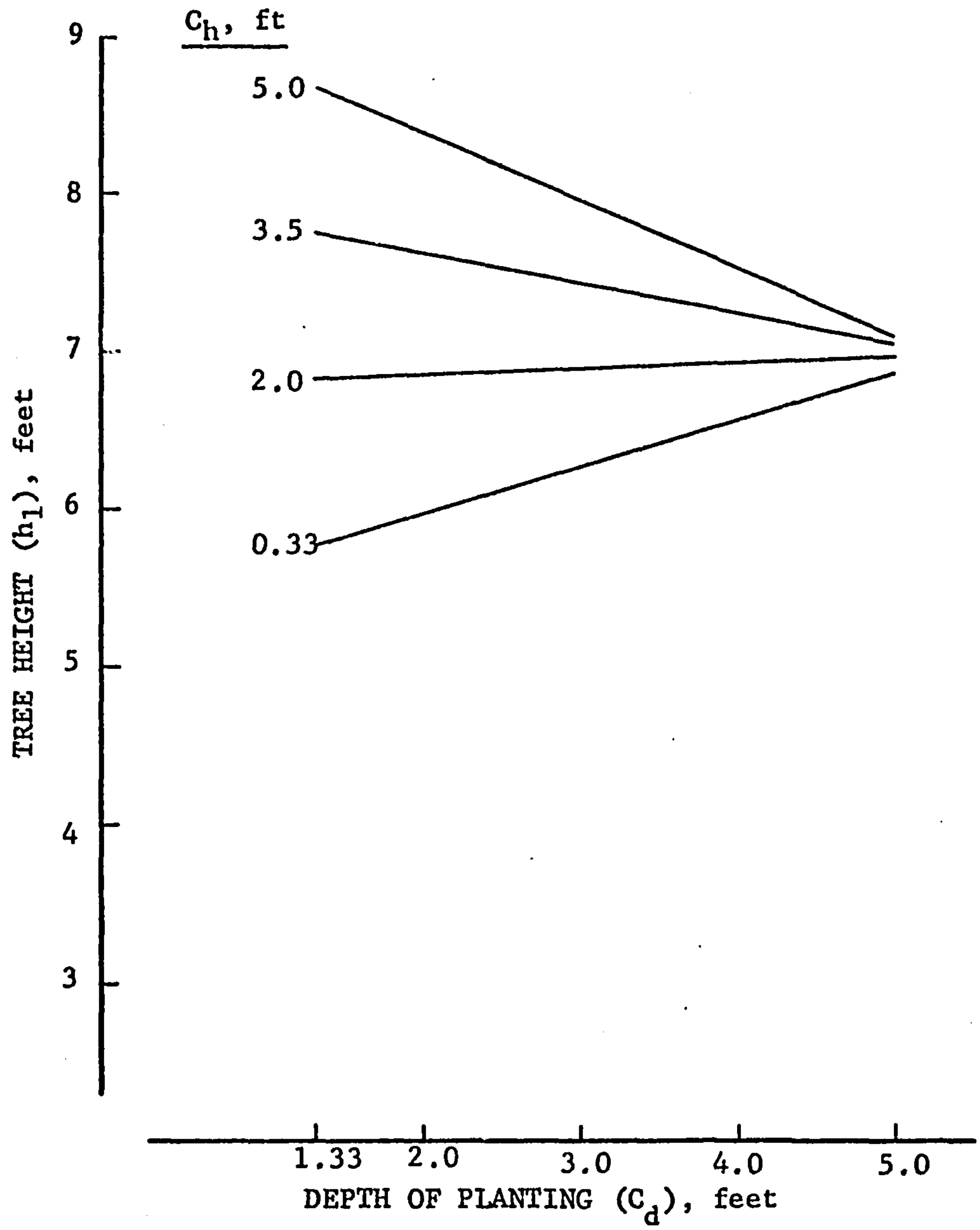

Figure 24. First-year tree height (h_1) in the 1961 plantation as related to C_d and C_h. Tree height was calculated from regression equation 6.

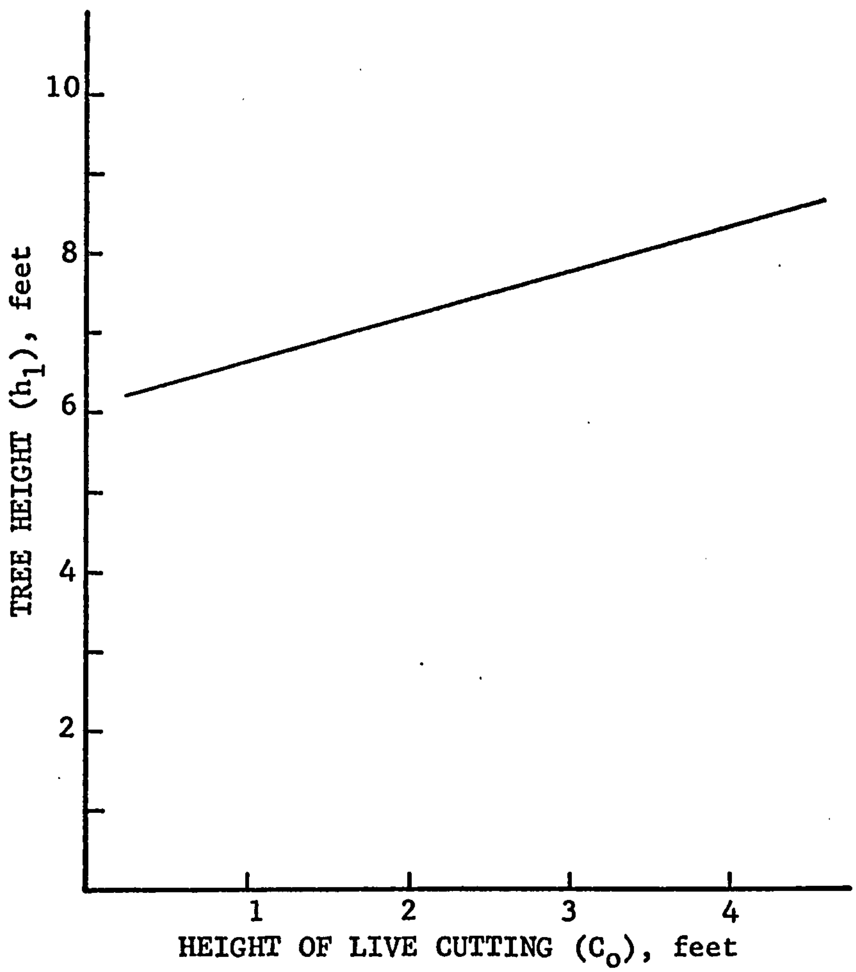

Figure 25. First-year tree height (h_1) in the 1961 plantation as related to height of live cutting (C_o). Tree height was calculated from regression equation 7.

between h_1 and C_o, and C_d and C_h are presented diagrammatically in Figure 26.

First-year tree height in the 1961 plantation was directly related to C_o (Figure 25), and the tallest trees grew from cuttings with C_h 5.00 or 3.50 feet, especially from those planted 1.35, 2.00, and 3.00 feet deep (Figure 24). Yet, considering a high percentage of mortality (Table 2) and a notable dieback (about 35 percent of C_h) in these cuttings (Figure 22), the application of these treatments in establishing commercial plantations would be rather undesirable. Cuttings planted 3 feet deep with C_h = 2.00 feet, although not growing the best during the first year, survived better (Table 2) and grew taller than cuttings planted by the standard method.

The significant relationship between first-year survival and soil properties as expressed by R_p in the 1961 plantation led the author to assume that not only survival but also tree growth would be improved through mixing the strata of different soil texture within a 3-foot profile by deep cultivation.

The results of analysis of variance of first-year tree height in the 1962 plantation (Table 47) showed that the effects of mixing the soil in 3-foot-deep and 14-inch-diameter holes (Treatment Q) and length of cutting above the ground (C_h) were significant at the 0.01 probability level even after removing the variation in tree height due to covariate $C_\emptyset{}^2$ (square of mid-diameter of cutting) which was also significant at the 0.01 probability level. Under the same condition the effect of fertilizer (Treatment E) was significant at the 0.01 probability level, while the effect of planting depth (C_d) was

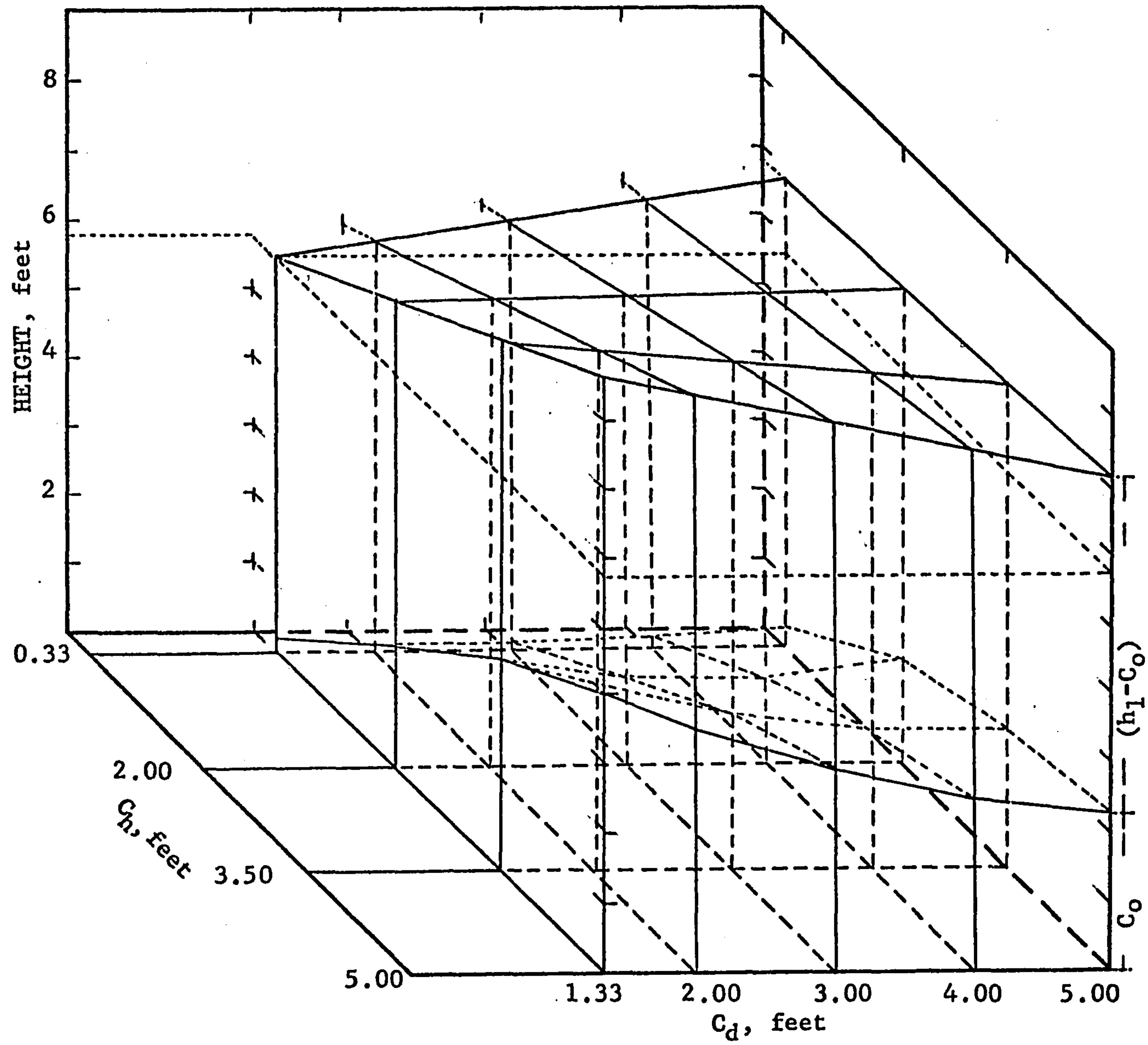

Figure 26. Relationships between h_1 and C_o, and C_d and C_h in the 1961 plantation.

significant at the 0.05 probability level. None of the treatment interactions were significant. This indicated that the effects of treatments (Q, C_d, and E) were independent one from another and that the results of these effects were additive. Only C_h had a highly significant effect on the variation of C_o in the 1962 plantation (Table 48), while the effects of fertilizer (E) and the covariate C_ϕ^2 were significant at the 0.05 probability level.

Since the effect of C_ϕ^2 was significant on both C_o and h_1, a series of multiple regression analyses of h_1 with C_d, C_h, diameter of the upper end of cutting $C_{\phi t}$, and diameter at the base of cutting ($C_{\phi b}$) as the independent variables was made in attempt to determine the optimum diameter of cutting.

A very slight but statistically significant quadratic effect of the diameter at the base of cutting ($C_{\phi b}$) on h_1 was discovered (Equation 8). Moreover, as revealed by regression equation 9 there is also a statistically significant effect of a cutting's upper-end diameter ($C_{\phi t}$) on h_1. Even though the variation in h_1 was explained only slightly by the variations in $C_{\phi b}$ (r^2 = 0.06) and $C_{\phi t}$) (r^2 = 0.09), ignoring these effects would be hazardous. Since h_1 increased directly with $C_{\phi t}$, this indicated that good cutting form was also contributing to first-year tree growth. Although in field practice it is difficult to consider such detail, measuring diameters of a cutting at both ends is a necessary procedure in making a progeny test.

By solving the first derivative of equation 8 under the condition $(h_1)' = f'(C_{\phi b}) = 0$, I found that the diameter at the base of a

cutting is optimum when it equals 1.04 inches. The relationship of h_1 to $C_{\emptyset b}$ is shown in Figure 27.

Least-squares means of first-year tree height by treatment combination in the 1962 plantation are given in Table 19. Data in this table reveal that the combined effect of any pair (Q and C_d, Q and C_h, C_d and C_h) of treatments was greater than the effect of a higher level of each single treatment separately. The effects of fertilizer levels on h_1 were opposite to those on survival (Table 8). Height growth was improved by (P+N) treatment, while P treatment alone produced a rather depressing effect on first-year height growth. On the other hand, first-year survival, especially of cuttings planted 1.33 feet deep in cultivated soil (Q treatment), was suppressed by (P+N) treatment.

The complete mortality of cuttings planted by some of the treatment combinations (control treatment included) in the 1963 plantation did not allow analysis of variance of first-year height growth that year. In spite of this, some information about the growth variation was obtained by analyzing average tree height (h_1) by treatment on site C_1 and C_2 (Tables 20 and 21). Plotting growth data from these tables against corresponding survival percentages from Table 9 and 10 as the independent variables (Figure 28) indicated that average tree height by treatment is related to survival percentage by treatment on both sites. The inherently moist site C_2 conserved vitality of cuttings better than the dry site C_1. Thus, both survival and growth on site C_2 were in all treatments correspondingly better than on site C_1. The result of a multiple regression analysis of mean h_1 on both sites together with

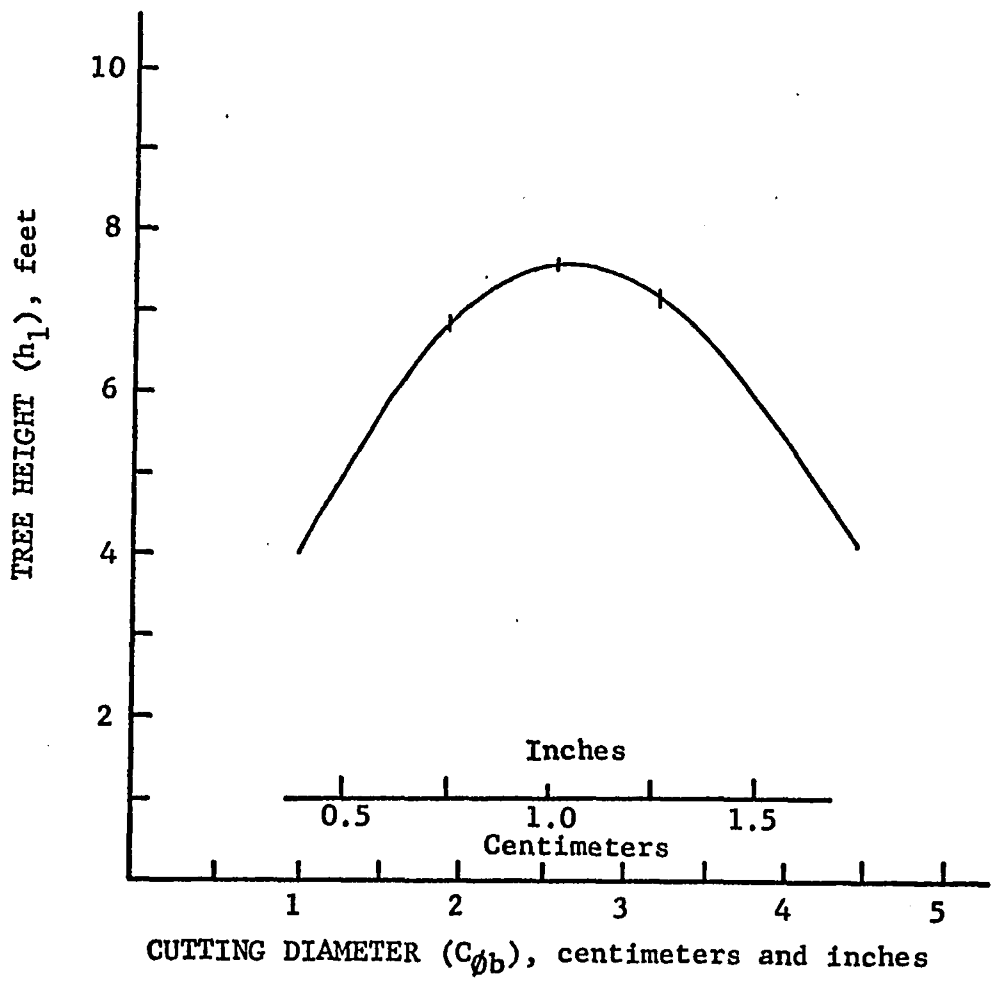

Figure 27. First-year tree height (h_1) in the 1962 plantation as related to diameter at the base of cutting ($C_{\emptyset b}$). Tree height was calculated from regression equation 8.

Table 19. Least-squares means of first-year tree height by treatment combinations on all three sites in the 1962 plantation

		-- C_d, feet --		-- C_h, feet --		Fertilizer [a]		
		1.33	3.00	0.33	2.00	None	P	P+N
		----------	----------	Tree height, feet	----------	----------	----------	----------
Deep cultivation	- Q	6.73	7.10	6.60	7.23	6.53	6.52	7.69
	+ Q	7.13	7.67	7.21	7.59	7.28	7.07	7.85
	C_h=0.33 ft	6.60	7.21			6.86	6.43	7.42
	C_h=2.00 ft	7.25	7.57			6.95	7.16	8.12
Fertilizer	None	6.86	6.95					
	P	6.55	7.04					
	P+N	7.37	8.17					

a/ P denotes superphosphate, and P+N denotes superphosphate + ammonium nitrate.

Table 20. First-year height growth by treatments on site C_1 in the 1963 plantation

Soil treatment	C_d, feet: 1.33			3.00		
	C_h, feet: 0.33	2.00	3.66	C_h, feet: 0.33	2.00	3.66
	Feet					
-B -M -Q	0	0	0	2.00	3.50	0
-B -M +Q	0	5.00	0	3.50	4.03	5.02
-B +M -Q	0	3.80	5.00	0	2.00	4.50
-B +M +Q	1.00	2.75	2.50	3.27	4.97	5.00
+B -M -Q	4.50	9.50	9.00	0	4.05	5.45
+B -M +Q	0	6.80	6.42	7.10	5.27	7.20
+B +M -Q	5.25	7.40	4.70	4.50	8.83	9.50
+B +M +Q	0	4.32	6.87	5.87	6.47	6.42
+B -M	----[a]	7.34	6.70	----	5.04	6.81
+B +M	----	5.09	6.03	----	7.18	6.93
+B -Q	----	8.10	5.41	----	6.92	7.47
+B +Q	----	5.31	6.64	----	5.79	6.74
+B	----	5.95	6.31	----	6.06	6.88

a/ ---- Denotes no means available because of several treatments with zero growth.

Table 21. First-year height growth by treatments on site C_2 in the 1963 plantation

Soil treatment			C_d, feet 1.33, C_h, feet 0.33	1.33, 2.00	1.33, 3.66	3.00, C_h, feet 0.33	3.00, 2.00	3.00, 3.66
			Feet					
-B	-M	-Q	0	6.50	6.25	5.73	7.00	8.50
-B	-M	+Q	5.00	5.75	4.75	7.20	5.00	6.50
-B	+M	-Q	5.67	6.33	6.50	5.25	7.33	5.25
-B	+M	+Q	7.17	5.75	7.50	7.33	7.37	8.00
+B	-M	-Q	8.75	9.00	7.67	6.00	8.00	4.00
+B	-M	+Q	0	9.00	8.25	8.33	9.50	8.00
+B	+M	-Q	5.50	8.17	9.66	8.83	13.50	11.50
+B	+M	+Q	11.00	7.00	6.50	7.75	7.50	8.75
-B	-M		----a/	6.20	5.50	6.57	5.67	7.30
-B	+M		----	6.10	7.00	6.50	7.35	6.90
+B	-M		----	9.00	8.00	7.75	8.85	7.00
+B	+M		----	7.87	8.40	8.40	10.50	9.30
-B		-Q	----	6.41	6.40	5.54	7.25	6.88
-B		+Q	----	5.75	6.40	7.25	6.58	7.16
+B		-Q	----	8.37	8.58	8.12	10.20	7.75
+B		+Q	----	8.00	7.66	8.10	8.91	8.42
	-M	-Q	----	7.00	7.10	5.80	7.75	7.00
	-M	+Q	----	6.83	7.08	7.68	8.00	7.16
	+M	-Q	----	7.25	8.08	7.40	9.80	7.33
	+M	+Q	----	6.17	7.17	7.50	7.41	8.42
-B			----	6.15	6.35	6.54	6.85	7.10
+B			----	8.25	8.16	8.11	9.45	8.27
	-M		----	7.00	7.09	7.00	7.90	7.11
	+M		----	6.88	7.63	7.45	8.50	8.10
		-Q	----	7.15	7.63	6.68	8.88	7.16
		+Q	----	6.50	7.09	7.60	7.70	7.88
Overall			----	6.90	7.38	7.21	8.21	7.65

a/ ---- Denotes no means available because of two treatments with zero growth.

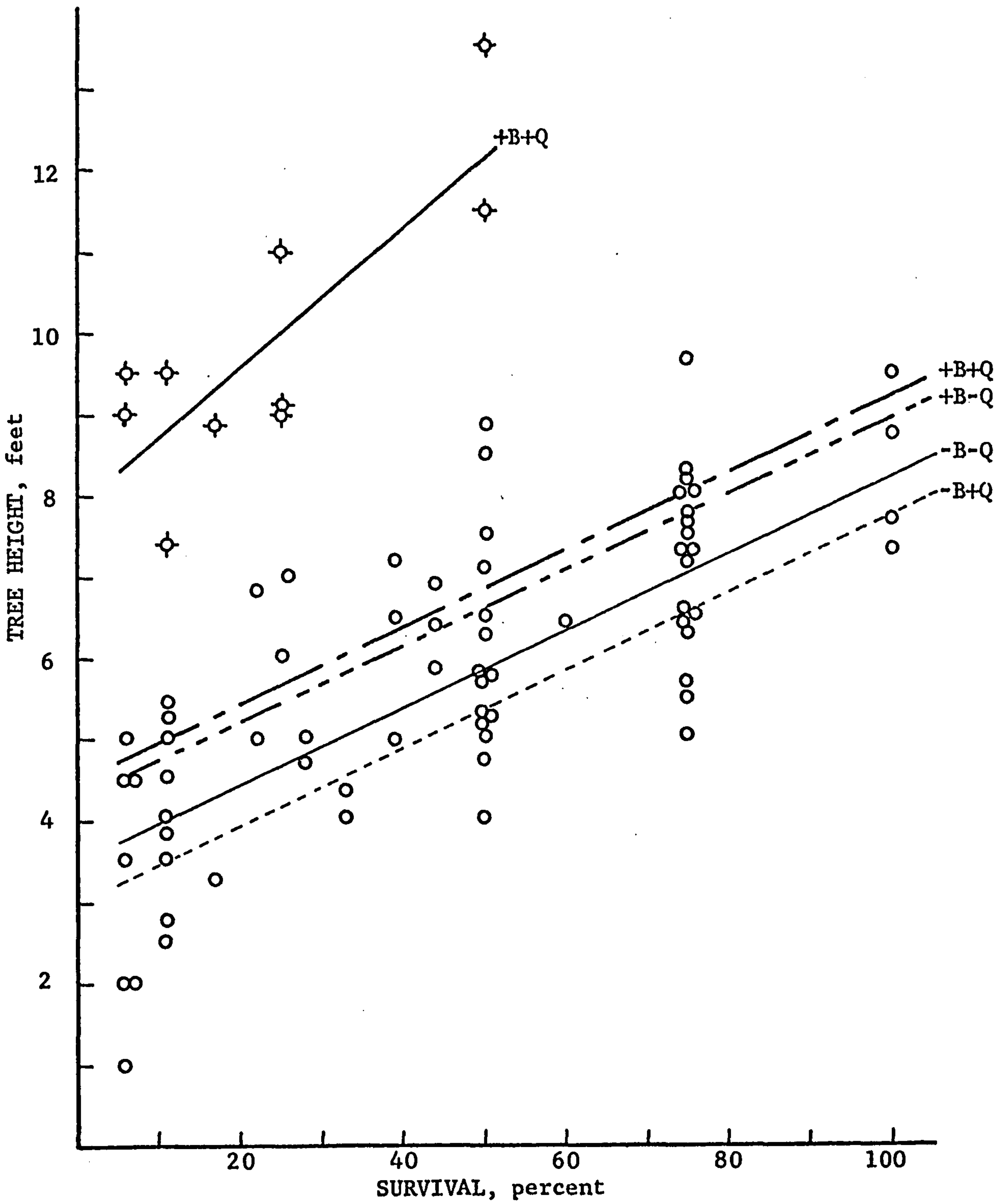

Figure 28. Relationship between first-year tree height (h_1) and survival percentage (T_s) by treatment combination in the 1963 plantation.

coded (1 or 2) B-treatment, coded (1 or 2) Q-treatment, and percentage of survival (T_s) as the independent variables revealed that tree height is directly related to survival percentage regardless of site. The variable T_s alone, and T_s with Q and (B x Q) interaction, accounted for 55.4 and 65.9 percent, respectively, of the h_1 variation (Equations 10 and 11). In the presence of T_s, treatment +B was less effective than +B and +Q together, while Q treatment alone was the least effective.

Moreover, five treatments from site C_1 and five treatments from site C_2 (6 percent of the trees which survived on both sites together), although of low survival (6 to 50 percent), produced exceptionally tall trees (upper left in Figure 28). All these trees were planted in mixed soil in holes with bedding treatment, using cuttings with C_h 2.00 or 3.66 feet. In spite of these exceptions, mean tree height in these treatments was also directly related to the percentage of their survival (Equation 12).

For a better understanding of the effects of treatments several trees planted by different treatments were excavated in order to study their root systems.

In a root system of a one-year-old tree grown from a cutting planted by the standard method in undisturbed soil but with bedding treatment, the upper lateral roots tended to escape from undisturbed surface soil into the bedded soil and to line up along the bed between the surface of the undisturbed soil and the bedded soil (Figure 29). Thus, if the beds had been directed perpendicularly to the direction of prevailing

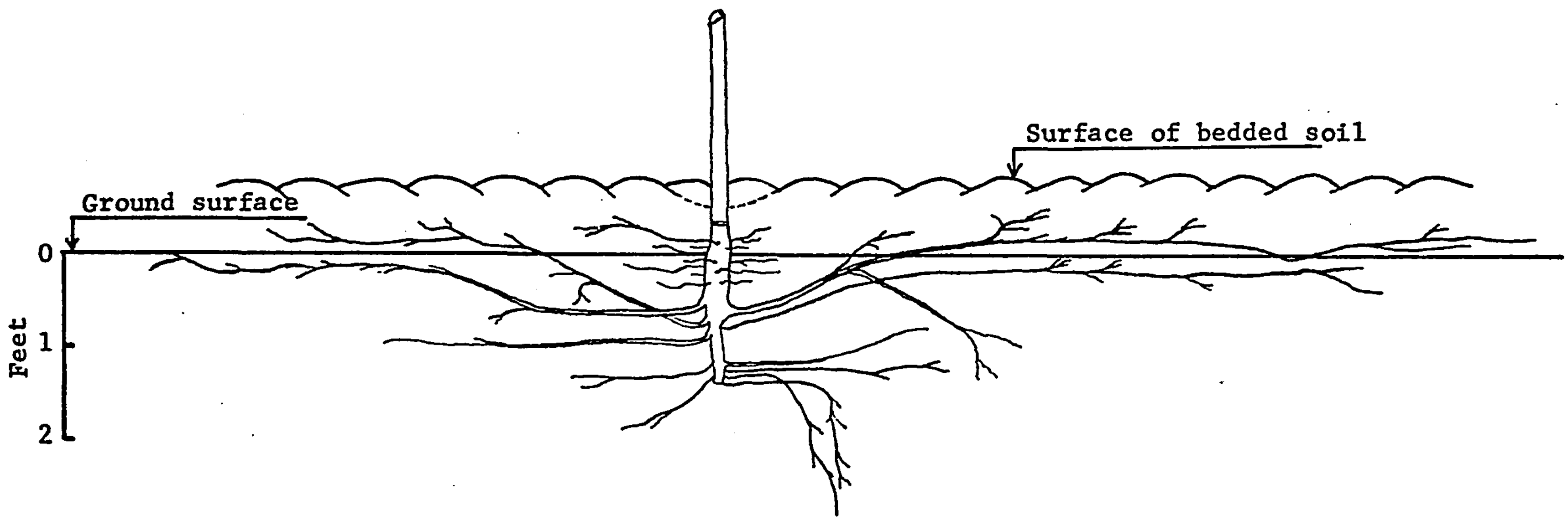

Figure 29. Root system of one-year-old tree planted by the standard method in sandy loam soil with bedding after planting.

wind, the trees would be easily uprooted because of the lack of anchoring roots in the wind direction.

The root system of a two-year-old tree established by planting a 5-foot-long cutting 3 feet deep in undisturbed soil extended in all directions horizontally and in depth (Figure 30). However, a hardpan layer presented a serious obstacle for root development. Only a few lateral roots passed through this layer, developing sparsely distributed absorptive rootlets. Some lateral roots in the surface soil extended in all directions more than 12 feet away from the tree. Although the lenticels with root-primordia were richly distributed in three rows on these lateral roots, the absorptive rootlets were scattered in widely separated clusters, indicating very selective root requirements in regard to soil conditions, or rather that only in certain widely scattered places soil conditions fit requirements for development of rootlets. Conversely, the absorptive rootlets were developed prolifically on all lateral roots in the soil stratum beneath the hardpan.

The root system of a one-year-old tree established with a 5-foot-long cutting planted 3 feet deep in mixed soil in a 14-inch diameter hole showed the benefit from breaking the hardpan (Figure 31). The mixed soil in the planting hole was interwoven with countless lateral and absorptive roots of all sizes. The number of well-developed lateral roots was much greater beneath the hardpan than in the surface soil. The main root with an ingrown cutting was nearly cylindric (cigar like form), compared with a conical (beet like form) main root in undisturbed soil (Figure 30), where the constriction of

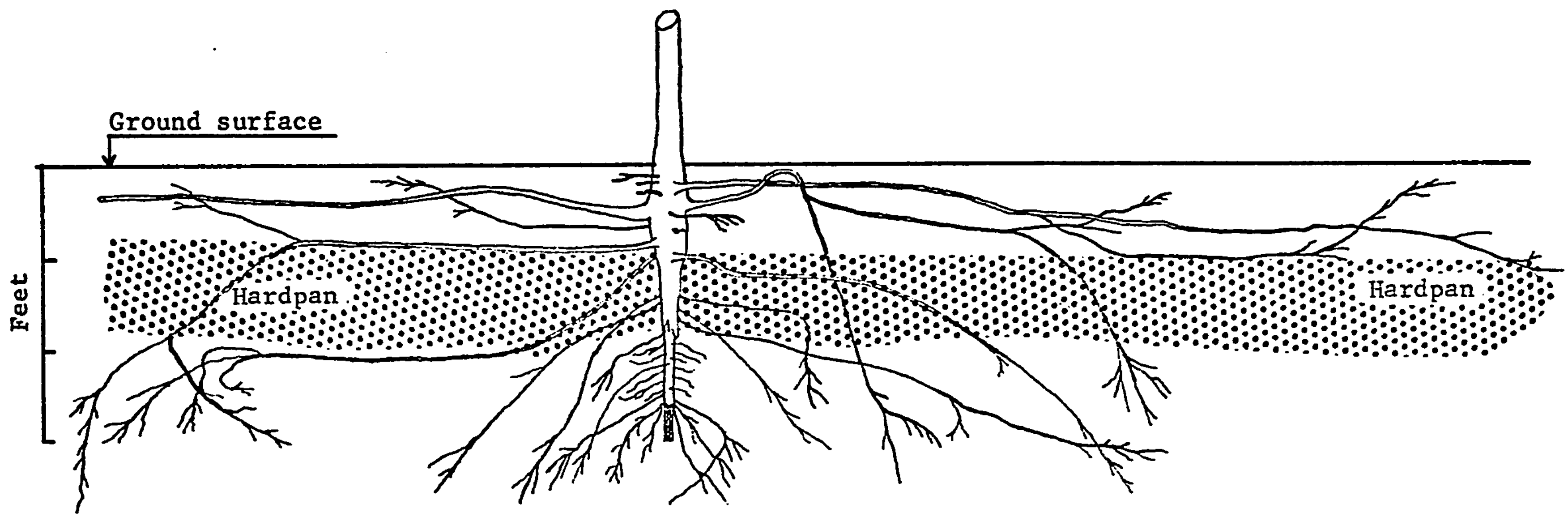

Figure 30. Two-year-old root system of cottonwood planted with 5-foot-long cutting 3 feet deep in undisturbed loam soil.

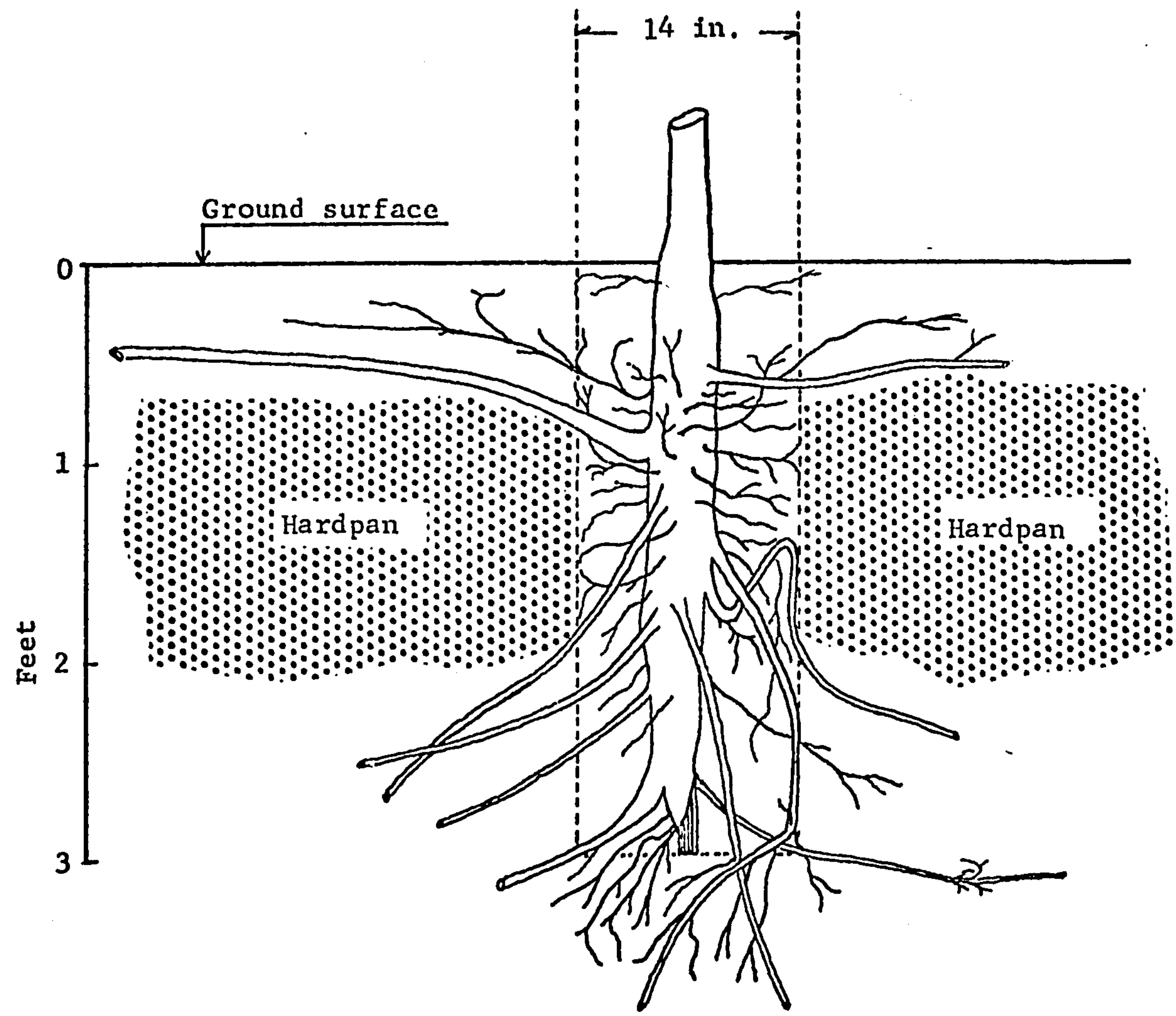

Figure 31. Central part of one-year-old root system of cottonwood planted with 5-foot-long cutting 3 feet deep in the soil mixed in 14-inch-diameter and 3-foot-deep hole.

the lower part of the root was caused by a compact hardpan. Yet a pot effect of hardpan was observed from an S-shaped root at the right side of the planting hole (Figure 31).

From the behavior of cottonwood roots as observed in the excavated root systems, it was inferred that, although each of the two mentioned planting treatments contributed to a better development of a root system, none of these treatments have stimulated the full physiological capacity of the species for prolific growth of absorptive roots. Since the development of absorptive roots was best beneath the hardpan or just above the hardpan, the author has postulated that a further improvement in survival and tree growth may be achieved by increasing the volume of mixed soil in the planting hole. If such a treatment would be at least as efficient as mixing the soil in a 9-inch-diameter hole plus the bedding of the surface soil, it will reduce site preparation to one operation and will result in the development of a root system which will guarantee a better tree support.

A new plantation was established in 1964 for testing the effects of mixing the soil in 3-foot-deep planting holes of 9, 14, and 18 inches in diameter on survival and growth of 20-inch-long cuttings planted 16 inches deep and of 40-inch-long cuttings planted 3 feet deep.

The result of analysis of variance of first-year tree height in the plantation revealed that the effects of both diameter of planting hole and depth of planting were significant at the 0.01 probability level (Table 49). The means of h_1 by treatment in the plantation are shown in Table 22.

Table 22. Least-squares means of first-year tree height in the 1964 plantation

Total cutting length	Depth of planting (C_d)	Cross section of 3-foot-deep planting hole --Square inches-- 1.0	64.0	154.0	254.0
Inches	Feet	--Feet--			
20	1.33	4.84	5.39	5.52	5.71
40	3.00	6.28	7.01	7.90	8.39

Twenty-inch-long cuttings planted 16 inches deep did not respond to mixing the soil in 3-foot-deep holes of either 9-, 14-, or 18-inch diameter, but 40-inch-long cuttings planted 36 inches deep increased the growth proportionally to the cross section of the planting hole (Equations 13 and 14; Figure 32).

The experimental cottonwood plantations of the 1961, 1962, 1963, and 1964 years were established using planting stock which originated from Louisiana. However, among the cuttings obtained for the 1963 plantation some cuttings were found with strikingly different morphological characteristics from those commonly observed in native cottonwood. Although such cuttings (Plate 10) were eliminated from the planting stock, nevertheless a probability of using some phenotypes which could not be optically recognized was not completely excluded. As a matter of fact, some variation in survival and tree growth in the experimental plantations was impossible to explain, either by the effect of planting treatments or by the variation in physical properties of soil. For determining the effect of genetic variation in planting

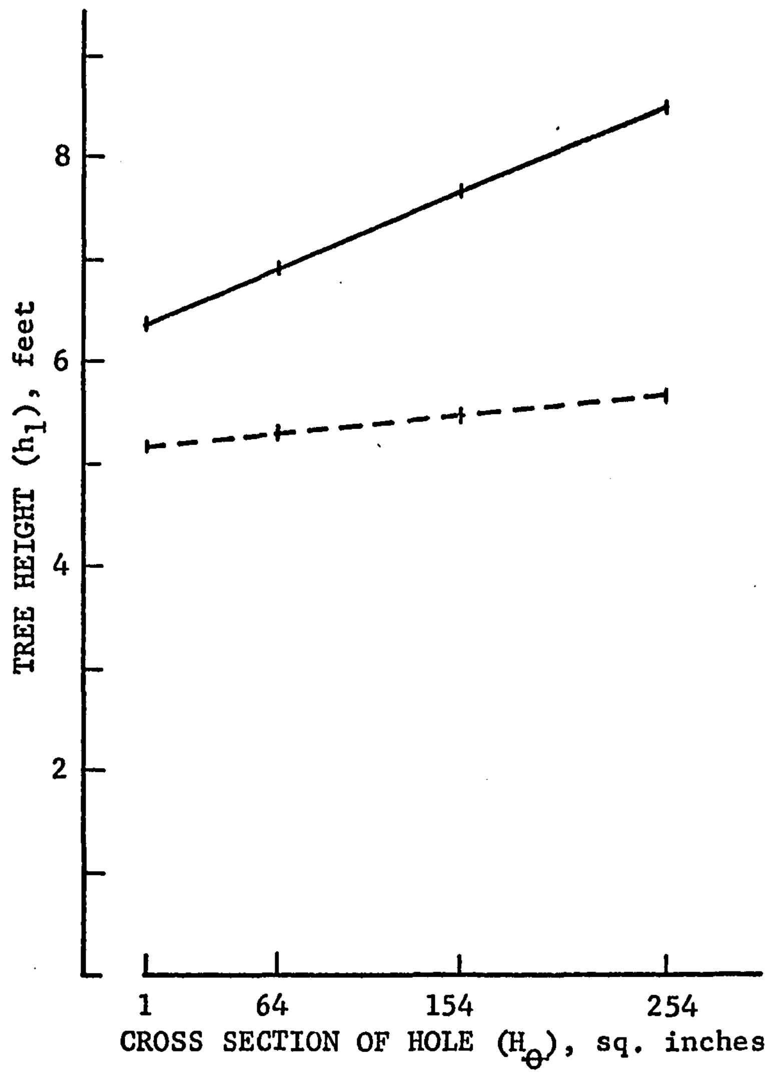

Figure 32. First-year tree height (h_1) in the 1964 plantation as related to cross section (H_θ) of 3-foot-deep planting hole. Solid line is for 40-inch-long cuttings planted 3 feet deep, and dashed line is for 20-inch-long cuttings planted 1.33 feet deep.

stock on the variation in growth of trees in plantations, the 1968 plantation was established.

Three different exotic poplar clones, with native cottonwood as the control,were used for testing the effect of clone on growth and form of trees under uniform conditions of soil and cultural treatments. The results of analyses of variance of first-year tree height, diameter at the base of tree, and tree diameters at 40 and 80 inches above the base showed that the effect of clone on these four dependent variables was highly significant even after removing the effect of diameter at the upper end of cutting, which was also significant at the 0.01 probability level (Tables 50, 51, 52, and 53). Least-squares means of first-year tree height and the diameters by clone are shown in Table 23.

Table 23. Least-squares means of first-year tree height and diameters at tree base, at 40 inches, and at 80 inches above the base of four poplar clones in the 1968 plantation

Clone	Tree height	Base diameter	Diameter at 40 in.	Diameter at 80 in.
	Feet	- - - - - -	Centimeters	- - - - - -
P. deltoides cl.'Mississippi'	9.33	2.45	1.64	1.09
P. x *euramericana* cl. 'I-488'	10.02	2.26	1.52	1.07
P. x *euramericana* cl. 'Belgian'	11.18	2.54	1.73	1.30
P. x *euramericana* cl. 'I-214'	9.51	2.56	1.61	1.03

The relationship between h_1 and $C_{\phi t}$ by clone is presented diagrammatically in Figure 33 where tree heights for each clone were calculated from the regression equations 15, 16, 17 and 18.

An optimum diameter of cutting was possible to calculate only for the 'Belgian' clone, and it was 0.928 inch (Equation 17). The range in diameters was probably too small for the other three clones. Therefore no effects of either larger diameters in clone 'I-214' and 'I-488' or of a smaller diameter in clone 'Mississippi' were detectable (Figure 33).

The results of five years' tests of the effects of various planting treatments have indicated the feasibility of first-year height-growth improvement of cottonwood.

Among the 20 treatment combinations tried in the 1961 plantation two treatment combinations resulted in first-year growth improvement from 40 to 50 percent, and another ten treatment combinations improved the growth from 20 to 40 percent over that attained from planting cuttings by the standard method (Table 18, Figure 24).

In the 1962 plantation each combination of the two highest ranking treatments such as +Q and C_d = 3.0 feet, +Q and C_h = 2.0 feet, +Q and (P+N), C_d = 3.0 feet and C_h = 2.0 feet, and C_d = 3.0 feet and (P+N) resulted in height growth from 115 to 120 percent of that attained by cuttings planted by the standard method (Table 19).

In the 1963 plantation, where none of the cuttings planted by the standard method survived because of severe drought during the growing season, cuttings with C_h = 3.66 feet planted 3 feet deep in the soil

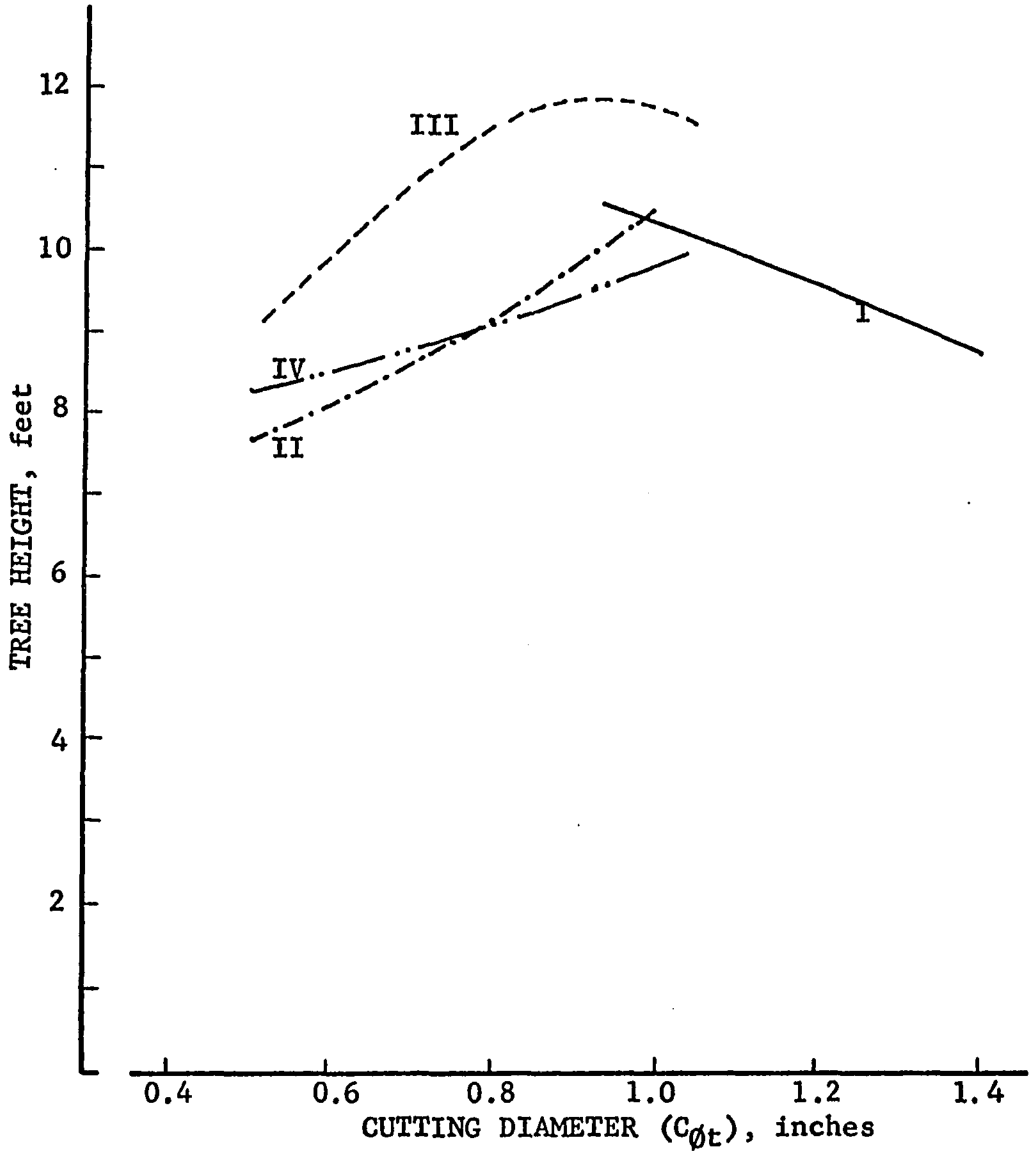

Figure 33. First-year tree heights of four (I-IV) poplar clones in the 1968 plantation as related to top diameter of cutting ($C_{\emptyset t}$). Where:

I - *Populus deltoides* cl. 'Mississippi'
II - " x *euramericana* cl. 'I-488'
III - " x *euramericana* cl. 'Belgian'
IV - " x *euramericana* cl. 'I-214'

receiving +B, +M, and +Q treatments together survived 61 and 100 percent, and their trees averaged 6.4 and 8.7 feet in height on sites C_1 and C_2, respectively.

In the 1964 plantation first-year height of trees from 40-inch-long cuttings planted in mixed soil in holes 3 feet deep and 18 inches in diameter was equivalent to 173 percent of tree height attained by cuttings planted by the standard method (Table 22).

Moreover, planting cuttings of an optimum diameter resulted in growth improvement of about 20 percent above the average height of trees established using cuttings of random diameter. This result was found in the 1962 plantation (Figure 27) and supported by findings from the 1968 plantation (Figure 33).

After two years of growth the differences (expressed in percent of the "standard") among average heights by treatments in the 1961 plantation diminished notably. In the second year only four of 20 treatments, instead of 12 of 20 treatments in the first year, resulted in tree height averages equivalent to 110 to 125 percent of the height attained by trees planted by the standard method. However, the best two treatments (C_d 1.33 ft C_h 5.0 ft and C_d 2.0 ft C_h 5.0 ft) in the first year also continued to be the best after two years (Table 24).

The diminution of both the difference in height and in the number of treatments having an average above 110 percent of tree height in the standard treatment did not signify a complete loss of growth potential in those eight treatments which did not continue to be among the best in height by the end of the second year.

Table 24. Least-squares means of two-year tree height by treatment in the 1961 plantation

Depth of planting (C_d)	C_h, feet			
	0.33	2.00	3.50	5.00
Feet	Feet			
1.33	14.16	16.09	14.21	17.62
2.00	14.33	14.31	15.45	16.14
3.00	12.46	15.37	14.57	14.52
4.00	15.40	15.12	14.69	15.78
5.00	14.77	14.81	15.32	14.57

With the appearance of measurable dbh during the second year the growth potential became distinctly distributed between increment in height and increment in diameter. As a matter of fact, during the first year a similar growth potential distribution was found based on the difference between length of shoot produced by cuttings with a short C_o and by cuttings with a long C_o (Figure 26). The growth potential of cuttings with a short C_o was concentrated on shoot elongation only, therefore the shoot (height increment) of such a cutting was much longer than the shoot of a cutting with a long C_o, where growth potential was distributed between height and diameter increment since the beginning of the first year of growth.

Least-squares means of dbh by treatments in the 1961 plantation (Table 25) showed that treatments which were no longer among the best in height during the second year remained among the treatments

with two-year dbh more than 110 percent of dbh produced by the standard treatment, and dbh of those two treatments which were the best in height after the first year were equivalent to 129 and 155 percent of two-year dbh in the standard treatment.

Table 25. Least-squares means of two-year dbh by treatment in the 1961 plantation

Depth of planting (C_d)	C_h, feet			
	0.33	2.00	3.50	5.00
Feet	Inches			
1.33	1.37	1.66	1.33	2.13
2.00	1.44	1.53	1.61	1.77
3.00	1.06	1.63	1.51	1.52
4.00	1.53	1.50	1.47	1.76
5.00	1.45	1.52	1.51	1.49

Analyses of variance of two-year tree height (Table 54) and two-year dbh (Table 55) showed that both the height and dbh were significantly dependent on C_h, hence also on C_o. But the second-year height increment was significantly (at the 0.01 probability level) dependent on planting depth (C_d), showing that growth potential after the first year depends on soil conditions (Table 56).

By comparing F values for significance of block effects on h_1 and h_2 (Tables 46 and 54) and on (h_1 - C_o) and (h_2 -h_1) (Tables 45 and 56), where respective F values increase with age, I deduced that a trend toward differentiation in both height and height increment with

age was apparent.

The result of regression analysis of h_2 as a function of h_1 and C_d (Equation 19) indicated that variation in these two independent variables accounted for 72 percent of the variation in h_2, while the independent variable h_1 alone explained 70 percent of the variation in h_2 (Equation 20). Only 37 percent of the variation in second-year height increment (h_2 - h_1) was explained by the variation in h_1 and C_d (Equation 21) and 33 percent by the variation in h_1 alone (Equation 22). The author concluded that second-year height increment was much more dependent on the capacity of a one-year-old tree itself to obtain everything necessary for growth from the soil than on the variation of soil factors within the undisturbed soil profile of the planting depth. Moreover, about 63 percent of the variation in second-year height increment was dependent on undetermined factors.

Analyses of variance of two-year tree height and dbh in the 1962 plantation (Tables 57 and 58) showed that the effects of fertilizer (E treatment) and of C_h were equally as significant (0.01 probability level) after two years, as they were in the first year (Table 47). The significance of the effect of C_d increased from the 0.05 probability level in the first year to the 0.01 probability level after two years. Although the significance of mixing the soil in the planting hole (treatment Q) on h_2 decreased slightly below the 0.05 probability level ($F = 3.69$ versus tabulated $F = 3.86$ with 341 d.f.), the effect of Q on dbh_2 was significant at the 0.01 probability level. The significance of covariate $C_\emptyset^2$ decreased from 0.01 in the first year to 0.05 probability in the second year.

Considering the significance of C_d and C_h, and of the covariate C_ϕ^2 on h_1 and h_2 and on dbh_2, the author concluded that size of planting stock in both length ($C_h + C_d$) and cross section (C_ϕ^2) is of major importance for achieving good growth of trees in height and diameter.

Least-squares means of h_2 and dbh_2 (Tables 26 and 27) in the 1962 plantation supported this conclusion. The additive pattern of the effects of various treatment combinations remained the same after two years as it was in the first year.

The effects of high level treatment combinations on h_2 decreased slightly when compared with the effects on h_1 (Table 19), but the effects of the treatment combinations on dbh_2 were much greater than on h_2, confirming the distribution of growth potential between growth in height and diameter as was observed in the 1961 plantation.

The positive effect of C_h on tree growth was consistent in the 1961 and 1962 plantations during the first two years (Tables 18, 19, 24, 25, 26, 27, 45, 46, 47, 48, 54, 55, 57 and 58). The persistence of C_h effect throughout the next five consecutive years was evidenced by the result of a multiple regression analysis of height growth progress during the first seven-year period in the 1961 plantation with C_o (the effective part of C_h) and tree age as the independent variables (Equation 23, Figure 34). The effect of C_o in this regression equation was significant at the 0.01 probability level. However, the prediction of height growth was more accurate using h_1 instead of C_o as the independent variable (Equation 24); the F values for b-coefficients of

Table 26. Least-squares means of two-year tree height by treatment combinations on all three sites in the 1962 plantation

		C_d, feet		C_h, feet		Fertilizer[a/]		
		1.33	3.00	0.33	2.00	None	P	P+N
		Tree height, feet						
Deep cultivation	-Q	16.50	17.73	16.40	17.83	16.36	16.73	18.26
	+Q	16.96	18.63	17.11	18.47	17.28	17.51	18.59
C_h=0.33 ft		15.76	17.74			16.36	16.34	17.57
C_h=2.00 ft		17.70	18.61			17.29	17.90	19.28
Fertilizer	None	16.38	17.26					
	P	16.54	17.69					
	P+N	17.26	19.58					

a/ P denotes superphosphate, and P+N denotes superphosphate plus ammonium nitrate.

Table 27. Least-squares means of two-year dbh by treatment combinations on all three sites in the 1962 plantation

		C_d, feet		C_h, feet		Fertilizer [a]		
		1.33	3.00	0.33	2.00	None	P	P+N
		Dbh, inches						
Deep cultivation	-Q	1.70	1.90	1.63	1.96	1.65	1.74	2.00
	+Q	1.81	2.21	1.86	2.16	1.86	1.96	2.22
	C_h=0.33 ft	1.57	1.92			1.62	1.70	1.92
	C_h=2.00 ft	1.93	2.19			1.89	1.99	2.30
Fertilizier	None	1.64	1.87					
	P	1.74	1.95					
	P+N	1.87	2.34					

a/ P denotes superphosphate, and P+N denotes superphosphate plus ammonium nitrate.

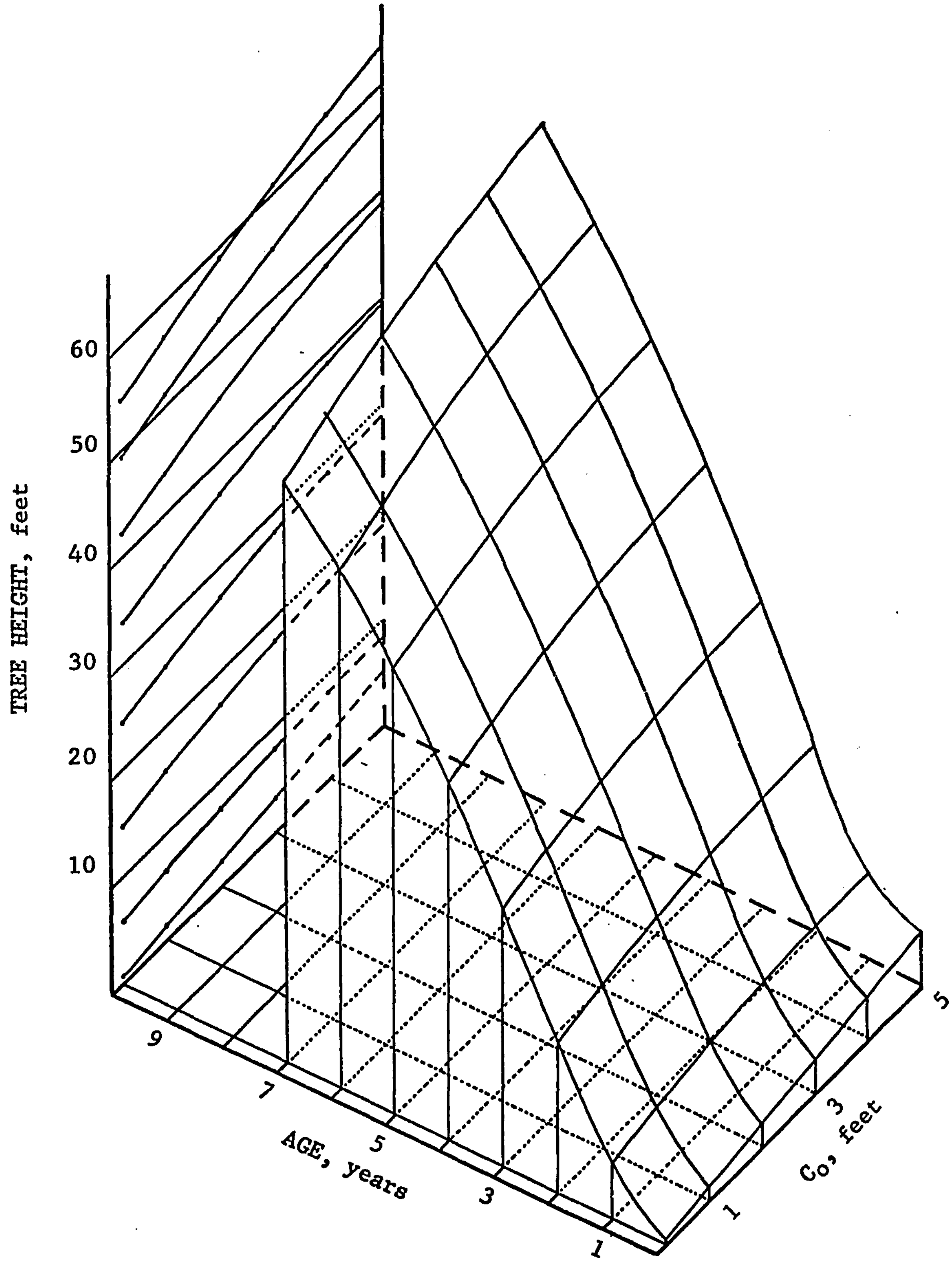

Figure 34. Height growth of cottonwood in the 1961 plantation as related to C_0 and the age of trees. Tree height was calculated from regression equation 23.

h_1 were ten times greater (Equation 24) than those of C_o (Equation 23). The determination coefficient (R^2 = 0.912) in the equation with h_1 was also greater than in the equation with C_o (R^2 = 0.888).

The growth potential of a tree is distributed between height and diameter, and the proportion of this distribution varies with environmental factors and with age of tree. This can be seen by comparing b-coefficients and the correspondent F values in the equations 25, 26, 27, and 28. Although h_6 was predicted from h_1 with R^2 = 0.501 (Equation 23), the best early prediction of tree height and dbh was obtained using h_2 and dbh_2 as the independent variables (Equations 30, 31, 32, 33, 34, and 35). The relationships of tree height and dbh at different ages with h_2 and dbh_2 are presented diagrammatically in Figure 35.

A partial view of the 1961 plantation at age six is shown in Plate 13.

For a comparison of the effects of planting treatments on tree growth in the 1961 plantation, seven-year height, dbh, and total-tree volume outside bark were averaged by treatments (Table 28). The points of height when plotted over corresponding dbh in a scatter diagram (Figure 36) resembled a scatter of height-over-dbh points of individual trees in a stand. By an analogy to silvicultural crown-class classification the points which are distributed above the mean height could be classified as belonging to "dominant and codominant" treatments. But ranking of individual treatments, especially of those with nearly equal height average, would require an additional ranking

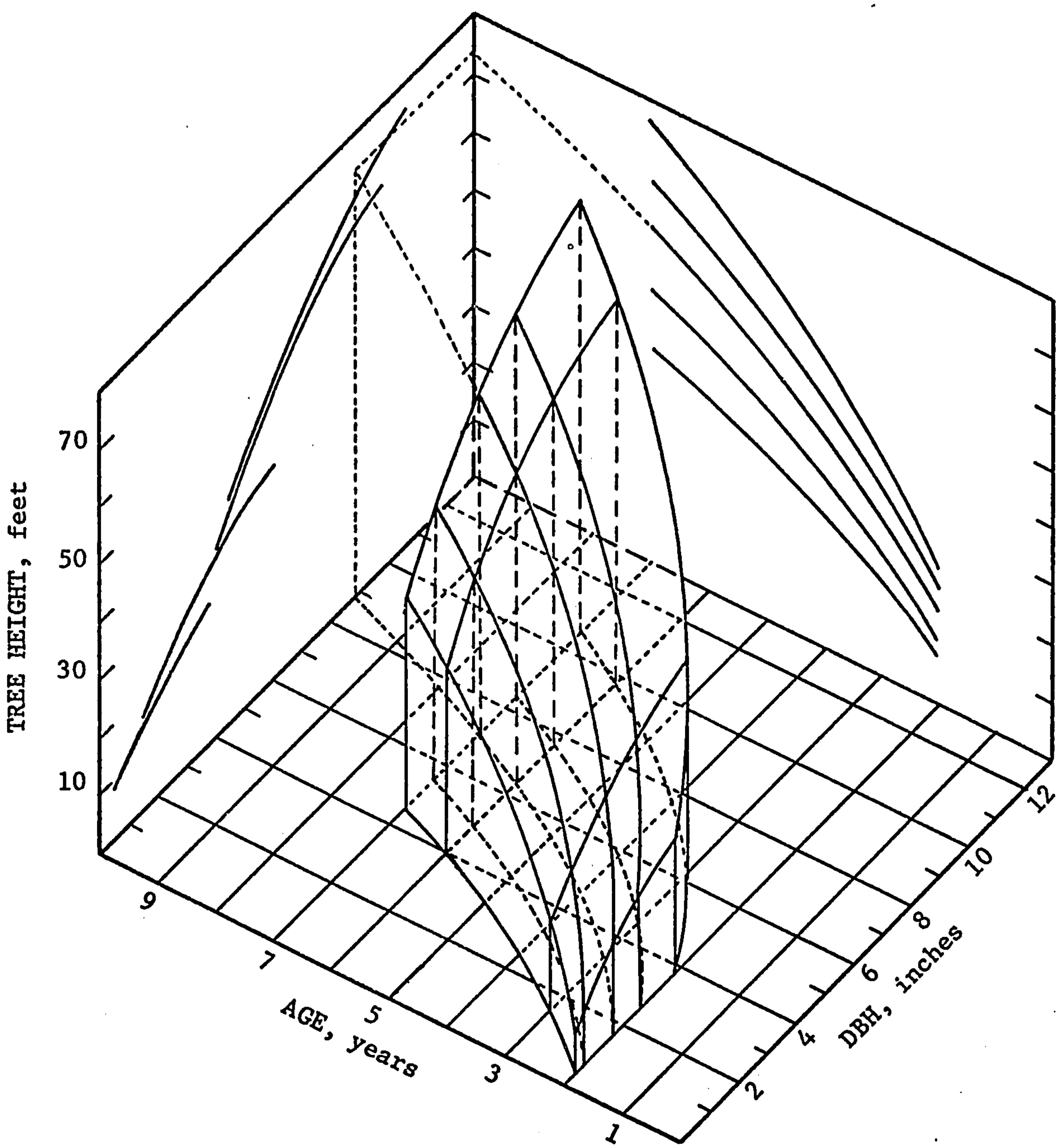

Figure 35. Tree height and dbh at different ages predicted from height and dbh at age of two.

Plate 13. Partial view of the 1961 plantation at the age of six years.

Table 28. Seven-year tree parameters in the 1961 plantation

Treatment code	Survival	Measured: Average Dbh	Measured: Average Height	Measured: Average Tree volume	Measured: Total volume per treatment	Predicted: Average Tree volume[a/]	Predicted: Average Tree volume[b/]	Predicted: Total volume per treatment[c/]
No.	Percent	Inches	Feet	Cu ft	Cu ft	Cu ft	Cu ft	Cu ft
11	58	6.51	56.5	5.535	77.5	5.497	5.545	77.3
12	58	6.98	60.1	6.485	90.8	6.585	6.628	91.4
13	38	6.40	51.2	5.288	47.6	5.432	5.303	48.8
14	62	7.99	64.6	9.146	137.2	9.342	9.208	132.8
21	62	7.50	58.5	8.200	123.0	7.942	7.914	118.4
22	58	7.42	59.1	7.650	107.1	7.738	7.710	108.2
23	54	6.82	58.1	6.107	79.4	6.219	6.250	81.5
24	54	7.27	63.9	7.261	94.4	7.319	7.332	93.6
31	62	6.31	53.6	5.146	77.2	5.145	5.108	77.8
32	62	7.57	60.1	7.873	118.1	8.131	8.093	119.8
33	62	7.26	61.3	7.280	109.2	7.310	7.308	106.9
34	54	6.94	58.5	6.338	82.4	6.515	6.531	85.3
41	54	6.35	52.3	5.484	71.3	5.299	5.194	69.5
42	42	7.14	58.3	7.300	73.0	7.027	7.013	73.5
43	58	7.21	58.8	7.178	100.5	7.199	7.184	100.7
44	71	7.35	59.6	7.547	128.3	7.556	7.532	126.5
51	50	6.58	54.0	5.741	68.9	5.762	5.702	70.3
52	75	6.90	57.1	6.188	111.4	6.445	6.438	116.2
53	50	7.23	60.2	7.600	94.8	7.240	7.234	88.2
54	29	6.90	56.4	6.014	42.1	6.465	6.438	47.7

a/ Equation 39; b/ Equation 37; c/ Equation 40.

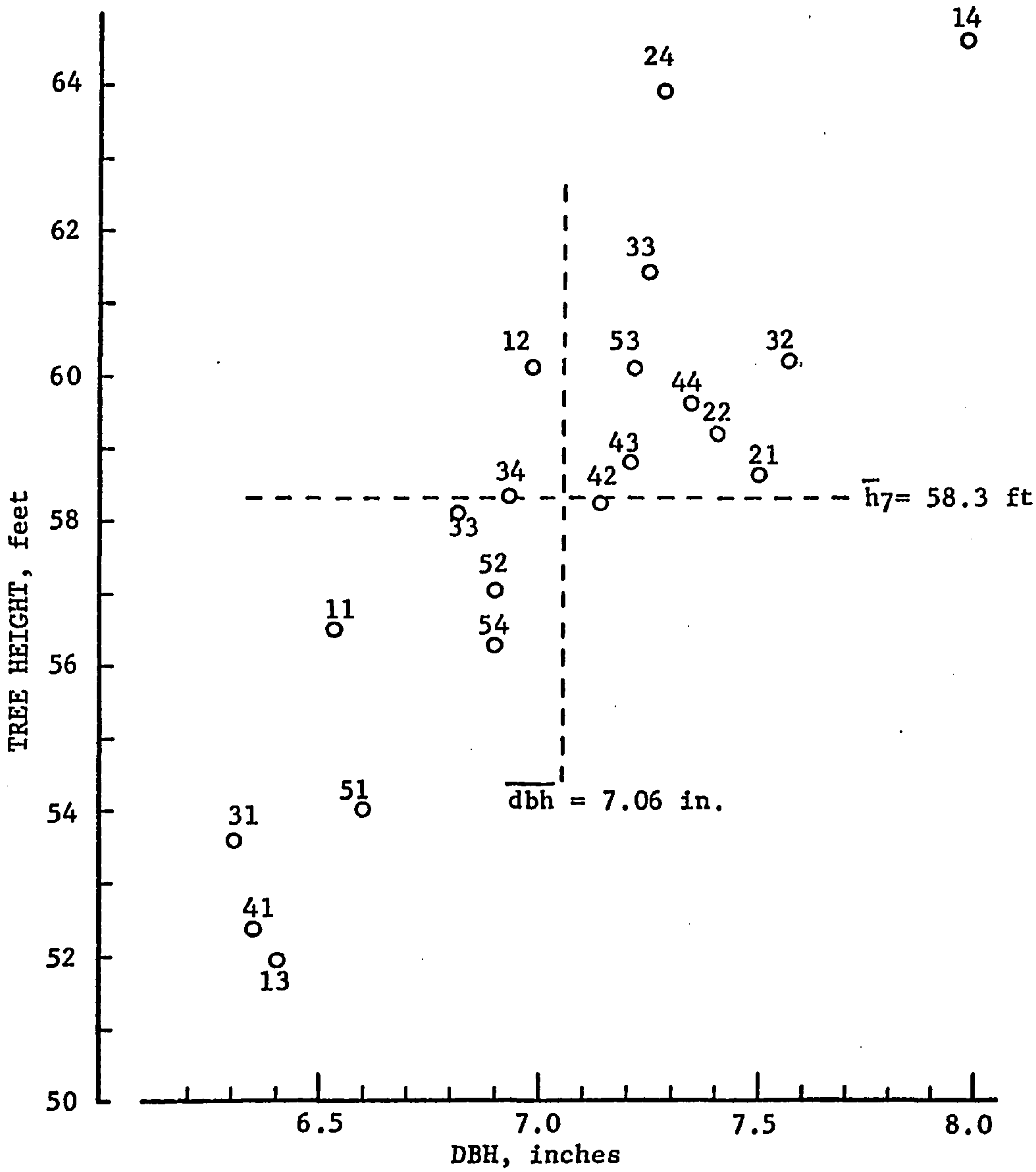

Figure 36. Mean tree height and dbh by treatment in the 1961 plantation at age seven.

by dbh. To avoid the inconsistency in ranking procedure, ranking of treatments was made based on tree volume, which is an expression of both height and diameter.

Regression analyses of average per treatment tree volume ($\bar{V}$) with average tree height and average dbh per treatment as the independent variables provided a series of equations (Equation 36, 37, 38, and 39).

Although all four of these equations show nearly perfect functional relationship between average tree volume per treatment and the independent variables, equations 36 and 37 seem to be most applicable because they include ($-b_1\bar{h}_7$) component which likely corrects $\bar{V}$ according to tree form.

The predicted average volumes per treatment were calculated using equations 37 and 39, and total volume per treatment was computed from equation 40. These predicted volumes may be compared with measured volumes as presented in Table 28. In spite of discrepancies between measured and predicted volumes for individual treatments, the overall mean volume (6.844 cu. ft) for 20 treatments calculated from equation 39 was exactly the same as the measured overall mean volume. Overall mean volume calculated from equation 37 was slightly greater (6.868 cu. ft). Relationship of average tree volume to average dbh per treatment is shown in Figure 37. It appeared that ranking of treatments should be based on the average dbh per treatment rather than on average tree height, because the variation in $\bar{h}_7$ accounted only for 68 percent of the variation

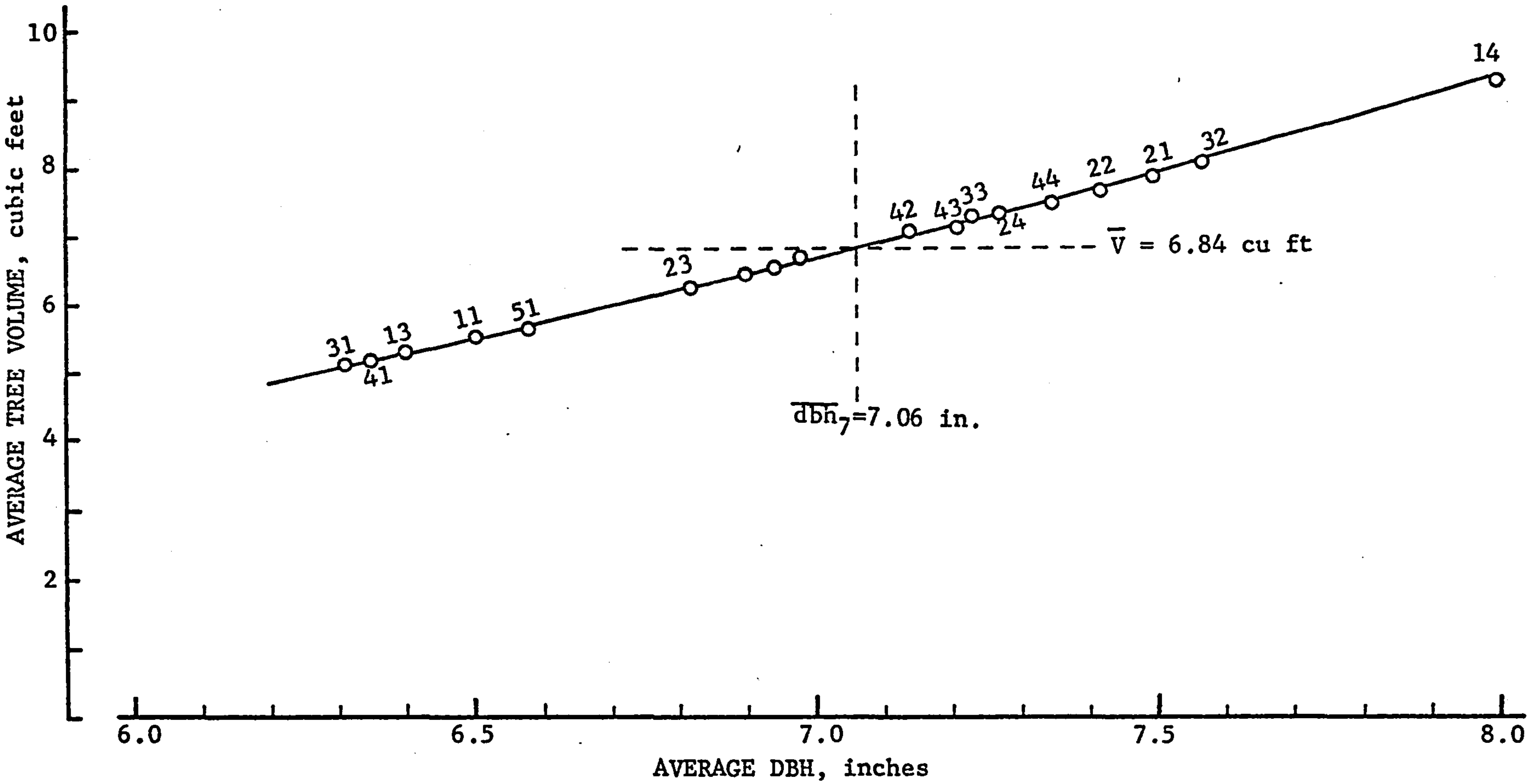

Figure 37. Relationship between average tree volume and average dbh by treatment at age seven in the 1961 plantation. Tree volume was calculated from equation 39.

in average tree volume per treatment (Equation 41) compared with 95.4 percent accounted for by the variation in $\overline{dbh}_7$ (Equation 39).

While h_7 and dbh_7, and thus the average tree volume per treatment, are predictable from h_2 and dbh_2, an early prediction of total volume per treatment is impossible because this volume depends on survival after 7 years (Equation 40). Sixty-eight percent of the variation in survival percentage per treatment after seven years was accounted for by the variation in survival percentage by treatment after two years (Equation 42). Consequently only 64 percent of the variation in total volume per treatment was also accounted for by the variation in average tree volume per treatment (Equation 43).

The reason for the relatively poor relationship between survival after 7 years and survival after 2 years by treatment, and for a similar relationship between total volume and average tree volume per treatment, was the loss of trees caused by hurricane "Hilda" (Figure 16).

According to Dunn and Miller (1964) 34 tropical cyclones were recorded through a 68-year period (1889-1957) in southern Louisiana. Nine of these cyclones of hurricane intensity were very destructive and occurred at intervals of 1 to 13 years. Neither the occurrence nor the path of the hurricanes could be predicted accurately.

Thus, an early prediction of volume in a plantation at the end of the rotation, even for such a short one as in cultivated cottonwood (12 to 15 years for pulpwood and saw-timber), seems to be rather speculative.

The comparison of the effects of planting treatments in the 1961 plantation by ranking average tree volume and average dbh by treatment (Figure 37) showed that 10 treatments produced trees of average dbh and volume which were greater than overall mean dbh and volume in the plantation. Among these 10 treatments were 3 treatments (14, 24, and 44) with C_h = 5.0 ft, 3 treatments (33, 43, and 53) with C_h = 3.5 ft, 3 treatments (22, 32, and 42) with C_h = 2.0 ft, and one treatment (21) with C_h = 0.33 ft. Mean volumes for these four treatment groups were 7.997, 7.426, 7.646, and 8.200 cu. ft, respectively. Another 10 treatments produced average dbh and volume smaller than overall mean dbh and volume in the plantation. There were two treatments (34 and 54) with C_h = 5.0 ft, two treatments (13 and 23) with C_h = 3.5 ft, two treatments (12 and 52) with C_h = 2.0 ft, and four treatments (11, 31, 41, and 51) with C_h = 0.33 feet. Average volumes for each of these four treatment groups were 6.225, 5.772, 6.318, and 5.461 cu. ft, respectively. Among the four groups of treatments with average dbh and volume smaller than overall mean dbh and volume, one group (with C_h = 0.33 feet) included the largest number (4) of treatment combinations; while among the groups with average dbh and volume larger than the overall means, three groups included an equal number (3) of treatment combinations. The calculated percentages of the occurrence of average tree volume by treatment to be (1) larger than, (2) nearly equal to, or (3) smaller than the overall mean tree volume (Table 29) resulted in a more detailed rating of treatment combinations (Table 30).

Table 29. Percentages of the occurrence of average tree volume by treatment to be larger (+), nearly equal to (±), or smaller (-) than overall mean tree volume in the 1961 plantation at age seven

Depth of planting (C_d)	Occurrence	C_h, feet			
		0.33	2.00	3.50	5.00
Feet		Percent			
1.33	(+)	5	15	15	15
	(±)	35	55	55	55
	(-)	60	30	30	30
2.00	(+)	15	45	45	45
	(±)	65	45	45	45
	(-)	20	10	10	10
3.00	(+)	10	30	30	30
	(±)	50	50	50	50
	(-)	40	20	20	20
4.00	(+)	15	45	45	45
	(±)	65	45	45	45
	(-)	20	10	10	10
5.00	(+)	5	15	15	15
	(±)	35	55	55	55
	(-)	60	30	30	30

Table 30. Treatment combinations by group of the occurrence of average tree volume to be larger than, nearly equal to, and smaller than overall mean tree volume in the 1961 plantation at age seven

Occurrence group	Treatment combinations	Occurrence of $\overline{\overline{V}}$: Larger than overall $\overline{\overline{V}}$	Nearly equal to overall $\overline{\overline{V}}$	Smaller than overall $\overline{\overline{V}}$
No.	Code No.	Percent	Percent	Percent
1	22, 23, 24, 42, 43, 44	45	45	45
2	32, 33, 34	30	50	20
3	21, 41	15	65	20
4	12, 13, 14, 52, 53, 54	15	55	30
5	31	10	50	40
6	11, 51	5	35	60

Although very distinct differences were found between the occurrence percentages of group 1 and group 6, it was impossible to rate the treatment combinations within these groups.

Data in Table 30 indicates that there probably should be either a parabolic or logarithmic response of average-tree volume by treatment to C_h. The results of multiple regression analyses of V, dbh_7, and h_7 with C_h, C_h^2, C_h^3, log C_h, $1/C_h$, C_d, C_d^2, and $(C_d \times C_h)$ as the independent variables showed no significant relationship between any of the three dependent variables and any independent variables which included C_d. Yet, h_7 and dbh_7 tended to increase with log C_h (Equations 44 and 45; Figure 38), whereas such a trend in V was not significant (Equation 46). Slightly more pronounced trends of h_7, dbh_7, and V to increase with log C_h were found in trees planted, 3, 4, and 5 feet deep (Figure 38; Equations 47, 48, and 49). This indicated that the variations in the dependent variables were also influenced, although very slightly, by planting depth.

It is evident that neither C_d nor C_h can be considered as the factors which directly control tree growth at more advanced ages (seven years), although these variables were basic in designing the experiment and had significant effects on tree growth in the first and the second year. The C_h was subject to a dieback during the first growing season, and after that only its live part (C_o) remained to affect tree growth during the season. At the end of the first growing season C_o became an integrated part of h_1. The second-year growth was proportional to h_1 (Equation 20), and in a similar way

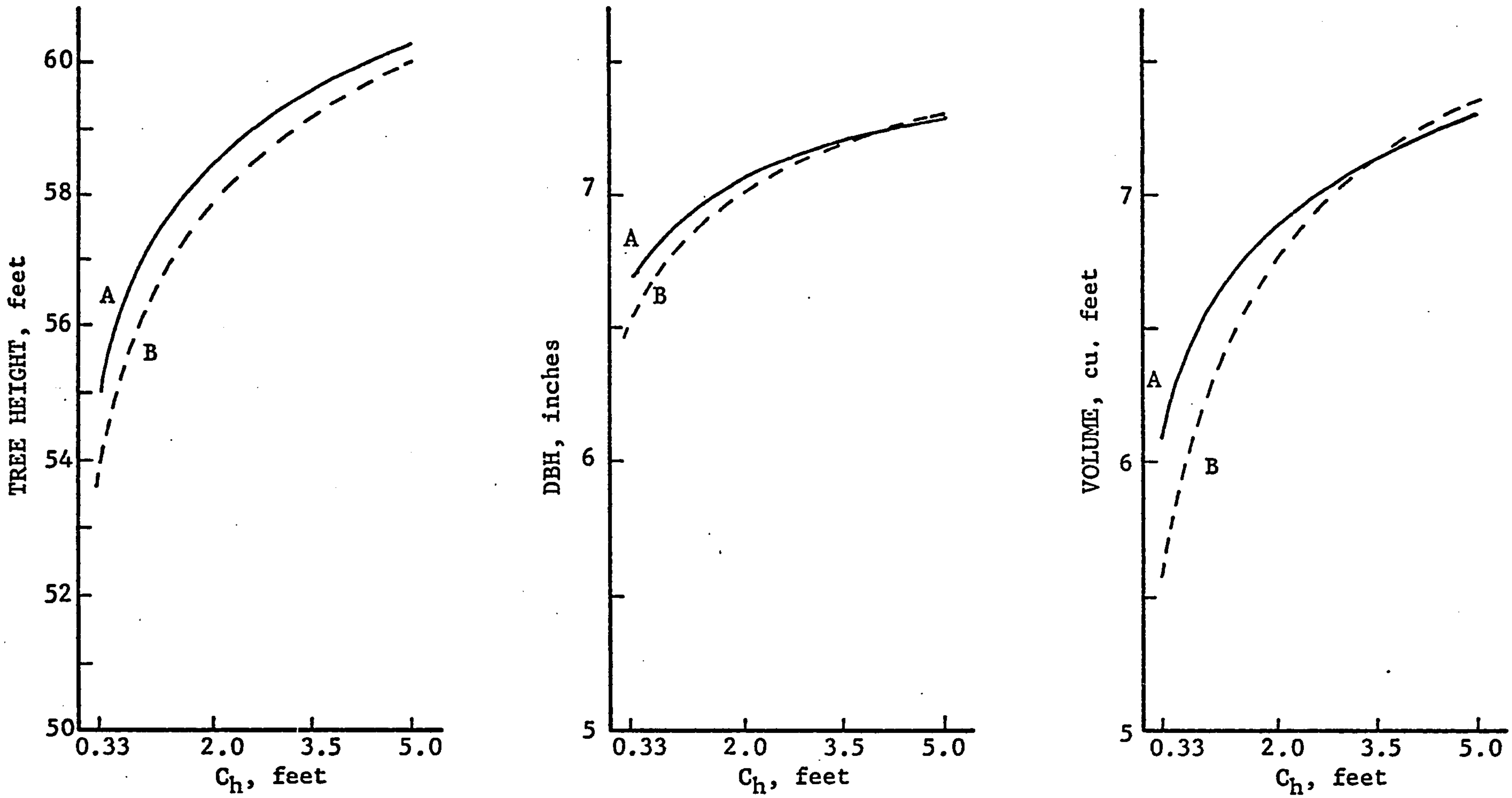

Figure 38. Response trends of average tree height, dbh, and tree volume per treatment to C_h in the 1961 plantation at age seven. Where: A-curves are for all trees in the plantation, and B-curves are for trees planted 3, 4, and 5 feet deep.

tree height of each consecutive year was proportional to tree height of the preceding year.

The depth of planting C_d did not correspond to the combined magnitude (level) of numerous soil factors which varied from place to place in the plantation. This was demonstrated by the significance of block-effect on tree growth (Tables 45, 46, 54, 55, 56) and much more by the variation in physical properties and the chemical status of soil within the profiles of each depth represented numerically by C_d, but which were not directly related to planting depth (Tables 33 and 35).

The effects of treatments which were significant during the first two years (Tables 45, 46, 55, and 56) gradually declined during the next five years (Tables 59 and 60), while the effects of various other factors gradually increased. A weak logarithmic trend in response of tree growth to C_h (Figure 38) was the only relict effect of planting treatments after seven years of growth.

Nevertheless, the combined effects of planting treatments and other factors, which were not controlled by the treatments, resulted in a considerable variation in total-tree volume per acre per treatment (Table 31; Figure 39).

The effects of some other factors which dominated the effects of planting treatments are discussed in the section which follows.

Effects of Soil Properties on Tree Growth

Several methods are actually in use for determining soil

Table 31. Total-tree volume o.b. per acre per treatment in trees of dbh equal and greater than the indicated minimum in the 1961 plantation at age seven

Treatment code	C_d	C_h	Minimum dbh o.b., inches								
			4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0
No.	Feet	Feet	Cubic feet a/								
11	1.33	0.33	1125	1035	890	745	345	185			
12	1.33	2.00	1320	1320	1120	865	775	200			
13	1.33	3.50	690	645	530	120					
14	1.33	5.00	1990	1955	1860	1785	1340	940	940	240	
21	2.00	0.33	1785	1720	1650	1455	1455	1015	500		
22	2.00	2.00	1555	1535	1450	1225	1125	555			
23	2.00	3.50	1155	1155	930	800	500	370			
24	2.00	5.00	1370	1370	1225	1225	520	210			
31	3.00	0.33	1120	1000	900	830	410				
32	3.00	2.00	1715	1715	1685	1340	1045	475	260		
33	3.00	3.50	1585	1565	1480	1345	830	395			
34	3.00	5.00	1195	1165	1065	795	410	275	275	275	
41	4.00	0.33	1035	930	810	735	550	425	260		
42	4.00	2.00	1060	1060	985	695	495	345	345	345	345
43	4.00	3.50	1460	1435	1350	1065	950	540			
44	4.00	5.00	1865	1850	1755	1425	1340	575			
51	5.00	0.33	1000	920	835	715	715	165			
52	5.00	2.00	1620	1590	1410	1065	555	395			
53	5.00	3.50	1375	1360	1190	1105	780	630	630	630	340
54	5.00	5.00	610	610	610	220	220	220			

a/ Volumes rounded-up to the nearest 5 cu. feet.

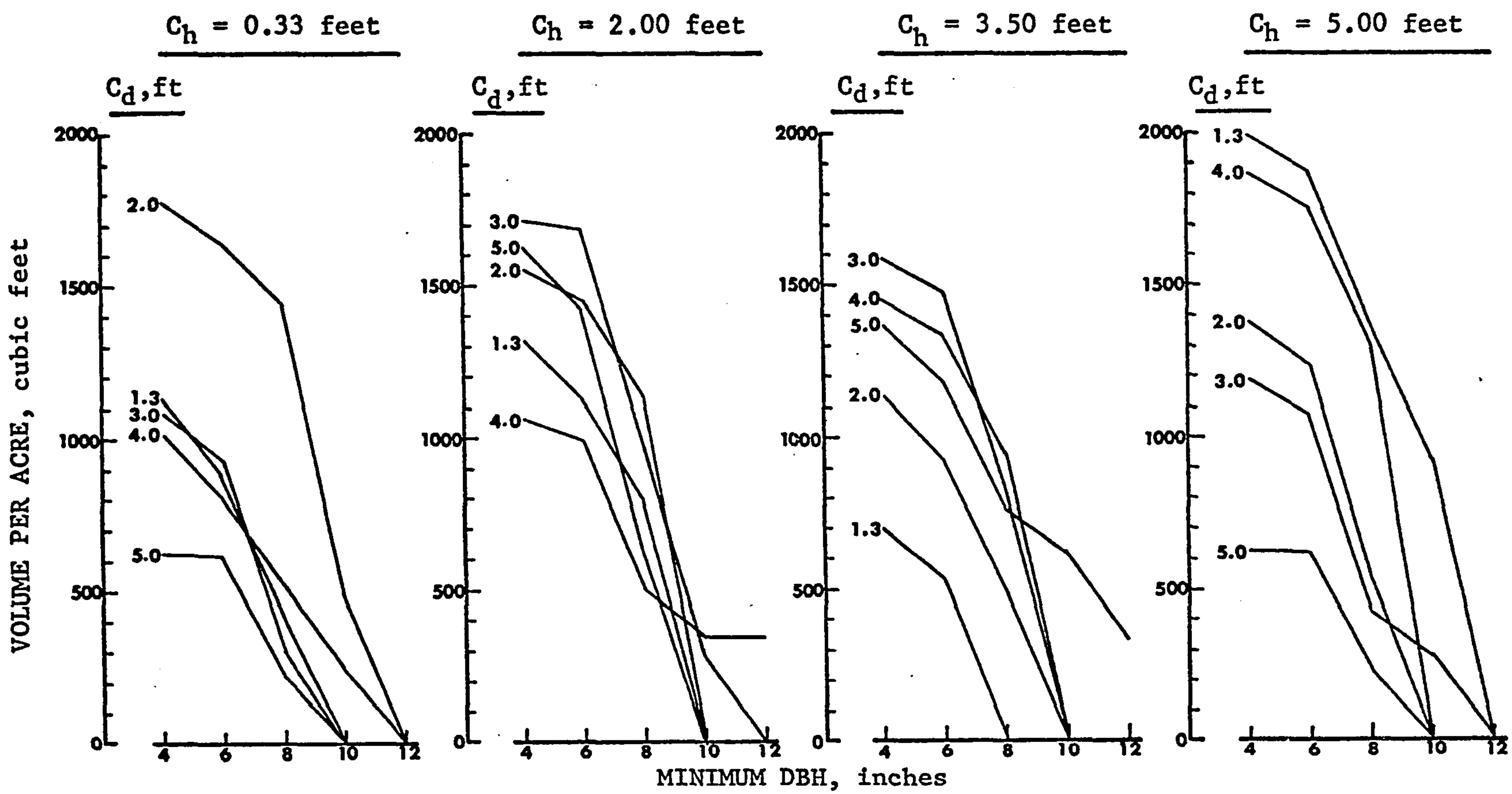

Figure 39. Total-tree volume o.b. per acre per treatment in trees of dbh equal and greater than the indicated minimum in the 1961 plantation at age seven.

suitability for cottonwood (Brendemuehl 1957; Maisenhelder 1960; Broadfoot 1960, 1964, and 1969; McKnight 1970).

Broadfoot (1960) based his method on pedogenic characteristics of locality, soil texture, internal drainage, inherent moisture conditions, and pH of soil. As a consequence of this method, in 1964 Broadfoot considered soil series as a basis for site classification. Broadfoot (1969) was of the opinion that "available moisture, probably, is the single most important determinant of productivity." The other authors agreed also that a moist loamy soil of recent alluvium with a good internal drainage and with pH ranging from 5.5 to 8.5 is the most productive site for cottonwood.

The area of the 1961 plantation (1.37 acres) was too small to permit using soil series as an independent variable. The variation in site, as considered in the experimental design, should be reflected by the variation in soil characteristics of the samples taken from four soil sampling pits (one pit for six replication blocks) in the plantation (Tables 33 and 35).

In order to explain the reason for nonsignificance of C_d on tree growth at age three (Table 59), the relationships between the growth and various properties of the soil were studied.

The results of regression analyses of h_3 and dbh_3 with percentages of sand, silt, and clay as the independent variables (Equations 50 through 55) revealed that the optimum composition of textural soil fractions for height growth differs considerably from the composition

required for best growth in diameter. Diameter growth was the best when the soil contained 47.9, 38.6, and 15.9 percent of sand, silt, and clay, respectively, while height growth was the best when the respective contents were 33.6, 46.2, and 19.0 percent. This difference in soil requirement was supported by the results of regression analyses of h_3 and dbh_3 with available moisture as the independent variable (Equations 56 and 57), which showed that height growth is the best when available moisture by volume is 23.0 percent, while 18.3 percent available moisture is an optimum for diameter growth. In spite of this difference, the best soil for growth of both height and diameter was a loam (Figure 48).

The texture of soil in the 1961 plantation varied from sand to silty clay loam. Moreover, there was no sequence either in an increase or a decrease of any textural soil fraction within the soil profile (Table 33). The values of the water constants and of the pore space were also distributed similarly.

Tree growth was best in a loam soil; hence, an increase of either sand or clay in the soil resulted in a decrease of growth in height and diameter. Consequently, at most, 14.4 to 30.3 percent of the variation in tree growth was accounted for by the individual variations in percentages of sand, silt, clay, and available moisture (Equations 50 through 55).

Multiple regression analyses of h_3 and dbh_3 with sand, silt, clay, and available moisture combined or in combinations of two or three of

these factors as independent variables did not improve determination coefficients either for h_3 or dbh_3 because of a strong interrelationship among these factors. Yet, tree growth is controlled by the combination of these and some other soil factors.

In relating the first-year mortality in the 1961 plantation to physical properties of soil, R_p quotient was used as an expression of the soil properties. Variations in R_p and C_d accounted for 55.4 percent of the variation in first-year mortality (Equation 2).

The R_p, which is a ratio of available moisture (AW) by volume to volume of large pores (BP) in the soil profile of planting depth (C_d), comprises two of the most vital plant growth factors, the availability of water and the aeration of soil in the root zone. These two factors are closely related to the soil texture, the organic matter content, the bulk density and soil compaction, and to the former use of the site (Broadfoot and Burke 1958), or to the plant community which occupied the site (Cajander 1926, Oosting 1958, Sukachev 1960). The extreme proportions of AW and BP in soil either preclude or greatly reduce the development of soil microorganisms which play an essential role in maintaining the nutritional status of soil (Winogradsky 1952, Waksman 1966) and in sustaining the life of higher plants.

The values of R_p in the 1961 plantation varied with soil series, type of soil, and depth of soil profile (Figure 40) according to the compound physical properties of soil in the profile.

The results of multiple regression analyses of h_3 and dbh_3, using

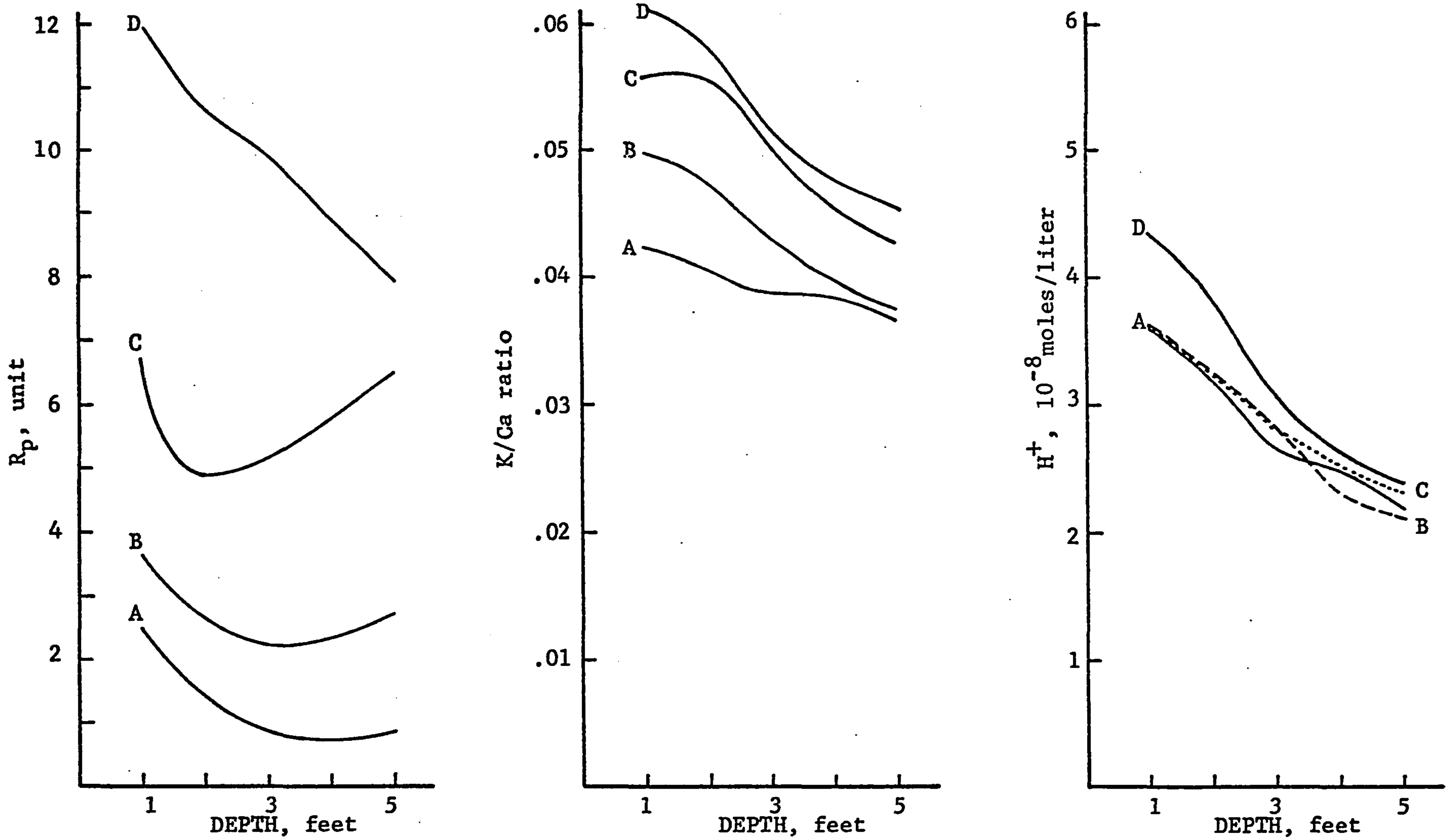

Figure 40. Relationships between R_p unit, K/Ca ratio, H^+ activity, and the depth of profile in different soil series in the 1961 plantation. Where: A = loamy sand and B = sandy loam of Robinsonville-Crevasse, C = loam of Robinsonville, and D = silt loam of Commerce series.

C_d, C_o, and R_p as the independent variables (Equations 58 and 59) showed that, in presence of R_p and C_o, C_d was significant at the 0.05 probability level. Moreover, the ($C_d \times R_p$) interaction was significant at the 0.01 probability level. The variations in C_d, C_o, and R_p explained 44.4 percent of the variation in h_3 and 23.3 percent of the variation in dbh_3, as compared with 30.3 and 15.7 percent, respectively, which were explained by the variations in C_o and sand content in the soil (Equations 50 and 53).

The depth of planting C_d, which was nonsignificant in the analysis of variance (Table 59), appeared to be significant in presence of R_p (Equation 58).

In order to examine the consistency of significance of C_o, C_d, and R_p, a series of multiple regression analyses of tree height and dbh at different ages was made (Equations 58 through 66).

The results of the analyses were that R_p either alone or in interaction with C_d or C_o was significant at the 0.01 probability level in all these regression equations.

To portray the effect of R_p on tree growth progress the heights at different ages for trees planted by the standard method (as an example) were computed from equations 58, and 60 through 63. The relationships of the different-age tree heights to R_p are presented in Figure 41.

The relationship of seven-year dbh to R_p and C_o is presented diagrammatically in Figure 42.

The relationship of seven-year tree height to C_o, R_p, and C_d is presented diagrammatically in Figure 43. For a better portrayal of

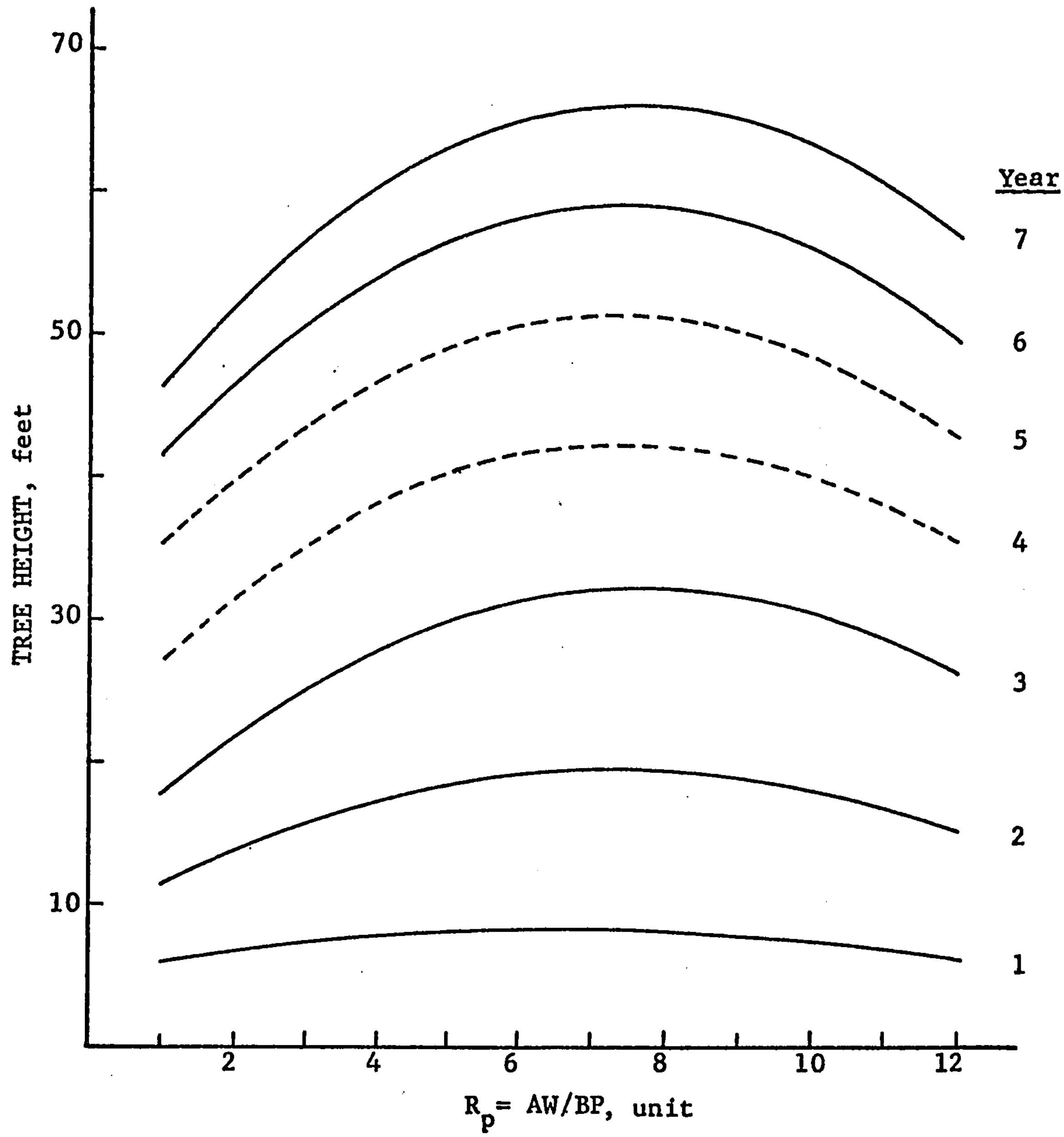

Figure 41. Seven-year progress of height growth of trees planted by the standard method as related to R_p in 1.33-foot-deep soil profile in the 1961 plantation.

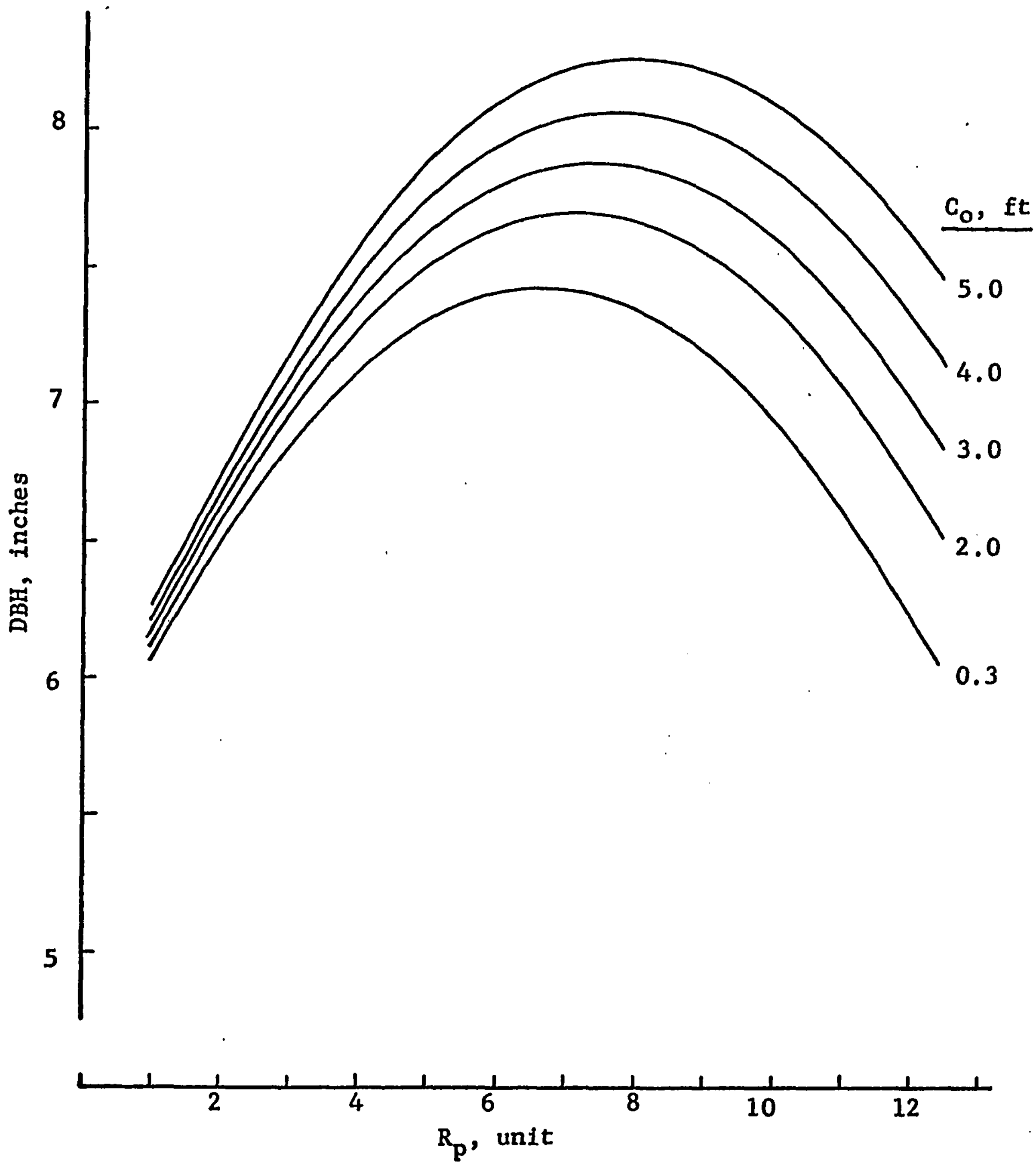

Figure 42. Relationship of seven-year dbh to R_p and C_o in the 1961 plantation. Dbh was calculated from regression equation 66.

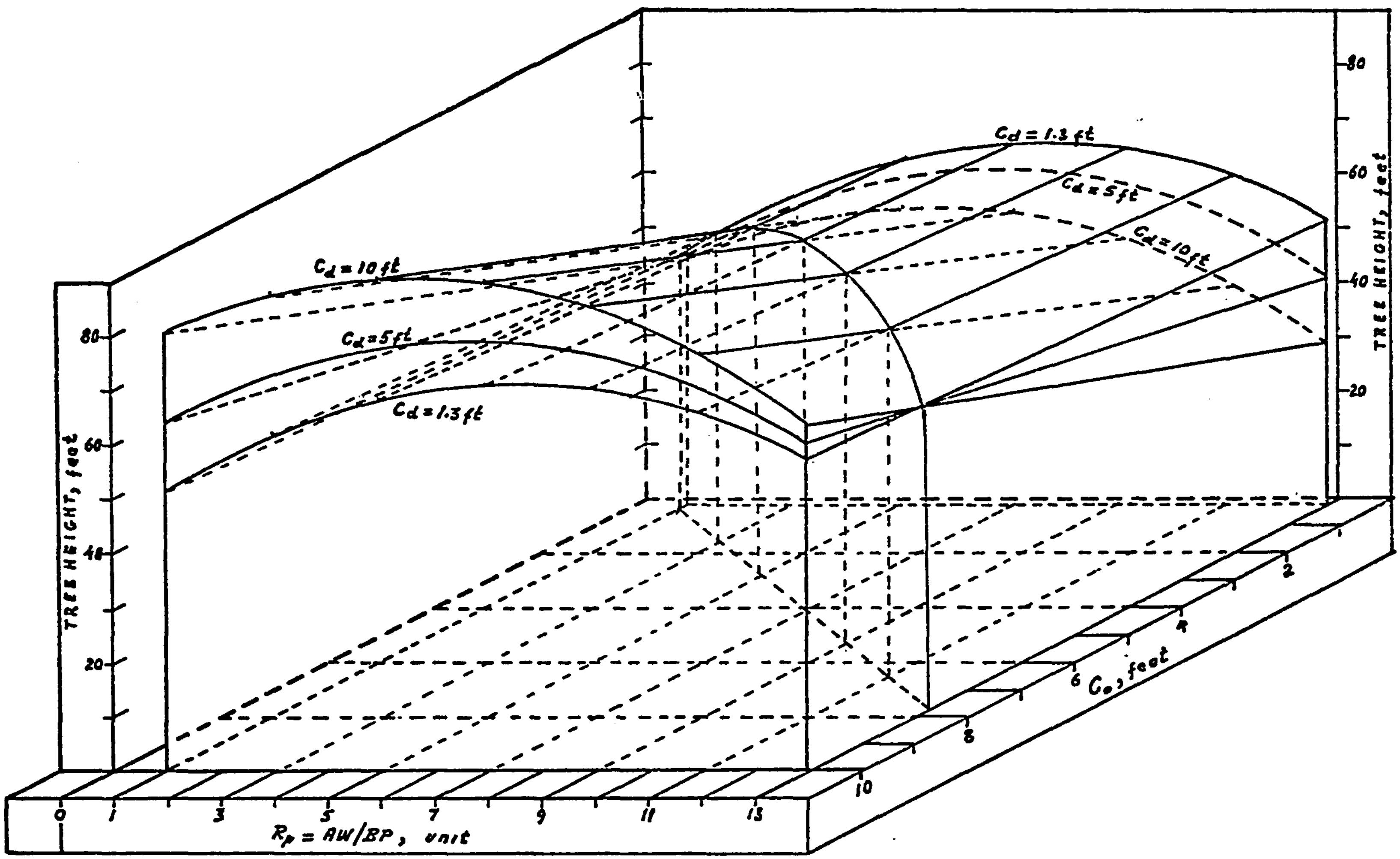

Figure 43. Relationship of seven-year tree height to C_o, R_p, and C_d in the 1961 plantation. Tree height was calculated from regression equation 63.

the relationship, C_o and C_d were extrapolated from 5 feet to 10 feet.

In spite of a high significance of the R_p quotient, and its merits in representing various physical properties of soil, and in disclosing the significance of C_d which remained hidden when the site of the plantation was treated as a uniform unit, the use of R_p is not an ideal method for determining exhaustively the productive capacity of cottonwood site. This is because R_p does not embrace the chemical status of the soil which is of no less importance than its physical properties.

The works of Kostychev (1931), Young and Carpenter (1967), Hacskaylo et al. (1969), and White and Carter (1970) present explicitly the effects of various nutritional elements on growth of trees and other plants.

Kostychev stated that the composition of ash of different plants grown in the same soil is not entirely alike, and that the proportions of the ash components in all plants are very different from the proportions of nutritional elements in soil. This is because there is a selective absorption of various ions from the soil by the plants. The works of Young and Carpenter (1967) and of Hacskaylo et al. (1969) plainly support the statement of Kostychev.

If a plant species is selective in respect to the uptake of nutritional elements, then the elements are used by the plant in certain proportions of one to another. And if this is so, then any of two elements are absorbed in a certain constant proportion unless either one of these two elements, or any one of the other elements required

by this plant, is greatly deficient or absent in the nutritional medium.

A great deficiency or the complete absence of any one of the elements in the nutritional medium produces disturbances in the plant's nutrition causing either a reduced uptake of some elements or an increased uptake of some other elements which may be toxic at certain rates.

This is clearly demonstrated in my summary of the analysis of the data presented by Hacskaylo et al. (1969) on uptake of macro- and micro-elements by cottonwood (Table 32).

Thus, the symptoms of deficiency of one element often may be confused with the toxic effect of the excessive uptake either of another, or of many several elements.

Such a philosophy led the author of this report to the conviction that for maximum tree growth a certain optimum proportion of extractable ions in the soil , especially of antagonistic ions, is much more indispensable than a sufficiency of all.

White and Carter (1970) found that extractable potassium accounted for 94 percent of the variation in height growth of cottonwood.

Steward (1963) reported that the contents of glutaminic acid, glutamine, and aspartic acids (amino acids of RNA, which is responsible for the synthesis of protein) are directly related to Ca/K ratio in the nutritional medium.

This information generated the exploration of the effect of the K/Ca ratio on tree growth in the 1961 plantation.

By an analogy to R_p, the K/Ca ratio in the soil profile of planting

Table 32. Relative concentration of nutrient elements in cottonwood grown in various solutions, as calculated from data given by Hacskaylo et al. (1969)

Solution	Tissue[a]	Elements in tissue											
		N	P	K	Ca	Mg	S	Fe	Mn	Zn	B	Cu	Mo
	L		[b] 177	91	169	76	81	88	141	457	97	473	85
-N	S		130	115	176	82	24	112	200	550	138	283	100
	R		102	103	84	54	56	111	114	508	247	161	200
	L	96		84	101	61	86	120	128	436	94	273	69
-P	S	96		118	156	94	208	96	211	712	131	517	100
	R	64		82	90	58	106	148	200	254	247	146	57
	L	89	178		169	202	130	50	167	250	120	732	631
-K	S	84	109		146	94	98	71	178	462	123	667	133
	R	98	143		153	138	92	113	540	246	147	66	400
	L	70	86	62		108	78	59	73	193	46	123	92
-Ca	S	109	167	111		276	269	79	200	338	138	617	233
	R	79	69	36		221	114	141	100	223	140	156	257
	L	96	123	142	114		131	88	116	214	91	118	31
-Mg	S	79	139	102	256		176	67	189	250	123	417	67
	R	77	153	42	231		97	96	508	223	113	163	71
	L	38	237	128	154	94		111	341	529	125	Tr.	692
-S	S	158	242	92	176	118		75	533	450	123	Tr.	300
	R	100	142	69	104	75		156	492	362	120	100	128
	L	117	128	100	123	122	119		259	257	116	223	169
-Fe	S	102	123	117	128	129	188		333	275	138	567	167
	R	103	113	103	102	100	106		292	277	120	375	228
	L	146	112	105	103	118	124	106		257	115	91	138
-Mn	S	111	114	86	133	147	104	75		225	131	467	67
	R	106	133	80	114	92	73	58		138	107	38	71
	L	106	104	108	128	131	145	97	173		144	200	285
-Zn	S	136	109	103	115	141	329	117	244		123	667	233
	R	103	99	107	94	112	51	64	119		107	82	171
	L	91	93	94	118	55	116	72	196	343		382	92
-B	S	232	174	171	209	124	337	133	367	425		583	167
	R	152	135	129	151	75	111	79	551	277		150	171
	L	124	101	96	118	96	127	108	96	164	91		108
-Cu	S	136	126	140	122	141	153	104	144	200	115		133
	R	120	115	106	83	96	74	71	119	138	100		71
	L	110	112	111	121	137	133	106	94	207	126	114	
-Mo	S	127	133	127	117	153	165	154	156	263	146	567	
	R	130	136	141	130	158	137	135	135	246	153	63	

a/ L - leaves, S - stems, R - roots
b/ In percent of that amount absorbed from complete nutrient solution.

depth C_d has been named R_e, which means a ratio of elements. The relationship of R_e = K/Ca with the depth of soil profile and soil series is shown in Figure 40.

The results of regression analysis of h_7 with C_o, C_d, R_p, and R_e showed that R_e in the presence of other variables (Equation 67) was significant at the 0.05 probability level, whereas R_p was significant at the 0.01 probability level. As can be concluded from the comparison of F values for b-coefficients, the R_p remained in a leading position as the soil factor. The use of R_e in the regression analysis improved the determination coefficient very little ($R^2 = 0.322$) if compared with $R^2 = 0.308$ of regression equation 67.

Nevertheless, the use of R_e as the independent variable has introduced certain precision into the relationship of tree growth to soil properties.

The relationships of seven-year tree heights to R_p and R_e in two extreme planting treatments in the 1961 plantation are shown in Figures 44 and 45. As shown in the diagrams, maximum tree growth takes place when both R_p and R_e are at their optima.

Although the R_e appeared to be a significant growth-controlling factor, determining site productivity for cottonwood purely by the knowledge of K/Ca ratio is still impossible, because the R_e quotient of large values for K and Ca may be the same as for small values.

Multiple regression analyses of h_7 and dbh_7 with the independent variables K, C_d, R_p, R_e, and interactions of one with another, after automatic deletion, provided two equations (Equation 68 and 69) from

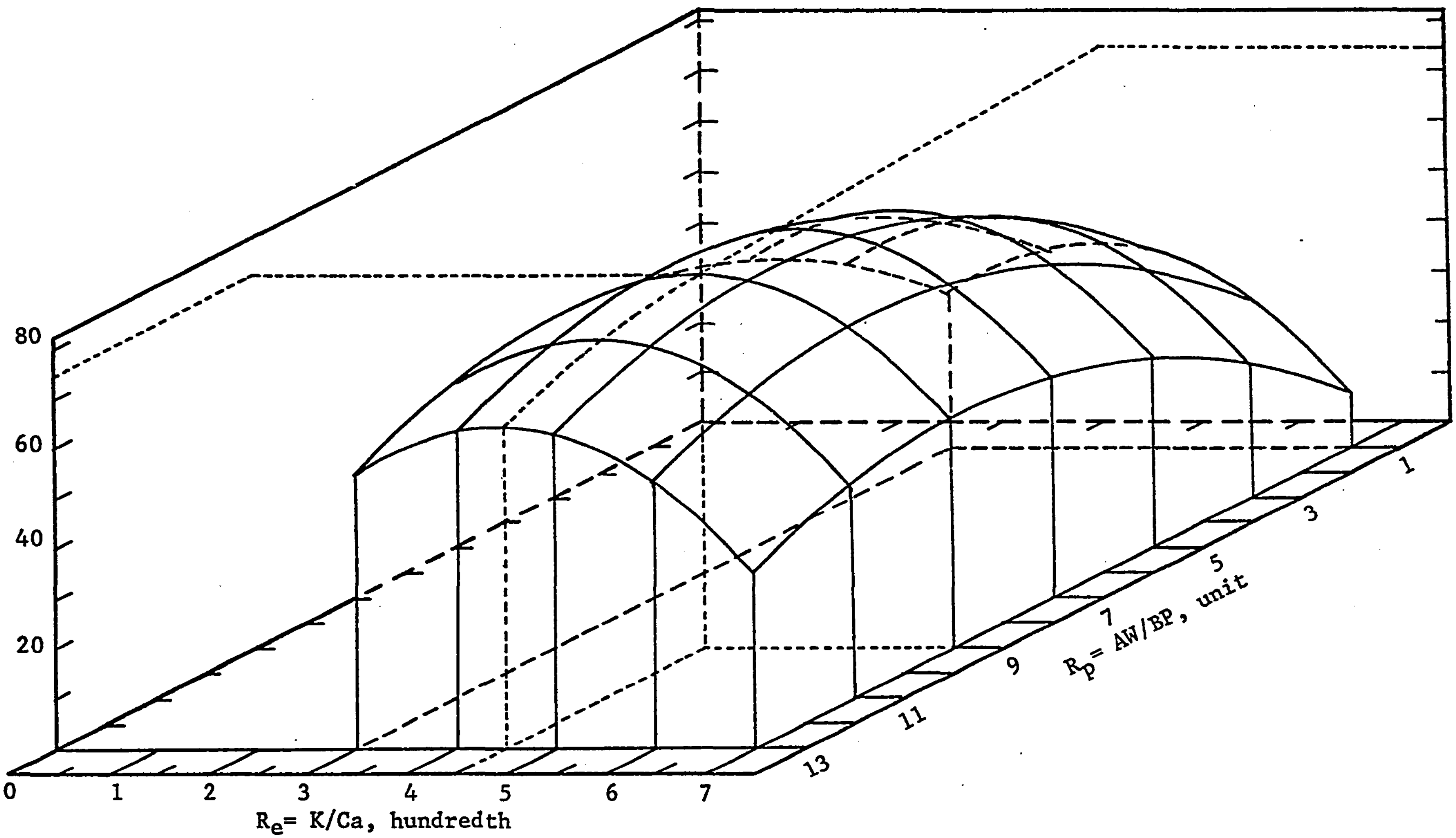

Figure 44. Seven-year height of trees planted by the standard method as related to R_p and R_e in 1.33-foot-deep soil profile in the 1961 plantation. Tree height was calculated from regression equation 67.

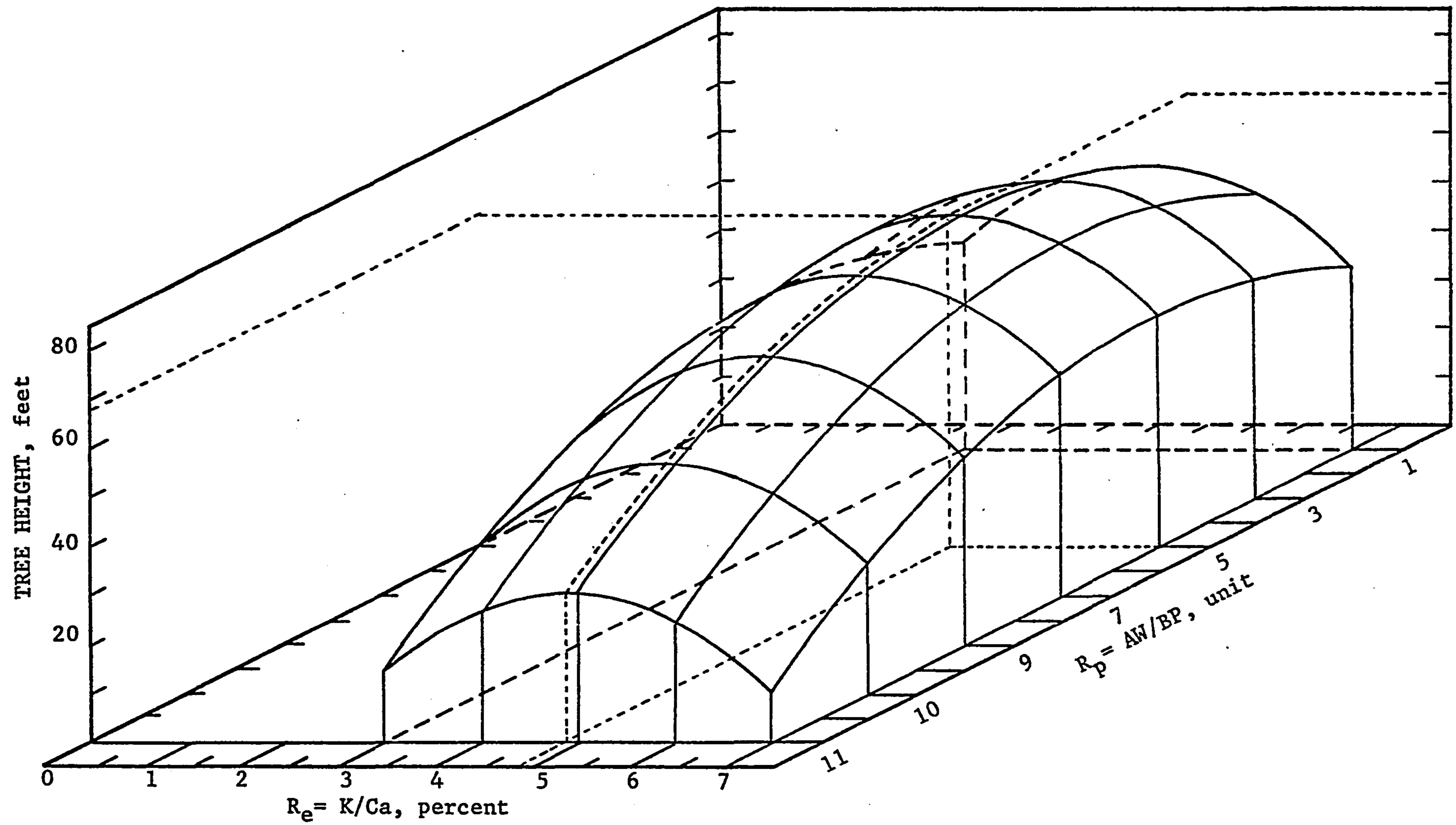

Figure 45. Seven-year heights of trees grown from cuttings of C_o = 5 feet planted 5 feet deep as related to R_p and R_e in the soil profile of planting depth in the 1961 plantation. Tree heights were calculated from regression equation 67.

which the optimal levels of K can be easily calculated for tree height and diameter. Once the optimum level of K is known, the optimum Ca level can be calculated from the optimum R_e = K/Ca.

The calculated optimum K level for maximum height growth of trees planted by the standard method was 171 ppm and for maximum diameter growth was 194 ppm. Corresponding optimal levels of Ca were 3420 ppm and 3880 ppm. This difference between the optima levels of K could be assigned either to a discrepancy due to rounding of b-coefficients or to different K requirements for maximum height and diameter growth. This would support previously discussed differences in respect to the composition of soil textural fractions, and to the available moisture in the soil. These problems should be investigated in the future with other nutritional elements and other soil characteristics.

For instance, the R_p optimum calculated from equation 61 for h_3 was 7.67, and calculated from equation 62 the R_p optimum for dbh_3 was 7.16.

The author believes that there will be no lack of opportunity to find other examples to prove that growth in height depends on different soil conditions from growth in dbh.

The results of regression analyses of tree heights at different ages with C_d, C_o, R_p, and hydrogen ion activity (H^+) were quadratic and exhibited pronounced optima. Moreover, the H^+ optimum was directly related to R_p. The calculated relationships of optimal H^+ for h_6 and h_7 were H^+ (10^{-8}moles/liter) = 0.4151 R_p, and H^+ (10^{-8}moles/liter) = 0.4152 R_p, respectively (Equations 70 and 71).

Since the value of optimum R_p varied with C_d, C_o, and tree age (Equations 58, 60, 61, 62, 63, and 67), and this variation was the largest for 7-year-old trees ($R_p = 8.67$ for trees planted by the standard method, and $R_p = 5.02$ for trees planted 5 feet deep), the optimum pH in the 1961 plantation at age seven varied from 7.44 to 7.68.

SUMMARY AND CONCLUSIONS

Four experimental cottonwood (*Populus deltoides* Bartr.) plantations were established in the Mississippi River bottomlands in the vicinity of St. Francisville, Louisiana, during the period from 1961 through 1964.

An additional plantation of cottonwood, with three exotic poplars for comparison, was established in a nursery on the LSU campus in Baton Rouge, Louisiana , in 1968.

The 1961 plantation was the main plantation of this study. The other four plantations were established one at a time to test the hypotheses resulting from preliminary analyses of the data obtained during the progress of the study.

The objective of the study was evaluation of various methods of planting cottonwood cuttings in comparison with the standard method (20-inch-long cuttings planted 16 inches deep) commonly used in the South.

The effects on survival and growth of 20 combinations of five planting depths (1.3, 2.0, 3.0, 4.0, and 5.0 feet) with four lengths of cutting above the ground (0.3, 2.0, 3.5, and 5.0 feet) were tested over a seven-year period (until pulpwood maturity) in the 1961 plantation.

The effects of 24 combinations of two levels of deep cultivation of soil (none, mixing the soil in 3-foot-deep and 14-inch-diameter

holes), two depths of planting (1.3 and 3.0 feet), two lengths of cutting above the ground (0.3 and 2.0 feet), and three levels of fertilizer (none, superphosphate, and superphosphate with ammonium nitrate) were tested on first-year survival and tree growth in the 1962 plantation. The effect of cutting diameter was also tested.

The effects of 48 treatment combinations of two levels of post-planting cultivation (none, cultivation by bedding), two levels of mulch (none, 2-ft-sq. laminated Kraft paper pads), two levels of deep cultivation of soil (none, mixing the soil in 3-foot-deep and 9-inch diameter holes), two depths of planting (1.3 and 3.0 feet), and three lengths of cutting above the ground (0.3, 2.0, and 3.6 feet) were tested on first-year survival and tree growth in the 1963 plantation.

The effects of four levels of deep cultivation of soil (none, mixing the soil in 3-foot-deep holes of 9, 14, and 18 inches in diameter) and two lengths of cutting (20-inch-long cutting planted 16 inches deep and 40-inch-long cutting planted 36 inches deep) were tested on first-year survival and tree growth in the 1964 plantation.

The effects of clone (cottonwood, compared with three exotic poplars) and cutting diameter were tested on first-year growth and form of switches in the 1968 plantation.

The 1961-1964 experiments were carried on without weeding.

Cuttings which were used for establishment of the 1961-1964 plantations did not represent any definite single clone. They were prepared from switches grown in a nursery from wildings.

Physical properties and nutritional status of soils in the plantations were determined by corresponding analyses of samples and cores taken from each 1-foot soil stratum in 3- or 5-foot-deep profiles, depending on planting treatment.

Survival and growth data were analyzed according to experimental designs by analyses of variance, and by regression analyses where necessary to explain relationships between survival and growth and treatments or other factors not embraced by the designs.

The results of statistical analyses are documented by corresponding tables and regression equations.

The relationships of survival percentages to treatments, physical properties of soil, and climatic conditions, and the relationships of tree growth in height, diameter, and volume to treatments, and physical and chemical properties of soil are portrayed in numerous diagrams.

A concept of adjusted seasonal moisture balance (ΣMb), which was developed by the author of this report, was applied in weighing both the effect of climatic conditions and the efficiency of planting treatments in regard to first-year survival of cottonwood.

A concept of an ecological determinant of soil (R_p), which was developed by the author, was used as a single independent variable in relating first-year mortality and tree growth at various ages to the entire complex of physical properties of soil in the root zone. The R_p is a ratio of available moisture percentage by volume to the percentage of large pore space in the soil profile of planting depth.

A concept of an optimal proportionality of nutritional elements (R_e) in a nutrient medium, which was formulated by the author and was based on a synthesis of information provided by other researchers, was tested by examining the effect of R_e = K/Ca in the soil profile of planting depth on tree growth.

Cottonwood root behavior was studied by excavation of root systems which were developed in natural conditions and in conditions modified by planting treatments. In connection with this study the literature on mycorrhizae associated with roots of cottonwood and other poplars was reviewed.

Major Findings

The major findings of this study are as follows:

1. Fifty-three percent of the variation in first-year mortality of cottonwood cuttings planted in undisturbed soil in the 1961 plantation was explained by the variations in depth of planting and length of cutting above the ground. Regression analysis indicated that the lowest predicted percentage of mortality (14.3 percent) would occur when 5-foot-long cuttings were planted 3 feet deep. This mortality was only 55 percent of the mortality of cuttings planted by the standard method.

2. Proper balance between soil aeration and available soil moisture was a significant ecological factor controlling first-year survival and tree growth. The ecological determinant of soil (R_p), as an expression of the whole complex of physical soil properties,

explained 55.4 percent of the variation in the mortality in the 1961 plantation. The lowest predicted (by regression) percentage of mortality (5.6 percent) would occur when cuttings were planted 2.3 feet deep in the soil with $R_p = 7.5$, i.e. in soil containing approximately 17.5 percent of clay. In similar soil, predicted mortality of cuttings planted by the standard method was 9.3 percent. Some of the factors which probably contributed to the remaining unexplained 45 percent variation in mortality were variations in incidence of leaf beetles, viability of cutting, competition (especially of vines), and quality of planting procedure.

3. Survival of cuttings increased with increase of size of planting hole. The survival of 20-inch-long cuttings was improved from 37 percent when cuttings were planted by the standard method in undisturbed soil (i.e. in a 1-sq.-inch cross-section hole) to 83 percent when planted 16 inches deep in the soil mixed in holes of 18 inches in diameter and 3 feet deep. The survival of 40-inch-long cuttings reached a maximum of 92 percent when the cuttings were planted 36 inches deep in 14-inch-diameter holes.

4. Cuttings planted in the soil mixed in holes of 9 inches in diameter and 3 feet deep with the surface soil cultivated by bedding and mulched with 2-foot-square laminated Kraft-paper pads had 61 percent survival in a season of severe drought ($\Sigma Mb = -19.5$ inches) on a dry site and 100 percent survival on an inherently moist site, while cuttings planted by the standard method did not survive on either of these sites.

5. The annual variation in first-year survival of cottonwood cuttings planted by identical treatments was directly related to adjusted seasonal moisture balance (ΣMb). Cuttings planted by the standard method survived satisfactorily (73.8 percent) only during a season with an excess of moisture (ΣMb = 15 inches) above the long-term seasonal average.

6. An accurate prediction of survival in a southern Louisiana cottonwood plantation at the end of the rotation, even for such a short one as 12 to 15 years (for pulpwood and sawtimber), is difficult because of the unpredictable frequency and intensity of hurricanes in this region.

7. First-year height growth of cottonwood planted in undisturbed soil in the 1961 plantation was significantly dependent on depth of planting, length of cutting above the ground, and on interaction between these two factors. The effect of length of cutting above the ground on tree growth decreased with an increase of planting depth. Differences among first-year heights of trees grown from cuttings planted 5 feet deep with different lengths of cutting above the ground were insignificant. However, predicted heights of these trees were significantly taller than the height of trees planted by the standard method. On the other hand, no significant effect of planting depth was found on growth of cuttings with 2 feet of length above the ground. The best height growth was obtained from 6.33-foot-long cuttings planted 1.33 feet deep.

8. Length of cutting above the ground was the only factor whose effect lasted through the seven-year period, being highly significant at the beginning of the period and with declining significance by the end of the period. This was partly because tree growth in height during the seven-year period was proportional to the length of live cutting above the ground, which was related to the initial length of cutting above the ground (r = 0.68). The variation in tree height at different ages was dependent on the age and length of live cutting above the ground (R^2 = 0.888), or on age and first-year tree height (R^2 = 0.912).

9. Cuttings planted 1.33 feet deep with 5 feet length above the ground, in spite of only 56.8 percent first-year survival (53 percent survival after 7 years), produced 1990 cubic feet of total tree-volume o.b. per acre at age seven, compared with 1125 cubic feet produced by cuttings planted by the standard method, which had 54 percent survival after 7 years and 73.8 percent survival at the end of the first year.

10. Tree growth, especially in the third year (age of maximum current annual growth), was related to the length of live cutting above the ground and to variations in physical and nutritional properties of soil in the planting-depth profile. The effect of live cutting above the ground was directly linear, and the effects of physical and nutritional properties of soil as expressed by R_p and R_e were quadratic and exhibited certain optima. The best tree growth was obtained from cuttings with the longest live length above the ground and planted in soil with optimal R_p and R_e.

11. No single optimum soil reaction was found for different sites. Optimum hydrogen ion activity was directly related to R_p. The higher the percentage of available soil moisture and the smaller the volume of large pores in soil, the lower was the H^+ activity and the higher was the pH. The value of optimum R_p was dependent on planting method (depth of planting and length of cutting above the ground). Moreover, R_p optimum varied with tree age. The calculated pH optimum for seven-year-old trees planted by the standard method was 7.44; for trees grown from cuttings planted 5 feet deep optimum pH was 7.68.

12. The results of examination of relationships of tree height and dbh to various soil properties indicated that growth in height and dbh depend on different soil conditions. Three-year height was the best when soil was composed of 33.6, 46.2, and 19.0 percent of sand, silt, and clay, respectively, the available water constant was 23 percent by volume, and R_p = 7.67. Three-year dbh was the best when sand silt, and clay contents in soil were 47.9, 38.6, and 15.9 percent, respectively, the available water was 18.3 percent by volume, and R_p = 7.16. The calculated optimum K level in soil for maximum seven-year height growth of trees planted by the standard method was 171 ppm and for maximum diameter growth was 194 ppm. Corresponding optimal levels of Ca were 3420 ppm and 3880 ppm.

13. The earliest effective data for projecting tree growth in the 1961 plantation were two-year tree height and dbh measurements. Seven-year tree height and dbh in this plantation were predicted from two-year tree height and dbh (R^2 = 0.651 and 0.533, respectively).

14. Diameter and vitality of cutting had significant effects on first-year tree growth. The effect of cutting diameter on tree height in the 1962 plantation was quadratic with a very pronounced optimum. The calculated optimum diameter of cutting was 1.04 inches. The effect of vitality of cutting on tree growth was detected by examining the effect of survival on average tree height by treatment in the 1963 plantation. Tree height was proportional to survival percentage regardless of site. Both survival and growth on an inherently moist site were in all treatments correspondingly better than on a dry site.

15. Use of cuttings of differing diameters and of differing genetic origins for establishing a plantation resulted in a significant variation in first-year tree height, diameter, and tree form. This was found in the 1968 plantation by comparing the growth of 20-inch-long cottonwood cuttings with cuttings of three exotic poplars, which were planted on a homogeneous site and treated alike during the whole growing season.

16. Planting cuttings in the soil mixed in 3-foot-deep and 14-inch-diameter holes increased significantly the percentage of live cutting above the ground (reduced the dieback) and increased height and diameter growth. Two-year-old trees grown from 5-foot-long cuttings planted 3 feet deep in such holes had 40 percent larger dbh and were 20 percent taller than trees planted by the standard method.

17. First-year height growth of cuttings planted in the soil mixed

in 9-inch-diameter holes was significantly improved by cultivation of the surface soil by bedding regardless of site, depth of planting, and length of cutting above the ground. The average increase in tree height was about 25 percent over the height of trees grown from cuttings which did not receive cultivation by bedding.

18. Twenty-inch-long cuttings planted 16 inches deep did not respond to mixing the soil in 3-foot-deep holes of either 9-, 14-, or 18-inch diameter, whereas 40-inch-long cuttings planted 36 inches deep increased growth proportionally to the cross section of planting hole. One-year-old trees grown from 40-inch-long cuttings planted in 18-inch-diameter holes were 73 percent taller than trees planted by the standard method in undisturbed soil.

19. The dimension of the root system, the extent and distribution of lateral roots, and the amount of absorptive roots varied with planting method. The excavated root systems of one- and two-year-old trees grown from cuttings planted 3 feet deep, especially in the soil mixed in holes 14 inches in diameter, were much larger and more abundantly developed than root systems of trees planted by the standard method in undisturbed soil.

20. Based on a synthesis of information provided by other researchers, that mycorrhizae are found in soils with pH below 6, and cottonwood grows satisfactory at pH above 6 and thrives best in mildly alkaline soils, the author has inferred that mycorrhizal fungi are of little silvicultural importance for cottonwood.

Conclusions

The results of this study plainly support the hypothesis that the effects of different cutting sizes, different planting methods, different silvicultural treatments, and different soil properties are reflected in the survival and in the subsequent growth of cottonwood trees.

The results of the 1961-1968 experiments indicate that first-year survival of cottonwood depends significantly on planting depth, length of cutting above the ground, method of soil cultivation, physical properties of soil, incidence of leaf beetles, competition (especially from vines), and on climatic conditions during the first growing season. Tree growth is dependent on diameter and vitality of cutting, genetic make-up of planting stock, planting depth, length of cutting above the ground, method of soil cultivation, and the pH, physical, and nutritional properties of the soil.

Planting long cuttings at a depth adjusted for the texture of soil can extend the range of satisfactory conditions (conditions which are as good or better than the best conditions for the standard method of planting) to sites which are considered poor or even unproductive for planting cottonwood by the standard method (sandy bottomland soils and the soils with clay content about 30 percent). Trees grown from long cuttings planted in sandy soil attain nearly the same average height as trees planted by the standard method on the best site. In soils with clay content of about 25 percent the average dbh of trees grown from long cuttings is equal to the standard.

Survival and growth of cottonwood can be improved significantly regardless of site and climatic conditions by deep planting of long cuttings in soil mixed in holes, by bedding the surface soil, and by spreading a mulch on the bedded soil around a planted cutting.

For better survival and growth, planting depth and diameter of the planting hole should be adjusted for the texture of soil. Planting cuttings 3 feet deep or deeper in holes with a diameter not larger than 9 inches should be done in a sandy soil, whereas holes 14 to 18 inches in diameter and about 2 feet deep should be applied in soil with 20 to 30 percent clay content. Planting holes 2 to 3 feet deep and 14 inches in diameter should be used in a medium-textured soil. Length of cutting above the ground should not be shorter than 2 feet. This length can be extended up to 5 feet in soil with clay content above 20 percent with benefit to both survival and tree growth. Bedding of the surface soil along planting rows and the spreading of mulch should be done as soon as possible after terminating planting operations. Only cuttings of uniform size (from 0.75 to 1.25 inches in diameter at the base) and rigidly graded for vitality should be used. The use of random-size cuttings may result in considerable first-year mortality and in a reduced number of merchantable-size trees at the end of a rotation. Frequent pest control and periodic control of vines should be obligatory.

Consideration should be given to both physical and chemical (pH included) properties of soil in selection of a site for cottonwood, because knowledge of only one type of soil property is insufficient.

The application of improved methods of planting opens a further possibility for shortening the rotation and for increases in yield and quality of timber.

The results of this study have provided strong evidence that the standard method of planting should not be considered as the universal method for establishment of cottonwood plantations in bottomlands of the Lower Mississippi Valley.

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APPENDIX A

DATA AND DESCRIPTION OF SOILS IN THE EXPERIMENTAL COTTONWOOD PLANTATIONS

Table 33. Physical properties of soil in the 1961 plantation

Soil pit	Soil depth	Textural fraction[a/] Sand	Silt	Clay	Soil texture[b/]	Wilting point	Available moisture	Field capacity	Bulk density	Soil pores Large	Small	Total	Perco-lation
No.	Feet	---- Percent	----			------- Percent		--------	g/cc	----- Percent		-----	In./hr.
1	0 - 1	57.5	25.0	17.5	SL	8.10	23.50	31.60	1.38	7.90	39.88	47.78	0.163
	1 - 2	90.0	4.5	5.5	S	2.40	3.33	5.73	1.43	18.20	27.70	45.90	1.230
	2 - 3	86.3	5.0	8.7	LS	3.53	5.71	9.24	1.38	26.40	21.40	47.80	4.972
	3 - 4	86.3	7.0	6.7	LS	3.13	6.24	9.37	1.46	18.00	26.68	44.68	1.872
	4 - 5	75.0	16.2	8.8	SL	3.82	10.28	14.10	1.40	9.60	37.45	47.05	0.218
2	0 - 1	48.8	36.2	15.0	L	7.12	21.61	28.73	1.46	6.50	38.28	44.78	0.042
	1 - 2	80.0	11.0	9.0	SL	3.82	10.02	13.84	1.36	10.20	38.39	48.59	0.281
	2 - 3	83.8	7.4	8.8	LS	3.53	9.51	13.04	1.44	10.00	35.70	45.70	0.863
	3 - 4	71.2	18.3	10.5	SL	4.04	11.38	14.42	1.47	4.70	39.84	44.54	0.129
	4 - 5	58.8	30.5	10.7	SL	4.11	12.42	16.53	1.37	2.70	45.40	48.10	0.050
3	0 - 1	27.5	52.5	20.0	SiL	8.43	25.67	34.10	1.44	4.00	41.40	45.40	0.014
	1 - 2	57.5	30.0	12.5	SL	5.28	13.11	18.39	1.39	7.10	40.30	47.40	0.115
	2 - 3	48.8	38.7	12.5	L	5.44	16.03	21.47	1.47	4.10	40.20	44.30	0.147
	3 - 4	35.0	48.8	16.2	SiL	7.21	23.61	30.82	1.43	4.10	41.90	46.00	0.190
	4 - 5	36.0	48.3	15.7	SiL	6.89	22.91	29.80	1.38	2.80	45.00	47.80	0.141
4	0 - 1	26.0	52.8	21.2	SiL	8.58	24.85	33.43	1.48	2.70	41.10	43.80	0.106
	1 - 2	31.0	50.2	18.8	SiL	7.37	21.67	29.04	1.45	3.60	41.80	45.40	0.379
	2 - 3	22.5	53.5	24.0	SiL	9.18	26.82	36.00	1.43	4.40	41.60	46.00	0.125
	3 - 4	30.0	52.0	18.0	SiL	7.40	22.84	30.24	1.39	4.60	42.70	47.30	0.032
	4 - 5	14.0	49.0	37.0	SiCL	14.52	23.55	38.07	1.52	6.30	36.20	42.50	0.046

a/ Clay below 0.002 mm in diameter, silt 0.002 - 0.05 mm, sand 0.05 - 2.0 mm.
b/ S = sand, LS = loamy sand, SL = sandy loam, L = loam, SiL = silt loam, SiCL = silty clay loam.

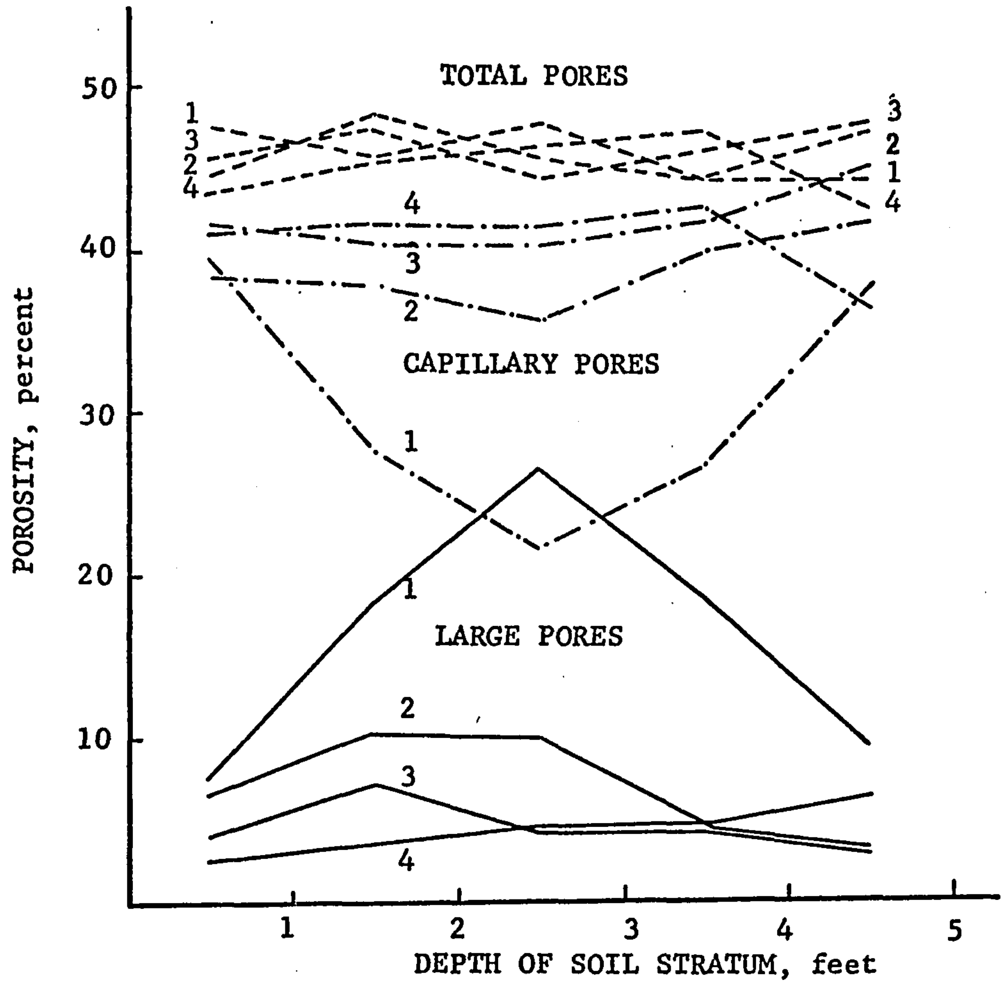

Figure 46. Distribution of pores in different soil strata in four (1-4) sampling pits in the 1961 plantation.

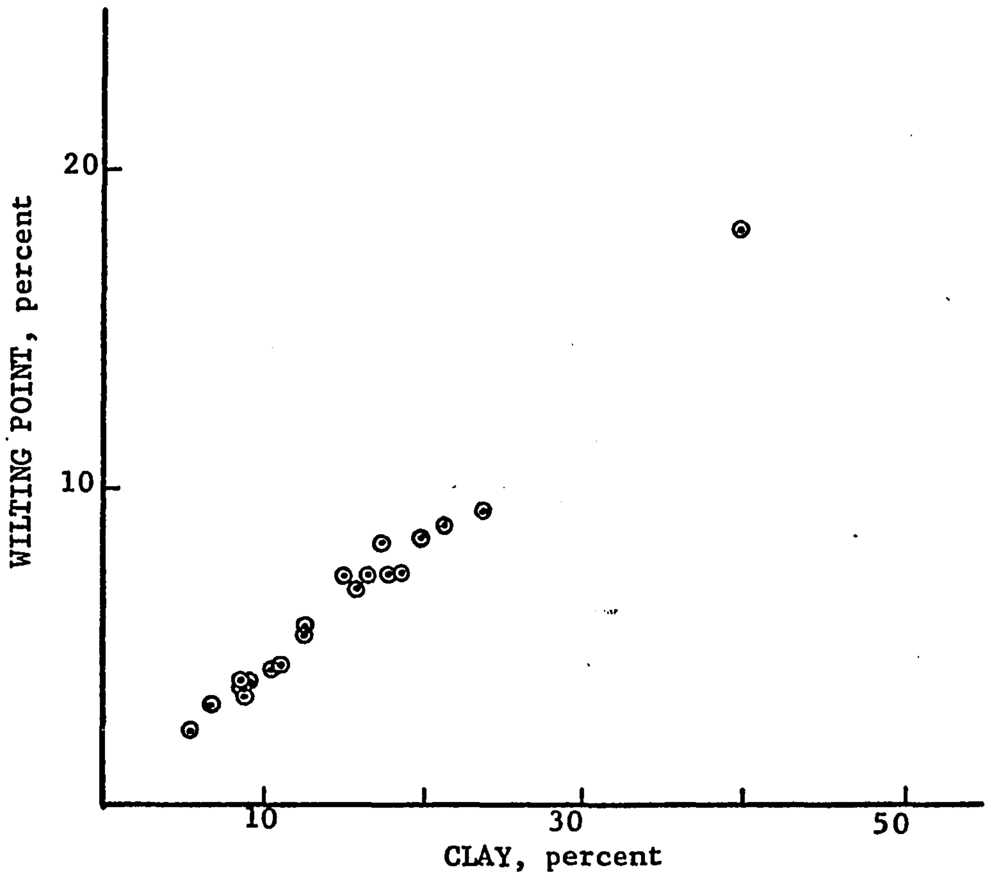

Figure 47. Relationship between wilting point and clay content in soil samples from the 1961 plantation.

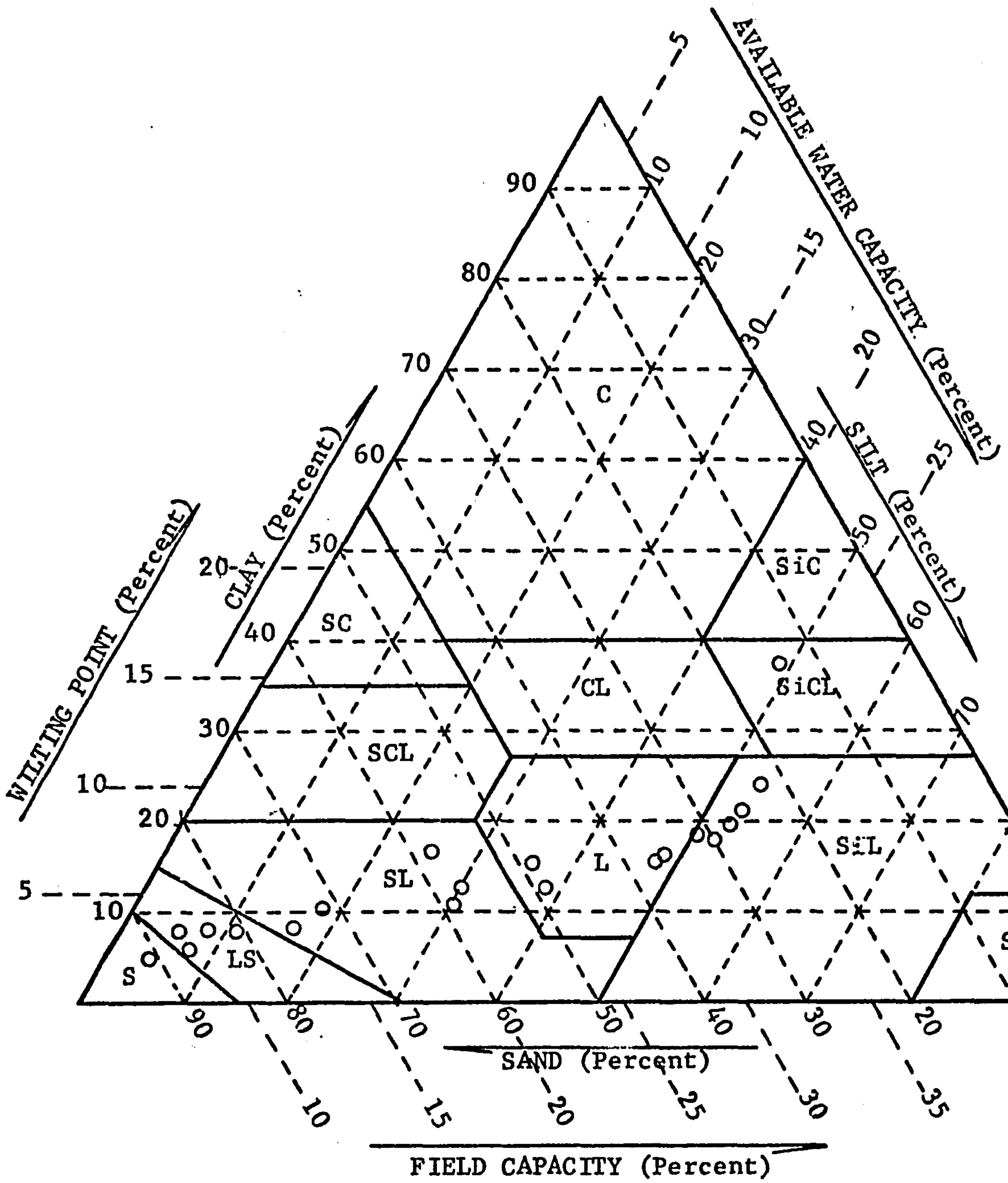

Figure 48. Relationships between soil-moisture constants and texture of soil samples from the 1961 plantation (cf. Curlin 1960). The circles (o) indicate the coordinates of textural soil fractions and soil-water constants in 20 samples.

Table 34. Soil textures in the 1962, 1963, and 1964 plantations

Pit	Soil depth	Textural fraction			Soil
		Sand	Silt	Clay	texture
No.	Feet	--------Percent--------			
		1962 Plantation			
5	0 - 1	70.3	18.1	11.6	SL
	1 - 2	62.0	23.2	14.8	SL
	2 - 3	77.0	12.4	10.6	SL
6	0 - 1	60.0	22.6	17.4	SL
	1 - 2	53.2	31.8	15.0	SL
	2 - 3	62.5	26.1	11.4	SL
7	0 - 1	51.5	34.9	13.6	SL
	1 - 2	47.4	40.9	11.7	L
	2 - 3	55.1	27.0	17.9	SL
8	0 - 1	55.0	26.3	18.7	SL
	1 - 2	35.0	38.2	26.8	L
	2 - 3	58.1	26.5	15.4	SL
9	0 - 1	23.5	49.2	27.3	SiL
	1 - 2	26.0	51.3	22.7	SiL
	2 - 3	32.8	46.0	21.2	L
10	0 - 1	14.5	51.5	34.0	SiCL
	1 - 2	17.2	53.0	29.8	SiCL
	2 - 3	24.9	48.0	27.1	CL
		1963 Plantation			
11	0 - 1	76.1	16.9	7.0	SL
	1 - 2	81.2	10.4	8.4	LS
	2 - 3	89.0	6.2	4.8	S
12	0 - 1	86.1	6.3	7.6	LS
	1 - 2	85.0	7.1	7.9	LS
	2 - 3	90.0	4.9	5.1	S
13	0 - 1	20.5	52.8	26.7	SiL
	1 - 2	21.8	47.2	31.0	CL
	2 - 3	18.0	49.1	32.9	SiCL
		1964 Plantation			
14	0 - 1	61.3	22.6	16.1	SiL
	1 - 2	50.2	31.0	18.8	CL
	2 - 3	57.0	28.6	14.4	SiCL
15	0 - 1	53.4	27.9	18.7	SL
	1 - 2	43.0	35.2	21.8	L
	2 - 3	59.7	29.9	10.4	SL

Table 35. Chemical status of soil in the 1961 plantation

Soil pit	Soil depth	Soil reaction	Hydrogen ion activity	Extractable ions P	K	Ca	Mg
No.	Feet	pH	10^{-8} moles/liter	ppm			
1	0 - 1	7.4	3.981	200	155	3530	1000+
	1 - 2	7.6	2.512	195	125	3280	1000
	2 - 3	7.8	1.585	159	90	2580	1000
	3 - 4	7.7	1.995	144	75	2120	1000
	4 - 5	7.9	1.259	137	75	2540	1000
2	0 - 1	7.4	3.981	171	190	3630	1000
	1 - 2	7.6	2.512	171	145	3430	1000
	2 - 3	7.7	1.995	168	115	3330	1000
	3 - 4	8.0	1.000	161	90	3280	1000
	4 - 5	7.9	1.259	178	115	4000+	1000
3	0 - 1	7.4	3.981	183	230	3580	1000
	1 - 2	7.6	2.512	200	155	3280	1000+
	2 - 3	7.7	1.995	220	110	2850	1000
	3 - 4	7.8	1.585	215	130	4000+	1000
	4 - 5	7.8	1.585	222	140	4000+	1000
4	0 - 1	7.3	5.012	224	265	3880	962
	1 - 2	7.6	2.512	212	175	3680	1000
	2 - 3	7.8	1.585	200	145	3940	1000
	3 - 4	7.9	1.259	224	155	4000+	1000
	4 - 5	7.9	1.259	224	155	4000+	1000+

Table 36. Chemical status of soil in the 1962 plantation

Soil pit	Soil depth	Soil reaction	Hydrogen ion activity	Extractable ions P	K	Ca	Mg
No.	Feet	pH	10^{-8} moles/liter	------------ppm	-------------		
5	0 - 1	7.5	3.162	205	150	2900	1000+
	1 - 2	7.7	1.995	198	145	3330	1000+
	2 - 3	7.8	1.585	188	135	3630	1000+
6	0 - 1	7.3	5.012	259	235	3530	1000+
	1 - 2	7.6	2.512	229	215	3380	1000+
	2 - 3	7.7	1.995	229	220	3630	1000+
7	0 - 1	7.3	5.012	210	200	3380	1000+
	1 - 2	7.5	3.162	215	150	3280	1000+
	2 - 3	7.7	2.512	188	105	2800	1000+
8	0 - 1	7.4	3.981	195	190	3480	1000+
	1 - 2	7.5	3.162	205	155	2580	1000+
	2 - 3	7.6	2.512	203	115	2360	1000+
9	0 - 1	7.6	2.512	166	165	4000+	1000+
	1 - 2	7.9	1.259	195	135	4000+	1000+
	2 - 3	7.8	1.585	188	135	4000+	1000+
10	0 - 1	7.7	1.995	142	185	4000+	1000+
	1 - 2	8.0	1.000	154	135	4000+	1000+
	2 - 3	7.8	1.585	176	145	4000+	1000+

Table 37. Chemical status of soil in the 1963 plantation

Soil pit	Soil depth	Soil reaction	Hydrogen ion activity	Extractable ions P	K	Ca	Mg
No.	Feet	pH	10^{-8} moles/liter	ppm			
11	0 - 1	7.6	2.512	176	145	3830	1000+
	1 - 2	7.9	1.259	171	115	4000	1000+
	2 - 3	7.9	1.259	166	90	3680	1000+
12	0 - 1	7.7	1.995	176	105	2800	1000+
	1 - 2	7.8	1.585	156	100	3330	1000+
	2 - 3	7.9	1.259	166	80	2950	1000+
13	0 - 1	7.7	1.995	190	175	4000+	1000+
	1 - 2	7.8	1.585	200	145	3330	1000+
	2 - 3	7.9	1.259	171	135	4000+	1000+

Table 38. Chemical status of soil in the 1964 plantation

Soil pit	Soil depth	Soil reaction	Hydrogen ion activity	Extractable ions P	K	Ca	Mg
No.	Feet	pH	10^{-8} moles/liter	ppm			
14	0 - 1	7.4	3.981	195	230	3680	1000+
	1 - 2	7.5	2.162	181	185	3780	1000+
	2 - 3	7.7	1.995	176	140	3000	1000+
15	0 - 1	7.5	2.162	207	190	3430	1000+
	1 - 2	7.7	1.995	185	135	3000	1000+
	2 - 3	7.8	1.585	171	100	2670	1000+

COMMERCE SERIES

The Commerce series is a member of a fine-silty, mixed, non-acid, thermic family of Aeric Fluventic Haplaquepts. They have nearly uniform grayish brown colors from the surface downward, medium acid to alkaline reaction, and medium to moderately fine texture throughout. Textures of the A horizon are very fine sandy loam, silt loam, loam, silty clay loam, and clay loam. The B horizon has weak to moderate subangular blocky structure and lack stratification indicative of very recent deposits. The C horizon is weakly calcareous in some places. They have formed from fairly recent alkaline Mississippi River alluvium of mixed mineralogy. The soils have sufficient age to have formed structure in the B horizon, and typically they have pH values that increase with depth.

The Commerce soils are on nearly level flood plains on flat or slightly convex slopes of about 0.5 to 3 percent. Most areas are protected by levees. These soils are somewhat poorly drained. Surface runoff is medium to slow. Permeability is moderately slow. The supply of moisture is adequate for plants in most years.

The principal associated soils are of usually adjacent Robinsonville, Tunica, Mhoon, and Sharkey series.

The representative profile of Commerce silt loam in the 1961 plantation is described below.

COMMERCE SILT LOAM

Location: West Feliciana Parish, Louisiana. Township 4S; Range 2W; Section 49. Forest lands of St. Francisville Paper Company. Cottonwood plantation 1961; soil sampling pit #4.

Vegetation: Cottonwood plantation. Until 1961 an abandoned cotton field.

Topography: Level. Altitude 40 feet.

Drainage and permeability: Moderately to poorly drained. Permeability is moderately slow in the upper part of the solum and slow in the lower part.

Parent Material: Mississippi alluvium.

Horizon	Depth	Description
Ap	0-6"	Dark grayish-brown (10YR 4/2) silt loam; moderate, medium and fine, granular structure; friable; slightly alkaline; abrupt, smooth boundary.

Horizon	Depth	Description
A12	6-14"	Grayish-brown (10YR 5/2) silt loam with common, medium, distinct, dark-brown (10YR 4/3) mottles; massive to weak, platy structure; friable; common worm casts; few, soft, black concretions; slightly alkaline; clear, smooth boundary.
B2	14-20"	Grayish-brown (10YR 5/2) silt loam with common, medium and coarse, distinct, dark yellowish-brown (10YR 4/4) mottles; massive to weak, medium, subangular blocky structure; slightly alkaline; gradual, smooth boundary.
B3g	20-34"	Gray (10YR 5/1) silt loam with grayish-brown (10YR 5/2) and brown (10YR 5/3) mottles; weak, medium, subangular blocky structure; slightly alkaline; friable; few black concretions; clear smooth boundary.
C1g	34-44"	Gray (10YR 5/1) silt loam with dark yellowish-brown (10YR 4/4) mottles; massive to weak, medium subangular blocky structure; friable; slightly alkaline; clear, smooth boundary.
C2g	44-54"	Gray (10YR 5/1) silt clay with common, medium and coarse, distinct, dark yellowish-brown (10YR 4/4) mottles; few lenses, to 3 inches thick, of silty clay loam, massive to weak, medium, subangular blocky structure; friable; slightly alkaline.

ROBINSONVILLE SERIES

The Robinsonville series is a member of the coarse-loamy, mixed, nonacid, thermic family of Typic Udifluvents. These soils have dark grayish brown A horizons and brown loamy stratified C horizons.

The Robinsonville series consists of well drained soils that formed medium-textured sediments deposited by the Mississippi River. The A horizon is silt loam, very fine sandy loam, fine sandy loam or loam. The C horizon is strata of silt loam, loam, fine sandy loam, loamy very fine sand, or loamy fine sand. Reaction in all horizons ranges from alightly acid to moderately alkaline.

These soils are on natural levees of flood plains and are nearly level to gently sloping. They are well drained. Runoff is slow to medium. Permeability is moderately rapid.

These soils are associated with Crevasse and Commerce soils. They are finer textured than the Crevasse soils. They are better drained than the Commerce soils and are mottled at greater depths.

The original forest cover consisted of cottonwood, sycamore, pecan, sweetgum, American elm, and boxelder, and a dense undergrowth of vines.

The representative profile of Robinsonville very fine sandy loam in the 1962 plantation (site B_2; soil sampling pit #8) is described below.

ROBINSONVILLE VERY FINE SANDY LOAM

Location: West Feliciana Parish, Louisiana. Township 4S; Range 2W; Section 48. Forest lands of Crown Zellerbach Corporation. Cottonwood plantation 1962; site B_2; soil sampling pit #8.

Vegetation: Cottonwood plantation; until 1962 an abandoned cotton field.

Topography: Level. Altitude 40 feet.

Drainage and permeability: Well drained. Runoff medium. Permeability moderate to moderately rapid.

Parent Material: Mississippi alluvium.

Horizon	Depth	Description
Ap	0-6"	Dark-brown (10YR 4/3) very fine sandy loam; weak, fine, granular structure; loose when dry, very friable when moist; numerous grass roots; alkaline; abrupt smooth boundary.
AC	6-18"	Brown (10YR 5/3) very fine sandy loam; stratified; loose when dry, very friable when moist; numerous grass roots; few old tree-root channels; slightly alkaline; clear smooth boundary.
C1	18-24"	Yellowish-brown (10YR 6/3) very fine sandy loam; stratified; loose when dry, very friable when moist, many fine grass roots; moderately alkaline; abrupt smooth boundary.
C2	24-36"	Pale-brown (10YR 6/3) very fine sandy loam; stratified; loose when dry, very friable when moist; few fine grass roots; old tree-root channels; moderately alkaline.

CREVASSE SERIES

The Crevasse series is a member of the mixed, thermic family of Typic Udipsamments. Typically these soils are grayish brown sand

throughout the 10- to 40-inch control section. These soils were laid down by very fast moving water, and they occur near old levee breaks along the Mississippi River. Texture of the A horizon is sand, loamy sand, or sandy loam. The C horizon is sand or loamy sand and lacks strata of finer materials. Soil reaction ranges from medium acid to moderately alkaline, and the soil is calcareous in some places. Crevasse soils are on nearly level to gently sloping flood plains having slopes of 0 to 5 percent. They are excessively drained. Runoff is slow and permeability is rapid. These soils flood in some places. The water table is below 40 inches. The principal associated soils are of Beulah, Bruno, Robinsonville, and the Commerce series. The Commerce soils are not as well drained and have finer texture.

The representative profile of Crevasse loamy sand soil in the 1963 plantation (site C_1, soil sampling pit #12) is described below.

CREVASSE LOAMY SAND

Location: West Feliciana Parish, Louisiana. Section 48 - forest lands of Crown Zellerbach Corporation. Cottonwood plantation 1963, site C_1, soil sampling pit #12.

Vegetation: Cottonwood plantation with a dense giant ragweed, until 1963 an abandoned cotton field.

Topography: Nearly level (0-1% slope); altitude 45 feet.

Drainage and Permeability: Excessively drained. Moderately permeable in the upper part of the solum and rapidly in the lower part.

Parent Material: Mississippi alluvium.

Horizon	Depth	Description
A1	0-8"	Grayish-brown (10YR 5/2) loamy sand; weak, granular structure; very friable; numerous grains of clear quartz crystals; mildly alkaline; gradual smooth boundary.
AC	8-20"	Pale brown (10YR 6/3) loamy sand; single grain; loose; moderately alkaline; diffuse, irregular boundary.
C	20-40"	Pale brown sand; single grain; loose; numerous grains of clear quartz crystals; moderately alkaline.

APPENDIX B

TABLES OF ANALYSES OF VARIANCE

In all the tables the following notations are used:

** = Significant at the 0.01 level of probability.
 * = Significant at the 0.05 level of probability.

Table 39. Analysis of variance of first-year survival in the 1961 plantation

Source	d.f.	Mean square	F
Total	479		
Blocks	23	0.538	3.202**
Depth of planting (C_d)	4	0.512	3.048**
Regr. linear	1	0.623	3.708
Regr. quadratic	1	1.398	8.321**
Regr. cubic	1	0.014	0.083
Regr. quartic	1	0.016	0.095
Length of cutting above the ground (C_h)	3	0.746	4.440**
Regr. linear	1	1.495	8.899**
Regr. quadratic	1	0.689	4.101*
Regr. cubic	1	0.054	0.321
Interaction (C_d) x (C_h)	12	0.275	1.637
Error	430	0.168	

Table 40. Analysis of variance of first-year survival in the 1962 plantation (site B_1)

Source	d.f.	Mean square	F
Total	239		
Blocks	9	0.331	1.578
Deep cultivation of soil in hole (Q)	1	0.393	1.873
Depth of planting (C_d)	1	4.892	23.316**
Length of cutting above the ground (C_h)	1	1.356	6.462*
Fertilizer (E)	2	0.582	2.777
Interaction (Q) x (C_d)	1	0.139	0.663
Interaction (Q) x (C_h)	1	0.150	0.716
Interaction (Q) x (E)	2	0.283	1.351
Interaction (C_d) x (C_h)	1	1.171	5.582*
Interaction (C_d) x (E)	2	0.247	1.179
Interaction (C_h) x (E)	2	0.079	0.380
Error	216	0.209	

Table 41. Analysis of variance of first-year survival in the 1962 plantation (site B_2)

Source	d.f.	Mean square	F
Total	239		
Blocks	9	0.123	0.537
Deep cultivation of soil in hole (Q)	1	1.378	6.018*
Depth of planting (C_d)	1	0.596	2.604
Length of cutting above the ground (C_h)	1	0.272	1.190
Fertilizer (E)	2	0.701	3.064
Interaction (Q) x (C_d)	1	0.442	1.930
Interaction (Q) x (C_h)	1	0.006	0.025
Interaction (Q) x (E)	2	0.911	3.979*
Interaction (C_d) x (C_h)	1	1.472	6.429*
Interaction (C_d) x (E)	2	0.308	1.343
Interaction (C_h) x (E)	2	0.013	0.055
Error	216	0.229	

Table 42. Analysis of variance of first-year survival in the 1962 plantation (site B_3)

Source	d.f.	Mean square	F
Total	239		
Blocks	9	0.515	2.268
Deep cultivation of soil in hole (Q)	1	0.035	0.154
Depth of planting (C_d)	1	0.048	0.212
Length of cutting above the ground (C_h)	1	0.253	1.114
Fertilizer (E)	2	0.240	1.056
Interaction (Q) x (C_d)	1	0.303	1.334
Interaction (Q) x (C_h)	1	0.000	
Interaction (Q) x (E)	2	0.099	0.438
Interaction (C_d) x (C_h)	1	0.817	3.594
Interaction (C_d) x (E)	2	0.673	2.964
Interaction (C_h) x (E)	2	0.674	2.965
Error	216	0.227	

Table 43. Analysis of variance of first-year survival in the 1963 plantation (site C_1)

Source	d.f.	Mean square	F
Total	863		
Blocks	17	0.230	1.04
Cultivation by bedding (B)	1	4.740	21.43**
Error (a)	17	0.221	
Mulch (M)	1	0.462	4.35*
Interaction (B x M)	1	0.004	0.04
Error (b)	34	0.106	
Deep cultivation of soil in hole (Q)	1	7.782	54.69**
Interaction (B x Q)	1	1.185	8.33*
Interaction (M x Q)	1	0.074	0.52
Interaction (B x M x Q)	1	0.115	0.81
Error (c)	68	0.142	
Depth of planting (C_d)	1	2.449	17.49**
Interaction (Q x C_d)	1	2.893	20.67**
Interaction (M x C_d)	1	0.166	1.19
Interaction (M x Q x C_d)	1	0.018	0.13
Interaction (B x C_d)	1	0.018	0.13
Interaction (B x Q x C_d)	1	0.074	0.53
Interaction (B x M x C_d)	1	0.004	0.03
Interaction (B x M x Q x C_d)	1	0.004	0.03
Error (d)	136	0.139	
Length of cutting above the ground (C_h)	2	0.910	8.94**
Interaction (C_d x C_h)	2	0.181	1.79
Interaction (Q x C_h)	2	0.334	3.28*
Interaction (Q x C_d x C_h)	2	0.077	0.76
Interaction (M x C_h)	2	0.049	0.48
Interaction (M x C_d x C_h)	2	0.010	0.10
Interaction (M x Q x C_h)	2	0.001	0.01
Interaction (M x Q x C_d x C_h)	2	0.035	0.35
Interaction (B x C_h)	2	0.244	2.41
Interaction (B x C_d x C_h)	2	0.209	2.07
Interaction (B x Q x C_h)	2	0.112	1.11
Interaction (B x Q x C_d x C_h)	2	0.466	4.57*
Interaction (B x M x C_h)	2	0.358	3.54*
Interaction (B x M x C_d x C_h)	2	0.015	0.15
Interaction (B x M x Q x C_h)	2	0.070	0.69
Interaction (B x M x Q x C_d x C_h)	2	0.188	1.86
Error (e)	544	0.101	

Table 44. Analysis of variance of first-year survival in the 1963 plantation (site C_2)

Source	d.f.	Mean square	F
Total	191		
Blocks	3	0.614	3.26
Cultivation by bedding (B)	1	0.333	1.77
Error (a)	3	0.188	
Mulch (M)	1	0.333	1.86
Interaction (B x M)	1	0.187	1.04
Error (b)	6	0.179	
Deep cultivation of soil in hole (Q)	1	0.333	1.54
Interaction (B x Q)	1	0.187	0.86
Interaction (M x Q)	1	0.520	2.41
Interaction (B x M x Q)	1	0.083	0.38
Error (c)	12	0.216	
Depth of planting (C_d)	1	0.333	1.32
Interaction (Q x C_d)	1	1.687	6.66**
Interaction (M x C_d)	1	0.187	0.74
Interaction (M x Q x C_d)	1	0.083	0.33
Interaction (B x C_d)	1	0.020	0.08
Interaction (B x Q x C_d)	1	0.333	1.32
Interaction (B x M x C_d)	1	0.000	
Interaction (B x M x Q x C_d)	1	0.020	0.08
Error (d)	24	0.253	
Length of cutting above the ground (C_h)	2	0.109	0.48
Interaction (C_d x C_h)	2	0.380	1.67
Interaction (Q x C_h)	2	0.255	1.12
Interaction (Q x C_d x C_h)	2	0.046	0.20
Interaction (M x C_h)	2	0.036	0.16
Interaction (M x C_d x C_h)	2	0.203	0.89
Interaction (M x Q x C_h)	2	0.098	0.43
Interaction (M x Q x C_d x C_h)	2	0.036	0.16
Interaction (B x C_h)	2	0.192	0.84
Interaction (B x C_d x C_h)	2	0.255	1.12
Interaction (B x Q x C_h)	2	0.484	2.13
Interaction (B x Q x C_d x C_h)	2	0.192	0.84
Interaction (B x M x C_h)	2	0.203	0.89
Interaction (B x M x C_d x C_h)	2	0.953	4.20*
Interaction (B x M x Q x C_h)	2	0.036	0.16
Interaction (B x M x Q x C_d x C_h)	2	0.348	1.53
Error (e)	96	0.227	

Table 45. Analysis of variance of first-year shoot growth (h_1-C_o) in the 1961 plantation

Source	d.f.	Mean square	F
Total	314		
Blocks	23	9.911	4.203**
Depth of planting (C_d)	4	3.618	1.534
Regression linear	1	6.210	2.634
" quadratic	1	5.648	2.395
" cubic	1	2.456	1.042
" quartic	1	0.158	0.067
Length of cutting above the ground (C_h)	3	31.712	13.449**
Regression linear	1	83.193	35.282**
" quadratic	1	5.643	2.393
" cubic	1	6.299	2.672
Interaction (C_d x C_h)	12	3.722	1.579
Error	272	2.358	

Table 46. Analysis of variance of first-year tree height (h_1) in the 1961 plantation

Source	d.f.	Mean square	F
Total	314		
Blocks	23	12.206	5.223**
Depth of planting (C_d)	4	1.381	0.591
Regression linear	1	2.990	1.279
" quadratic	1	0.946	0.405
" cubic	1	0.856	0.366
" quartic	1	0.733	0.314
Length of cutting above the ground (C_h)	3	24.667	10.554**
Regression linear	1	68.569	29.338**
" quadratic	1	0.165	0.070
" cubic	1	5.269	2.254
Interaction (C_d x C_h)	12	5.788	2.477**
Error	272	2.337	

Table 47. Analysis of variance of first-year tree height (h_1) in the 1962 plantation

Source	d.f.	Mean square	F
Total	383		
Site	2	83.648	12.481**
Block/site	27	6.710	
Deep cultivation of soil in hole (Q)	1	20.054	7.002**
Depth of planting (C_d)	1	15.489	5.409*
Length of cutting above the ground (C_h)	1	19.960	6.970**
Fertilizer (E)	2	32.306	11.280**
Interaction (Q) x (C_d)	1	0.582	0.203
" (Q) x (C_h)	1	1.418	0.495
" (Q) x (E)	2	2.560	0.894
" (C_d) x (C_h)	1	1.761	0.615
" (C_d) x (E)	2	3.478	1.215
" (C_h) x (E)	2	3.724	1.300
Covariate ($C_\emptyset^2$) b -linear	1	23.641	8.255**
" " b -quadr.	1	2.195	0.767
" " b -cubic	1	1.167	0.408
Error	336	2.864	

Table 48. Analysis of variance of live part of cutting (C_o) in the 1962 plantation

Source	d.f.	Mean square	F
Total	381		
Site	2	2.062	7.392**
Blocks/Site	27	0.279	
Deep cultivation of soil in hole (Q)	1	2.024	0.942
Depth of planting (C_d)	1	0.131	0.611
Length of cutting above the ground (C_h)	1	72.508	337.642**
Fertilizer (E)	2	0.797	3.712*
Interaction ($Q \times C_d$)	1	0.117	0.545
" ($Q \times C_h$)	1	0.218	1.017
" ($Q \times E$)	2	0.061	0.287
" ($C_d \times C_h$)	1	0.026	0.121
" ($C_d \times E$)	2	0.117	0.546
" ($C_h \times E$)	2	0.236	1.102
Covariate $C_{\emptyset}^2$	1	1.039	4.842*
Error	337	0.214	

Table 49. Analysis of variance of first-year tree height (h_1) in the 1964 plantation

Source	d.f.	Mean square	F
Total	319		
Blocks	17	1644.338	5.25**
Diameter of hole ($H_\emptyset$)	3	2638.627	8.43**
Error (a)	51	312.912	
Depth of planting (C_d)	1	27573.543	99.25**
Interaction ($H_\emptyset$ x C_d)	3	591.872	2.13
Error (b)	244	277.825	

Table 50. Analysis of variance of first-year tree height (h_1) of four clones in the 1968 plantation

Source	d.f.	Mean square	F
Total	188		
Clones	3	0.275	9.192**
Regr. linear of covariate $C_{\emptyset t}$	1	0.614	20.482**
Regr. quadr. of covariate $C_{\emptyset t}$	1	0.428	14.273**
Error	183	0.030	

Table 51. Analysis of variance of first-year diameter at the base of tree of four clones in the 1968 plantation

Source	d.f.	Mean square	F
Total	188		
Clones	3	92.971	5.655**
Regr. linear of covariate $C_{\phi t}$	1	306.375	18.636**
Regr. quadr. of covariate $C_{\phi t}$	1	195.505	11.892**
Error	183	16.439	

Table 52. Analysis of variance of first-year diameter at 40 inches above the base of tree of four clones in the 1968 plantation

Source	d.f.	Mean square	F
Total	188		
Clones	3	38.197	3.125*
Regr. linear of covariate $C_{\phi t}$	1	225.017	18.408**
Regr. quadr. of covariate $C_{\phi t}$	1	151.338	12.380**
Error	183	12.224	

Table 53. Analysis of variance of first-year diameter at 80 inches above the base of tree of four clones in the 1968 plantation

Source	d.f.	Mean squares	F
Total	188		
Clone	3	68.211	5.263**
Regr. linear of covariate $C_{\phi t}$	1	233.453	18.013**
Regr. quadr. of covariate $C_{\phi t}$	1	161.044	12.426**
Error	183	12.960	

Table 54. Analysis of variance of two-year tree height (h_2) in the 1961 plantation

Source	d.f.	Mean square	F
Total	314		
Blocks	23	123.225	16.231**
Depth of planting (C_d)	4	14.876	1.959
Regression linear	1	7.680	1.012
" quadratic	1	19.281	2.540
" cubic	1	5.616	0.740
" quartic	1	26.927	3.547
Length of cutting above the ground (C_h)	3	27.486	3.620**
Regression linear	1	60.881	8.019**
" quadratic	1	0.169	0.022
" cubic	1	21.408	2.820
Interaction (C_d x C_h)	12	12.816	1.688
Error	272	7.592	

Table 55. Analysis of variance of two-year dbh in the 1961 plantation

Source	d.f.	Mean square	F
Total	314		
Blocks	23	339.404	11.539**
Depth of planting (C_d)	4	37.474	1.274
Regression linear	1	47.068	1.600
" quadratic	1	24.575	0.835
" cubic	1	2.950	0.100
" quadratic	1	75.304	2.560
Length of cutting above the ground (C_h)	3	160.077	5.442*
Regression linear	1	340.821	11.587**
" quadratic	1	2.359	0.080
" cubic	1	137.052	4.660*
Interaction (C_d x C_h)	12	44.425	1.510
Error	272	29.413	

Table 56. Analysis of variance of second-year height increment (h_2-h_1) in the 1961 plantation

Source	d.f.	Mean square	F
Total	314		
Blocks	23	65.124	20.057**
Depth of planting (C_d)	4	12.878	3.966**
Regression linear	1	0.414	0.128
" quadratic	1	24.911	7.672**
" cubic	1	2.981	0.918
" quartic	1	23.206	7.147**
Length of cutting above the ground (C_h)	3	2.821	0.869
Regression linear	1	0.403	0.124
" quadratic	1	0.067	0.021
" cubic	1	7.994	2.462
Interaction (C_d x C_h)	12	3.268	1.007
Error	272	3.247	

Table 57. Analysis of variance of two-year tree height (h_2) in the 1962 plantation

Source	d.f.	Mean square	F
Total	361		
Site	2	243.652	4.530*
Blocks/site	27	53.775	
Deep cultivation of soil in hole (Q)	1	36.639	3.639
Depth of planting (C_d)	1	141.704	14.074**
Length of cutting above the ground (C_h)	1	137.591	13.665**
Fertilizer (E)	2	76.034	7.552**
Interaction (Q x C_d)	1	4.105	0.408
" (Q x C_h)	1	0.117	0.012
" (Q x E)	2	2.568	0.255
" (C_d x C_h)	1	22.028	2.188
" (C_d x E)	2	15.168	1.506
" (C_h x E)	2	4.556	0.453
Covariate $C_\emptyset^2$ b-linear	1	39.707	3.944*
" " b-quadr.	1	1.584	0.157
" " b-cubic	1	6.140	0.610
Error	314	10.068	

Table 58. Analysis of variance of two-year dbh in the 1962 plantation

Source	d.f.	Mean square	F
Total	361		
Site	2	1374.370	5.465*
Blocks/site	27	251.481	
Deep cultivation of soil in hole (Q)	1	359.517	9.318**
Depth of planting (C_d)	1	615.918	15.964**
Length of cutting above the ground (C_h)	1	691.624	17.926**
Fertilizer (E)	2	351.709	9.116**
Interaction (Q x C_d)	1	80.204	2.079
" (Q x C_h)	1	2.852	0.074
" (Q x E)	2	0.137	0.004
" (C_d x C_h)	1	16.908	0.438
" (C_d x E)	2	55.584	1.441
" (C_h x E)	2	9.363	0.243
Covariate C_ϕ^2 b-linear	1	156.584	4.058*
" " b-quadr.	1	14.895	0.386
" " b-cubic	1	53.070	1.375
Error	314	38.583	

Table 59. Analysis of variance of three-year tree height (h_3) in the 1961 plantation

Source	d.f	Mean square	F	
Total	268			
Blocks	23	203.980	16.018**	
Depth of planting (C_d)	4	5.729	0.450	
Regression linear	1	2.547	0.200	
" quadratic	1	11.714	0.920	
" cubic	1	0.156	0.012	
" quartic	1	8.497	0.667	
Length of cutting above the ground (C_h)	3	31.305	2.458	Sign. at 0.10 p.l.
Regression linear	1	33.493	2.638	Sign. at 0.10 p.l.
" quadratic	1	7.847	0.616	
" cubic	1	52.477	4.121*	
Interaction (C_d x C_h)	12	17.521	1.376	
Error	225	12.734		

Table 60. Analysis of variance of seven-year tree height (h_7) in the 1961 plantation

Source	d.f.	Mean square	F	
Total	268			
Blocks	23	566.762	7.435**	
Depth of planting (C_d)	4	47.156	0.619	
Regression linear	1	4.945	0.065	
" quadratic	1	149.020	1.955	Sign. at 0.25 p.l.
" cubic	1	30.019	0.394	
" quartic	1	4.640	0.061	
Length of cutting above the ground (C_h)	3	169.755	2.227	Sign. at 0.10 p.l.
Regression linear	1	262.801	3.447	Sign. at 0.10 p.l.
" quadratic	1	44.049	0.578	
" cubic	1	202.415	2.655	
Interaction (C_d x C_h)	12	67.870	0.890	
Error	225	76.231		

APPENDIX C

REGRESSION EQUATIONS

In all regression equations the following notations are used:

** = Significant at the 0.01 level of probability.
 * = Significant at the 0.05 level of probability.
The values of F for b-coefficients are given also.

$$T_m = 47.99 - 19.93\ C_d - 7.14\ C_h + 3.59\ C_d^2 + 2.03\ C_h^2 \qquad (1)$$

with F for coeff.: b_1--3.22; b_2--1.76; b_3--4.26; b_4--4.26;
Multiple F = 4.30* with 4 & 15 d.f.; R-square = 0.534;

where T_m is the percentage of first-year mortality in the 1961 plantation.

$$T_m = 105 - 31.3\ C_d - 17.4\ R_p + 4.08\ C_d^2 + 0.91\ R_p^2 + 1.76\ C_d R_p \qquad (2)$$

with F for coeff.: b_1--7.58*; b_2--9.61**; b_3--5.83*; b_4--6.94*; b_5--6.31*;

Multiple F = 3.47* with 5 & 14 d.f.; R-square = 0.554.

$$C_o = -4.13 + 1.3\ C_h + 0.003\ C_d^2 - 0.0047\ C_h^2 - 0.014\ C_d\ C_h \qquad (3)$$

with F for coeff.: b_1--116.87**, b_2--10.2**, b_3--5.97*, b_4-- 47.28**;

Multiple F = 150.97** with 4 & 344 d.f.; R-square = 0.637

$$(h_1 - C_o) = 4.35 + 1.247\ C_d - 0.564\ C_h - 0.162\ C_d^2 + 0.088\ C_h^2 - 0.045\ C_d\ C_h \qquad (4)$$

with F for coeff.: b_1--7.80**, b_2--5.03*, b_3--5.58*, b_4--4.80*, b_5--3.91*;

Multiple F = 5.95** with 5 & 343 d.f.; R-square = 0.08

$$(h_1 - C_o) = 6.12 - 0.44\ C_o \qquad (5)$$

F = 44.64** with 1 & 348 d.f.; R-square = 0.114

$$h_1 = 5.10 + 0.357\ C_d + 0.828\ C_h - 0.157\ C_d\ C_h \qquad (6)$$

with F for coeff.: b_1--6.57*, b_2--32.86**, b_3--11.92**;
Multiple F = 17.74** with 3 &345 d.f.; R-square = 0.134

$$h_1 = 6.13 + 0.557\ C_o \qquad (7)$$

F = 70.78** with 1 & 348 d.f.; R-square = 0.169

$$h_1 = -1.46 + 6.78\ C_{\emptyset b} - 1.27\ C_{\emptyset b}^2 \qquad (8)$$

with F for coeff.: b_1--8.93**, b_2--6.43*;
Multiple F = 12.57** with 2 & 380 d.f.; R-square = 0.062
where $C_{\emptyset b}$ is in centimeters.

$$h_1 = 3.49 + 0.38\ C_d + 0.27\ C_h + 1.47\ C_{\emptyset t} \quad (9)$$

with F for coeff.: b_1--9.91**, b_2--5.28*, b_3--27.17**;

Multiple F = 12.70** with 3 & 379 d.f.; R-square = 0.091,

where $C_{\emptyset t}$ is in centimeters.

$$h_1 = 3.64 + 0.04968\ T_s \quad (10)$$

F = 88.27** with 1 & 71 d.f.; R-square = 0.554

$$h_1 = 4.05 - 1.25\ Q + 0.7218\ (B \times Q) + 0.04735\ T_s \quad (11)$$

with F for coeff.: b_1--12.88**, b_2--20.31**, b_3--96.82**;

Multiple F = 44.34** with 3 & 69 d.f.; R-square = 0.659

where Q-treatment is coded: -Q = 1, and +Q = 2, and
B-treatment is coded: -B = 1, and +B = 2.

$$h_1 = 7.897 + 0.08522\ T_s \quad (12)$$

F = 14.35** with 1 & 8 d.f.; R-square = 0.642

$$h_1 = 5.16 + 0.0019\ H_\theta \quad (13)$$

F = 1.18^{ns} with 1 & 134 d.f.; R-square = 0.0087

where h_1 is first-year height of trees planted with
20-inch-long cuttings 16 inches deep.

$$h_1 = 6.37 + 0.0087\ H_\theta \quad (14)$$

F = 35.64** with 1 & 182 d.f.; R-square = 0.164

where h_1 is first-year height of trees planted with
40-inch-long cuttings 3 feet deep.

$$h_1 = 11.77 - 1.539\ C_{\phi t}^2 \quad (15)$$

$F = 6.24*$ with 1 & 39 d.f.; R-square = 0.138

where h_1 in feet is for P. deltoides cl. 'Mississippi', and $C_{\phi t}$ is in inches.

$$h_1 = 6.69 + 3.831\ C_{\phi t}^2 \quad (16)$$

$F = 8.22**$ with 1 & 48 d.f.; R-square = 0.146

where h_1 in feet is for P. x euramericana cl. 'I-488', and $C_{\phi t}$ is in inches.

$$h_1 = -4.06 + 34.2445\ C_{\phi t} - 18.434\ C_{\phi t}^2 \quad (17)$$

with F for coeff.: b_1--15.68**, b_2--11.47**;

Multiple $F = 15.29**$ with 2 & 47 d.f.; R-square = 0.394

h_1 is maximum when $dh_1/dC_{\phi t} = b_1 - 2b_2\ C_{\phi t} = 0$, and it is

when $C_{\phi t} = b_1/2b_2 = 34.2445 / 36.868 = 0.928$ inches,

where h_1 in feet is for P. x euramericana cl. 'Belgian', and $C_{\phi t}$ is in inches.

$$h_1 = 7.75 + 2.151\ C_{\phi t}^2 \quad (18)$$

$F = 8.16**$ with 1 & 46 d.f.; R-square = 0.151

where h_1 in feet is for P. x euramericana cl. 'I-214', and $C_{\phi t}$ is in inches.

$$h_2 = 3.43 + 2.698\ h_1 - 2.962\ C_d + 0.031\ C_d^2 - 0.0076\ h_1^2 + 0.012\ h_1\ C_d \quad (19)$$

with F for coeff.: b_1--40.22**, b_2--16.39**, b_3--11.14**, b_4--9.64**, b_5--4.66**;

Multiple $F = 161.13**$ with 5 & 309 d.f.; R-square = 0.723

$$h_2 = -3.49 + 3.413\ h_1 - 0.1\ h_1^2 \qquad (20)$$

with F for coeff.: b_1--54.77**, b_2--12.21**;

Multiple F = 307.75** with 2 & 265 d.f.; R-square = 0.699

$$(h_2-h_1) = 3.21 + 1.72\ h_1 - 2.827\ C_d + 0.0.29\ C_d^2 - 0.007\ h_1^2 + 0.0116\ h_1\ C_d \qquad (21)$$

with F for coeff.: b_1--15.38**, b_2--14.14**, b_3--9.54**,

b_4--9.31**, b_5--4.13*;

Multiple F = 36.14** with 5 & 309 d.f.; R-square = 0.369

$$(h_2-h_1) = 2.10 + 2.062\ h_1 - 0.0078\ h_1^2 \qquad (22)$$

with F for coeff.: b_1--27.00**, b_2--9.55**;

Multiple F = 79.42** with 2 & 312 d.f.; R-square = 0.337

$$h_X = -4.54 + 1.2369\ C_o - 0.1918\ C_o^2 + 9.9074\ X + 0.0297\ X^3 + 0.2261\ C_o\ X \qquad (23)$$

with F for coeff.: b_1--6.69**, b_2--4.01*, b_3--871.41**,

b_4--30.33**, b_5--15.54**;

Multiple F = 2124.12** with 5 & 1334 d.f.; R-square = 0.888

$$h_X = -33.13 + 5.1751\ h_1 - 0.26312\ h_1^2 + 11.321\ X - 0.74799\ X^2 + 0.00972\ X^3 + 0.43356\ h_1\ X \qquad (24)$$

with F for coeff.: b_1--71.47**, b_2--53.86**, b_3--16.20**,

b_4--12.99**, b_5--4.07*, b_6--89.94**;

Multiple F = 1842.35** with 6 & 1065 d.f.; R-square = 0.912

$$h_2 = 5.11 + 8.048\ dbh_2 - 0.795\ dbh_2^2 \quad (25)$$

with F for coeff.: b_1--271.63**, b_2--39.20**;

Multiple F = 914.91** with 2 & 265 d.f.; R-square = 0.873

$$h_3 = 2.60 + 9.367\ dbh_3 - 0.601\ dbh_3^2 \quad (26)$$

with F for coeff.: b_1--122.91**, b_2--27.71**;

Multiple F = 509.10** with 2 & 265 d.f.; R-square = 0.793

$$h_6 = -2.38 + 12.068\ dbh_6 - 0.512\ dbh_6^2 \quad (27)$$

with F for coeff.: b_1--99.19**, b_2--31.53**

Multiple F = 401.42** with 2 & 265 d.f.; R-square = 0.752

$$h_7 = 3.69 + 9.953\ dbh_7 - 0.296\ dbh_7^2 \quad (28)$$

with F for coeff.: b_1--60.80**, b_2--11.70;

Multiple F = 429.79** with 2 & 265 d.f.; R-square = 0.764

$$h_6 = 3.11 + 9.519\ h_1 - 0.368\ h_1^2 \quad (29)$$

with F for coeff.: b_1--43.69**, b_2--17.01**;

Multiple F = 133.00** with 2 & 265 d.f.; R-square = 0.501

$$h_3 = 1.42 + 1.9789\ h_2 - 0.02973\ h_2^2 + 0.06578\ (h_2 \times dbh_2) \quad (30)$$

with F for coeff.: b_1--151.35**, b_2--19.79**, b_3--10.08**;

Multiple F = 994.62** with 3 & 264 d.f.; R-square = 0.919

$$dbh_3 = 0.22 + 0.2623\ h_2 - 0.0112\ h_2^2 + 0.0687\ (h_2 \times dbh_2) \quad (31)$$

with F for coeff.: b_1--55.43**, b_2--58.64**, b_3--229.32**;

Multiple F = 609.19** with 3 & 264 d.f.; R-square = 0.874

$$h_6 = 0.05 + 5.07\ h_2 - 0.13559\ h_2^2 + 0.26864\ (h_2 \times dbh_2) \qquad (32)$$

with F for coeff.: b_1--88.87**, b_2--36.82**, b_3--15.04**;

Multiple F = 206.16** with 3 & 264 d.f.; R-square = 0.701

$$dbh_6 = 1.01 + 0.54\ h_2 - 0.0253\ h_2^2 + 0.11994\ (h_2 \times dbh_2) \qquad (33)$$

with F for coeff.: b_1--32.49**, b_2--41.31**, b_3--96.55**;

Multiple F = 150.96** with 3 & 264 d.f.; R-square = 0.632

$$h_7 = 6.76 + 4.981\ h_2 - 0.1509\ h_2^2 + 0.4335\ (h_2 \times dbh_2) \qquad (34)$$

with F for coeff.: b_1--58.08**, b_2--30.88**, b_3--26.53**;

Multiple F = 164.31** with 3 & 264 d.f.; R-square = 0.651

$$dbh_7 = 2.10 + 0.5135\ h_2 - 0.02649\ h_2^2 + 0.1325\ (h_2 \times dbh_2) \qquad (35)$$

with F for coeff.: b_1--19.44**, b_2--29.96**, b_3--78.08**;

Multiple F = 100.42** with 3 & 264 d.f.; R-square = 0.533

$$\overline{V} = 7.123 - 0.15486\ \overline{h}_7 + 0.002984\ (\overline{dbh}_7^{\,2} \times \overline{h}_7) \qquad (36)$$

with F for coeff.: b_1--10.85**, b_2--94.15**;

Multiple F = 167.18** with 2 & 17 d.f.; R-square = 0.952

$$\overline{V} = 7.74 - 0.32339\ \overline{h}_7 + 0.043517\ (\overline{dbh}_7 \times h_7) \qquad (37)$$

with F for coeff.: b_1--27.94**, b_2--101.44**;

Multiple F = 178.80** with 2 & 17 d.f.; R-square = 0.955

$$\overline{V} = 0.853 + 0.0020424\ (\overline{dbh}_7^{\,2} \times \overline{h}_7) \qquad (38)$$

F = 209.05** with 1 & 18 d.f.; R-square = 0.921

$$\overline{V} = -1.688 + 0.17068\ \overline{dbh}_7^{\,2} \qquad (39)$$

F = 369.20** with 1 & 18 d.f.; R-square = 0.954

$$V_t = 1.833 - 2.517\ T_{s7} + 0.5856\ (T_{s7} \times \overline{dbh_7}) \qquad (40)$$

with F for coeff.: b_1--115.44**, b_2--401.87**;

Multiple F = 607.17** with 2 & 17 d.f.; R-square = 0.986

$$\overline{V} = -8.863 + 0.2691\ \overline{h}_7 \qquad (41)$$

F = 38.94** with 1 & 18 d.f.; R-square = 0.684

$$T_{s7} = 8.16 + 0.726\ T_{s2} \qquad (42)$$

F = 38.28** with 1 & 18 d.f.; R-square = 0.68

$$V_t = -35.52 + 18.799\ \overline{V} \qquad (43)$$

F = 32.23** with 1 & 18 d.f.; R-square = 0.64

$$h_7 = 57.22 + 4.472 \log C_h \qquad (44)$$

F = 9.29** with 1 & 266 d.f.; R-square = 0.034

Where h_7 and C_h are for all trees in the 1961 plantation.

$$dbh_7 = 6.93 + 0.51 \log C_h \qquad (45)$$

F = 502* with 1 & 266 d.f.; R-square = 0.019

Where dbh_7 and C_h are for all trees in the 1961 plantation.

$$V = 6.579 + 1.048 \log C_h \qquad (46)$$

F = 3.40^{ns} with 1 & 266 d.f.; R-square = 0.013

Where V and C_h are for all trees in the 1961 plantation.

$$h_7 = 56.23 + 5.3777 \log C_h \qquad (47)$$

F = 6.87** with 1 & 159 d.f.; R-square = 0.041

Where h_7 and C_h are for trees planted 3, 4, and 5 feet deep in the 1961 plantation.

$dbh_7 = 6.81 + 0.6957 \log C_h$ (48)

F = 5.38* with 1 & 159 d.f.; R-square = 0.033

Where dbh_7 and C_h are for trees planted 3, 4, and 5 feet deep in the 1961 plantation.

$V = 6.301 + 1.499 \log C_h$ (49)

F = 3.89* with 1 & 159 d.f.; R-square = 0.024

Where V and C_h are for trees planted 3, 4, and 5 feet deep in the 1961 plantation.

$h_3 = 22.55 + 0.777\ C_o + 0.2677\ (S) - 0.00398\ (S)^2$ (50)

F for coeff.: b_1--15.88**, b_2--17.03**, b_3--32.25**;

Multiple F = 44.25** with 3 & 305 d.f.; R-square = 0.303

h_3 is maximum when $(S) = \frac{b_2}{2b_3} = \frac{0.26770}{0.00796} = 33.6$ percent

$h_3 = 16.85 + 0.832\ C_o + 0.5086\ (Si) - 0.0055\ (Si)^2$ (51)

F for coeff.: b_1--18.13, b_2--3.55**, b_3--19.61**;

Multiple F = 43.26** with 3 & 305 d.f.; R-square = 0.298

h_3 is maximum when $(Si) = \frac{b_2}{2b_3} = \frac{0.5086}{0.0110} = 46.2$ percent

$h_3 = 15.59 + 0.8313\ C_o + 0.944\ (C) - 0.02485\ (C)^2$ (52)

F for coeff.: b_1--16.19**, b_2--48.51**, b_3--35.23**;

Multiple F = 30.4488 with 3 & 305 d.f.; R-square = 0.230

h_3 is maximum when $(C) = \frac{b_2}{2b_3} = \frac{0.9440}{0.0499} = 19.0$ percent

$$dbh_3 = 2.35 + 0.1382\ C_o + 0.0470\ (S) - 0.00049\ (S)^2 \quad (53)$$

F for coeff.: b_1--13.23**, b_2--13.84**, b_3--19.85**;

Multiple F = 19.00** with 3 & 305 d.f.; R-square = 0.157

$$dbh_3 \text{ is maximum when } (S) = \frac{b_2}{2b_3} = \frac{0.04700}{0.00098}\ 47.9 \text{ percent}$$

$$dbh_3 = 2.11 + 0.148\ C_o + 0.06348\ (Si) - 0.000822\ (Si)^2 \quad (54)$$

F for coeff.: b_1--15.03**, b_2--14.47**, b_3---9.33**;

Multiple F = 17.00** with 3 & 305 d.f.; R-square = 0.144

$$dbh_3 \text{ is maximum when } (Si) = \frac{b_2}{2b_3} = \frac{0.06348}{0.00164} = 38.6 \text{ percent}$$

$$dbh_3 = 2.05 + 0.143\ C_o + 0.10671\ (C) - 0.003355\ (C)^2 \quad (55)$$

F for coeff.: b_1--13.34**, b_2--17.25**, b_3--17.77**;

Multiple F = 13.60** with 3 & 305 d.f.; R-square = 0.118

$$dbh_3 \text{ is maximum when } (C) = \frac{b_2}{2b_3} = \frac{0.10671}{0.00671} = 15.9 \text{ percent}$$

$$h_3 = 14.78 + 0.747\ C_o + 1.009\ (AW) - 0.0194\ (AW)^2 \quad (56)$$

F for coeff.: b_1--14.08**, b_2--60.06**, b_3--38.37**;

Multiple F = 40.75** with 3 & 305 d.f.; R-square = 0.286

$$h_3 \text{ is maximum when } (AW) = \frac{b_2}{2b_3} = \frac{1.00908}{0.04380} = 23.0 \text{ percent by volume}$$

$$dbh_3 = 1.84 + 0.131\ C_o + 0.1304\ (AW) - 0.00356\ (AW)^2 \quad (57)$$

F for coeff.: b_1--11.59**, b_2--26.81**, b_3--21.35**;

Multiple F = 17.74** with 3 & 305 d.f.; R-square = 0.149

$$dbh_3 \text{ is maximum when } (AW) = \frac{b_2}{2b_3} = \frac{0.13040}{0.00712} = 18.3 \text{ percent by volume}$$

$$h_3 = 11.57 + 1.0423\ C_d + o.5646\ C_o + 5.2657\ R_p - 0.263\ C_d\ R_p - 0.3201\ R_p^{\ 2} \quad (58)$$

with F for coeff.: b_1--4.93*, b_2--9.06**, b_3--86.18**, b_4--11.81**, b_5--99.08**;

Multiple F = 41.92** with 5 & 262 d.f.; R-square = 0.444

$$dbh_3 = 1.36 + 0.1915\ C_d + 0.7478\ R_p - 0.0492\ C_d\ R_p + 0.0151\ C_o\ R_p - 0.0478\ R_p^{\ 2} \quad (59)$$

with F for coeff.: b_1--3.91*, b_2--41.25**, b_3--9.69**,

Multiple F = 15.88** with 5 & 262 d.f.; R-square = 0.233

$$h_1 = 5.35 + 0.6436\ R_p + 0.0726\ C_o\ R_p - 0.0529\ R_p^{\ 2} \quad (60)$$

with F for coeff.: b_1--33.42**, b_2--60.40**, b_3--35.47;

Multiple F = 40.42** with 3 & 264 d.f.; R-square = 0.315

$$h_2 = 8.69 + 2.9917\ R_p - 0.09449\ C_d\ R_p + 0.0676\ C_o\ R_p - 0.1972\ R_p^{\ 2} \quad (61)$$

with F for coeff.: b_1--107.02**, b_2--13.90** b_3--12.16**, b_4--96.05**;

Multiple F = 45.36** with 4 & 263 d.f.; R-square = 0.408

$$h_6 = 35.15 + 6.572\ R_p + 0.2173\ C_d\ R_d - 0.3711\ C_d\ R_p - 0.3476\ C_o\ R_d + 0.4739\ C_o\ R_p - 0.4283\ R_p^{\ 2} \quad (62)$$

with F for coeff.: b_1--81.63**, b_2--4.22*, b_3--6.70**, b_4--4.61*, b_5--7.26**, b_6--70.40**;

Multiple F = 25.59** with 6 & 261 d.f.; R-square = 0.370

$$h_7 = 39.42 + 7.3421\ R_p + 0.3663\ C_d\ C_o - 0.2166\ C_d\ R_p - 0.4699\ R_p^2 \qquad (63)$$

with F for coeff.: b_1--75.78**, b_2--7.86**, b_3--7.72**, b_4--62.32**;

Multiple F = 29.26** with 4 & 263 d.f.; R-square = 0.308

$$\dot{d}bh_2 = 0.584 + 0.461\ R_p - 0.0152\ C_d\ R_p + 0.0147\ C_o\ R_p - 0.0317\ R_p^2 \qquad (64)$$

with F for coeff.: b_1--64.97**, b_2--9.18**, b_3--14.73**, b_4--63.63**;

Multiple F 28.16** with 4 & 263 d.f.; R-square = 0.300

$$dbh_6 = 4.70 + 0.5989\ R_p + 0.02426\ C_o\ R_p - 0.045197\ R_p^2 \qquad (65)$$

with F for coeff.: b_1--30.95**, b_2--7.58**, b_3--29.08**;

Multiple F = 15.75** with 3 & 264 d.f.; R-square = 0.152

$$dbh_7 = 5.55 + 0.5497\ R_p + 0.0239\ C_o\ R_p - 0.04185\ R_p^2 \qquad (66)$$

with F for coeff.: b_1--20.87**, b_2--5.90*, b_3--20.00**;

Multiple F = 10.90** with 3 & 264 d.f.; R-square = -.110

$$h_7 = -58.97 + 0.93\ C_o + 3876.7795\ R_e + 11.724\ R_p + 102.22\ C_d\ R_e - 1.1565\ C_d\ R_p - 44939.96\ R_e^2 - 0.5899\ R_p^2 \qquad (67)$$

with F for coeff.: b_1--5.17*, b_2--5.05*, b_3--23.84**, b_4--6.24*, b_5--10.68**, b_6--6.20* b_7--28.74**;

Multiple F = 17.64** with 7 & 260 d.f.; R-square = 0.322

$$h_7 = -244.28 + 3.322\ K + 20.28\ C_d + 0.276\ C_d\ C_o - 0.1166\ C_d\ K - 0.009229\ K^2 - 7.667\ R_p + 181.898\ R_e\ R_p \quad (68)$$

with F for coeff.: b_1--48.71**, b_2--20.37**, b_3--4.39*, b_4--14.88**, b_5--38.54**, b_6--5.49*, b_7--7.88**;

Multiple F = 21.54** with 7 & 259 d.f.; R-square = 0.368

$$dbh_7 = -16.35 + 0.2334\ K + 2.0576\ C_d + 0.02356\ C_o\ R_p - 0.000558\ K^2 - 0.01226\ K\ C_d \quad (69)$$

with F for coeff.: b_1--16.47**, b_2--7.60**, b_3--5.88*, b_4--16.57**, b_5--7.38**;

Multiple F = 7.54** with 5 & 261 d.f.; R-square = 0.126

$$h_6 = 66.7 - 4.22\ C_d + 0.272\ C_d\ C_o + 0.405\ C_d\ R_p - 0.548\ R_p^{\ 2} + 2.1879\ R_p\ H^+ - 2.635\ H^+ \quad (70)$$

with F for coeff.: b_1--13.87**, b_2--5.66*, b_3--14.26**, b_4--46.81**, b_5--50.34**, b_6--15.37**;

Multiple F = 26.19** with 6 & 261 d.f.; R-square = 0.376.

h_6 is maximum when $dh_6/dH^+ = 0$

$dh_6/dH^+ = 2.1879\ R_p - 2\ 2.635\ H^+$

thus h_6 is maximum when $H^+ = \frac{2.1879}{2 \times 2.635} R_p = 0.4151\ R_p$.

where H^+ is in 10^{-8} moles/liter.

$$h_7 = 67.59 - 4.02\ C_d + 0.427\ C_d\ R_p - 0.578\ R_p^2 + 2.3123\ R_p\ H^+ - 0.5783\ H^+ \qquad (71)$$

with F for coeff.: b_1--12.42**, b_2--15.71**, b_3--52.48**,

b_4--56.88**, b_5--17.01**;

Multiple F = 29.77** with 5 & 262 d.f.; R-square = 0.362

h_7 is maximum when $dh_7/dH^+ = 0$

$dh_7/dH^+ = 2.3123\ R_p - 2\ 2.784\ H^+$

thus h_7 is maximum when $H^+ = \frac{2.3123}{2 \times 2.784} R_p = 0.4152\ R_p$

where H^+ is in 10^{-8} moles/liter.

$$V = 0.2217 + 0.001999\ (h_7 \times dbh_7^2) \qquad (72)$$

F = 22.78** with 1 & 118 d.f.; R-square = 0.888

VITA

Anatol Kaszkurewicz was born on February 21, 1911, in Baranowicze, Poland.

He received his early education at W. Szulicki's private High School (Gymnasium) in Baranowicze, where he graduated in June 1929.

He entered the Department of Forestry at the College of Agriculture (Szkola Glowna Gospodarstwa Wiejskiego) in Warsaw, Poland, in October 1929 and received a Master of Forestry degree (Magister inzynier lesnik) in June 1936.

He was employed by L. Kroze & Assoc., consulting foresters, as associate forester at Brest n/B., Poland, from July 1936 until September 1939.

He was employed by the State Forest Administration (Russian occupation) at Baranowicze, Poland, as a forester in timber logging operations from October 1939 until June 1941.

He was employed by the State Forest Administration (German occupation) as a manager of two saw-mills in Baranowicze, Poland, from July 1941 until May 1944.

He was employed as a worker in a metallurgical factory at Kallies in Ost Pommern, Germany, from June 1944 until May 1945.

He was employed as a manager of the U.N.R.R.A. (later of I.R.O.) warehouse at Rosenheim, Germany, from August 1945 until March 1949.

He was employed by the Forestry Department of Industries Klabin do

Parana de Celulose S.A. at Monte Alegre, Parana, Brazil, as a forester from June 1949 until July 1952, when he was promoted to a Forestry Delegate of the same company with the task of organizing logging operations in leased forests. In July 1954 he was promoted to Deputy Director of the Forestry Department of this company and remained in this position until February 1958, when he resigned after receiving an immigration visa to U.S.A.

From February 1958 until August 1958, when he moved to U.S.A., he continued working for the same company as a consulting forester in acquisition of Parana pine forests for a new pulp and paper plant intended for Central Parana.

He was employed by F. W. Bennett & Assoc., consulting foresters, as a forester in timber inventory from November 1958 until September 1959.

Since September 1959 he has been employed by the Louisiana Forestry Commission, Baton Rouge, Louisiana, as a forester in hardwood planting research.

In 1961 he entered Louisiana State University as a graduate student and is currently seeking a Doctor of Philosophy degree.

He is married and has no children.

EXAMINATION AND THESIS REPORT

Candidate: Anatol Kaszkurewicz

Major Field: Forestry

Title of Thesis: Establishment and Early Growth of Populus deltoides Bartr.

Approved:

Major Professor and Chairman

Dean of the Graduate School

EXAMINING COMMITTEE:

Date of Examination:

April 13, 1973