1969

Survival and First-Year Growth of Water Tupelo (Nyssa Aquatica L.) in Relation to Flooding and Siltation.

Harvey Ellis Kennedy Jr
Louisiana State University and Agricultural & Mechanical College

KENNEDY, Jr., Harvey Ellis, 1933-
SURVIVAL AND FIRST-YEAR GROWTH OF WATER TUPELO (*Nyssa aquatica* L.) IN RELATION TO FLOODING AND SILTATION.

The Louisiana State University and Agricultural and Mechanical College, Ph.D., 1969
Agriculture, forestry and wildlife

SURVIVAL AND FIRST-YEAR GROWTH OF WATER TUPELO (*Nyssa aquatica* L.) IN RELATION TO FLOODING AND SILTATION

A Dissertation

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy

in

The School of Forestry and Wildlife Management

by
Harvey Ellis Kennedy, Jr.
B.S., Louisiana State University, 1963
M.F., Louisiana State University, 1964
August, 1969

ACKNOWLEDGMENTS

The author is indebted to the U.S. Forest Service, Southern Forest Experiment Station, and Southern Hardwoods Laboratory for permission to use this study for a dissertation. Acknowledgment is made to Mr. J. S. "Sid" McKnight, Project Leader for Timber Management Research at the Southern Hardwoods Laboratory, for his advice and encouragement during the study.

The author is also indebted to Dr. N. E. Linnartz for his advice and help in the completion of this study and the preparation of this dissertation; and to Drs. W. H. Patrick, Jr., P. Y. Burns, T. Hansbrough, and B. A. Bateman for their critical review of the manuscript.

Special thanks are extended to Mr. R. L. Johnson for his advice and suggestions during the study; to Mr. R. M. Krinard for his statistical advice and writing the computer programs used; and to Mr. W. D. Boykin for his assistance in the field and laboratory work.

Special acknowledgment is made to the author's wife for her typing of this manuscript and for her understanding and encouragement, without which the study may never have been completed.

TABLE OF CONTENTS

Page

LIST OF TABLES

Number		Page

LIST OF FIGURES

LIST OF PLATES

ABSTRACT

The effects of flooding and siltation on survival and first-year growth of planted water tupelo (*Nyssa aquatica* L.) were studied on the Delta Experimental Forest near Stoneville, Mississippi. The study consisted of three phases which were conducted concurrently.

The hypothesis tested was that there were no differences in survival and first-year growth of planted water tupelo seedlings subjected to the following treatments.

Phase I:

Three flooding depths: 0 to 3 and 6 to 10 inches above groundline, 4 to 6 inches above tallest seedlings.

Three flooding durations: Until June 1, July 1, or August 1

Phase II:

Two flooding depths: 6 to 10 inches above groundline, and 4 to 6 inches above tallest seedlings.

Two siltation depths: 3 to 4 and 6 to 8 inches above groundline.

Two flooding durations: Until June 1 or July 1

Phase III:

Two reflood dates: July 1 or August 1

Two reflood durations: 1 week or 2 weeks

Plots in Phase III were initially flooded above the seedlings and drained on June 1 before being subjected to reflooding.

A series of levees were constructed in grid-like fashion to delineate the 66 plots used in the study. An irrigation system was installed to supply surface water to be used for flooding from nearby Shell Lake.

A completely randomized design with a factorial arrangement of treatments was used in each phase. Treatment combinations were randomly assigned among plots selected for use in each phase.

During the first week of February 1968, 30 1-year-old seedlings (six rows of five seedlings) were planted on a 2- by 2-foot spacing. The interior four rows were designated for measurements. In order to test the hypothesis, survival, total heights, and root-collar diameters were measured on the seedlings after 1 year in the field.

Soil samples collected on three dates and leaves collected at the end of the growing season were chemically analyzed. Soil and water temperatures and oxygen content of the water in each plot were measured periodically.

Analyses of covariance were used to compare total heights and root-collar diameters. Factorial analyses of variance were used to analyze survival and one-way analyses of variance were used to compare nutrient contents of leaves. Duncan's multiple range test was used to compare means.

It was concluded that depth and duration of flooding significantly affected total heights and root-collar diameters.

Generally, heights and diameters decreased as depth and duration of flooding increased.

Siltation in combination with depth and duration of flooding caused a reduction in heights and diameters when compared to plots flooded to the same depth but without siltation, even though the siltation depths used did not differ significantly in their effect on growth.

Date and duration of reflooding did not differ significantly in their effects on growth, but seedlings were smaller in plots reflooded during the growing season than in plots which were not reflooded.

Survival was good in most treatments but flooding depths which covered the seedlings caused severe dieback.

Under flooded conditions redox potentials were lower, ammonium accumulated, nitrates were reduced, extractable phosphorus increased, exchangeable potassium and calcium decreased, and pH values were higher than before flooding. Flooding did not appear to adversely affect nutrient uptake by seedlings.

INTRODUCTION

Water tupelo (*Nyssa aquatica* L.) is a valuable timber species in swamps which cover more than four million acres in the southern and southeastern United States. Because of its occurrence in swamps, water tupelo is subject to annual flooding from January or February until late May or early June. Flooding and the accompanying wet conditions have discouraged people from working with this species and only recently has great interest been shown in better management and use of tupelo swamps. Little is known about the effects of these floods and accompanying siltation on survival and growth of water tupelo seedlings. However, this is a problem which must be understood before this species can be successfully regenerated, either naturally or by planting or direct seeding.

Past work with water tupelo seems to fall into three broad categories: (1) site-species relationships and growth and yield studies involving older trees, (2) flooding studies conducted with current-year seedlings, and (3) requirements for seed germination. This study basically differs from past work in category (2) in that seedlings were grown for 1 year in the nursery and outplanted in the field before any treatments were applied.

The study investigated effects of flooding and siltation on survival and first-year growth of planted water tupelo seedlings.

It was conducted on Alligator clay, a soil type found in many swamps. The study consisted of three phases which were conducted concurrently.

Specific objectives were to compare the survival and first-year growth of planted water tupelo seedlings under:

Phase I: three depths and three durations of flooding;

Phase II: two depths of siltation and two depths and two durations of flooding;

Phase III: two dates and two durations of reflooding.

The hypothesis to be tested was that there was no difference in survival and first-year growth of planted water tupelo seedlings grown under these selected flooding depths and levels of siltation. In order to test the hypothesis, survival, total height, and root-collar diameter were measured on water tupelo seedlings after 1 year in the field. A factorial arrangement of treatments with a covariance analysis was used to analyze the data. Soil samples collected on three dates and leaves collected at the end of the growing season were chemically analyzed. These were used in studying the effects of flooding on various soil properties and nutrient uptake by the seedlings.

One term used in this study may be used differently elsewhere. As used in this study, siltation refers to the deposition of soil particles, either sand, silt, or clay, by water around the base of seedlings or trees.

REVIEW OF THE LITERATURE

Flooding Studies with Water Tupelo and Various Other Hardwoods

Very little work had been done, prior to about 1940, to determine the effects of flooding and siltation on survival and growth of water tupelo. In fact, no literature on the effects of siltation was found.

In one of the earliest studies, data were collected on forest communities in the Blue Girth swamp near Selma, Alabama (Hall and Penfound 1943). These forest communities consisted primarily of baldcypress /*Taxodium distichum* (L.) Rich./, water tupelo, and swamp tupelo /*Nyssa sylvatica* var. *biflora* (Walt.) Sarg./. Water depth seemed to be the controlling factor in species distribution. The water tupelo-baldcypress-swamp tupelo forest occupied the more shallow (0 to 2 feet) swamp margin. Water tupelo-baldcypress and baldcypress communities occupied the deeper water (2 to 7 feet) in the swamp.

Silker (1948) reported on survival, growth, and development of 5- and 12-year-old plantations of some water-tolerant trees planted along margins of fluctuating-level reservoirs. Two zones were studied: (1) the zone 1 to 15 feet above normal pool level which was infrequently flooded during the growing season, and (2) the area in the upper drawdown zone which was intermittently flooded with 1 to 3 feet of water during the growing

season. Baldcypress, water tupelo, and sweetgum (Liquidambar styraciflua L.) flooded by 2 to 4 feet of trapped water through June of the third growing season showed no apparent damage. Water from 2 to 7 feet deep during the dormant season had caused no apparent damage. Water tupelo was well adapted to flats in the zone intermittently covered by water, but at higher elevations it grew well only on seepage areas. Prolonged flooding, which covered the top of the plant, during the growing season caused dieback in water tupelo, but the trees sprouted when the water level was lowered.

In a study of tolerance of 39 species to various durations of flooding by Hall and Smith (1955), the authors reported that all woody species were killed where the root collars were periodically flooded more than 54 percent of the time during all growing seasons the project had been in operation. Water tupelo showed signs of necrosis when flooded about 38 percent of the time during the growing season.

Briscoe (1957) studied the effects of flooding during the growing season on current-year seedlings of northern red oak (Quercus rubra L.), cherrybark oak (Quercus falcata var. pagodaefolia Ell.), slash pine (Pinus elliottii var. elliottii Engelm.), water tupelo, and swamp tupelo. The degree of species tolerance to flooding and submersion was strongly correlated with the frequency of flooding of the typical natural site on which the species occurred. Swamp tupelo and water tupelo showed less injury than the other species. Submersion of

seedlings seemed to reduce growth more than surface-flooding the soil with the severity of effect increasing with increased duration of surface-flooding or submersion. Water temperature had a pronounced effect upon growth. Least injury was caused by 68°F water, but water at lower and higher temperatures caused severe injury. Surface-flooding reduced root growth more than shoot growth; submersion reduced root and shoot growth to a similar degree. The author concluded that, in general, the longer the period of surface-flooding or submersion, the greater the reduction in growth.

Applequist (1959) found that seedlings of water tupelo and swamp tupelo in surface-flooded soil made better initial height growth under greenhouse conditions than seedlings in well drained soil. Flooding also increased seedling shoot-root ratios. Flooded water tupelo grew taller and produced more dry weight than similarily treated swamp tupelo. He concluded that water tupelo and swamp tupelo growth and development are largely determined by quantity of water. Water may be deficient or excessive and both conditions are important depending on time and quantity. Intermittent flooding during the growing season, just short of continuous flooding, may provide near optimum growing conditions for these two species.

Results from a site-species study by Applequist (1960) indicated soil properties which increased the amount of available soil moisture during the growing season increased height

growth of water tupelo and swamp tupelo. Time and duration of flooding during the growing season may be of critical importance. He concluded that water and swamp tupelo may not only tolerate, but literally thrive, under flooded or near-flooded conditions.

Klawitter (1963) found sweetgum sites in Coastal Plain bottomland areas to be better drained, higher in soil pH, and have less organic matter than tupelo sites. Water tupelo sites had a high clay content and flooded deeply. Soils under swamp tupelo had lowest pH, organic matter, and silt-plus-clay values. Site factors which led to abundant soil moisture and long periods of flooding were directly related to total height of water tupelo. Radial growth responded favorably to warm, moist springs and intermittent flooding throughout the year.

Hosner and Leaf (1962) investigated the effects of water-saturated soil upon the dry weight, ash content, and nutrient absorption of various bottomland tree seedlings. They found water tupelo, pumpkin ash /*Fraxinus profunda* (Bush) Bush/, black willow (*Salix nigra* Marsh.), and cottonwood (*Populus deltoides* Bartr.) had higher values for all factors investigated under saturated conditions than under nonsaturated conditions. On the basis of root and shoot growth and nutrient absorption, they grouped the species according to their tolerance to water-saturated soil. Water tupelo, pumpkin ash, black willow, and green ash (*Fraxinus pennsylvanica* Marsh.) were classified as tolerant; other species studied were classified as intermediate or intolerant.

Flooding killed cherrybark oak, Shumard oak (Quercus shumardii Buckl.), sugarberry (Celtis laevigata Willd.), cottonwood, and American elm (Ulmus americana L.), but several other species were alive after 60 days of flooding (Hosner and Boyce 1962). Green ash, water tupelo, pumpkin ash, and pin oak (Quercus palustris Meunch.) in saturated soil significantly outgrew seedlings of the same species in nonflooded soil. Saturated soil significantly reduced growth of sweetgum and willow oak (Quercus phellos L.) compared to seedlings of the same species grown in well drained soil. There was no difference between seedlings in well drained soil and seedlings in saturated soil of the other species studied.

Dickson, Hosner, and Hosley (1965) grew seedlings of four species under four moisture regimes: (1) saturated soil, (2) soil water brought to moisture equivalent each day, (3) soil water brought to moisture equivalent when 50 percent of available water was used, and (4) soil water brought to moisture equivalent when wilting point was reached. On the basis of height growth and total dry weight, water tupelo and green ash grew best under continuously saturated conditions; pin oak and American sycamore (Platanus occidentalis L.) grew best under the daily moisture-equivalent regime. With few exceptions, seedlings grown under the wilting-point regime were smallest. The authors stated the response of water tupelo under saturated conditions was surprising when compared to the moisture-equivalent regime

which is assumed to be near optimum conditions for most plants. Growth of some seedlings was apparently restricted even at the low tensions associated with the moisture-equivalent regime because a distinct wilting of the upper leaves was noticed in water tupelo and green ash on hot afternoons.

Using the same species and soil moisture regimes as in the preceeding study, Hosner, Leaf, Dickson, and Hart (1965) studied the effects of the four moisture regimes upon seedling top weight and contents of ash, nitrogen, phosphorus, potassium, calcium, and magnesium in seedlings. Generally, seedling top weight and nutrient uptake for pin oak, American sycamore, and green ash were best in the daily moisture-equivalent regime, followed by saturated soil, then the 50 percent available moisture, and poorest in the wilting-point regime. Water tupelo showed decreasing values from saturated soil through wilting point.

Klawitter (1964) reported that some people feel that a minimum water level fluctuation of about 3 feet is required by water tupelo, but best growth occurs when swamp soils remain wet. Water tupelo sites probably do not remain flooded continuously, because evidence suggests that its seed must be germinated during periods when the site is not inundated. A study along the Santee River in South Carolina confirmed the needs of water tupelo for swamp conditions. Taller trees were found when soil and other site conditions were characteristic of poor drainage and long periods of wetness. Flooding also affected radial growth with best annual growth occurring when the Santee River overflowed into the swamps.

In a recent study, Hook and Stubbs (1967) reported the effects of six artificially imposed water regimes on growth and stem form of seedlings of swamp tupelo and water tupelo from six seed sources. Water regimes were both moving and stagnant water in combination with surface saturation, intermittent flooding, and continuous flooding 8 inches above soil level. Results showed height growth and dry weight varied significantly between seed sources of each species. Both height growth and dry weight were lower in the intermittent- and continuous-flooding treatments than under continuous surface-saturated conditions. With the exception of one seed source for each species, dry weight production was less in the intermittent-flooding than continuous-flooding treatments. Stem form appeared to be related more to the presence of flooding than to seed source.

Hook (1968) found that swamp tupelo seedlings grown under controlled flooded conditions grew about twice as fast in moving water as in stagnant water. Lenticels and water roots developed under certain flooded conditions and evidence suggested these structures may function in gas exchange between atmosphere and roots. Carbon dioxide concentrations were much higher and oxygen concentrations lower in stagnant than in moving water. High carbon dioxide and low oxygen concentrations (31% CO_2 and 1% O_2) reduced height growth, root development, root respiration rate, and respiration rate of seedlings while lower carbon dioxide concentrations at the same oxygen level (2 and 10% CO_2 and 1% O_2) did not affect the seedlings. Coating seedling stems

with a 9:1 paraffin-lanolin mixture did not affect height or root growth any more in near-anaerobic than in aerobic root environments. The author concluded that swamp tupelo appears to have a dual metabolic system in its roots and both aerobic and anaerobic respiration are active in the presence of oxygen, while in the absence of oxygen, lactic acid fermentation serves as an energy source.

Flooding Studies with Species Exclusive of Water Tupelo

Much work has been done on the reaction of other hardwoods and conifers to impoundment water. In an early study, Green (1947) reported on growth and mortality of various hardwoods which were flooded as a result of dams being built on the Mississippi River. Bottomland trees which did not have their root collars permanently flooded survived very well. However, trees that had their root collars permanently flooded, regardless of depth, had heavy mortality.

Hosner (1958) found that flooding in bottomland hardwood areas during the growing season exercised a selective effect upon the survival of the various tree seedlings studied. Only black willow survived 32 days or more of complete inundation; other species survived 16 days or less of complete inundation. Black willow and green ash recovered rapidly, but the other species showed the effects of submergence longer.

Hardwoods exhibit different mechanisms which enable them to withstand flooding for various periods of time. Hosner (1959)

reported that cottonwood, sycamore, and green ash seedlings developed adventitious root systems when flooded, but cherrybark oak, pin oak, and hackberry (Celtis occidentalis L.) did not. Green ash also developed new laterals well below the soil surface. He explained the ability of cottonwood, green ash, and sycamore to withstand flooding by their ability to form the adventitious root systems and the ash to form new laterals.

Parker (1950) studied the effects of flooding on the transpiration and survival of overcup oak (Quercus lyrata Walt.), cypress, and several other species. Baldcypress seedlings had a very high transpiration rate, but the roots did not grow as well in the more poorly aerated portions of the soil in containers as in the better aerated portions. Overcup oak transpiration rates declined after flooding, but a few days before the experiment was terminated the oak produced a second crop of leaves and transpiration increased. All species except baldcypress had transpiration rates considerably below normal transpiration rates.

McDermott (1954) flooded several bottomland tree species when the first true leaves appeared. He found stunting effects similar in all species. Internodes were short, giving the plants a general rosette appearance. River birch (Betula nigra L.), American sycamore, and red maple (Acer rubrum L.) recovered rapidly when the soil was drained. Winged elm (Ulmus alata Michx.) recovered at a moderate rate.

In a study of 14 shallow-water impoundment areas, Broadfoot (1958, 1960) found that 6 to 12 inches of water impounded in September or October and released in April increased the amount of water stored in the soil. This additional water increased tree growth by making more moisture available during hot, dry summers. However, water left standing from year to year caused severe mortality. The author found that 3 years of continuous impoundment with 1 to 3 feet of water killed all forest trees in the impoundment areas except a few overcup oak and green ash.

Hosner (1960) reported relative tolerances of 14 bottomland tree species to complete inundation. Many species exhibited a greater or lesser tolerance to flooding than site-species relationships indicated. He concluded that water is likely to become the limiting factor only on sites that are flooded for extended periods during the growing season.

The results of 3 to 4 days of flooding in a yellow-poplar (Liriodendron tuplipifera L.) plantation were reported by McAlpine (1959). Flooding occurred in May when the trees were in full leaf, but the tops stayed above water. For several weeks after flooding, the trees appeared in good condition. In July leaves began to wilt and within a week many trees were dead or severely damaged. Mortality was associated with slight changes in elevation, with trees at higher elevations (1 to 1½ feet higher) being damaged less than others.

In a follow-up to the preceding study, McAlpine (1961) flooded 1-year-old yellow-poplar, sweetgum, and green ash in

55-gallon drums during March, May, and June. Green ash and sweetgum were not affected by up to 14 days of flooding during any month. Yellow-poplar seedlings were not affected by flooding during the dormant season; however, mortality occurred after 4 days of flooding in May and 3 days in June. Number of seedlings wilting and dying increased as duration of flooding increased. After 14 days of flooding all yellow-poplar seedlings were dead.

Bonner (1966) planted 1-year-old seedlings of American sycamore, sweetgum, and Nuttall oak in clay pots and then saturated the soil by placing the pots in reservoirs. He found that soil saturation of up to 16 weeks did not significantly affect survival, date of bud-break, or initiation of height growth. In mid-April, when temperatures were rising, soil saturation of more than 10 weeks did severely reduce height, root, and stem-diameter growth. The critical period of soil saturation to avoid retarding height and root growth of these species appeared to be 10 to 12 weeks, but high soil temperatures may shorten the critical period.

Broadfoot (1967) found that water impounded during the winter and spring and held until July 1 significantly increased soil moisture during the growing season with a resulting increase in radial growth. The flooded area, in early July, had 6.5 cm more soil moisture per 30 cm of soil than control plots. Timber growth increased about 50 percent. Oxygen in the water

was depleted after 15 days without rain but was quickly replenished by rain.

In a flooding study with 1-year-old loblolly pine (Pinus taeda L.), shortleaf pine (Pinus echinata Mill.), and pond pine (Pinus serotina Michx.), Hunt (1951) found that the only effect after 12 weeks of flooding was slightly reduced growth of seedlings continuously flooded in stagnant water. No significant differences in mortality due to flooding occurred. The author concluded these pine seedlings proved unusually resistant to injury by flooding.

McReynolds (1960) reported on a study of the four southern pines in which seedlings up to 25 days old were flooded for various periods. He found that 15- to 20-day-old loblolly and shortleaf pine seedlings had developed some resistance to flooding. Most 25-day-old loblolly survived 20 days flooding, but shortleaf died when flooded more than 12 days. Longleaf pine (Pinus palustris Mill.) 25 days old was damaged by any flooding and completely killed if flooded more than 12 days. Slash pine survived 10 days of flooding and about 60 percent survived 20 days of flooding. Spring flooding in all species was less damaging than summer flooding.

Loblolly and slash pine seedlings were subjected to various flooding and drainage regimes for two growing seasons by Walker, Green, and Daniels (1961). They found mortality to be inversely related to height of seedlings. Flooding to 4- and 8-inch depths caused high mortality with slash beginning to die 68 days

and loblolly 133 days after initiation of flooding. Seedlings whose terminals were under water had excessive mortality. Drainage to 4 and 8 inches below ground level considerably increased height growth over 0, 4, and 8 inches of flooding.

Effects of Flooding on Various Soil Properties

Several changes occur in a soil when it is submerged compared to conditions that are found in a well aerated soil. Ponnamperuma (1955) conducted an intensive study of the chemistry of submerged soils in relation to the growth and yield of rice. From soil analyses made during the study, he found the root zone of a submerged soil to be characterized by a low oxygen content, high carbon dioxide content, large ammounts of reduced iron and manganese, a virtual absence of nitrates and sulfates, an accumulation of ammonia, and the presence of products of anaerobic organic matter decomposition. Physio-chemical changes which occurred during submergence were an increase in pH and specific conductance and a decrease in redox potentials.

One of the more important changes which occurs in flooded soils is the reduction of nitrate nitrogen with an accompanying loss of nitrogen from the soil; also, ammonium nitrogen accumulates under submerged conditions. Spurgeon and Grisson (1963) found high nitrogen losses when clay soil was flooded, in some cases over 100 pounds per acre. Heavy nitrogen losses, up to 50 percent of total lost, occurred in 2 to 5 days after flooding. High temperatures increased nitrogen losses.

Spurgeon (1964) flooded a Sharkey clay soil for 3 years during the winter and took soil samples before and during flooding and at various times after drainage. Ammonium nitrogen increased 15 to 55 pounds per acre during flooding, while nitrate nitrogen decreased until it was not detectable. The nitrification rate in unflooded soil was twice that in the flooded soil. Soil pH increased from 6.3 to 6.6 during flooding. Available phosphorus decreased slightly but potassium and organic matter were not affected. After drainage, soil pH and ammonium nitrogen decreased and nitrate nitrogen increased. Nitrate nitrogen remained higher in the flooded than in unflooded soil for 12 weeks after drainage.

Patrick and Wyatt (1964) reported successive cycles of submergence and drying caused a 15 to 20 percent loss of total soil nitrogen with most of the loss occurring during the first three cycles. Nitrification proceeded during the drying cycle and nitrogen was lost through denitrification upon submergence. Oxidation-reduction potentials decreased rapidly after initial submergence but decreased more slowly after each cycle of submergence and drying.

A study of amounts of available nitrogen in rice fields and reservoirs at rice seeding time was conducted by Sims (1964). Soils studied included 42 silt loam, 19 clay, and 11 reservoir soils. He found about equal amounts of nitrate and ammonium nitrogen in the silt loam and clay soils, but almost all the

available nitrogen in the reservoirs was in the ammonium form. Soils were incubated for 6 days during which almost twice as much available nitrogen was produced in the clay and reservoir soils as in the silt loam soils. Silt loam soils had about one-half as much organic matter as the clay and reservoir soils.

Redman and Patrick (1965) reported on the effects of submergence on several biological and chemical properties of 26 Louisiana soils. Nitrate nitrogen was reduced in all soils under submerged conditions and the rate of reduction was positively correlated with organic matter content. Submergence resulted in large increases in ammonium nitrogen and large quantities of iron in the ferrous form were released. About six times as much manganese was extracted from submerged soil as from air-dry soil. Flooding tended to shift pH values toward the neutral point. Flooding also caused a sharp decrease in redox potentials (Eh) and these potentials were closely related to pH. About 21 percent more extractable phosphorus was found in submerged soils as in dry soils. Appreciable phosphate release was found only in soils which contained large amounts of ferrous iron and thus appeared to be related to an increase in extractable iron compounds.

Ammonification and nitrification of soil nitrogen were almost directly proportional to soil moisture between 50 percent of saturation and 20 percent moisture content as reported by Reichman, Grunes, and Viets (1966). Additions of fertilizer

had no effect on nitrogen transformations. Small but measurable amounts of ammonification and nitrification occurred at 20 percent moisture content.

Jordan, Patrick, and Willis (1967) isolated 59 microorganisms from waterlogged Crowly silt loam and evaluated their ability to reduce nitrate and nitrite nitrogen. Nitrates were reduced by 22 of the microorganisms, but some could not reduce nitrites or reduced it so slowly that nitrite nitrogen accumulated in some cultures. Nitrite accumulations of 100 to 200 ppm temporarily reduced nitrate reduction in some cultures and completely inhibited it in others.

MacRae, Ancajas, and Salandanan (1968) found that nitrates disappeared rapidly after flooding and losses were most rapid in soils high in organic matter. Nitrogen in the form of N^{15} was applied to the soil to determine the fate of nitrate nitrogen in soils. The applied N^{15} was completely gone in two weeks from soils with high organic matter contents. Much of the nitrogen was recovered from the organic fraction of the soil; thus the authors concluded that a high proportion of the applied nitrate nitrogen had been immobilized into the soil organic fraction.

Shapiro (1958) found that flooding a soil increased the availability of both the soil phosphorus and synthetic iron and aluminum phosphates applied to an acid soil. Phosphorus-free cellulose applied to the soil had the same effect as flooding.

Reduction was shown to be the more important effect of both flooding and organic matter additions.

Orlov (1963) reported that, in the absence of oxygen in the root zone due to flooding, the accumulation of phosphorus by spruce, pine, and birch seedlings dropped sharply or completely stopped. Brief flooding did not cause permanent changes of the absorbing surfaces, and absorption was rapidly restored after drainage. Flooding from 6 to 8 days during the summer caused a sharp and prolonged depression of absorption in all cases. Seedlings that were 3 years old endured longer periods of flooding without disruption than 1- and 2-year-old seedlings. When pine and birch were flooded before initiation of root growth, 2-month flooding caused less damage than 6- to 8-day flooding durations in the summer.

Redox potential and phosphorus availability in submerged soil were investigated by Savant and Ellis (1964). They reported that redox potentials dropped rapidly during the first 15 to 20 days and reached near equilibrium conditions after 75 days of flooding. Organic matter additions accelerated the drop in redox potentials. Increases in phosphorus availability were closely correlated with decreases in redox potentials.

Pierce (1953) found the mineral content of ground water and its degree of stagnation to be closely correlated with its specific conductance and oxidation-reduction potential. He found a definite relationship between the properties of ground water

and the natural distribution of forest stands on lowland and peat soils.

Decreases in redox potentials were favored by higher temperatures (21 to 27°C) and the addition of an organic substrate as reported by Bonner and Ralston (1968). Lower redox potentials were recorded for soil incubated with sucrose than for soil incubated with pine needles or leaves. Addition of nutrients to soils incubated with organic matter at 21° to 27°C decreased the drop in redox potentials but did not affect soils incubated with sucrose. Potential drops were small and slow at 5°C.

Ponnamperuma, Tianco, and Loy (1967) studied redox potentials (Eh) in flooded soils and developed three theoretical equations to describe the main iron hydroxide redox systems. The equations were: (1) $Eh = 1.058 - 0.059 \log Fe^{++} - 0.177\ pH$; (2) $Eh = 1.373 - 0.0885 \log Fe^{++} - 0.263\ pH$; (3) $Eh = 0.429 - 0.059\ pH$. The Eh, pH, and Fe^{++} activity of the soil solution of 32 soils conformed closely to equation (1) during the entire flooding period and to equation (2) and (3) after a peak in water-soluble iron. The authors felt this confirmed the participation of $Fe(OH)_3$ and $Fe_3(OH)_8$ in the redox equilibria in flooded soils.

<u>Summary</u>

Hardwoods and conifers vary widely in their response to flooding. Water tupelo and a few other species appear to like wet conditions. Various researchers have described water tupelo as making its best growth in near-saturated to saturated conditions

and even as literally thriving in water. Stage of development, water conditions, and several other factors seem to have a bearing on the response of water tupelo to flooding.

Generally, flooding during the dormant season and early growing season have little or no effect on most hardwoods and conifers. However, mismanagement of impounded water can cause severe mortality.

Several soil properties are affected by flooding. Some of the more important changes in flooded soils are reduction of nitrates and thereby probable loss of nitrogen, accumulation of ammonium nitrogen, release of large quantities of ferrous iron, more extractable manganese and phosphorus, shift in pH, and lower redox potentials.

METHODS AND PROCEDURES

This study was conducted on an area on the Delta Experimental Forest about 4½ miles north of Stoneville, Mississippi. The study area was chosen because of its proximity to a ready supply of surface water. Merchantable timber, mostly willow oak, was removed from approximately 4 acres with conventional logging equipment. The remaining trees and stumps were sheared as close to the groundline as practical so that the stumps would interfere with levee building and planting as little as possible. Tops were pushed from the study area with a bulldozer, and small trash was carried off by hand to eliminate the need for burning. Soil disturbance was minimized as much as possible during the clearing operations.

Physical Layout

As illustrated in Figure 1, 66 plots (six rows of 11 plots) were delineated by constructing a series of levees in grid-like fashion. The plots occupied approximately 1½ acres near the center of the cleared area. Soil used in constructing the levees was taken from the exterior of the cleared area. Final touch-up of the levees was done with shovels. Levees were about 3½ feet high and 12 feet wide at the base; individual plots were approximately 15 feet square. Work was completed in September 1967 to allow the levees to settle before planting and flooding.

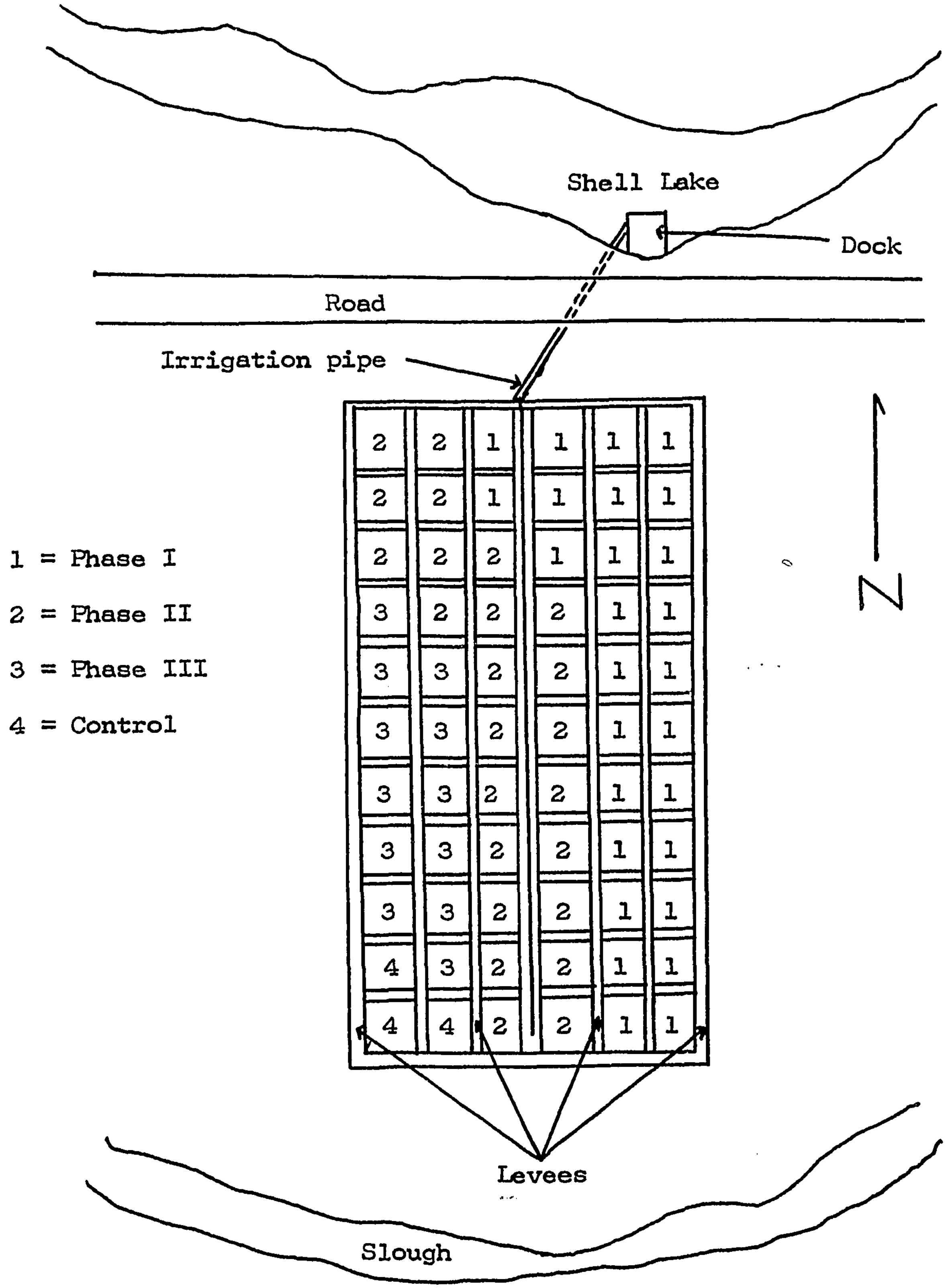

Figure 1. Diagrammatic layout of plots and irrigation system.

A dock was constructed from the shoreline and extended over Shell Lake (Plate 1). An irrigation pump powered by a tractor was installed on the platform. The irrigation pump was manufactured by House Manufacturing Company, Hickory Ridge, Arkansas, and was capable of supplying 1800 gallons of water per minute.

An irrigation system was installed to move water from the lake to the plots, a distance of about 75 feet. A 6-inch aluminum pipe was laid from the pump, under the road, to the north levee (Figure 1). At this point a reducer was connected to a 4-inch pipe, equipped with shut-off valves and 1-inch plastic hose, which traversed the entire length of the center levee (Plate 2).

Plot Selection and Treatments

Early visual inspection of the study area indicated no macro-differences in site. Therefore, for ease of handling, plots for each phase were delineated as shown in Figure 1.

A completely randomized design with a factorial arrangement of treatments was used in the study, so treatment combinations were randomly assigned among plots selected for use in each phase as illustrated in Figure 2. Treatments were as follows:

Phase I;

Three flooding depths: 0 to 3 inches above groundline (shallow), 6 to 10 inches above groundline (moderate), 4 to 6 inches above tallest seedlings (deep).

Three durations of flooding: Until June 1, July 1, or August 1

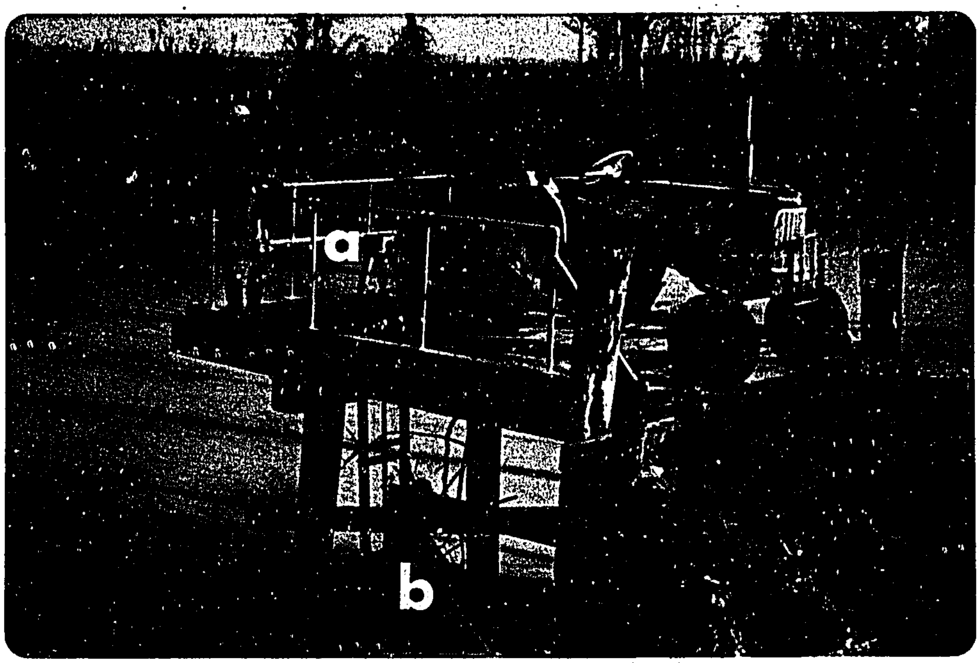

Plate 1. Dock extending over Shell Lake with pump (a) installed and attached to the power unit. Note irrigation pipe (b).

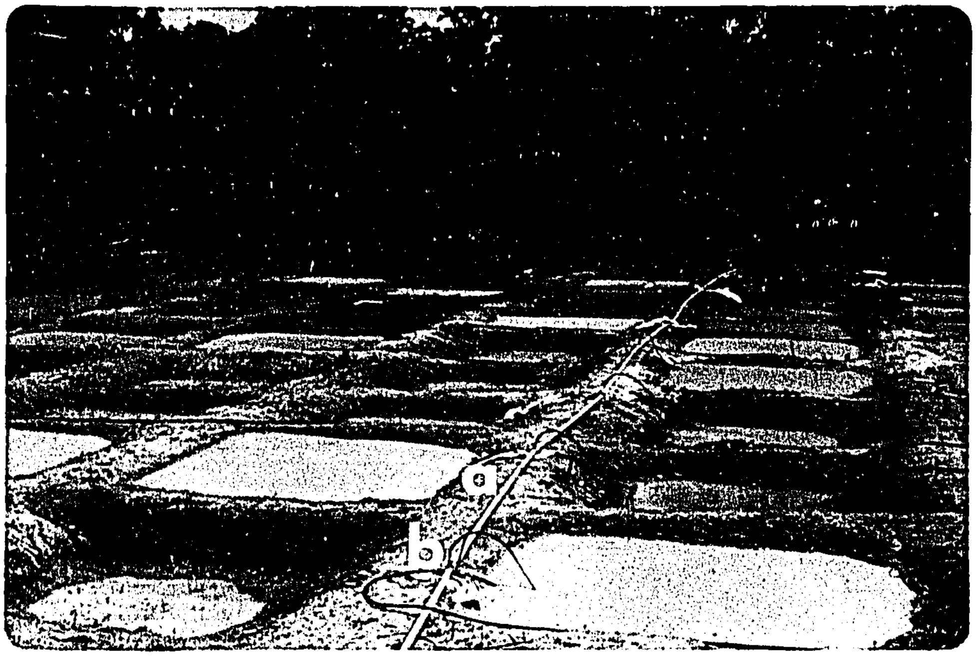

Plate 2. Overall view of plots showing irrigation pipe (a) on center levee with plastic hose (b) attached to a shut-off valve.

Scale:

3/10" = 15'

11	12	4	2	1	3
15	16	9	5	6	2
15	14	11	8	8	9
21	16	10	13	5	2
21	18	14	12	4	1
19	18	15	12	9	7
20	18	17	16	6	8
21	20	17	11	5	4
20	19	10	17	7	3
22	19	10	14	1	7
22	22	13	13	3	6

TREATMENTS:

Phase I.
1. 0-3" water, June 1
2. 0-3" water, July 1
3. 0-3" water, August 1
4. 6-10" water, June 1
5. 6-10" water, July 1
6. 6-10" water, August 1
7. 4-6" water above seedlings, June 1
8. 4-6" water above seedlings, July 1
9. 4-6" water above seedlings, August 1

Phase II.
10. 6-10" water, 3-4" sand, June 1
11. 6-10" water, 3-4" sand, July 1
12. 6-10" water, 6-8" sand, June 1
13. 6-10" water, 6-8" sand, July 1
14. 4-6" water above seedlings, 3-4" sand, June 1
15. 4-6" water above seedlings, 3-4" sand, July 1
16. 4-6" water above seedlings, 6-8" sand, June 1
17. 4-6" water above seedlings, 6-8" sand, July 1

Phase III.
18. July 1, 1 week
19. July 1, 2 weeks
20. August 1, 1 week
21. August 1, 2 weeks

22. Control

Figure 2. Diagrammatic layout of plots with randomly assigned treatments.

Phase II:

Two flooding depths: 6 to 10 inches above groundline (moderate), 4 to 6 inches above tallest seedlings (deep).

Two siltation depths: 3 to 4 inches of sand above groundline (shallow), and 6 to 8 inches of sand above groundline (deep).

Two durations: Until June 1, or July 1

Phase III:

Two reflood dates: July 1 and August 1

Two reflood durations: 1 week and 2 weeks.

Plots in Phase III were initially deep flooded and drained on June 1 before being subjected to reflooding. The control plots received no treatment after planting and were included to determine the response of water tupelo to nonflooded conditions. They were not included in the statistical analyses of treatment effects, but general comparisons were made between the control plots and treated plots in the other phases. There were three replications of each treatment combination in each phase.

Planting and Flooding

Seedlings were grown in the nursery at the Southern Hardwoods Laboratory from seed collected near Minter City, Mississippi. Seed were stratified in moist sand at 35° to 40°F for approximately four months before sowing.

Plots were drained with portable marine pumps prior to planting. During the first week of February 1968, 30 1-year-old seedlings (six rows of five seedlings) were planted in each plot

on a 2- by 2-foot spacing. All seedlings were 15 inches (38 cm) or taller. The interior four rows were designated for measurements. Leaves were to be collected from the two exterior rows for chemical analyses. A small wooden stake was driven flush with the groundline in Phases I and III and flush with the sand in Phase II, about 2 inches from each seedling, to serve as a reference point for measurements.

Sand used to simulate siltation in Phase II was shoveled into the plots immediately after planting. The sand was spread so that it uniformly covered the entire plot to the desired depth.

Flooding treatments were initiated about 2 weeks after planting. Within a few days after flooding, it was realized that water was seeping from the deep-flooded plots to the shallow- and moderate-flooded plots so that it was difficult to maintain the desired water levels. Most of the seepage occurred between the base of the levee and the groundline. The problem was discussed with Messrs. Roy Foil and Charles Hodges, engineers for Sam Hailey Mud and Chemical Company, Canton, Mississippi. They recommended the use of bentonite clay to stop the seepage. Being an inert substance, it would not injure the seedlings. So, bentonite clay was applied to the deep-flooded plots. A trench approximately 3 inches deep was dug at the base of the levee and filled with a band of clay. Clay was also scattered on the base of the levee and covered with soil from the trench. A thin layer of bentonite clay was also spread on

the sides of the levee. This work was completed during the dormant season and stopped most of the seepage.

Portable marine pumps were to be used to remove excess water after heavy rains and to drain the plots according to schedule. However, after using the pumps to remove excess water from the shallow- and moderate-flooded plots after several heavy rains, a better method for removal of water was devised. Excess water was not a problem in the deep-flooded plots. Therefore, trenches were dug through a levee in each shallow- and moderate-flooded plot, a 2-inch plastic hose installed at the desired water level, and the trench refilled. These were installed during the first week of April 1968. The hose enabled the desired water levels to be maintained without pumping water from the plots.

After the plots were drained they were kept free of weeds and vines the remainder of the growing season.

Measurements

Total heights and root-collar diameters were measured soon after planting and at the end of the growing season on the interior four rows of seedlings in each plot. Heights were measured to the nearest centimeter with a meter stick, diameters to the nearest millimeter with vernier calipers. It should be recalled that heights and diameters in Phase II were measured at the top of the sand.

Soil and water temperatures were obtained periodically from each plot with mercury-bulb thermometers. Soil temperatures

were measured 1 inch below the soil surface. Water temperatures were measured approximately 6 inches below the water's surface in deep-flooded plots and 1 inch below the water's surface in the other plots. Oxygen content of the water was determined with a Sargent Oxygen Analyzer at the same time temperatures were taken.

<u>Chemical Analyses</u>

Soil samples were collected during October 1967 and May and September 1968 from the 0- to 6-inch layer of each plot in Phase I, Phase III, and the control. Soil from the first and third collections was air dried, ground, and passed through a 2-mm sieve in preparation for chemical analyses. In the second collection (May 1968), wet soil was collected in ½-gallon glass jars, sealed, and stored in a refrigerator at 35° to 40°F until the analyses could be made.

Seedlings from the two exterior rows did not provide enough leaves for chemical analyses, so leaves from all seedlings in a plot were collected at the end of the growing season, dried at 70°C, and ground in preparation for chemical analyses. Seedlings from each of the Phase I plots treated by deep flooding until August 1, the Phase II plots deep flooded until July 1 with siltation 6 to 8 inches deep, and the Phase III plots reflooded on August 1 for 2 weeks did not yield enough leaves in each plot for chemical analyses. Therefore, the three plots within each treatment combination were composited to get enough leaf tissue for chemical analyses.

Soil ammonium and nitrate nitrogen were determined on a Kjeldahl apparatus with methods four and five of Sims et al. (1967). Total nitrogen in leaves was also determined on a Kjeldahl with normal procedures. Emission spectrophotometry with the Beckman DU was used for calcium and potassium analyses (Jackson 1958). Phosphorus determinations were made by absorption spectrophotometry on a Bausch and Lomb Spectronic 20 (Louisiana Agr. Exp. Sta. 1965). Dry combustion in a baffle furnace was used to analyze soil organic matter, and the pH measurements were made with a Beckman Model 72 pH meter. Results of these chemical analyses were expressed on an oven-dry basis. Details of the procedures used are given in Appendix A.

Before any redox measurements were made, the platinum electrode was cleaned electrolytically in 1N hydrochloric acid. This was done by connecting the positive pole of a 22½-volt dry cell battery to a carbon electrode and the negative pole of the battery to the platinum electrode, immersing both electrodes into the hydrochloric acid, and allowing hydrogen to bubble from the platinum electrode for 3 minutes. The electrode was then checked by comparing redox potentials of quinhydrone solutions of pH 4.00 and 7.00 with previously calculated values given in Beckman Instruments Bulletin 99-D.

Redox measurements were made on air-dry soil samples by placing 80 g of soil in a beaker, adding 80 ml of distilled water, stirring, and reading the redox potentials within a few minutes after stirring. In the wet soil, the electrodes were

inserted into the soil in the jar, 30 minutes allowed to reach equilibrium, and the redox potentials read. Readings were taken on a Beckman Model 72 pH meter with the platinum electrode and a saturated calomel electrode as a reference.

Chemical determinations of nitrogen, phosphorus, potassium, calcium, and pH of the water from Shell Lake were made on two dates. The determinations were made with standard laboratory procedures by Agricultural Research Service personnel stationed at the Mississippi State University Delta Branch Experiment Station.

Statistical Analyses

A completely randomized design with a factorial arrangement of treatments was used in each phase. Covariance analysis was used in each phase to test for differences in total heights and root-collar diameters due to treatments, with the covariants being initial heights and initial root-collar diameters, respectively. A factorial analysis of variance was used in each phase to test for differences in survival due to treatments. Survival percentages were transformed to arcsin $\sqrt{\text{percentage}}$ before analyses. Duncan's multiple range test was used to compare means of heights, diameters, and survival in Phase I and nutrient contents in Phase II. The control plots were not included in any of the statistical analyses, but merely served as comparisons with the results of the applied treatments. Significance was tested at the 0.05 level of probability. An

Olivetti-Underwood Programma 101 Computer was employed in these statistical analyses.

Analyses of total heights, root-collar diameters, and survival were made using the following skeleton forms:

Phase I:

Source of Variation	d.f.
Depth (A)	2
Duration (B)	2
AB	4
Error	18
Total	26

Phase II:

Source of Variation	d.f.
Flooding depth (A)	1
Siltation depth (B)	1
Flooding duration (C)	1
AB	1
AC	1
BC	1
ABC	1
Error	16
Total	23

Phase III:

Source of Variation	d.f.
Reflood date (A)	1
Duration (B)	1
AB	1
Error	8
Total	11

The factorial arrangement of treatments was destroyed when the previously mentioned treatments did not yield enough leaves for chemical analyses. So, a one-way analysis of variance was used to test for treatment differences in nutrient contents of the leaves. Nutrients in each phase were tested using the following skeleton forms:

Phase I:

Source of Variation	d.f.
Treatments	7
Error	16
Total	23

Phase II:

Source of Variation	d.f.
Treatments	6
Error	14
Total	20

Phase III:

Source of Variation	d.f.
Treatments	2
Error	6
Total	8

RESULTS AND DISCUSSION

Effects of Flooding and Siltation on Growth and Survival

In this chapter, the results of depth and duration of flooding, date and duration of reflooding, and siltation depth on total heights, root-collar diameters, survival, and dieback of 1-year-old water tupelo seedlings are presented and discussed. Because the effects of the major treatment combinations on total heights and on root-collar diameters were very similar, they are presented and discussed together.

Total heights and root-collar diameters.--Total heights (height) and root-collar diameters (diameter) for Phases I, II, and III are given in Tables 1, 2, and 3, respectively. Heights and diameters, except for control plots, were compared in analyses of covariance (Appendix B, Tables 12, 13, 15, 16, 18, and 19), revealing that both depth and duration of flooding had a significant effect. The one exception was that duration of flooding in Phase II did not significantly affect height. It should be recalled that plots in Phase II were subjected to moderate and deep flooding until June 1 and July 1 plus siltation.

As stated in the preceding chapter, the control plots were included to study the response of water tupelo to non-flooded conditions. Because the three replications of the control plots

Table 1. Average heights, diameters, and survival of water tupelo by flooding depth and drainage date (Phase I)[1/]

Drainage date	Shallow flooding					Moderate flooding					Deep flooding				
	Height		Diameter			Height		Diameter			Height		Diameter		
	Initial	Final	Initial	Final	Survival	Initial	Final	Initial	Final	Survival	Initial	Final	Initial	Final	Survival
	---cm---		---mm---		%	---cm---		---mm---		%	---cm---		---mm---		%
June 1	49	101	7	22	100	47	74	6	16	92	50	67	7	14	93
July 1	47	76	7	16	98	50	80	7	16	100	50	44	8	11	87
Aug. 1	50	89	7	20	100	50	67	7	13	95	46	22	7	6	32

1/ Each value is the average of 3 replications.

Table 2. Average heights, diameters, and survival of water tupelo by siltation depth, flooding depth, and drainage date (Phase II)[1]

Flooding depth	Drainage date	3 to 4 inches of sand: Height: Initial	Height: Final	Diameter: Initial	Diameter: Final	Survival	6 to 8 inches of sand: Height: Initial	Height: Final	Diameter: Initial	Diameter: Final	Survival
		cm	cm	mm	mm	%	cm	cm	mm	mm	%
Moderate	June 1	44	54	5	8	87	45	63	5	12	95
Moderate	July 1	44	56	6	10	87	42	51	5	9	88
Deep	June 1	46	38	6	9	68	39	33	4	7	62
Deep	July 1	40	31	5	6	68	37	20	5	6	30

1/ Each value is the average of 3 replications.

Table 3. Average heights, diameters, and survival of water tupelo by date and duration of reflooding (Phase III)[1/]

Reflood date	Reflood duration	Height Initial	Height Final	Diameter Initial	Diameter Final	Survival
		cm		mm		Percent
July 1	1 week	45	47	6	9	92
July 1	2 weeks	48	41	6	8	85
August 1	1 week	46	37	6	7	90
August 1	2 weeks	43	35	5	6	75

1/ Each value is the average of 3 replications.

were not actually included as part of the other three phases of the study, they were not included in the analyses of covariance.

Means of heights and diameters for the major treatments in Phase I are compared below by Duncan's multiple range test.

Growth variable	Depth of flooding: Deep	Moderate	Shallow
Mean ht. (cm)	44.47	73.50	88.76
Mean diam. (mm)	10.27	14.93	19.33

	Duration of flooding: Until August 1	Until July 1	Until June 1
Mean ht. (cm)	59.27	66.63	80.83
Mean diam. (mm)	12.97	14.17	17.40

Means as given above were adjusted according to Steel and Torrie (1960) before making comparisons. In all Duncan's multiple range tests in this paper means connected by the same rule do not differ significantly at the 0.05 level of probability.

Generally, as shown by Duncan's multiple range test, as flooding depth and duration were increased, heights and diameters decreased.

Seedlings in shallow-flooded plots were significantly taller, about 14 cm, and had significantly larger diameters, about 4.5 mm, than seedlings in moderate-flooded plots. Early in the growing season, seedlings in the shallow-flooded plots had much larger, healthier crowns than seedlings in the moderate-flooded plots (Plates 3 and 4). This may be partially explained on the

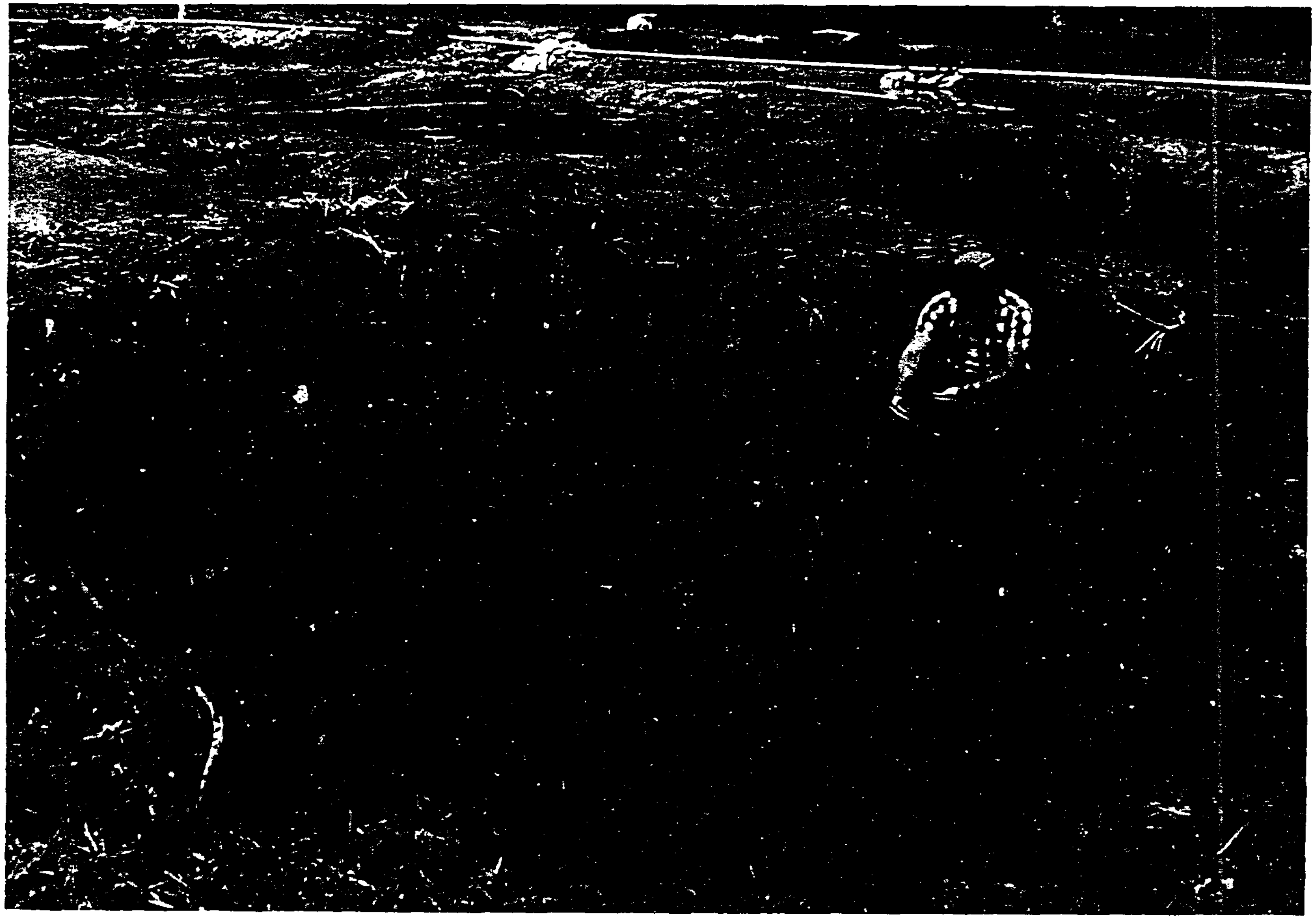

Plate 3. A shallow-flooded plot photographed early in the growing season. Note large crowns on these seedlings.

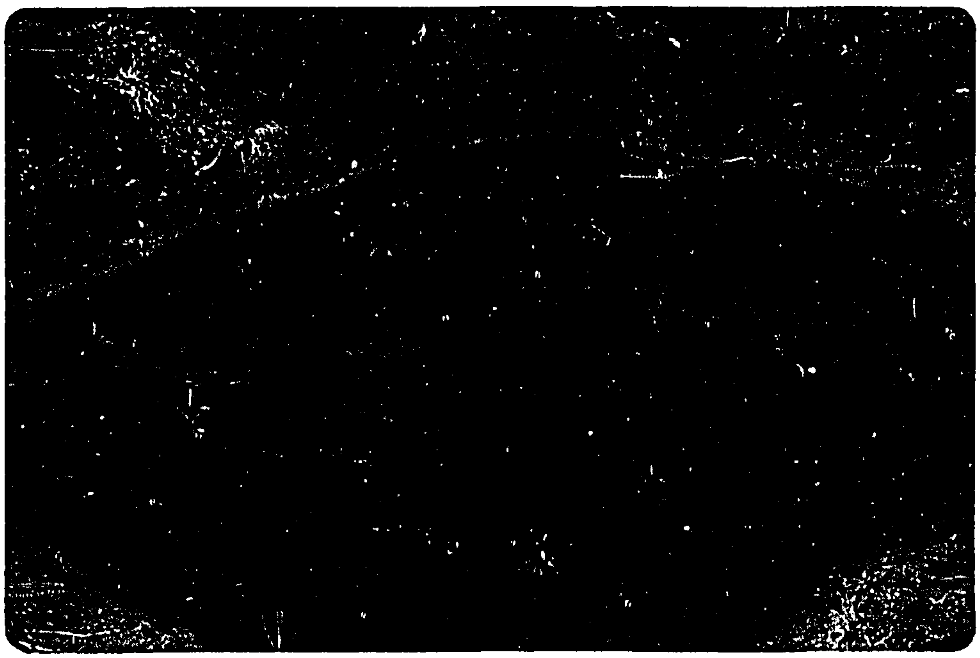

Plate 4. A moderate-flooded plot photographed early in the growing season. Note smaller crowns on these seedlings compared to those in the shallow-flooded plot shown on the previous plate.

basis of soil temperatures. As shown in Table 4, soil temperatures until early June were 5° to 9°F lower in the moderate-flooded than in the shallow-flooded plots. These lower soil temperatures could have caused lower metabolic activity in the roots, high enough for the seedlings to survive but not enough for them to make appreciable growth. After the soil warmed up in the moderate-flooded plots, the seedlings developed larger crowns and grew faster during the remainder of the growing season. As shown in Plates 5 and 6, seedling crowns at the end of the growing season appeared about the same in the moderate-flooded as in the shallow-flooded plots.

Heights and diameters by depth and duration of flooding in Phase I are shown graphically in Figures 3 and 4, respectively. Note that height and diameter for the shallow flooding until July 1 was less than the same flooding depth drained on August 1. This may be explained by the fact that one plot in the July 1 drainage date contained seven seedlings with dieback which averaged 21 cm per seedling.

The smaller seedlings in the deep-flooded plots were probably the result of a shorter growing season and excessive dieback. The shorter growing season was due to the seedlings being under water and they did not leaf out until the plots were drained. Dieback in seedlings will be discussed later in this paper.

As shown in the following tabulation and in Tables 1 and 2, siltation in combination with depth and duration of flooding

Table 4. Soil and water temperatures and oxygen content of water in Phase I plots[1/]

Measurement date	Shallow			Moderate			Deep		
	Temperature		Oxygen content	Temperature		Oxygen content	Temperature		Oxygen content
	Water	Soil		Water	Soil		Water	Soil	
	---°F---		ppm	---°F---		ppm	---°F---		ppm
4/17	73	69	8.1	72	67	6.4	69	65	5.3
5/7	84	73	6.6	80	68	6.0	68	67	4.4
5/21	88	79	7.5	84	71	5.8	69	68	3.7
6/17	90	86	6.5	86	83	9.1	83	82	6.0
7/9	81	81	11.0	83	82	8.3	79	81	5.5
7/18	90	87	7.9	86	86	7.1	85	86	5.3
8/1	93	90	7.1	91	90	5.7	87	90	5.7
8/16	--	89	--	--	88	--	--	89	--
9/13	--	72	--	--	71	--	--	71	--

Flooding depth: Shallow, Moderate, Deep.

1/ Each value is the average of 3 replications.

Plate 5. Seedlings in a shallow-flooded plot at the end of the growing season.

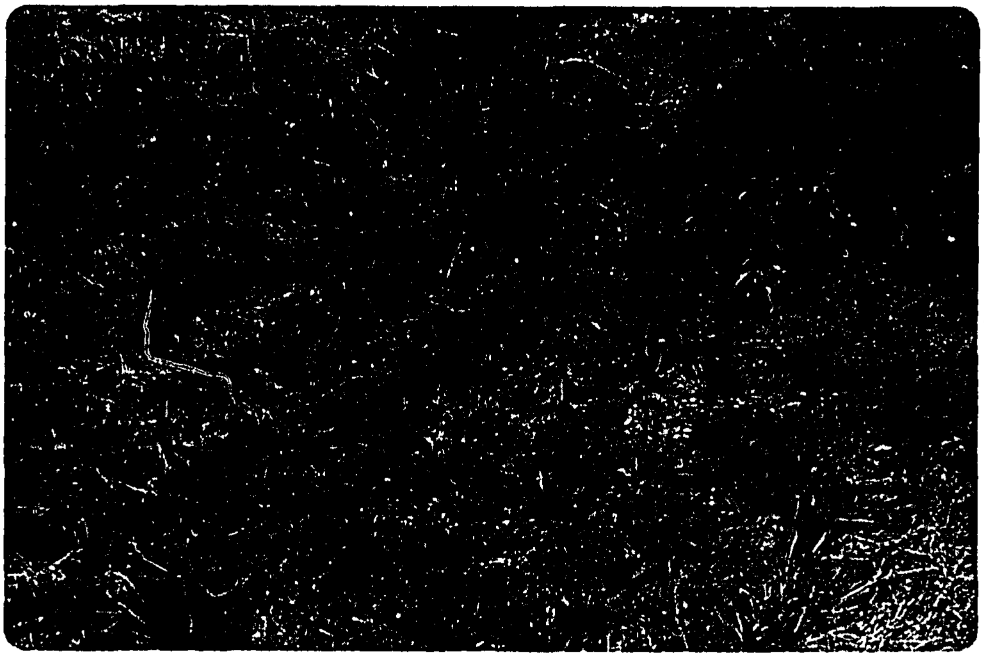

Plate 6. Seedlings in a moderate-flooded plot at the end of the growing season. Note that these seedlings appear about the same as ones in the shallow-flooded plot shown in the previous plate.

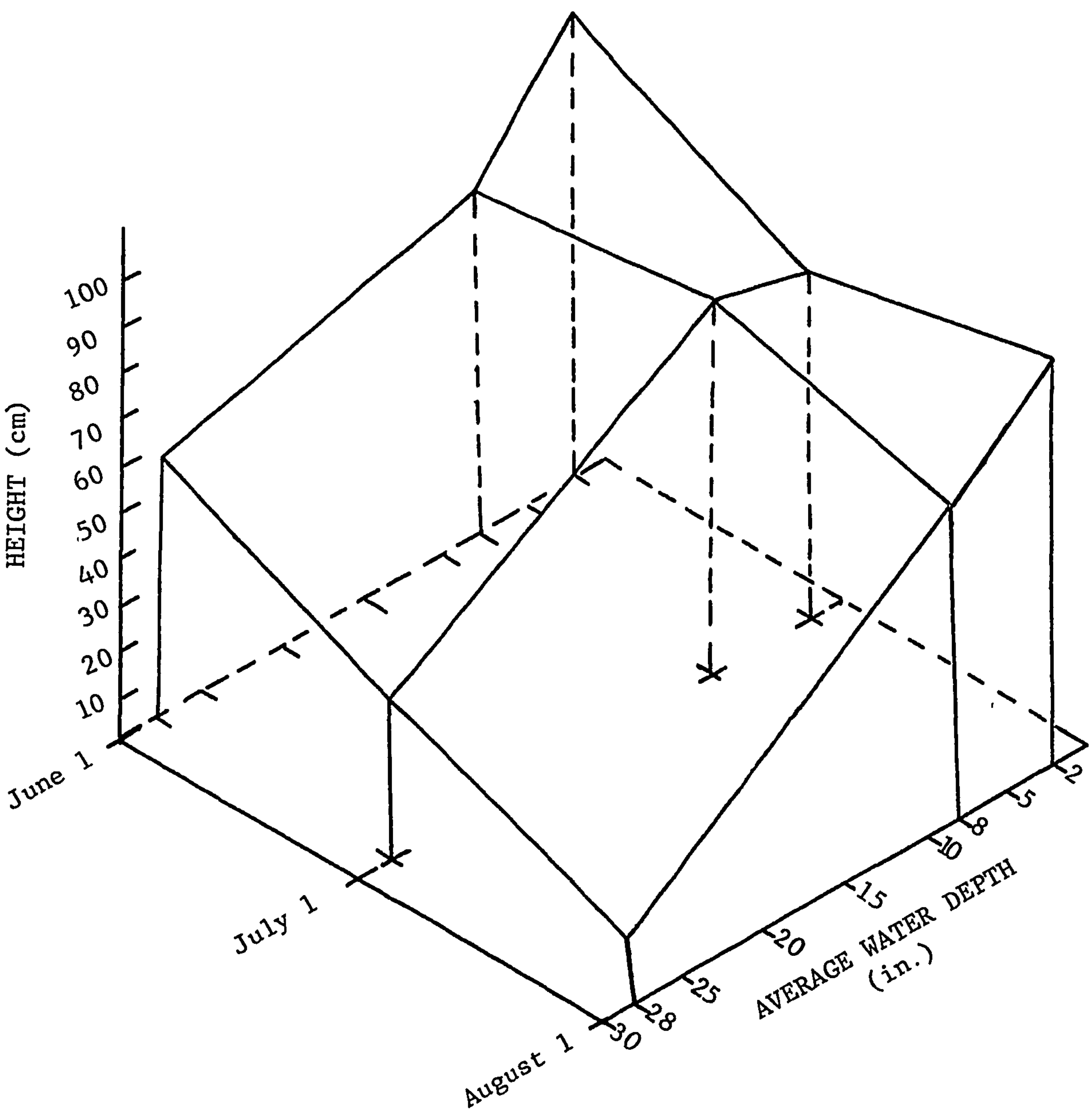

Figure 3. Response of total height to depth and duration of flooding in Phase I.

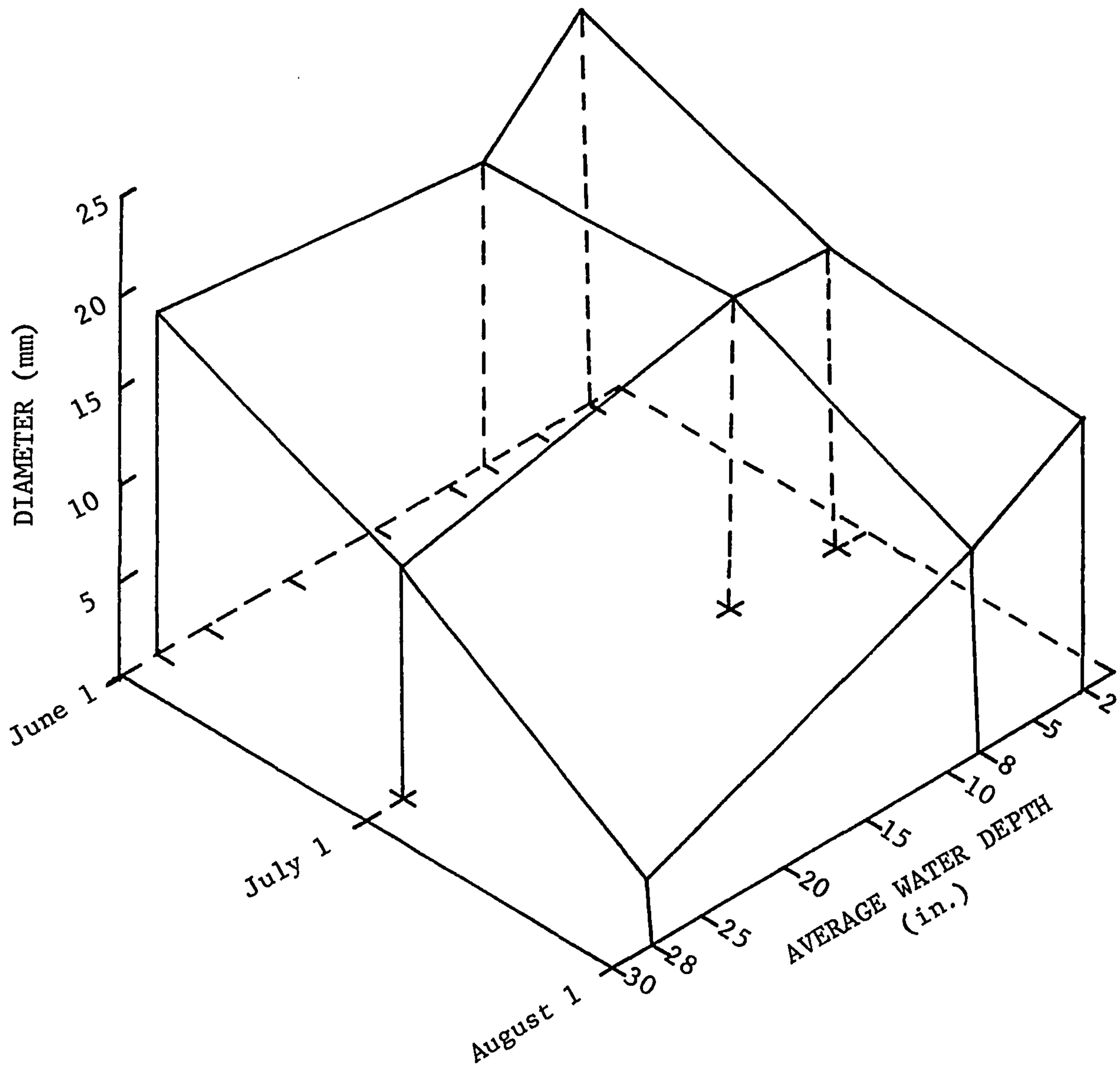

Figure 4. Response of root-collar diameters to depth and duration of flooding in Phase I.

(Phase II) caused a reduction in heights and diameters when compared to plots with similar depths and durations of flooding but without siltation.

Depth and duration of flooding	Siltation[1/]		No siltation	
	Height	Diameter	Height	Diameter
	cm	mm	cm	mm
Moderate flooding, June 1	54	8	74	16
Moderate flooding, July 1	56	10	80	16
Deep flooding, June 1	38	9	67	14
Deep flooding, July 1	31	6	44	11

1/ These measurements were made from the top of the sand in plots with 3 to 4 inches of siltation.

Seedlings were 13 to 24 cm shorter and had diameters 5 to 8 mm smaller in plots with siltation than without siltation, but the two siltation depths used did not differ significantly in their effect on heights and diameters. The above differences may be significant, but treatments with and without siltation could not be compared statistically. As shown in Plates 7 and 8, seedlings in plots with siltation did not develop large, healthy crowns as in plots without siltation, even after the soil warmed up.

Seedlings which were reflooded during the growing season (Phase III) were smaller than seedlings receiving most of the other treatment combinations. Reflood dates (July 1 and August 1) and reflood durations (1 and 2 weeks) used, however, did not differ significantly in their effects on heights and diameters.

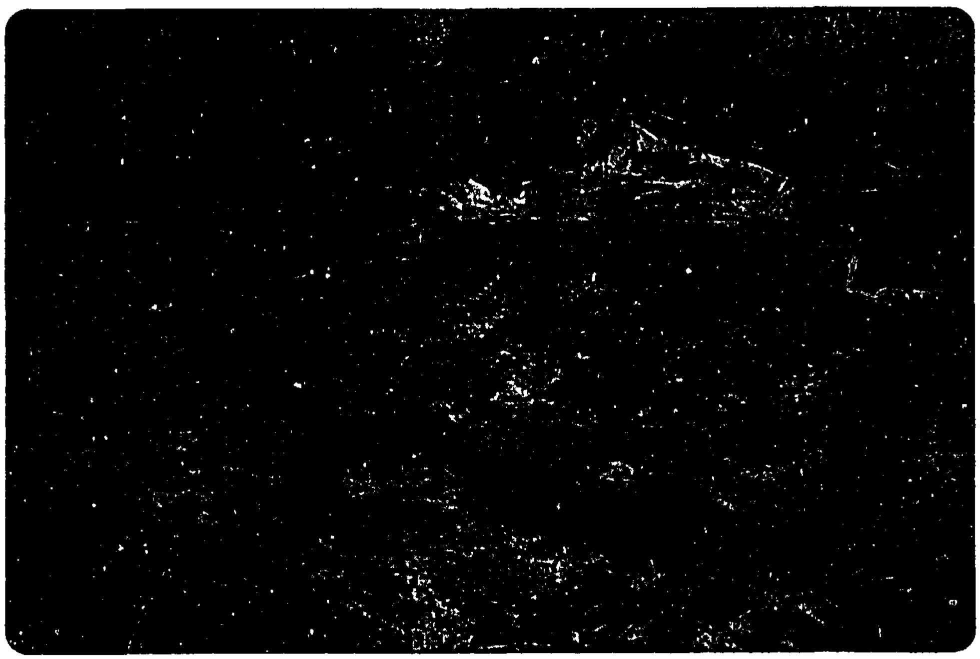

Plate 7. Seedlings in a plot subjected to 6 to 8 inches of siltation in conjunction with moderate flooding until June 1. Note the small crowns on these seedlings when photographed at the end of the growing season.

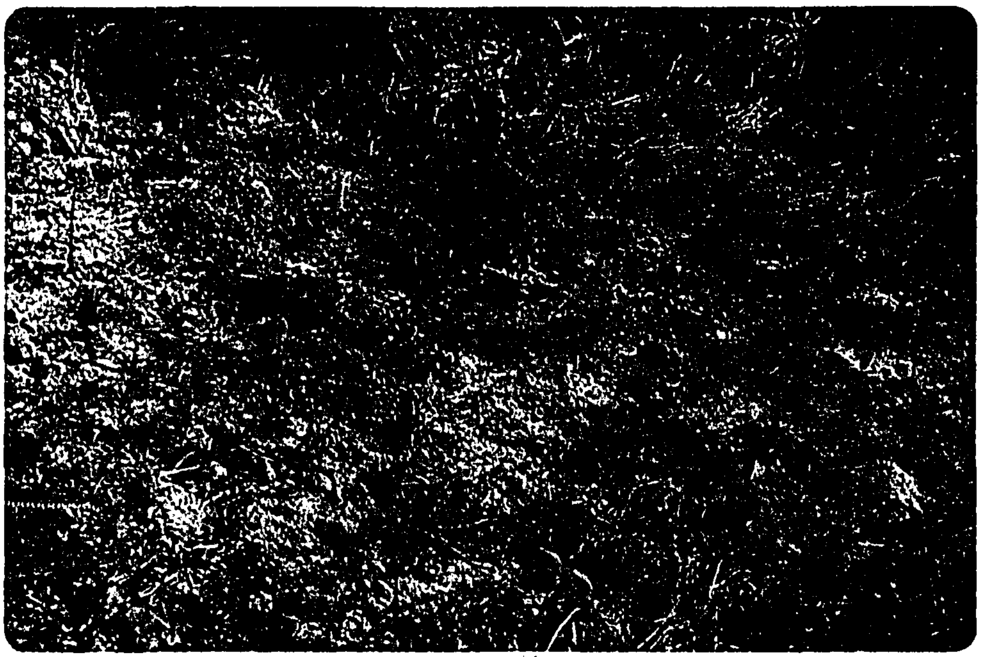

Plate 8. Seedlings in a plot subjected to 6 to 8 inches of siltation in conjunction with deep flooding until June 1. Note the small size and small crowns of these seedlings at the end of the growing season.

The seedlings had leafed out by the time they were reflooded. It should be recalled that these seedlings were initially deep flooded and reflooded to the same depth. Both reflooding dates and durations of reflooding killed the leaves. However, within about a week after the plots had been drained after the reflooding, the seedlings began to leaf out a second time. Thus, a combination of shorter growing season because of being under water until drained and dieback probably caused the smaller seedlings (Plate 9) in plots reflooded during the growing season.

The control plots received no treatments after planting, only water from rainfall, and rains were frequent and evenly distributed throughout the growing season. Average total heights, root-collar diameters, and survival for the control plots are given below.

Total height		Root-collar diameter		
Initial	Final	Initial	Final	Survival
cm		mm		%
47	108	5	21	95

Seedlings in the control plots were slightly taller and had about the same diameter size (Plate 10) as the seedlings in the best of the treatment combinations--shallow flooding until June 1.

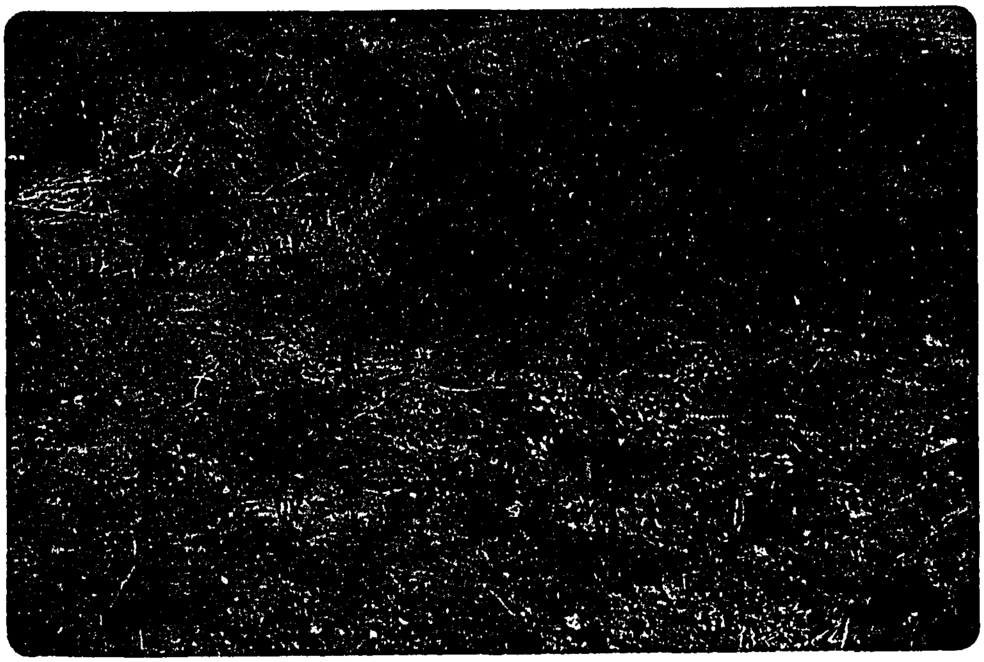

Plate 9. Seedlings in this plot were reflooded during the growing season. They averaged about 40 cm total height compared to about 67 cm in similar plots not reflooded. This photograph was made at the end of the growing season.

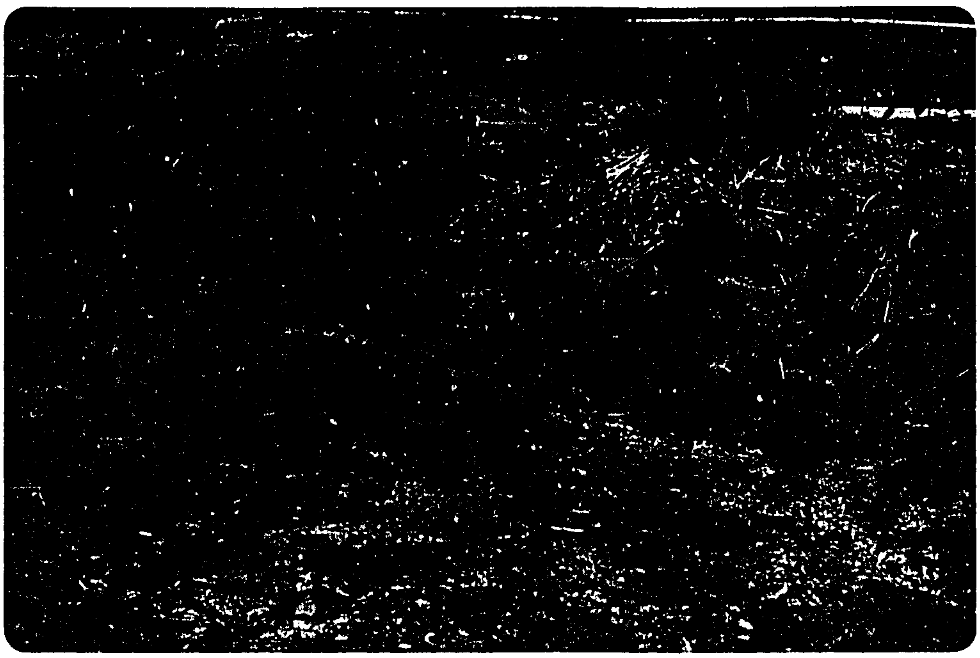

Plate 10. Photograph of seedlings in one of the control plots. These seedlings averaged 108 cm total height and 21 mm in diameter at the end of the growing season.

The leaf weights of seedlings subjected to the various treatment combinations are shown in the following tabulation.

Treatment	Weight[1/] Grams
Phase I:	
Shallow flooding, June 1	191.5
Shallow flooding, July 1	86.5
Shallow flooding, August 1	165.2
Moderate flooding, June 1	81.4
Moderate flooding, July 1	105.4
Moderate flooding, August 1	52.6
Deep flooding, June 1	69.1
Deep flooding, July 1	36.6
Deep flooding, August 1	7.8
Phase II:	
Moderate flooding, 3 to 4" sand, June 1	25.6
Moderate flooding, 3 to 4" sand, July 1	25.3
Moderate flooding, 6 to 8" sand, June 1	45.9
Moderate flooding, 6 to 8" sand, July 1	35.8
Deep flooding, 3 to 4" sand, June 1	20.3
Deep flooding, 3 to 4" sand, July 1	6.9
Deep flooding, 6 to 8" sand, June 1	8.3
Deep flooding, 6 to 8" sand, July 1	1.2
Phase III:	
July 1, 1 week	19.0
July 1, 2 weeks	6.6
August 1, 1 week	7.0
August 1, 2 weeks	3.9
Control	178.1

1/ Each value is the average of 3 replications.

These leaf weights indicate that seedling size generally decreased as flooding depth, flooding duration, siltation depth, and reflooding increased in severity.

Survival.--Survival percentages for Phase I, II, and III are also given in Tables 1, 2, and 3, respectively. Survival, except for control plots, was compared in analyses of variance for factorial designs (Appendix B, Tables 14, 17, and 20) revealing that depth and duration of flooding and their interaction in Phase I had a significant effect. Flooding depth and the flooding-depth X siltation-depth interaction in Phase II, and duration of reflooding in Phase III, also had a significant effect on survival.

Comparisons of arcsin-transformed means of survival for the major treatments in Phase I are shown below in Duncan's multiple range test.

Depth of flooding		
Deep	Moderate	Shallow
58.5	78.1	82.9

Duration of flooding		
Until August 1	Until June 1	Until July 1
63.8	77.5	78.2

As shown above, the significant difference in depth and duration of flooding was accounted for by the deep-flooding-until-August-1 treatment. Survivals, except for this one

treatment, ranged from 87 to 100 percent. In the deep-flooding-until-August-1 treatment, all seedlings died in one replication, all except one in the second replication, but only two died in the third replication. Duncan's multiple range test (Appendix B, Table 14) revealed that the significant interaction was caused by the high mortality in this treatment. Means of the other eight treatments were not significantly different.

Siltation in conjunction with depth and duration of flooding appeared to reduce survival when compared to plots with similar depths and durations of flooding but without siltation; however, survival percentages between treatments with and without siltation could not be compared statistically. Moderate-flooded plots with siltation averaged 87 percent survival compared to about 96 percent in similar plots without siltation. Deep-flooded plots with siltation averaged 57 percent survival compared to 90 percent in similar plots without siltation.

Reflood durations used in Phase III also significantly affected survival, with survival being less after 2 weeks of reflooding than 1 week. Even though a significant difference did exist, the most severe treatment (reflooded August 1 for 2 weeks) had 75 percent survival. If this survival could be maintained, it would probably be a satisfactory survival rate in most plantings.

From these data, it appears that survival was satisfactory in all treatments except under deep flooding until August 1 in Phase I and under deep flooding plus siltation in Phase II.

Dieback.--Deep-flooding treatments caused severe dieback in seedlings. No statistical analysis of dieback was planned, but observations were made throughout the study. In plots drained on June 1 and July 1 in Phase I, an average of 15 of the 20 seedlings in each plot had dieback. In plots drained on August 1, over 90 percent of the live seedlings had dieback. The range was 3 to 54 cm with an average of 32 cm.

Siltation appeared to have an effect on dieback also, as dieback occurred under all flooding depths in plots with siltation. Even though water did not cover the seedlings in the moderate-flooded plots, an average of six seedlings per plot had dieback in plots with siltation compared to practically no dieback in the moderate- and shallow-flooded plots without siltation. The range was 6 to 24 cm with an average of 15 cm. Dieback in plots flooded above the seedlings was about the same with or without siltation.

Dieback was severe in reflooded plots also. However, the dieback was caused by initial deep flooding, as the dieback had already occurred when the plots were drained in June, before any reflooding was done. Over 80 percent of the seedlings in the reflooded plots had dieback. The range was 1 to 52 cm with an average of 25 cm. As shown in Table 5, water temperatures had not been above 70°F before June, so the water probably had not been warm enough for heat to cause the dieback.

One important characteristic of seedlings with dieback was their ability to sprout. All live seedlings sprouted just below

Table 5. Soil and water temperatures and oxygen content of water in Phase III plots[1/]

Measurement date	Treatment[2/]											
	July 1, 1 week			July 1, 2 weeks			August 1, 1 week			August 1, 2 weeks		
	Temperature		Oxygen	Temperature		Oxygen	Temperature		Oxygen	Temperature		Oxygen
	Water	Soil	content	Water	Soil	content	Water	Soil	content	Water	Soil	content
	---°F----		ppm	---°F----		ppm	---°F----		ppm	---°F----		ppm
4/17	68	65	5.2	65	66	5.1	70	66	5.2	69	66	5.2
5/7	65	65	5.4	69	67	4.3	69	66	4.8	66	65	5.3
5/21	67	65	4.7	70	68	4.5	70	67	4.9	68	67	4.9
6/17	--	86	--	--	89	--	--	87	--	--	88	--
7/9	--	87	--	83	82	--	--	88	--	--	87	--
7/18	--	90	--	--	92	--	--	91	--	--	89	--
8/1	--	95	--	--	98	--	--	95	--	--	93	--
8/16	--	94	--	--	96	--	--	93	--	--	92	--
9/13	--	74	--	--	77	--	--	76	--	--	72	--

1/ Each value is the average of 3 replications.
2/ Reflooded on dates shown for one or two week duration as indicated.

the lowest point of dieback. Usually the first bud below the dieback asserted dominance and became the new leader for the seedling. In plots that were deep flooded until June 1 in Phase I the seedlings averaged 67 cm in height at the end of the growing season (Plate 11). However, total height was less in plots receiving other treatment combinations (Plate 12). In a number of plots final seedling heights were less than initial heights of the same seedlings (Tables 1, 2, and 3). The only explanation that can be given for the dieback is that possibly the oxygen content of the water was low enough to cause dieback or the water simply disrupted the normal physiological processes and thereby caused dieback.

Effects of Flooding on Some Soil Properties and Nutrient Uptake by Seedlings

Water from Shell Lake, used in the flooding phases, was sampled and analyzed on two dates. Results of these analyses are given below.

		Concentration				
Sampling date	pH	P_2O_5	NO_3	K	Ca	Mg
		Parts per million				
March 1	7.7	1.2	2.6	3.1	25.5	25.8
July 1	6.9	4.5	4.2	4.3	35.2	29.2

The nutrient concentration in the flood water, when considered in conjunction with the volume of water used in each plot, probably did not appreciably influence the nutrient status of the soil.

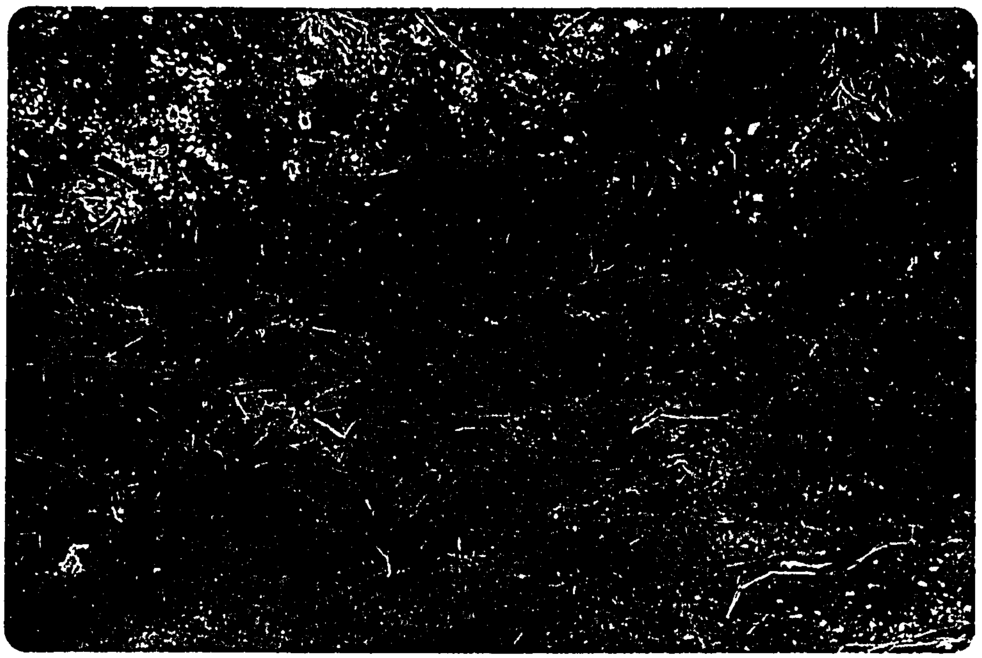

Plate 11. A plot subjected to deep flooding until June 1. These seedlings averaged 67 cm total height at the end of the growing season.

Plate 12. A plot subjected to deep flooding until July 1. These seedlings averaged 44 cm total height at the end of the growing season.

Soil samples were collected on three dates and chemically analyzed. The results of these analyses will be discussed individually in this section. At the time the flooded soil samples were collected, plots in Phase III were deep flooded and thus had received the same treatment as plots flooded the same depth in Phase I. The only difference among the plots in the two phases when the flooded soil samples were collected was their location within the study area.

Results of the soil analyses on the control plots are also given in the tables presented in this section. These results are presented for comparative purposes only, as no statistical comparisons were made between the control plots and plots receiving other treatments. There was some variation in the nutrient status of the control plots by sampling date, but these probably were caused by differences in soil moisture content by sampling date or variation in soil nutrient content due to different sampling dates.

Oxidation-reduction potentials.-- Oxidation-reduction (redox) potentials of air-dry soil samples taken before flooding averaged 269 millivolts after correcting for the potential of the calomel electrode and adjusting to pH 7. A correction factor of 60 millivolts per pH unit was used (Bonner and Ralston 1968). Adjusted redox potentials in millivolts for the flooded soil are given below.

Treatment	Redox potential[1/]
Phase I:	
Shallow flooding, June 1	-50
Shallow flooding, July 1	-43
Shallow flooding, August 1	-33
Moderate flooding, June 1	-38
Moderate flooding, July 1	-39
Moderate flooding, August 1	-30
Deep flooding, June 1	-72
Deep flooding, July 1	-35
Deep flooding, August 1	-56
Phase III:	
July 1, 1 week	-81
July 1, 2 weeks	-71
August 1, 1 week	-78
August 1, 2 weeks	-52

1/ Each value is average of 3 replications.

The redox potentials for air-dry soil are lower and for flooded soil higher than those given by Redman and Patrick (1965). However, they did not study Alligator clay, the soil type used in this study, so no direct comparisons can be made. Soils in shallow- and moderate-flooded plots had slightly higher redox potentials than soils that were deep flooded.

The lower redox potentials in the deep-flooded plots could have been caused by a combination of factors. Oxygen

concentrations (Table 4 and 5) in the deep-flooded plots were lower than in the other plots. The oxygen concentrations are comparable with concentrations reported by Broadfoot (1967). He found that oxygen in impounded water was depleted quickly in periods of no rainfall but was recharged by even small showers. Generally, there was less oxygen near the bottom than near the surface of the water in impoundment areas. Thus, higher oxygen concentrations and more rapid diffusion into the soil, because of the shorter distance between water surface and soil surface, may have prevented the shallow- and moderate-flooded plots from becoming as reduced as those flooded deeply.

Ammonium accumulations.--As shown in Table 6, flooding brought about increases in ammonium nitrogen. Ammonium nitrogen contents in flooded soils did not vary appreciably by flooding depths in Phase I. There was about 2.5 times more ammonium nitrogen during flooding than before initial flooding. But, ammonium nitrogen contents during flooding in the Phase III plots were about twice as high as in plots flooded the same depth in Phase I. The only explanation that can be given for the higher ammonium contents in Phase III plots compared to Phase I plots is possibly a difference in microbial activity could account for the difference in the two areas.

Nitrate reduction.--Nitrates were reduced under all levels of flooding. In most plots (Table 6), nitrates could not be measured in the soil samples collected during flooding. Trace

Table 6. Nitrogen content of soil by treatment before, during, and after flooding[1/]

Treatment	Before flooding			During flooding			After flooding		
	NH_4	NO_3	Total	NH_4	NO_3	Total	NH_4	NO_3	Total
	Parts per million								
Phase I:									
Shallow flooding, June 1	8.9	19.6	28.5	25.3	2.4	27.7	9.8	5.4	15.2
Shallow flooding, July 1	9.9	26.3	36.2	31.2	5.0	36.2	12.4	26.1	38.5
Shallow flooding, Aug. 1	9.7	25.2	34.9	28.3	8.6	36.9	9.0	29.3	38.3
Moderate flooding, June 1	10.6	18.9	29.5	16.0	0	16.0	12.3	11.5	23.8
Moderate flooding, July 1	12.7	24.1	36.8	27.0	3.3	30.3	18.4	16.4	34.8
Moderate flooding, Aug. 1	9.3	39.7	49.0	18.0	0	18.0	9.3	25.9	35.2
Deep flooding, June 1	8.1	23.8	31.9	17.2	0	17.2	8.5	6.3	14.8
Deep flooding, July 1	14.1	31.6	45.7	28.8	0	28.8	18.1	12.6	30.9
Deep flooding, Aug. 1	8.2	24.1	32.3	28.8	0	28.8	22.0	77.5	99.5
Phase III:									
July 1, 1 week	9.6	13.1	22.7	74.7	0	74.7	20.8	59.1	79.9
July 1, 2 weeks	12.8	15.4	28.2	38.0	0	38.0	16.3	7.3	23.6
Aug. 1, 1 week	11.0	7.5	18.5	62.1	0	62.1	35.2	12.7	47.9
Aug. 1, 2 weeks	11.5	19.9	31.4	62.9	0	62.9	37.1	26.4	63.5
Control	9.8	22.1	31.9	17.5	11.9	29.4	12.3	12.6	24.9

1/ Each value is the average of 3 replications.

amounts were measured in some plots with shallow and moderate flooding. So, considerable quantities of available nitrogen were apparently lost from the soil through denitrification. No measure was made of the rate of nitrate reduction in this study. Spurgeon and Grissom (1963), however, stated that up to 50 percent of the total nitrogen lost from water-logged soil occurred in 2 to 5 days after water-logging.

Nitrogen contents measured on soil samples collected about two months after the last plots were drained indicated that the soil had returned to about the same ammonium and nitrate levels measured prior to flooding (Table 6).

Extractable phosphorus.--All plots showed an increase in extractable phosphorus during flooding (Table 7). Extractable phosphorus contents in flooded soils did not vary appreciably by flooding depths in Phase I. Flooding caused about a 30 percent increase in extractable phosphorus in Phase I, and there was about one-third more extractable phosphorus during initial flooding in the Phase III plots than in plots flooded the same depth in Phase I. Redman and Patrick (1965) found that increases in extractable phosphorus occurred only in soils which contained large quantities of ferrous iron. Because extractable ferrous iron was not measured in this study, increases in extractable phosphorus cannot definitely be attributed to increase in extractable ferrous iron. However, there could have been a difference in iron content of the soil which caused the difference in extractable phosphorus in the two areas.

Table 7. Phosphorus content of soil by treatment before, during, and after flooding[1/]

Treatment	Before flooding	During flooding	After flooding
	----Parts per million----		
Phase I:			
Shallow flooding, June 1	109	199	149
Shallow flooding, July 1	129	223	178
Shallow flooding, Aug. 1	137	192	172
Moderate flooding, June 1	122	147	169
Moderate flooding, July 1	144	184	178
Moderate flooding, Aug. 1	122	149	155
Deep flooding, June 1	111	158	184
Deep flooding, July 1	145	237	183
Deep flooding, Aug. 1	147	213	184
Phase III:			
July 1, 1 week	145	364	179
July 1, 2 weeks	120	289	170
Aug. 1, 1 week	131	364	156
Aug. 1, 2 weeks	103	362	160
Control	101	137	152

1/ Each value is the average of 3 replications.

Extractable phosphorus content in soil samples collected about 2 months after the last plots were drained was still somewhat higher than before flooding (Table 7), indicating that the effects of flooding on phosphorus may be a slowly reversible process upon drying in this clay soil.

Potassium.--Exchangeable potassium contents were about 40 percent less under flooded than under nonflooded conditions (Table 8). Losses were about the same regardless of the depth of flooding. Because of the highly soluble nature of potassium (Millar 1955), losses due to leaching below the 0- to 6-inch sampling depth and uptake by seedlings could account for the lower exchangeable potassium content under flooded conditions.

Analyses of soil samples taken after flooding indicated the exchangeable potassium content had returned to about the same level as before flooding. DeTurk et al., as cited by Millar (1955), found a decrease of about 40 percent in replaceable potassium in some Illinois soils during the growing season. But, the supply had been restored by the following spring. The results of this study appear to be in line with the results of DeTurk et al.

Calcium.--As shown in Table 9, calcium contents were lower during and after flooding than before flooding. Losses were similar in all flooding depths. As with potassium, leaching below the 0- to 6-inch sampling depth during flooding and

Table 8. Potassium content of soil by treatment before, during, and after flooding[1/]

Treatment	Before flooding	During flooding	After flooding
	----Parts per million----		
Phase I:			
Shallow flooding, June 1	422	262	393
Shallow flooding, July 1	423	265	540
Shallow flooding, Aug. 1	496	326	475
Moderate flooding, June 1	458	200	468
Moderate flooding, July 1	444	262	352
Moderate flooding, Aug. 1	493	249	515
Deep flooding, June 1	506	269	393
Deep flooding, July 1	440	320	494
Deep flooding, Aug. 1	454	253	498
Phase III:			
July 1, 1 week	481	308	441
July 1, 2 weeks	463	263	412
Aug. 1, 1 week	449	320	447
Aug. 1, 2 weeks	474	249	346
Control	408	346	412

1/ Each value is the average of 3 replications.

Table 9. Calcium content of soil by treatment before, during, and after flooding[1/]

Treatment	Before flooding	During flooding	After flooding
	-----Parts per million-----		
Phase I:			
Shallow flooding, June 1	5163	3997	2983
Shallow flooding, July 1	4165	4764	3975
Shallow flooding, Aug. 1	5045	3914	3769
Moderate flooding, June 1	4048	4348	2512
Moderate flooding, July 1	4400	4364	4326
Moderate flooding, Aug. 1	5918	5208	4107
Deep flooding, June 1	4884	4876	3980
Deep flooding, July 1	4253	5010	2904
Deep flooding, Aug. 1	4517	4415	2919
Phase III:			
July 1, 1 week	4224	3953	3535
July 1, 2 weeks	5676	4216	3857
Aug. 1, 1 week	3857	4480	3109
Aug. 1, 2 weeks	4620	3128	3828
Control	3996	4886	4018

1/ Each value is the average of 3 replications.

leaching and seedling uptake after flooding could account for the lower calcium contents.

Organic matter and pH.--Organic matter content and pH before, during, and after flooding are shown in Table 10. Organic matter was high but fairly uniform from plot to plot before flooding. There was about a 2 percent increase in organic matter during flooding. This increase could be due to sampling technique. When samples were collected before flooding, litter was removed from the sampling area. Samples were then air-dried, ground, and passed through a 2-mm sieve before storage in icecream cartons until chemical analyses could be made. It is possible that some organic matter was screened out in the preparation process. When samples were collected during flooding, the litter was not removed. Samples were stored wet in ½-gallon glass jars in a refrigerator until the analyses were made. The soil was not sieved before organic matter determinations were made, so none of the organic matter was screened out of the wet soil.

Organic matter content after flooding was about the same as during flooding. Samples collected after flooding were handled in the same manner as samples taken before flooding. No explanation can be given for the higher organic matter content unless it was from cutting weeds and vines after drainage and leaving them in the plots. The plots were hoed five or six

Table 10. Organic matter and pH of soil by treatment before, during, and after flooding[1/]

Treatment	Organic matter			pH		
	Before flooding	During flooding	After flooding	Before flooding	During flooding	After flooding
	---------Percent---------					
Phase I:						
Shallow flooding, June 1	7.5	9.0	9.6	5.1	6.1	5.6
Shallow flooding, July 1	8.0	9.7	10.2	5.2	6.3	5.6
Shallow flooding, Aug. 1	7.9	8.8	10.2	5.3	6.4	5.5
Moderate flooding, June 1	7.3	10.3	8.8	5.3	6.1	5.5
Moderate flooding, July 1	8.1	7.8	9.6	5.2	6.0	5.6
Moderate flooding, Aug. 1	7.2	8.5	9.7	5.2	6.2	5.4
Deep flooding, June 1	8.1	8.8	9.6	5.2	6.1	5.7
Deep flooding, July 1	8.3	8.9	10.9	5.2	6.4	5.5
Deep flooding, Aug. 1	7.8	9.2	10.1	5.0	6.6	5.5
Phase III:						
July 1, 1 week	8.2	10.7	10.6	5.3	6.8	5.5
July 1, 2 weeks	8.6	10.6	10.8	5.3	6.4	5.6
Aug. 1, 1 week	8.0	9.8	9.5	5.1	6.7	5.5
Aug. 1, 2 weeks	8.1	11.2	10.8	5.1	6.7	5.5
Control	8.0	10.3	10.3	5.1	6.0	5.5

1/ Each value is the average of 3 replications.

times during the remaining growing season. Leaving the weeds and vines in the plots may have added some organic matter.

Flooding caused an increase in pH in all plots (Table 10). Averaged over all flooding depths, pH increased about 1.2 units. All plots were strongly acid before flooding but decreased in acidity during flooding. The production of hydroxyl ions as a result of ammonium production and the reduction of iron and other compounds could account for pH rises of this magnitude in acid soils (Redman and Patrick 1965).

The pH of soil samples collected about 2 months after all plots were drained was lower than during flooding. However, it was not as low as before flooding, indicating that effects of flooding on pH may be slowly reversible on drying in this clay soil.

<u>Relationship of soil changes to growth and survival</u>.--As discussed in this chapter, the results reveal that flooding and siltation had a pronounced effect on the soil properties measured which may have in turn affected the growth and survival of the seedlings. Redox measurements revealed a reduced soil condition, even under the shallow flooding. Hook (1968) reported that swamp tupelo appeared to have a dual metabolic system in its roots. Both aerobic and anaerobic respiration are active in the presence of oxygen, whereas anaerobic respiration occurs in the absence of oxygen. Perhaps water tupelo has the same type of system in its roots. Hook (1968) also found that high carbon

dioxide (31 percent) and low oxygen (1 percent) concentrations reduced height growth, root primoridia development, root respiration rate, the transpiration rate in swamp tupelo seedlings. Lower carbon dioxide (2 and 10 percent) at the same oxygen level (1 percent) had no effect on the growth variables. In the present study, possibly a build-up of carbon dioxide could have caused the reduced growth in the moderate- and deep-flooded plots due to a poor gas exchange between the soil and atmosphere. The exchange may have been better in the shallow-flooded plots and carbon dioxide did not accumulate enough to become toxic, thus allowing the seedlings to make better growth.

Siltation in combination with flooding could have had the same effect by restricting gas exchange more than flooding alone. Another possibility, other than a carbon dioxide buildup, is that the oxygen content in the soil was low enough to restrict growth.

The other changes in soil properties appear to be in line with what one would expect after flooding a soil (Redman and Patrick 1965). Even though the changes in soil properties occurred, the author feels they were not of a magnitude that would seriously affect seedling growth and survival.

Nutrient uptake.--Nutrient contents of the leaves are shown in Table 11. It will be recalled that seedlings from each of the Phase I plots treated by deep flooding until August 1, the Phase II plots deep flooded until July 1 with siltation 6 to 8

Table 11. Nutrient contents of leaves at the end of the growing season

Treatment	N	P	K	Ca
	Percent			
Phase I:				
Shallow flooding, June 1	2.12	0.124	1.39	0.556
Shallow flooding, July 1	2.43	.131	1.41	.573
Shallow flooding, Aug. 1	2.33	.117	1.42	.610
Moderate flooding, June 1	2.37	.129	1.34	.570
Moderate flooding, July 1	2.46	.143	1.44	.542
Moderate flooding, Aug. 1	2.51	.126	1.36	.617
Deep flooding, June 1	2.17	.136	1.33	.560
Deep flooding, July 1	2.12	.132	1.30	.566
Deep flooding, Aug. 1 1/	2.97	.159	1.47	.643
Phase II:				
Moderate flooding, 3 to 4 inches sand, June 1	2.31	.129	1.29	.603
Moderate flooding, 3 to 4 inches sand, July 1	2.51	.133	1.42	.548
Moderate flooding, 6 to 8 inches sand, June 1	2.13	.122	1.35	.566
Moderate flooding, 6 to 8 inches sand, July 1	2.31	.134	1.19	.581
Deep flooding, 3 to 4 inches sand, June 1	2.43	.132	1.35	.538
Deep flooding, 3 to 4 inches sand, July 1	2.56	.146	1.47	.575
Deep flooding, 6 to 8 inches sand, June 1	2.28	.131	1.24	.592
Deep flooding, 6 to 8 inches sand, July 1 1/	2.35	.146	1.26	.620
Phase III:				
July 1, 1 week	2.08	.139	1.38	.521
July 1, 2 weeks	2.17	.139	1.34	.569
Aug. 1, 1 week	2.20	.137	1.38	.645
Aug. 1, 2 weeks 1/	2.28	.147	1.50	.643
Control	1.90	.131	1.36	.537

1/ Values in these treatments are from a composite sample of the 3 replications in each treatment. All other values are the average of 3 replications.

inches deep, and the Phase III plots reflooded on August 1 for 2 weeks did not yield enough leaves for the chemical analyses. Therefore, the three plots in each of these treatments were composited into one sample for the particular treatment and the one sample was chemically analyzed. Losing the one treatment in each phase in the nutrient chemical analyses destroyed the factorial arrangement of treatments, therefore, each nutrient content of leaves in each phase was compared in analyses of variance for a completely randomized design (Appendix B, Tables 21-32).

The analyses revealed that only phosphorus and potassium uptake in Phase II were significantly affected by the various treatment combinations. The differences appeared to be caused by treatments which produced the smallest seedlings and probably are due to a dilution factor. From a practical standpoint, the differences in nutrient contents of the leaves appeared to be minor. The nutrient content values are within the range one would expect to find in unfertilized plots (Broadfoot 1966).

SUMMARY AND CONCLUSIONS

Water tupelo is a valuable timber species in swamps which cover more than 4 million acres in the southern and southeastern United States. Flooding and the accompanying wet conditions have discouraged people from working with this species and only recently has great interest been shown in better management and use of tupelo swamps. Little is known about the effects of these floods and accompanying siltation on survival and growth of water tupelo seedlings. However, this is a problem which must be understood before this species can be successfully regenerated, either naturally or by planting or direct-seeding.

This study was conducted on the Delta Experimental Forest near Stoneville, Mississippi, on Alligator clay, a soil type found in many swamps. The study investigated effects of flooding and siltation on survival and first-year growth of planted water tupelo seedlings. It consisted of three phases which were conducted concurrently.

Specific objectives were to compare the survival and first-year growth of water tupelo seedlings under:

Phase I: three depths and three durations of flooding;

Phase II: two depths of siltation and two depths and two durations of flooding;

Phase III: two dates and two durations of reflooding.

The hypothesis to be tested was that there was no difference in survival and first-year growth of planted water tupelo seedlings grown under these selected flooding depths and levels of siltation.

A series of levees were constructed in grid-like fashion to delineate the 66 plots (six rows of 11 plots) used in the study. Levees were about 3½ feet high and 12 feet wide at the base; individual plots were approximately 15 feet square. An irrigation system was installed to pump water from nearby Shell Lake to the plots. This system supplied surface water for flooding and enabled each plot to be flooded individually.

Early visual inspection of the study area indicated no macro-differences in site. Therefore, for ease of handling, plots were systematically selected for each phase, and treatment combinations were randomly assigned among plots in each phase. A completely randomized design with a factorial arrangement of treatments was used in each phase.

Seedlings were grown in the nursery at the Southern Hardwoods Laboratory from seed collected near Minter City, Mississippi. During the first week of February 1968, 30 1-year-old seedlings (six rows of five seedlings) were planted on a 2- by 2-foot spacing. All seedlings were 15 inches (38 cm) or taller. The interior four rows were designated for measurements. In order to test the hypothesis, survival, total height, and root-collar diameter were measured on the seedlings after 1 year in

the field. Leaves were to be collected from the two exterior rows for chemical analyses.

Soil samples collected on three dates and leaves collected at the end of the growing season were chemically analyzed. These were used in studying the effects of flooding on various soil properties and nutrient uptake by seedlings. Soil and water temperatures and oxygen content of the water in each plot were measured periodically throughout the study.

Analysis of covariance was used to compare total heights and root-collar diameters. A factorial analysis was used to analyze survival. Analysis of variance for a completely randomized design was used to compare nutrient contents of the leaves in each phase. Duncan's multiple range test was used to compare means in Phases I and II. Significance was tested at the 0.05 level.

From the results of this study, the following conclusions can be drawn:

1. Depth and duration of flooding significantly affected total heights and root-collar diameters. Best growth was in the shallow-flooding-until-June-1 and control plots. Generally, heights and diameters decreased as depth and duration of flooding increased.

2. Siltation in combination with depth and duration of flooding caused a reduction in heights and diameters when compared to plots flooded to the same depth but without siltation, even

though the siltation depths used in Phase II did not differ significantly in their effect on growth.

3. Reflood date and reflood duration did not differ significantly in their effect on growth. However, growth was less in these plots than in many of the other plots, indicating that reflooding during the growing season was detrimental to growth.

4. Survival was good in all treatments except the deep-flooding-until-August-1 treatment and treatments where siltation was used in conjunction with flooding depth and duration.

5. Deep flooding caused severe dieback of seedlings. Dieback was noted in over 75 percent of the seedlings in the deep-flooded plots. However, seedlings usually sprouted just below the lowest point of dieback.

6. Flooding affected most of the soil chemical properties studied. Redox potentials revealed a reduced soil under flooded conditions. Ammonium nitrogen accumulated and nitrates were reduced. Extractable phosphorus increased while exchangeable potassium and calcium decreased. The pH values were increased about 1.2 units while flooded and shifted from a strongly acid soil toward neutrality.

7. Based on the percentages of nutrients in the leaves, flooding depth and duration, siltation depth, and reflooding did not appear to adversely affect nutrient uptake under the conditions of this study.

8. These data are in general agreement with most reports in the literature on this species (Hook 1968; Hook and Stubbs

1967). The results indicate that, if water tupelo seedlings are to be planted, it would be well to plant in areas which are subject to shallow flooding or where flood water recedes early in the growing season.

In future studies, if a physical layout similar to the one in this study is used, care should be exercised in levee construction and providing for drainage. Probably the next step after this study would be to apply these results in a field experiment. Such an experiment should include sites which would give a range of natural flooding depths and durations. Other species, such as green ash, should be included to determine their response as compared to water tupelo on sites similar to the one used in this study. Another logical study would be one designed to determine why the moderate flooding caused seedlings to have the small crowns compared to shallow flooding early in the growing season. This study could be continued, without reapplying the treatments, to determine how the seedlings respond in subsequent years and if dieback has any long-lasting effects. Another good study would be one designed to determine if there is any oxygen diffusion to the roots of water tupelo through the swollen base of the trees. There are still many unanswered questions with water tupelo and further studies with this species are needed before any planting recommendations can be made.

LITERATURE CITED

Applequist, M. B. 1959. A study of soil and site factors affecting the growth and development of swamp blackgum and tupelogum stands in southeastern Georgia. Unpubl. D. F. Diss., Duke Univ., Durham, N. C. 104 p.

__________. 1960. Soil-site studies of southern hardwoods, p. 49-64. In P. Y. Burns (Ed.), 8th (1959) Ann. Forestry Symp.: Southern Forest Soils. La. State Univ. Press, Baton Rouge.

Bonner, F. T. 1966. Survival and first-year growth of hardwoods planted in saturated soils. South. Forest Exp. Sta., U. S. Forest Serv. Res. Note SO-32. 4 p.

__________, and C. W. Ralston. 1968. Oxidation-reduction potential of saturated forest soils. Soil Sci. Soc. Amer. Proc. 32(1):111-112.

Briscoe, C. B. 1957. Diameter growth and effects of flooding on certain bottomland forest trees. Unpubl. D. F. Diss., Duke Univ., Durham, N. C. 103 p.

Broadfoot, W. M. 1958. Reaction of hardwood timber to shallow-water impoundments. Miss. State Univ. Agr. Exp. Sta. Inf. Sheet 595. 2 p.

__________. 1960. Soil-water shortages and a means of alleviating resulting influences on southern hardwoods, p. 115-119. In P. Y. Burns (Ed.), 8th (1959) Ann. Forestry Symp.: Southern Forest Soils. La. State Univ. Press, Baton Rouge.

__________. 1966. Five years of nitrogen fertilization in a sweetgum-oak stand. South. Forest Exp. Sta., U. S. Forest Service Res. Note SO-34. 3 p.

__________. 1967. Shallow-water impoundment increases soil moisture and growth of hardwoods. Soil Sci. Soc. Amer. Proc. 31(4):562-564.

Dickson, R. E., J. F. Hosner, and N. W. Hosley. 1965. The effects of four water regimes upon growth of four bottomland tree species. Forest Sci. 11:299-305.

Green, W. E. 1947. Effect of water impoundment on tree mortality and growth. Jour. Forestry 45:118-120.

Hall, T. F., and W. T. Penfound. 1943. Cypress-gum communities in the Blue Girth swamp near Selma, Alabama. Ecology 24(2):208-217.

__________, and G. E. Smith. 1955. Effects of flooding on woody plants, West Sandy Dewatering Project, Kentucky Reservoir. Jour. Forestry 53:281-285.

Hook, D. D. 1968. Growth and development of swamp tupelo /Nyssa sylvatica var. biflora (Walt.) Sarg./ under different root environments. Unpubl. Ph.D. Diss., Univ. of Ga., Athens, Ga. 109 p.

__________, and Jack Stubbs. 1967. Physiographic seed source variation in tupelo gums grown in various water regimes. South. Forest Tree Impr. Conf. Proc. 9:61-64.

Hortwitz, William, et al. (Ed.). 1960. Official methods of analysis, 9th ed., p. 12-13. Assoc. Offic. Agr. Chem., Washington, D.C.

Hosner, J. F. 1958. The effects of complete inundation upon seedlings of six bottomland tree species. Ecology 39:371-373.

__________. 1959. Survival, root, and shoot growth of six bottomland tree species following flooding. Jour. Forestry 57:927-928.

__________. 1960. Relative tolerance to complete inundation of fourteen bottomland tree species. Forest Sci. 6:246-251.

__________, and S. G. Boyce. 1962. Tolerance to water saturated soil of various bottonland hardwoods. Forest Sci. 8:180-186.

__________, and A. L. Leaf. 1962. The effect of soil saturation upon dry weight, ash content, and nutrient absorption of various bottomland tree seedlings. Soil Sci. Soc. Amer. Proc. 26:401-404.

__________, __________, R. E. Dickson, and J. B. Hart, Jr. 1965. Effects of varying soil moisture upon the nutrient uptake of four bottomland tree species. Soil Sci. Soc. Amer. Proc. 29:313-316.

Hunt, F. M. 1951. Effect of flooded soil on growth of pine seedlings. Plant Physiol. 26:363-368.

Jackson, M. L. 1958. Soil chemical analysis. Prentice-Hall, Inc., Englewood Cliffs, N. J. 498 p.

Jordan, J. H., Jr., W. H. Patrick, Jr., and W. H. Willis. 1967. Nitrate reduction by bacteria from waterlogged Crowley soil. Soil Sci. 104:129-133.

Klawitter, R. A. 1963. Sweetgum, swamp tupelo, and water tupelo sites in a South Carolina bottomland forest. Diss. Abstr. 24(1):12.

__________. 1964. Water tupelos like it wet. South. Lumberman 209(2609):108-109.

La. Agr. Exp. Sta. 1965. Procedures used by soil-testing laboratories in the Southern Region of the U. S. Bull. no. 102, Southern Cooperative Series. 49 p.

MacRae, K. C., R. R. Ancajas, and S. Salandanan. 1968. The fate of nitrate nitrogen in some tropical soils following submergence. Soil Sci. 105:327-334.

McAlpine, R. G. 1959. Flooding kills yellow-poplar. Forest Farmer 19(3):9, 13-14.

__________. 1961. Yellow-poplar seedlings intolerant to flooding. Jour. Forestry 59:566-568.

McDermott, R. E. 1954. Effects of saturated soil on seedling growth of some bottomland hardwood species. Ecology 35:36-41.

McReynolds, R. D. 1960. Mortality of newly germinated southern pine seedlings following inundation. Tree Planters' Notes 43:23-25.

Millar, C. E. 1955. Soil fertility. John Wiley and Sons, Inc., New York. p. 176-208.

Orlow, A. Ya. 1963. The effect of flooding root systems on the accumulation of phosphorus by tree seedlings. Doklady Akademii Nauk SSSR, 147(1):233-236. (Original not seen. Forestry Abstr. 24:257.)

Parker, Johnson. 1950. The effects of flooding on the transpiration and survival of some southeastern forest tree species. Plant Physiol. 25:453-460.

Patrick, W. H., Jr., and R. Wyatt. 1964. Soil nitrogen loss as a result of alternate submergence and drying. Soil Sci. Soc. Amer. Proc. 28:647-653.

Pierce, R. S. 1953. Oxidation-reduction potential and specific conductance of ground water: their influence on natural forest distribution. Soil Sci. Soc. Amer. Proc. 17:61-65.

Ponnamperuma, F. N. 1955. The chemistry of submerged soils in relation to the growth and yield of rice. Unpubl. Ph.D. Diss., Cornell Univ., Ithaca, N. Y. 414 p.

__________, E. M. Tianco, and T. Loy. 1967. Redox equilibria in flooded soils: I. The iron hydroxide systems. Soil Sci. 103:374-382.

Redman, F. H., and W. H. Patrick, Jr. 1965. Effect of submergence on several biological and chemical soil properties. La. State Univ. Agr. Exp. Sta. Bull. 592. 28 p.

Reichman, G. A., D. L. Grunes, and F. H. Viets, Jr. 1966. Effect of soil moisture on ammonification and nitrification in two northern plains soils. Soil Sci. Soc. Amer. Proc. 30:363-366.

Savant, N. K., and R. Ellis, Jr. 1964. Changes in redox potential and phosphorus availability in submerged soil. Soil Sci. 98:388-394.

Shapiro, R. E. 1958. Effect of organic matter and flooding on availability of soil and synthetic phosphates. Soil Sci. 85:267-272.

Silker, T. H. 1948. Planting water tolerant trees along margins of fluctuating-level reservoirs. Iowa State Coll. Jour. of Sci. 22(4):431-448.

Sims, J. L. 1964. Nitrogen availability in rice field and reservoir soils. Ark. Farm. Res. 13(@):2.

__________, J. P. Wells, and D. L. Tackett. 1967. Predicting nitrogen availability to rice: I. Comparison of methods for determining available nitrogen to rice from field and reservoir soils. Soil Sci. Soc. Amer. Proc. 31:672-675.

Spurgeon, W. I. 1964. Flooding of Sharkey clay studied. Miss. Farm Res. 27(9):6.

__________, and P. H. Grissom. 1963. More nitrogen lost when clay is water-logged. Miss. Farm Res. 26(6):1, 6-7.

Steel, R. G. D., and J. H. Torrie. 1960. Principles and procedures of statistics. McGraw-Hill Book Co., Inc., New York. p. 99-131, 305-331.

Walker, L. C., R. L. Green, and J. M. Daniels. 1961. Flooding and drainage effects on slash pine and loblolly pine seedlings. Forest Sci. 7:2-15.

APPENDIX A

ANALYTICAL PROCEDURES FOR CHEMICAL ANALYSES

Determination of Ammonium and Nitrate Nitrogen in Soils (Sims, et al. 1967)

Reagents.--1. A 4 percent H_3BO_3 solution: add 40 g H_3BO_3 and 5 ml brom cresol green-methyl red indicator and dilute to 1 liter with distilled water. Mix thoroughly.

2. Brom cresol green-methyl red indicator: dissolve 0.5 g brom cresol green and 0.1 g methyl red in 100 ml of 95 percent ethyl alcohol.

Procedure.--1. Shake for 1 hour a 100 g soil sample* in 250 ml of 1N NaCl-0.1N HCl solution in a 500 ml Erlenmeyer flask.

2. Filter sample and pipette a 100 ml aliquot of filtrate into an 800 ml Kjeldahl flask.

3. Add 300 ml distilled water.

4. Add approximately 1 teaspoon of MgO.

5. Add 25 ml of 4 percent H_3BO_3 containing brom cresol green-methyl red indicator to a 250 ml receiving flask. Place flask under delivery tube with tip of delivery tube below the surface of the indicator solution.

6. Place Kjeldahl flask on the distillation rack and distill for 30 minutes or until 125 ml of distillate is collected. Indicator solution turns from pink to blue as ammonium is distilled over.

7. Titrate with 0.01$\underline{N}$ HCl and calculate for NH_4^+-N. Indicator will change from blue to pink when endpoint is reached.

8. Proceed with the same Kjeldahl flask by adding 2-3 g of Devarda's alloy and 150 ml of distilled water.

9. Distill for an additional 30 minutes, collecting 125 ml distillate in 25 ml of fresh 4 percent H_3BO_3.

10. Titrate with 0.01$\underline{N}$ HCl and calculate for NO_3^--N. Indicator will change from blue to pink when endpoint is reached.

11. Calculation (use for NH_4^+-N and NO_3^--N):

$$\text{m.e./100 g. soil} = \frac{(\text{ml} - \text{blank})(\underline{N}\text{ of acid})}{\text{sample weight in grams}} \times \frac{250}{\text{ml of aliquot}} \times 100$$

$$\text{ppm} = (\text{m.e.})(10)(\text{equivalent weight of } NH_4^+ \text{ or } NO_3^-)$$

---

*For wet soils, the average moisture content was determined and a wet sample which would give approximately 100 g of air-dry soil was weighed out. After shaking and filtering, all the soil and filter paper were put back into the flask, dried at 105°C for 24 hours, and weighed to determine the oven-dry weight used in calculations. This procedure was used to determine the oven-dry weight of samples of wet soil in all the chemical analyses.

Determination of Extractable Soil Phosphorus (La. Agr. Exp. Sta. 1965)

Reagents.--1. A 0.03N NH_4F in 0.1N HCl extracting solution: add 146 ml of concentrated HCl and 20 g of NH_4F to approximately 5 liters of distilled water and mix. Bring up to 18 liters with distilled water and mix.

2. Stannous chloride solution: dissolve 25 g of $SnCl_2 \cdot 2H_2O$ in 100 ml concentrated HCl and dilute to 1 liter with distilled water. Cover with mineral oil to prevent contact with air.

3. Ammonium molybdate: dissolve 5 g of ammonium molybdate in warm distilled water. Dilute 55 ml of concentrated H_2SO_4 to 800 ml with distilled water. After the two solutions have cooled, slowly add the ammonium molybdate to the H_2SO_4 with constant stirring. Dissolve 40 g of H_3BO_3 in this solution and dilute to 1 liter with distilled water.

4. Phosphorus stock solution: dissolve 0.4393 g of dried C.P. KH_2PO_4 in 1 liter of distilled water. This solution contains 100 ppm of P. Dilute 50 ml of stock solution to 1 liter with distilled water for a working stock solution of 5 ppm of P.

Procedure.--1. Shake for 30 minutes a 2.5 g soil sample in 50 ml of extracting solution.

2. Prepare standard solutions by pipetting 0, 1, 2, 4, 6, 8, and 10 ml of the 5 ppm P stock solution into 50 ml volumetric flasks. Add 5 ml of extracting solution, 10 ml of ammonium molybdate, and bring to volume with distilled water. Add 3 drops of $SnCl_2 \cdot 2H_2O$ to each flask and mix. These standards give 0.0, 0.1, 0.2, 0.4, 0.6, 0.8, and 1.0 ppm P, respectively.

3. Run the standard curve on the Bausch and Lomb Spectronic 20, reading the optical density of each standard at 650 mu 10 minutes after $SnCl_2 \cdot 2H_2O$ is added. Use 0 ppm P standard to adjust instrument to 100 percent transmittance; adjust to zero without a sample in the instrument. Prepare a new standard curve with each group of samples analyzed.

4. Pipette a 5 ml aliquot of soil extract into a 50 ml volumetric flask, add 10 ml of ammonium molybdate, bring to volume with distilled water, and mix.

5. Add 3 drops of $SnCl_2 \cdot 2H_2O$ solution to each flask and mix.

6. Read percent transmittance 10 minutes after adding $SnCl_2 \cdot 2H_2O$ and convert to ppm by means of the standard curve. Multiply curve reading by the dilution factor to get ppm in soil.

Determination of Exchangeable Potassium and Calcium in Soils (Jackson 1958)

Reagents.--1. A 1000 ppm K^+ solution: dissolve 1.907 g of KCl in 1 liter of distilled water.

2. A 1000 ppm Ca^{++} solution: dissolve 2.500 g of clear calcite ($CaCO_3$) in 10 ml concentrated HCl, boil to expel CO_2, and dilute to 1 liter with distilled water.

3. A 1N NH_4OAc extracting solution: add separately 1060 ml of concentrated HOAc and 1260 ml of concentrated NH_4OH to approximately 10 liters of distilled water and mix. Dilute to 18 liters with distilled water and mix. Check the pH and adjust to pH 7 with HOAc or NH_4OH if necessary.

4. A 10 percent $LaCl_2$ solution: dilute 100 g of $LaCl_2$ to 1 liter with distilled water.

Procedure for potassium.--1. Shake for 30 minutes a 5 g soil sample in 20 ml of extracting solution.

2. Filter through number 1 filter paper.

3. Pipette a 5 ml aliquot for each sample into a 100 ml volumetric flask and bring to volume with distilled water.

4. Prepare standard solutions of 0, 10, 20, 30, 40, and 50 ppm K^+ by diluting aliquots of the 1000 ppm K^+ solution to 100 ml with the extracting solution.

5. Refer to Beckman Instruction Manual and standardize the Beckman DU. Run the standard curve. A new standard curve should be prepared each time a group of samples is analyzed.

6. Read percent emission for each sample.

7. Read K^+ values from the standard curve and calculate the results by multiplying the curve reading by the dilution factor.

Procedure for calcium.--1. Pipette a 5 ml aliquot of the diluted samples for K^+ and 2.5 ml of 10 percent $LaCl_2$ solution into 50 ml volumetric flasks, bring to volume, and mix.

2. Prepare standard solutions of 0, 10, 20, 30, 40, and 50 ppm Ca^{++} by diluting aliquots of the 1000 ppm Ca^{++} solution and 5 ml of the 10 percent $LaCl_2$ solution to 100 ml with distilled water.

3. Standardize the Beckman DU and run the standard curve. A new curve should be prepared each time a group of samples is analyzed.

4. Read percent emission for each sample.

5. Read Ca^{++} values from the standard curve and calculate the results by multiplying the curve reading by the dilution factor.

Determination of Organic Matter in Soils (Jackson 1958)

1. Place 10 to 20 g soil samples in tared glazed porcelain crucibles.

2. Oven-dry at 105°C for 24 hours and record weight.

3. Place samples in muffle furnace and gradually bring temperature to 700°C. Maintain this temperature for 1 hour. Samples and crucibles will exhibit a glowing bright-red appearance at this temperature.

4. Remove samples from muffle furnace with asbestos gloves and tongs, cool briefly on an asbestos pad, and place in dessicator to cool for weighing. Allow air in dessicator to expand for several minutes before fitting the cover tightly.

5. Weigh and compute the loss in weight on ignition as a percentage of the oven-dry sample weight.

Determination of pH in Soils (Jackson 1958)

1. Weigh out 20 g of dry soil into a 150 ml beaker; add 50 ml of distilled water and stir at least four times over a 30-minute period. For wet soil, a 1:1 ratio of 40 g of wet soil and 40 ml of distilled water were used.

2. Insert the electrode into the soil and turn the switch indicated by the instructions for the pH meter being used.

3. Read the pH on the dial of the pH meter.

4. Clean the electrodes with distilled water before making the next reading or before storage.

Determination of Total Nitrogen in Plant Material (Horwitz 1960)

1. Weigh out a 1.400 g sample of plant material.

2. Transfer sample to an 800 ml Kjeldahl flask and add one number 5 Kel-Pak. Kel-Pak contains 15 g of K_2SO_4 and 0.7 g of HgO.

3. Add 25 ml of concentrated H_2SO_4.

4. Digest on Kjeldahl apparatus for 1 hour after the solution clears.

5. After digestion, allow flask and contents to cool for 15 minutes.

6. Add 250 ml of distilled water, mix thoroughly, and cool for 30 minutes or longer.

7. Place a 250 ml receiving flask with 25 ml of 4 percent H_3BO_3 containing brom cresol green-methyl red indicator under delivery tubes with tip of delivery tube below the surface of the indicator.

8. Add 3 to 5 pieces of mossy zinc plus glass beads to the Kjeldahl flask.

9. Slowly add 100 ml of 50 percent NaOH to the Kjeldahl flask.

10. Attach flask to distillation unit, swirl to mix, and distill until 125 ml of distillate is collected. Indicator changes from pink to blue when nitrogen is added.

11. Titrate with 0.1<u>N</u> HCl. Indicator changes from blue to pink when endpoint is reached.

12. Calculation:

Percent N = ml acid used x <u>N</u> of acid

Determination of Potassium, Calcium, and Phosphorus in Plant Material (Jackson 1958)

Sample preparation.--1. Weigh out a 1.000 g sample of plant material and place in a porcelain crucible.

2. Place sample in a muffle furnace and ash at 550°C for at least 4 hours.

3. Remove sample from muffle furnace and allow to cool.

4. Add 10 ml of 3N HCl and heat on a hot plate until a visible vapor ascends from the solution.

5. Transfer sample to a 100 ml volumetric flask, bring to volume with distilled water, and mix.

Procedure for potassium.--1. Pipette 10 ml of the sample solution into a 100 ml volumetric flask and bring to volume with distilled water.

2. Prepare standard solutions of 0, 10, 20, 30, 40, and 50 ppm K^+ by diluting aliquots of a 1000 ppm K^+ solution to 100 ml with distilled water.

3. Refer to Beckman Instruction Manual and standardize the Beckman DU. Run the standard curve. A new standard curve should be prepared each time a group of samples is analyzed.

4. Read percent emission for each sample.

5. Read K^+ values from the standard curve and calculate the results by multiplying the curve reading by the dilution factor. Convert to percent by moving decimal point in ppm four places to the left.

Procedure for calcium.--1. Pipette 10 ml of the sample solution into a 100 ml volumetric flask.

2. Add 5 ml of 10 percent $LaCl_2$ solution and bring to volume with distilled water.

3. Prepare standard solutions of 0, 10, 20, 30, 40, and 50 ppm Ca^{++} by diluting aliquots of a 1000 ppm Ca^{++} solution and 5 ml of $LaCl_2$ solution to 100 ml with distilled water.

4. Refer to Beckman Instruction Manuel and standardize the Beckman DU. Run the standard curve. A new curve should be prepared each time a group of samples is analyzed.

5. Read percent emission for each sample.

6. Read Ca^{++} values from the standard curve and calculate the results by multiplying the curve reading by the dilution factor. Convert to percent by moving decimal point in ppm four places to the left.

Procedure for phosphorus.--1. Pipette a 5 ml aliquot of the sample solution and 10 ml of ammonium molybdate into a 50 ml volumetric flask and bring to volume with distilled water.

2. Prepare a set of standards by pipetting 0, 1, 2, 4, 6, 8, and 10 ml of a 5 ppm P stock solution and 10 ml of ammonium molybdate into 50 ml volumetric flasks and bring to volume with distilled water. Add 3 drops of $SnCl_2 \cdot 2H_2O$ solution to each flask and mix. These standard solutions give 0, 0.1, 0.2, 0.4, 0.6, 0.8, and 1.0 ppm P, respectively.

3. Run the standard curve on the Bausch and Lomb Spectronic 20, reading the optical density of each standard at 650 mu 10 minutes after the $SnCl_2 \cdot 2H_2O$ is added. Use 0 ppm P standard to adjust instrument to 100 percent transmittance; adjust to zero with no sample in the instrument. Prepare a new standard curve with each group of samples analyzed.

4. Add 3 drops of $SnCl_2 \cdot 2H_2O$ solution to each sample flask and mix thoroughly.

5. Read percent transmittance 10 minutes after adding $SnCl_2 \cdot 2H_2O$ and convert to ppm by means of the standard curve. Multiply curve reading by the dilution factor to get final ppm. Convert to percent by moving decimal point in ppm four places to the left.

APPENDIX B

STATISTICAL ANALYSES

Table 12. Analysis of covariance for total heights in Phase I

Source of variation	d.f.	X^2	XY	Y^2	d.f.	Adjusted S.S.	M.S.	F
Depth (A)	2	0.96	37.63	9538.30	2	9501.31	4750.66	34.72**
Duration (B)	2	3.19	-27.70	2397.63	2	2404.50	1202.25	8.79**
AB	4	55.70	335.48	2150.37	4	1250.54	312.63	2.29ns
Error	18	87.33	24.67	2333.33	17	2326.37	136.85	
Total	26	147.19	370.07	16419.63				
Depth + Error		88.30	62.30	11871.63		11827.68		
Duration + Error		90.52	-3.04	4730.96		4730.86		
AB + Error		143.04	360.15	4483.70		3576.90		

In this and all subsequent tables in this Appendix, the following notations are used:
** Significant at the 0.01 level of probability.
* Significant at the 0.05 level of probability.
ns Non-significant.

Table 13. Analysis of covariance for root-collar diameters in Phase I

Source of variation	d.f.	X^2	XY	Y^2	d.f.	Adjusted S.S.	M.S.	F
Depth (A)	2	0.07	-4.44	355.56	2	360.74	180.37	20.06**
Duration (B)	2	0.96	-7.56	80.22	2	88.17	44.09	4.90*
AB	4	3.26	-10.55	76.89	4	86.71	21.68	2.41ns
Error	18	24.67	16.56	164.00	17	152.89	8.99	
Total	26	28.96	39.11	676.67				
Depth + Error		24.74	12.11	519.56		513.63		
Duration + Error		25.63	9.00	244.22		241.06		
AB + Error		27.93	6.00	240.89		239.60		

Table 14. Factorial analysis of variance of arcsin-transformed survival percentages in Phase I

Source of variation	d.f.	S.S.	M.S.	F
Depth (A)	2	3010.5004	1505.2502	9.20**
Duration (B)	2	1192.4040	596.2020	3.65*
AB	4	2600.3931	650.0982	3.98*
Error	18	2943.8507	163.5472	
Total	26	9747.1482		

Duncan's multiple range test for flooding depth x duration interaction

Depth and duration of flooding								
Deep, Aug. 1	Deep, July 1	Moderate, July 1	Deep, June 1	Moderate, Aug. 1	Shallow, July 1	Moderate, June 1	Shallow, July 1	Shallow, June 1
30.30	69.55	73.40	75.57	77.41	81.41	83.58	83.58	83.58

Table 15. Analysis of covariance for total heights in Phase II

Source of variation	d.f.	X^2	XY	Y^2	d.f.	Adjusted S.S.	M.S.	F
Flooding depth (A)	1	63.38	495.63	3876.04	1	2308.93	2308.93	42.06**
Siltation depth (B)	1	40.04	40.04	40.04	1	0.44	0.44	<1.00ns
Flooding duration	1	51.04	126.88	315.38	1	103.91	103.91	1.89ns
AB	1	22.04	56.54	145.04	1	55.96	55.96	1.02ns
AC	1	5.04	14.21	40.04	1	18.36	18.36	<1.00ns
BC	1	1.04	-11.88	135.38	1	156.40	156.40	2.85ns
ABC	1	18.38	20.13	22.00	1	0.70	0.70	<1.00ns
Error	16	198.00	175.33	978.67	15	823.41	54.89	
Total	23	398.96	916.88	5552.63				
Flooding depth + Error		261.38	670.96	4854.71		3132.34		
Siltation depth + Error		238.04	215.38	1018.71		823.84		
Flooding duration + Error		249.04	302.21	1294.04		927.32		
AB + Error		220.04	231.88	1123.71		879.37		
AC + Error		203.04	189.54	1018.71		841.77		
BC + Error		199.14	163.46	1114.04		979.81		
ABC + Error		216.38	195.46	1000.67		824.11		

Table 16. Analysis of covariance for root-collar diameters in Phase II

Source of variation	d.f.	X^2	XY	Y^2	d.f.	Adjusted S.S.	M.S.	F
Flooding depth (A)	1	0.38	3.88	40.04	1	27.08	27.08	8.77**
Siltation depth (B)	1	2.04	-0.29	0.04	1	5.33	5.33	1.73ns
Flooding duration (C)	1	0.04	-0.88	18.38	1	21.08	21.08	6.83**
AB	1	1.04	3.13	9.37	1	1.69	1.69	<1.00ns
AC	1	1.04	1.88	3.38	1	0.02	0.02	<1.00ns
BC	1	0.38	-3.46	3.37	1	14.00	14.00	4.54*
ABC	1	1.04	5.00	15.04	1	0.25	0.25	<1.00ns
Error	16	8.67	14.33	70.00	15	46.29	3.09	
Total	23	14.63	24.88	159.63				
Flooding depth + Error		9.04	18.21	110.04		73.37		
Siltation depth + Error		10.71	14.04	70.04		51.63		
Flooding duration + Error		8.71	13.46	88.38		67.58		
AB + Error		9.71	17.46	79.37		47.98		
AC + Error		9.71	16.21	73.38		46.32		
BC + Error		9.04	10.87	73.37		60.29		
ABC + Error		9.71	19.33	85.04		46.54		

Table 17. Factorial analysis of variance of arcsin-transformed survival percentages in Phase II

Source of variation	d.f.	S.S.	M.S.	F
Flooding depth (A)	1	2711.6799	2711.6799	30.44^{**}
Siltation depth (B)	1	197.8578	197.8578	2.22ns
Flooding duration (C)	1	79.9715	79.9715	<1.00ns
AB	1	406.5283	406.5283	4.56^{*}
AC	1	208.5096	208.5096	2.34ns
BC	1	91.1431	91.1431	1.02ns
ABC	1	193.5599	193.5599	2.17ns
Error	16	1425.3344	1425.3344	
Total	23	5320.5845		

Table 18. Analysis of covariance for total heights in Phase III

Source of variation	d.f.	X^2	XY	Y^2	d.f.	Adjusted S.S.	M.S.	F
Reflood date (A)	1	14.08	53.08	200.08	1	123.63	123.63	5.44ns
Reflood duration (B)	1	0.08	2.08	52.08	1	49.52	49.52	2.18ns
AB	1	30.08	-20.58	14.08	1	39.21	39.21	1.73ns
Error	8	104.00	63.67	198.00	7	159.03	22.72	
Total	11	148.25	98.25	464.25				
Reflood date + Error		118.08	116.08	398.08		282.65		
Reflood duration + Error		104.08	65.75	250.08		208.55		
AB + Error		134.08	43.08	212.08		198.24		

Table 19. Analysis of covariance for root-collar diameters in Phase III

Source of variation	d.f.	X^2	XY	Y^2	d.f.	Adjusted S.S.	M.S.	F
Reflood date (A)	1	0.75	2.75	10.08	1	2.08	2.08	1.47ns
Reflood duration (B)	1	0.75	1.25	2.08	1	0.08	0.08	<1.00ns
AB	1	0.08	0.08	0.08	1	0.01	0.01	<1.00ns
Error	8	1.33	1.67	12.00	7	9.92	1.42	
Total	11	2.92	5.75	24.25				
Reflood date + Error		2.08	4.42	22.08		12.72		
Reflood duration + Error		2.08	2.92	14.08		10.00		
AB + Error		1.42	1.75	12.08		9.92		

Table 20. Factorial analysis of variance of arcsin-transformed survival percentages in Phase III

Source of variation	d.f.	S.S.	M.S.	F
Reflood date (A)	1	47.48	47.48	1.42ns
Reflood duration (B)	1	248.89	248.89	7.42*
AB	1	29.05	29.05	<1.00ns
Error	8	268.37	33.55	
Total	11	593.79		

Table 21. Analysis of variance for nitrogen content of leaves (Phase I)

Source of variation	d.f.	S.S.	M.S.	F
Treatments	7	0.5239	0.0748	2.57ns
Error	16	0.4657	0.0291	
Total	23	0.9886		

Table 22. Analysis of variance for phosphorus content of leaves (Phase I)

Source of variation	d.f.	S.S.	M.S.	F
Treatments	7	0.001317	0.000118	2.27ns
Error	16	0.001338	0.000083	
Total	23	0.002655		

Table 23. Analysis of variance for potassium content of leaves (Phase I)

Source of variation	d.f.	S.S.	M.S.	F
Treatments	7	0.0513	0.0073	0.98ns
Error	16	0.1201	0.0075	
Total	23	0.1714		

Table 24. Analysis of variance for calcium content of leaves (Phase I)

Source of variation	d.f.	S.S.	M.S.	F
Treatments	7	0.0132	0.0019	1.49ns
Error	16	0.0202	0.0013	
Total	23	0.0334		

Table 25. Analysis of variance for calcium content of leaves (Phase II)

Source of variation	d.f.	S.S.	M.S.	F
Treatments	6	0.009790	0.001631	0.43ns
Error	14	0.053746	0.003839	
Total	20	0.063536		

Table 26. Analysis of variance for nitrogen content of leaves (Phase II)

Source of variation	d.f.	S.S.	M.S.	F
Treatments	6	0.4006	0.0667	2.01ns
Error	14	0.4655	0.0332	
Total	20	0.8661		

Table 27. Analysis of variance for potassium content of leaves (Phase II)

Source of variation	d.f.	S.S.	M.S.	F
Treatments	6	0.1712	0.0285	3.28*
Error	14	0.1224	0.0087	
Total	20	0.2936		

Duncan's multiple range test

Flooding depth, siltation depth, and drainage date						
Moderate, 6 to 8", July 1	Deep, 6 to 8", June 1	Moderate, 3 to 4", June 1	Deep, 3 to 4", June 1	Moderate, 6 to 8", June 1	Moderate, 3 to 4", July 1	Deep, 3 to 4", July 1
1.1933	1.2366	1.2866	1.3500	1.3533	1.4233	1.4666

Table 28. Analysis of variance for phosphorus content of leaves (Phase II)

Source of variation	d.f.	S.S.	M.S.	F
Treatments	6	0.000928	0.000154	4.28*
Error	14	0.000514	0.000036	
Total	20	0.001442		

Duncan's multiple range test

Flooding depth, siltation depth, and drainage date

Moderate, 6 to 8", June 1	Moderate, 3 to 4", June 1	Deep, 6 to 8", June 1	Deep, 3 to 4", June 1	Moderate, 3 to 4", July 1	Moderate, 6 to 8", July 1	Deep, 3 to 4", July 1
.1223	.1293	.1306	.1320	.1326	.1336	.1463

Table 29. Analysis of variance for nitrogen content of leaves (Phase III)

Source of variation	d.f.	S.S.	M.S.	F
Treatments	2	0.0205	0.0102	0.18ns
Error	6	0.3336	0.0556	
Total	8	0.3541		

Table 30. Analysis of variance for phosphorus content of leaves (Phase III)

Source of variation	d.f.	S.S.	M.S.	F
Treatments	2	0.000006	0.000003	0.14ns
Error	6	0.000131	0.000021	
Total	8	0.000137		

Table 31. Analysis of variance for potassium content of leaves (Phase III)

Source of variation	d.f.	S.S.	M.S.	F
Treatments	2	0.001343	0.001343	0.14ns
Error	6	0.058269	0.009711	
Total	8	0.060956		

Table 32. Analysis of variance for calcium content of leaves (Phase III)

Source of variation	d.f.	S.S.	M.S.	F
Treatments	2	0.023474	0.011737	3.40ns
Error	6	0.020700	0.003450	
Total	8	0.044174		

VITA

Harvey Ellis Kennedy, Jr., was born on January 14, 1933, in Pearl River, Louisiana. He received his early education at Sixth Ward Junior High School where he completed the ninth grade and then went to Slidell High School in Slidell, Louisiana, where he graduated in May 1951. He then entered Spencer's Business College in New Orleans, Louisiana, and was graduated in May 1952 having completed the General Business Course.

He went to work for Western Electric Company in September 1952, where he repaired telephone sets and was working in the teletype department when he was granted a leave of absence to enter Louisiana State University at Baton Rouge in September 1959. He was graduated from Louisiana State University in January 1963 with the degree Bachelor of Science in Forestry.

He entered the Graduate School of Louisiana State University upon completion of his undergraduate work and was graduated from Louisiana State University in August 1964 with the Master of Forestry degree. He is now a candidate for the Doctor of Philosophy Degree in August 1969.

He is married to the former Alberta Thomas and they have one son, Richard Ellis.

EXAMINATION AND THESIS REPORT

Candidate: Harvey Ellis Kennedy, Jr.

Major Field: Forestry

Title of Thesis: Survival and First-year Growth of Water Tupelo (*Nyssa acquatica* L.) in Relation to Flooding and Siltation.

Approved:

Major Professor and Chairman

Dean of the Graduate School

EXAMINING COMMITTEE:

Date of Examination:

May 19, 1969