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Growth of six planted tree species under various cultural treatments on former agricultural bottomlands

Warren Downe Devine

To the Graduate Council:

I am submitting herewith a thesis written by Warren Downe Devine entitled "Growth of six planted tree species under various cultural treatments on former agricultural bottomlands." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Forestry.

John C. Rennie, Major Professor

We have read this thesis and recommend its acceptance:

Allan Houston, Vernon Reich, Donald Tyler

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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GROWTH OF SIX PLANTED TREE SPECIES UNDER VARIOUS CULTURAL TREATMENTS ON FORMER AGRICULTURAL BOTTOMLANDS

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Warren Downe Devine, III
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ABSTRACT

Falling soybean prices in the mid-1970s resulted in extensive abandonment of agricultural wetlands in the Mississippi Valley. Research has been conducted on the reforestation of these sites, but few studies have documented the long-term results of reforestation practices. This study was initiated to determine tree species and cultural treatments best suited to west Tennessee's former agricultural bottomlands. The effects of seed source, fertilization, disking and mowing on sweetgum (*Liquidambar styraciflua* L.), American sycamore (*Platanus occidentalis* L.) and green ash (*Fraxinus pennsylvanica* Marsh.) were examined 18 years after planting. Seventeen-year-old cherrybark oak (*Quercus pagoda* Raf.), yellow-poplar (*Liriodendron tulipifera* L.) and loblolly pine (*Pinus taeda* L.) under fertilization, disking and mowing also were examined. Variations in soil series and bulk density and the effects of water table depth on tree growth were analyzed. Overall survival was significantly higher for sweetgum (93%) and green ash (95%) than for sycamore (88%). Height growth of sweetgum was significantly greater than sycamore, which was significantly greater than that of green ash. Seed source (Virginia Coastal Plain vs. Louisiana Gulf Coast) had no effect on the growth of sycamore or sweetgum. Height and dbh of sweetgum, sycamore and green ash were significantly increased by fertilization only on plots that were not disked or mowed. Disking and mowing significantly increased the growth of unfertilized trees more than that of fertilized trees. Survival was 92%, 64% and 63% for yellow-poplar, cherrybark oak and loblolly pine, respectively. Growth of loblolly pine was significantly greater than that of cherrybark oak. The growth and survival of yellow-poplar, cherrybark oak and loblolly pine were not affected by cultural treatments. Natural regeneration on the same site resulted in dense stands (3,445 trees/acre and 4,340 trees/acre) dominated by sweetgum. The combination of fertilization and mowing significantly increased soil bulk density. Soils were much more variable than prior soil surveys indicated. Although a shallower water table increased survival of sweetgum and sycamore, growth was increased for these two species on better-drained soils.

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Introduction

In the mid-1970s, falling soybean prices resulted in extensive abandonment of Mississippi Valley agricultural wetlands which then became available for reforestation, either through artificial or natural regeneration (Waldrop et al. 1983). Financial models demonstrate that planting hardwoods on sites too wet for agriculture can be profitable on better soil types (Amacher et al. 1998, Smith 1973b), especially as cost-share programs, including the Conservation Reserve Program and the Wetlands Reserve Program, defray costs. In addition to providing eventual harvest revenue, reforestation offers benefits of flood control, erosion prevention, and restoration of nutrients and organic matter to the site. Although much research has focused on improving growth rates of intensively managed, short-rotation hardwood plantations (Malik et al. 1998), high-value species, such as oaks (*Quercus* spp.), also have been successfully established (Ozalp et al. 1998, Russell et al. 1998, Kennedy 1993).

An appropriate species-site and seed source match is essential to successful reforestation (Baker and Broadfoot 1979, Canonge 1979, Ferguson et al. 1977). Cultural treatments also are employed to improve plantation growth. Fertilization has resulted in significant growth increases in cottonwood (*Populus deltoides* Bartr. ex Marsh.) (Blackmon 1977), sweetgum (*Liquidambar styraciflua* L.) (Guo et al. 1998), yellow-poplar (*Liriodendron tulipifera* L.) (Blackmon 1974), and other hardwood species (Francis 1985). Adequate herbaceous and woody competition control is frequently necessary to promote the survival and growth of seedlings. Disking and mowing have been reported as effective and widespread methods of weed control on bottomland hardwood plantations (Krinard and Kennedy 1987, Kennedy 1984, Johnson 1983, Waldrop et al. 1983, Malac and Heeren 1979). However, few studies have reported the long-term effects of these establishment treatments. If early growth gains are lost later in the rotation, economic returns from such treatments may be greatly diminished. This study documents the 18-year results of cultural treatments on six planted tree species.

The study was established in 1980 to evaluate the effects of seed source, fertilization, disking and mowing on tree species planted on a previously farmed bottomland site. Sweetgum, American sycamore (*Platanus occidentalis* L.), green ash (*Fraxinus pennsylvanica* Marsh.), cherrybark oak (*Quercus pagoda* Raf.), yellow-poplar and loblolly pine (*Pinus taeda* L.) were planted on a former soybean field located on a minor river valley flood plain in Fayette County, Tennessee. Five areas on the same site were designated to reforest naturally. Economic analyses were performed for practical application of the study's results. Soils were tested to determine whether cultural treatments affected soil bulk density. In addition, extensive soil survey analyses were conducted to examine site variability and the influence of soil series, depth to water table, and depth to mottling on tree development and cultural treatment efficacy.

I. Literature Review

Hardwood Plantations

Interest in commercial hardwood plantations first arose in the 1960s as the demand for hardwood pulp increased. Major pulp and paper corporations explored the possibility of using short-rotation hardwood plantations as a source of pulpwood. Prior to this time, Tennessee Valley Authority and the Civilian Conservation Corps had established some hardwood plantations, but these generally proved unsuccessful (Smith 1973a).

Crown Zellerbach made the first large-scale commercial investment with the planting of 15,000 acres of cottonwood in 1960 (Johnson 1983). Other companies such as U. S. Gypsum and Chicago Mill soon followed and began producing hardwood products from their own cottonwood plantations in the Mississippi Delta Region (Canonge 1979). In 1967, Union Camp began an extensive hardwood plantation research project including species/site suitability, fertilization, site preparation, cultivation for weed control, and genetic improvement (Malac and Heeren 1979). Before long, Westvaco, International Paper, Hammermill, Champion, and other companies were also involved in planting hardwoods (Canonge 1979). Research in intensive plantation management increased following a rise in demand for hardwood products, such as high-quality paper, which require hardwood pulp (Malac and Heeren 1979).

Coppicing is sometimes used as an alternative to planting seedlings or cuttings. In this manner, hardwood plantations are managed with an initial planting followed by multiple rotations of coppice (sprout) origin (Malac and Heeren 1979, Steinbeck et al. 1972). Coppicing led to the production of large volumes of biomass over very short rotation lengths (Steinbeck et al. 1972).

In the South, hardwood growth exceeds harvest in natural stands, but much of this growing stock is made up of poor-quality trees and trees of non-commercial species. Natural regeneration of hardwoods on harvested sites is inexpensive, but it is sometimes undesirable because resultant species composition and stand density are beyond the landowner's control and often must be altered through timber stand improvement (Gresham 1985). Hardwood plantations offer the advantages of a decreased rotation length and a choice of species (Rich 1989). Although hardwood plantations are not always economical in theory, they provide strategic value to many forest product manufacturers who require a steady supply of wood (Smith 1973b).

In the 1989 U.S.D.A. Forest Service assessment, Tennessee had 688 million cu. feet of growing stock in plantations. Of this, 204 million cu. feet were in hardwoods. Bottomland hardwood plantations accounted for 28 million cu. feet. Two other states had greater volumes of bottomland hardwoods in plantations: Mississippi had 56 million cu. feet and Louisiana had 34 million cu. feet (Rosson 1995).

Bottomland Species

In the southern United States, plantation research has been conducted on many hardwoods including eastern cottonwood, American sycamore, sweetgum, black walnut (*Juglans nigra* L.), green ash, and a wide variety of oaks (Malac and Heeren 1979, Johnson 1983). Eastern cottonwood is the fastest growing of the bottomland hardwoods and has been the subject of much research focused on genetic improvement and artificial regeneration (Johnson 1983). Cottonwood's growth potential is best realized on well-drained, alluvial soils (Fowells 1965). Cottonwood is limited in its prevalence only because it is a very shade-intolerant species and is site-specific.

Sweetgum grows throughout the South and is associated with a wide variety of other tree species and cover types. Although it is found on a broad range of soils, best growth occurs in river bottoms on rich loam and clay (Schlaegel 1984a). Sweetgum can be successfully planted when weed competition is controlled for the first one or two years (Krinard 1988). Martindale (1958) and Burns and Honkala (1990) compiled complete reviews of the silvical characteristics of sweetgum.

Cherrybark oak is a fast-growing, valuable timber species but is less tolerant of flooding than many other bottomland oaks (Williams et al. 1993, Hosner and Boyce 1962). It attains its best growth on well-drained loam soils of terraces or first bottoms. Full descriptions of cherrybark oak appear in Lotti (1957) and Burns and Honkala (1990).

Green ash is more shade-tolerant than sweetgum and cottonwood, and it occurs naturally in the understory of forest stands. It often grows in riparian areas on moist, alluvial soils and can tolerate the poorly-drained soils of depressions and sloughs which stunt the growth of other hardwoods (Kellison 1977, Schlaegel 1984b). Green ash is a more valuable timber species than many of the other southern bottomland hardwoods (Krinard 1989). Hu and Burns (1989) provide a thorough bibliography of green ash research conducted during the 20th century.

American sycamore is a rapid-growing hardwood that thrives on alluvial soils. It is resistant to many insects and diseases, and it is not a species preferred by beaver (*Castor canadensis*) (Houston 1991). Sycamore is a popular plantation species in the southern United States (Schlaegel 1981). A bibliography of research pertaining to American sycamore was published by Hu et al. (1989).

On bottomlands, yellow-poplar grows well only on better-drained soils (Renshaw and Doolittle 1958, McCarthy 1933). It normally exhibits good form and rapid growth. Detailed descriptions of the silvical characteristics and management potential of yellow-poplar were published by McCarthy (1933) and later by Beck and Della-Bianca (1981).

West Tennessee Bottomlands

West Tennessee[1] bottomlands have undergone dramatic changes during the past century. The bottomlands of Fayette County once were covered in a forest containing "some of the finest hardwoods in Tennessee" (Burger 1964). This forest was first logged in scattered locations around 1890. Extensive logging of Fayette County began

[1] West Tennessee is defined as Henry, Carroll, Henderson, Chester and McNairy counties and all counties west of these.

in the early 1900s and continued for a quarter of a century. After that, woodlands were often "burned off" for livestock grazing. Wildfire suppression and some reforestation efforts began in the 1950s when over five million tree seedlings were planted (Burger 1964). Since that time, however, a steady decline of Tennessee's bottomland forests has continued.

Today, timberland occupies only around one third of the total land base of west Tennessee. The majority of this timberland is found in riparian zones and on uplands unsuitable for agriculture. Bottomland forest types, comprising 531,000 acres, account for approximately 27% of west Tennessee's total timberland. Between 1960 and 1975, the bottomland hardwood forests throughout Tennessee shrank by an average of 18,000 acres (two percent) per year (Turner et al. 1981). From 1980 to 1988, bottomland forest types in west Tennessee decreased by 14.4 percent (May and Vissage 1989).

During the middle and late 1900s, the clearing of forests and an increase in intensive row cropping had a major impact on the hydrology of west Tennessee. Runoff increased in both volume and velocity, which lead to a sharp rise in erosion and sedimentation. Soil losses in west Tennessee were worsened by the relatively severe storms of this region and by the easily-eroded loess soils (Talley and Monteith 1994).

Economic trends have been the motive for land conversions in west Tennessee. When the price of soybeans rose in the early 1970s, many bottomland sites were converted to cropland (Amacher et al. 1998). Bottomland hardwood forests were cleared, drained and leveled in preparation for soybean crops (Kramer and Shabman 1993). Although some of this cropland was located on terraces, much of it was on first bottoms. These bottoms were naturally prone to flooding and were especially susceptible to floods after the hydrology of the region had been altered. After a short period, a decrease in the price of soybeans, in addition to crop losses incurred from flooding, caused many landowners to abandon agriculture on marginal bottomland sites (Amacher et al. 1998, Waldrop et al. 1983). These wet fertile sites, no longer practical for use as farmland, were ideal for planting tree crops (Smith 1973b). Without the costs of land clearing, forest plantations became much more feasible (Malac and Hereen 1979).

Fertilization of Bottomland Hardwood Plantations

Forest fertilization is generally based on maintaining adequate levels of three elements: nitrogen (N), phosphorous (P), and potassium (K). Nitrogen is used by plants to produce amino acids and chlorophyll. Phosphorous is essential for energy storage and transfer as well as root growth and seed production. Potassium serves as a catalyst in metabolic reactions and controls osmotic pressure and water movement within the plant (Martini 1992). Organic matter is an important source of both nitrogen and phosphorous. Potassium occurs naturally in soil minerals and is released by weathering (Brady 1974). Forest fertilization is complicated by the fact the each mineral element behaves differently in the soil and has different physiological functions and interactions within the tree. There are at least 15 elements that are essential to tree growth. Insufficient levels of ten of these elements have been found in various forest plantations (Nambiar 1984).

Although research on cottonwood fertilization began as early as the 1940s (Blackmon 1977), it was not until the late 1950s that research on the fertilization of other hardwood species began at the Southern Hardwoods Laboratory in Stoneville, Mississippi. W. M. Broadfoot conducted one of these pioneer studies in which 20-year old oak and sweetgum were fertilized with either ammonium nitrate or NPK. The results of the study suggested that forest fertilization was economically viable (Blackmon 1974, Broadfoot 1966).

In 1958, another early study on bottomland plantation fertilization was initiated (McAlpine 1959). Yellow-poplar was fertilized with three levels of nitrogen shortly after planting. Survival was not affected by fertilization, but the nitrogen continued to have a positive effect on height growth through the second year. However, Wittwer et al. (1980) concluded that the broadcast application of nitrogen in the form of ammonium nitrate was an inefficient practice in a young bottomland sycamore plantation. Growth responses to the fertilizer, measured in above-ground biomass, were greatest in the fifth growing season.

The rich, alluvial soils of the bottomlands are normally high in nutrients and organic matter (Gresham 1985, Francis 1985). Uncommonly rapid tree growth and high site indexes are typical for most tree species planted on these sites. However, on old fields that have suffered nutrient depletion, fertilization may be a practical means of increasing tree growth rates (Francis 1985, Blackmon 1974). In a study on yellow-poplar, it was determined that fertilization increased height growth on eroded soils but not on uneroded soils (Blackmon 1974). Soils of old farmlands are often lacking in organic matter and nitrogen. Hansen and McComb (1958) warned that green ash is likely to perform poorly on sites that have been previously cultivated and on sites that have undergone erosion of the A-horizon. They found that the depletion of nitrogen was probably responsible for poor growth of green ash on old-fields.

Some research in hardwood fertilization conducted on upland sites can be applied to bottomland plantations. An example of this is the timing of fertilizer application. Malac and Heeren (1979) suggested that fertilization be delayed until after the first growing season if weeds are likely to be chief beneficiaries of early fertilization. Fertilizer applied at the time of planting has been shown to significantly reduce seedling survival (Buckner and Maki 1977) or to have no effect on survival and growth (Hopper et al. 1993).

On nutrient deficient sites, benefits may still be gained from fertilizer applied later in the rotation. Nelson and Switzer (1992) found significant growth increases when a 9-year old sweetgum plantation was fertilized with various levels of nitrogen. The effects of fertilization on growth lasted for three years. Broadfoot's (1966) study on 20-year old oak and sweetgum also showed the growth benefits of delayed fertilization.

Nitrogen fertilization generally has a shorter period of growth response than phosphorous fertilization. When applied to deficient forest soils, phosphorus can be absorbed by the soil and remain available to plants for many years (Guo et al. 1998, Ballard 1984). Guo et al. (1998) reported that nitrogen fertilization at age four significantly increased the growth of planted sweetgum. Trees that were fertilized with both nitrogen and phosphorous at that time showed a further increase in height growth but not until the age of 14.

There has been some concern that fertilization of forest plantations may increase growth at the expense of wood quality. Although this may be true for some conifers, the wood properties of planted sycamore are not affected by fertilization, even when volume growth is increased (Saucier and Ike 1969).

Biological and economic responses to fertilization are two distinctly separate issues (Blackmon 1977). Forest fertilization is complicated by the fact that applications must not simply increase growth but increase it enough to be economically worthwhile. Financial justification becomes increasingly difficult in situations where fertilization is repeated over multiple growing seasons. The process of determining the specific fertilization requirements of any species/site combination is complex but possible if soil analysis is done before planting (McGarity 1977).

Cultural Treatments for Weed Control in Bottomland Hardwood Plantations

Much bottomland hardwood plantation research has been focused on controlling weed competition. This is the goal of cultural treatments such as disking (clean cultivation) and mowing. Weed control is known to be essential in promoting early dominance of the planted seedlings (Malac and Heeren 1979). Disking not only removes weeds but also increases the availability of soil moisture and nutrients to the crop trees (Kennedy, 1984).

Among the commonly planted hardwoods, eastern cottonwood is the least tolerant of early competition, and weed control is nearly always essential in cottonwood plantations (Johnson 1983). Even though sycamore, sweetgum and green ash are slightly more tolerant of weed competition and shade, they still suffer a reduction in growth and survival when weeds are present (Blackmon 1977, Johnson 1983).

When land is cleared of trees to establish a plantation, stump sprouts are a principal concern because they can quickly overtake and shade out the planted seedlings. On former agricultural sites, competition from sprouting woody species is often not a problem, but other competitors, such as vines, can be devastating (Smith 1973a).

Mowing between rows reduces competing vegetation and prevents it from over-topping planted seedlings. Mowing does not kill all of the weeds, though. Instead, the weeds continue to utilize soil moisture which can become a limiting factor in the growth of the tree seedlings. Krinard and Kennedy (1981) found disking to be a much more effective method of weed control than mowing after five years of hardwood growth. During the years in which disking takes place, weed competition is reduced, and nutrient and soil moisture availability is increased relative to mowing. Disking also can cause seedling root proliferation as roots branch after being cut (Kennedy 1984). One-way cultivation is sometimes less effective than cross-cultivation because it leaves strips of vegetation between the seedlings (Zutter 1987).

Krinard and Kennedy (1987) found that, after 15 years, most hardwood species planted on clay soils had similar diameters and heights whether they were disked or mowed. But some species had different height growth patterns on disked and mowed plots. On mowed plots, sycamore grew roughly 13 feet during each of the first, second, and third five-year periods. On disked plots, sycamore grew 21, 10, and 7 feet, respectively, during each five-year period. In a study located on Coastal Plain sites, Hunt and Cleveland (1978) reported that disking between and across rows significantly increased the height and volume of planted sweetgum, sycamore, and loblolly pine after five years of growth. Mowing did not increase the heights or volumes of these species.

After seedlings have established a satisfactory root system and have achieved height dominance over the competing vegetation, weed control is no longer necessary. Cultural treatments generally do not need to be extended past the fifth growing season, and in situations where a species can capture the site earlier and shade out competition, less than five years of weed control may be sufficient (Krinard and Kennedy 1983).

Location of Seed Source

Research on the effect of transplanting sweetgum and sycamore seed and seedlings to different geographic locations has not provided consistent results. A study in West Virginia involving sweetgum found that the location of the seed source made a difference in growth, but the latitude of the seed source was unrelated to growth (Cech et al. 1981). In a study which focused on the Piedmont and Coastal Plain physiographic provinces, geographic origin of the seed was not a significant factor in determining growth (Sprague and Weir 1973). Sweetgum from the Piedmont was successfully moved to the Coastal Plain, but it was concluded that best growth and survival would be achieved when seedlings were planted in their native physiographic province.

Fogg (1966) reported that, in Louisiana, sycamore seedlings of local origin provided the maximum height growth after two years. Seedlings from elsewhere in the South and East differed in height growth, but no pattern relating growth to the seedlings' geographic origins was detected. Schmitt and Webb (1971) found that heights of sycamore planted in Mississippi were significantly related to the geographic location of the seed-source. Dbh differences were not significant but were expected to become so in the future. Land (1981) evaluated 320 sycamore and found no significant relationship between latitudinal or longitudinal variation in seed source and eight phenotypic characteristics.

Earlier Work on This Study

Two papers were previously published on this study: one after three growing seasons and one after five growing seasons. Waldrop et al. (1983) described the growing conditions of the first year as poor because of drought. However, after three years, survival was reported as 93% for sweetgum and sycamore and 98% for green ash. Fertilization provided a significant increase in height over unfertilized plots for all three species. Trees on disked plots were significantly taller than those on mowed and control plots for all species.

Houston and Buckner (1989) reported that, after five growing seasons, survival rates for the three species were practically identical to those after three growing seasons. Fertilization and disking continued to provide superior height growth.

II. Methods

The Study Area

Location and Physiography

The study took place on the Ames Plantation in Fayette County, Tennessee. The Ames Plantation is located near the town of Grand Junction, 50 miles east of Memphis (Figure 1). The Trustees of the Hobart Ames Foundation administer and maintain the Plantation in a cooperative agreement with The University of Tennessee, in which Ames Plantation is regarded as one of 11 Branch Experiment Stations. The study occupies approximately 26 acres of former soybean cropland on the flood plain of the North Fork of the Wolf River (35° 07' North and 89° 19' West). The elevation is 400 feet above sea level.

The study site is located within the West Tennessee Plain of the Gulf Coastal Plain physiographic province. It is in Major Land Resource Area 134: Southern Mississippi Valley Silty Uplands. The topography is rolling to nearly flat in some areas, and the streams have broad flood plains. The West Tennessee Plain slopes gradually downward from East to West until it reaches the Mississippi River flood plain (Miller 1974).

During the Cretaceous and Tertiary Periods the region was covered by a sea known as the Mississippi Embayment. Marine sediments, mostly sand with some silt and clay, were deposited on the Coastal Plain before the water receded. Later, during the Pleistocene Epoch of the Quaternary Period, the West Tennessee Plain was covered

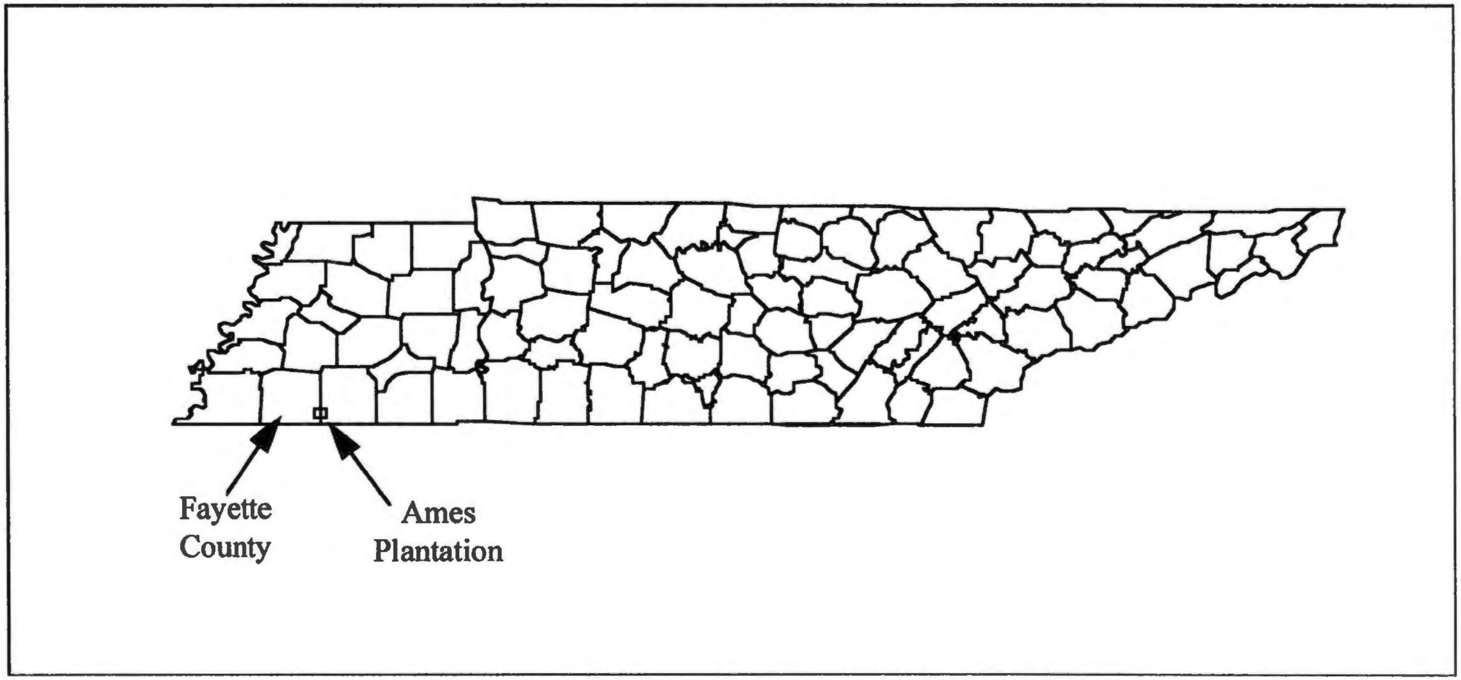

Figure 1. Location of Hardwood Planting and Cultivation Study in Fayette County, Tennessee.

in windblown loess originating from the glacial erosion of rocks (Miller 1974). Today, the parent material of Fayette County's soils is composed of marine sediments. The layer of loess still covers the parent material except in areas where it has been removed by erosion. The alluvial soils of Fayette County's bottomlands are made up of eroded marine sediments and loess (Springer 1964).

Soils

The study area is mapped as containing soils of Collins series which are coarse-silty, mixed, active, acid, thermic Aquic Udifluvents. They are "moderately well drained, nearly level, acid soils that are along bottom lands and narrow drainageways" (Flowers 1964). Silty and sandy alluvium, eroded from nearby lands, makes up the soils of this series. The surface layer is moderate in permeability and consists of brown silt loam to brown fine sandy loam. Frequently, a recent silt loam alluvial layer occupies one to three feet of the subsoil, above a layer of earlier, poorly-drained soil (Flowers 1964).

The Collins series is very high in available water capacity, and runoff is slow (Flowers 1964). These alluvial flood plain soils are known for their productivity, but when the existing vegetation is cleared they are susceptible to erosion (Talley and Monteith 1994). Fifty-year site indexes for the Collins soil series are: green ash 89, sycamore 114, yellow-poplar 118, cherrybark oak 113, and sweetgum 108 (Broadfoot 1976).

Soil pH at the study site ranged from 5.4 to 6.6 at the beginning of the study. Tests conducted at that time revealed that levels of phosphorus and potassium were low for agricultural purposes (Waldrop et al. 1983).

Climate

The climate of Fayette County is characterized by hot summers and mild winters. The average daily temperature during the summer ranges from a low of 65° to 70° Fahrenheit and a high of about 90°. During the winter months, the average daily temperature ranges from about 32° to between 50° and 55°. It is rare for the soils to freeze deeper than three inches (Dickson and Springer 1964).

Fayette County has an average of 69 days per year when the temperature is greater than 90° and approximately 60 days annually when the temperature falls below 32° (Dickson and Springer 1964). On average, there are 205 days per year between the last frost of the spring and the first frost in the fall (Ruffner 1978). The mean annual precipitation is 53.1 inches, and the average snowfall is 4.6 inches. The wettest months of the year are December through March when large storms are most common (Dickson and Springer, 1964).

Past Land Use of the Study Site

The study site had been in cultivation for at least 20 years prior to the establishment of hardwoods in 1980 and 1981. Soybeans were grown on the site during the three years immediately prior to the planting of hardwoods.

Experimental Design

The study consisted of two independent experiments: Study A and Study B. Both studies were randomized, complete-block design, strip-plot experiments with four blocks (replications) each. Study A was established in 1980 when 1,210 green ash, 2,420 sweetgum, and 2,420 sycamore seedlings were planted. A Virginia Coastal Plain seed source was used for sweetgum, sycamore, and green ash, and a Louisiana Gulf Coast seed source also was included for sweetgum and sycamore.

Main treatments were arranged as a 5 x 2 factorial: each of the five species/seed source combinations were fertilized or unfertilized for a total of ten whole plots on each of the four blocks. One hundred and fifty seedlings were planted on each whole plot. These plots were divided into three sub-plots of 50 seedlings that were either mowed, disked, or an untreated control. Because of mechanical constraints, the subplots could not be randomized within each whole plot. They were instead randomized within each block, thus creating the strip-plot arrangement (Figures 2 and 3).

In addition to the four blocks of Study A, four designated areas were allowed to regenerate naturally. These areas ranged in size from approximately 0.6 to 1.0 acre. One natural area was located adjacent to each of the four blocks. These areas were

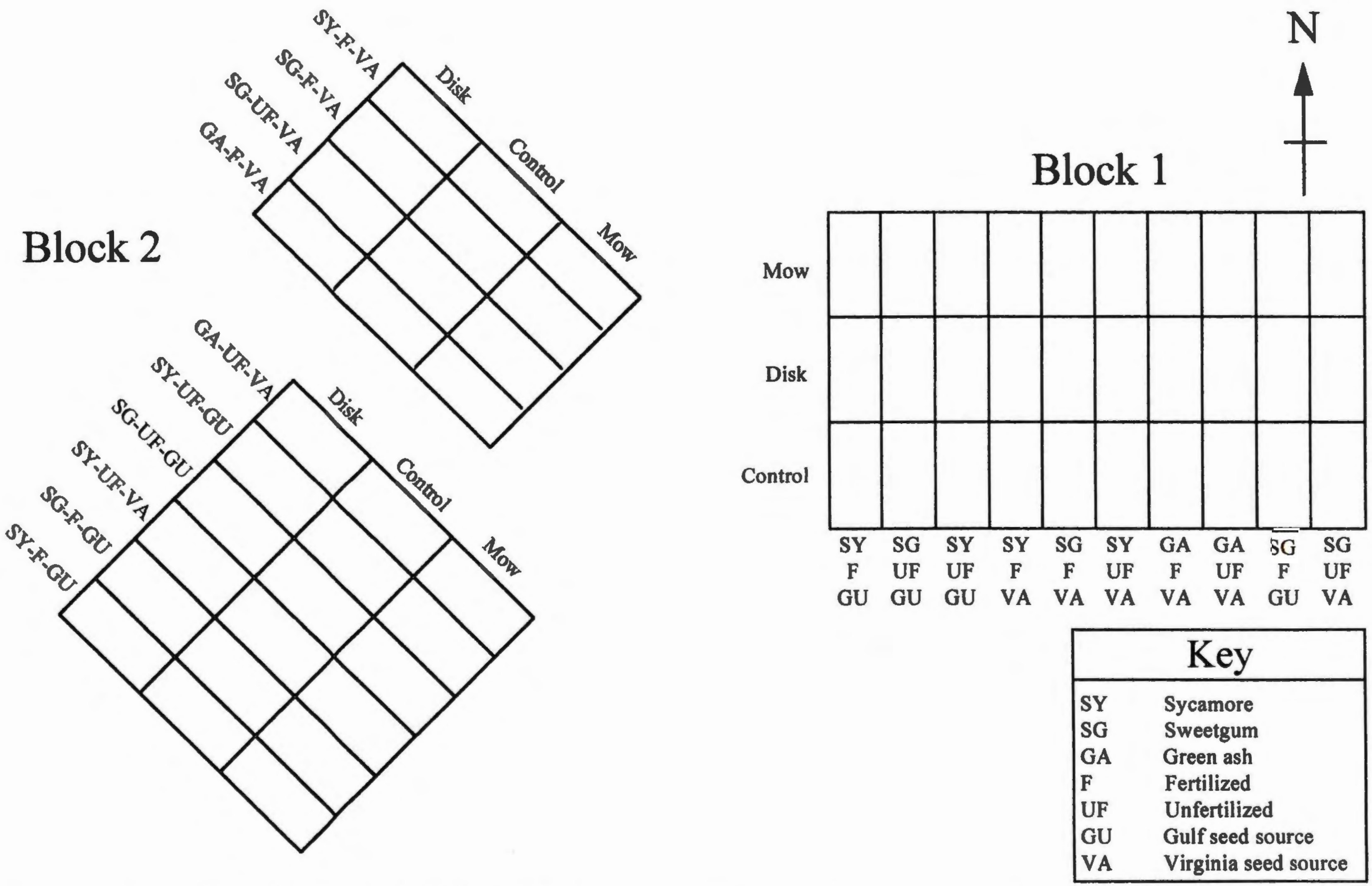

Figure 2. Blocks 1 and 2 of Bottomland Hardwood Study A, Ames Plantation, Fayette County, Tennessee.

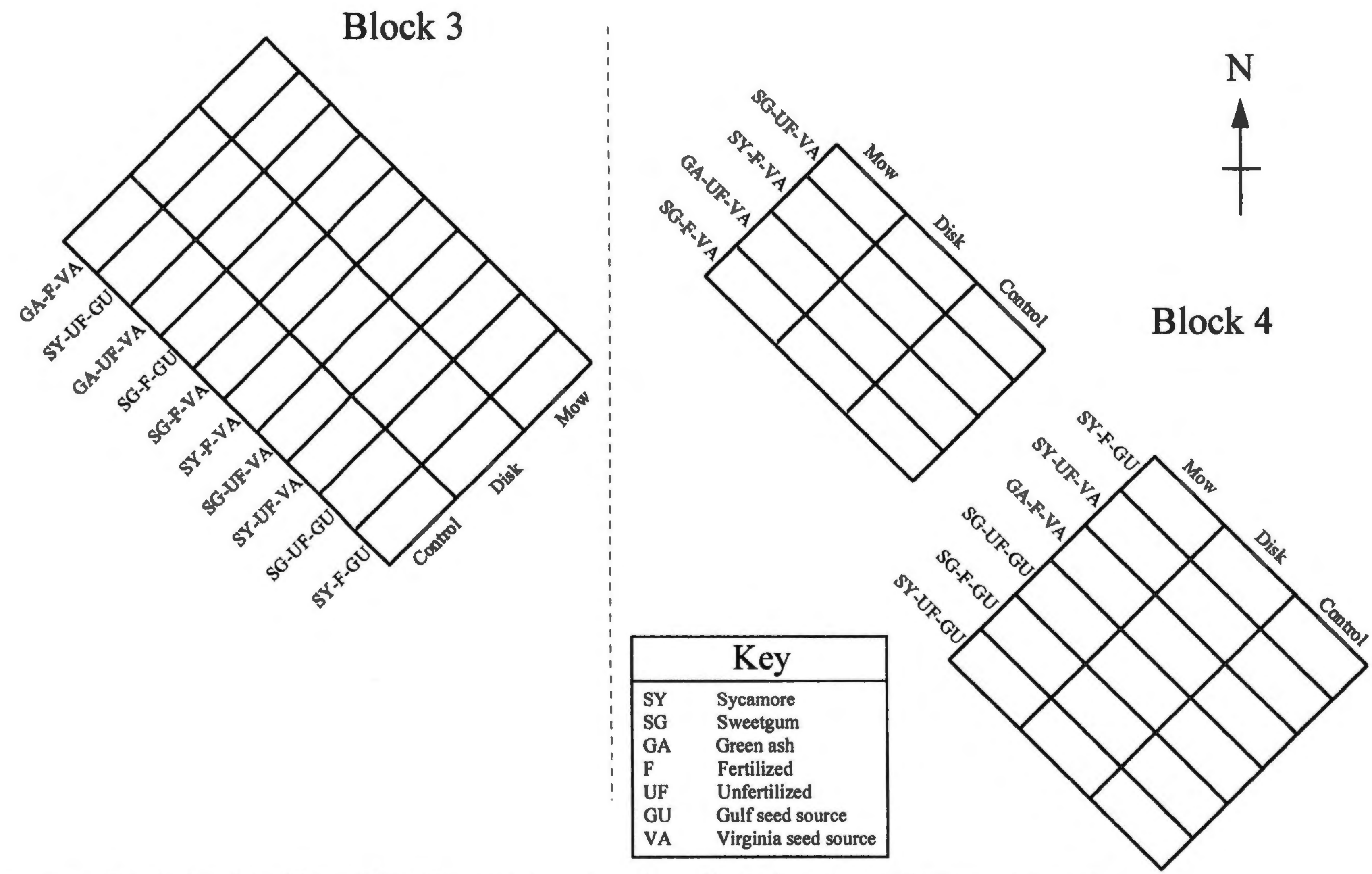

Figure 3. Blocks 3 and 4 of Bottomland Hardwood Study A, Ames Plantation, Fayette County, Tennessee.

originally part of the same soybean field; they underwent no site preparation, fertilization or cultivation.

Study B was established in 1981 with the planting of 1,200 loblolly pine, 1,200 cherrybark oak, and 1,200 yellow-poplar seedlings. The study had six whole plots within each of the four blocks: one fertilized and one unfertilized plot of each species (Figure 4). The sub-plots were arranged in the same manner as in Study A. Whole plots contained 150 seedlings, and sub-plots contained 50 seedlings. A centrally located 1.2-acre area was left to regenerate naturally.

Planting and Treatments

Seedlings in Study A were root-pruned, and tops were trimmed to 18 inches above the root collar. Seedlings were hand-planted in soybean stubble at a 10- x 10-foot spacing with no site preparation. One-way disking and mowing began in April, 1980 and was repeated as needed (three to five times annually) until the end of the fifth growing season to control competing vegetation. One hundred and fifty lbs/ac of elemental nitrogen and 35 lbs/ac of elemental phosphorus were applied at the beginning of the second, fourth and tenth growing seasons. None of the plantings were thinned.

The seedlings in Study B were hand-planted in the spring of 1981, also at a 10- x 10-foot spacing. No site preparation was performed, and cultural treatments were applied following the same procedure as in Study A. The composition of the fertilizer was the same as in Study A, but it was only applied once: before the third growing season.

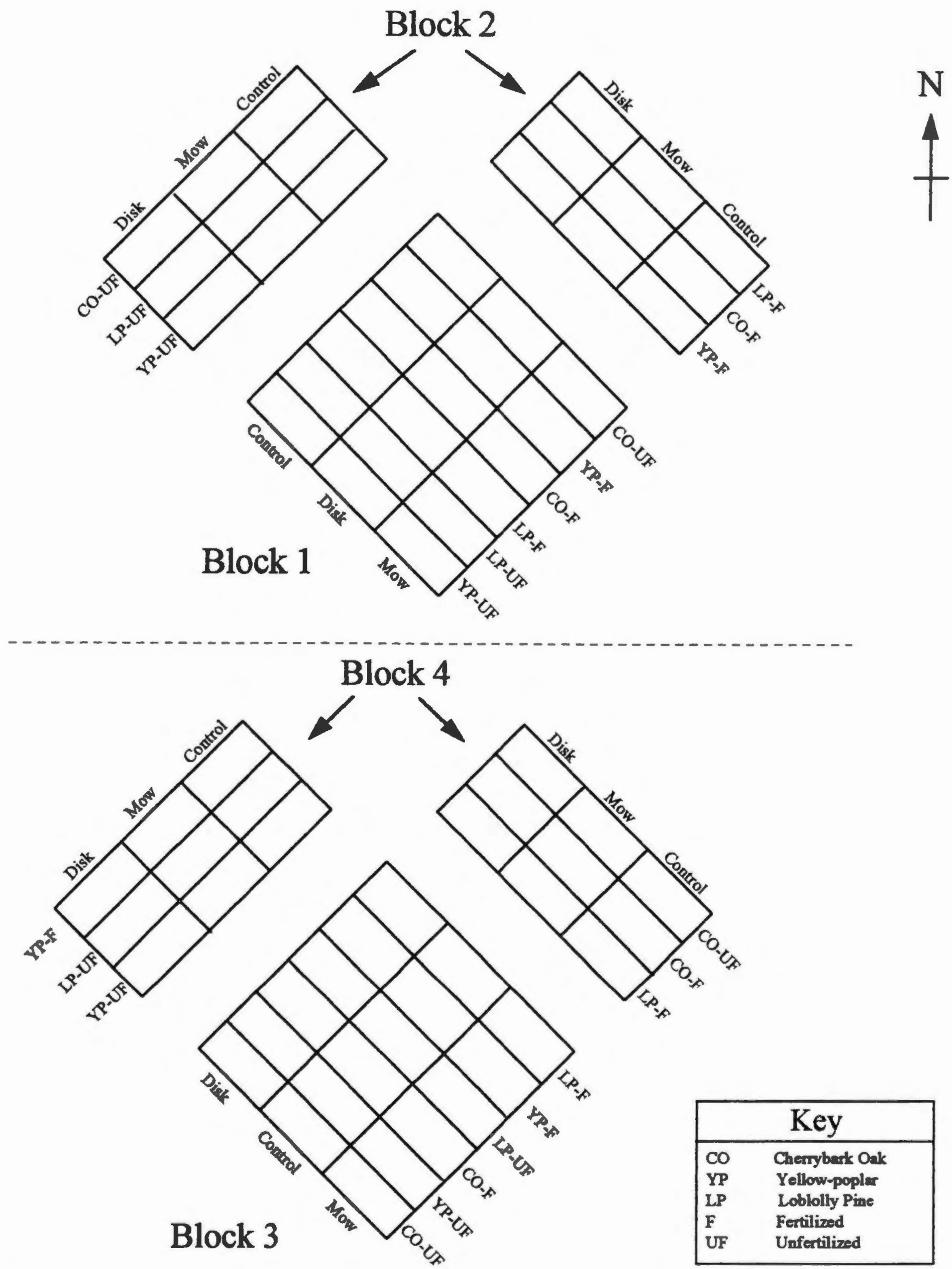

Figure 4. Bottomland Hardwood Study B, Ames Plantation, Fayette County, Tennessee.

Previous Measurements

Prior to the January 1998 measurements, total heights of the trees in Study A were measured seven times and dbh was measured once. Heights were measured after the first, second, third, fifth, ninth, tenth, and twelfth growing seasons, and dbh was measured after the twelfth growing season. The heights of all trees in Study B were measured after the first and second growing seasons. No measurements were made on the naturally regenerated stands prior to 1998.

Data Collection

<u>Plantations</u>

In January 1998, measurements were made representing 18 years of growth after out-planting on Study A and 17 years of growth after out-planting on Study B. The total height (nearest 1.0 foot) of each surviving tree was measured with a Haga altimeter, and the dbh (nearest 0.1 inch) was measured with a caliper. For growth comparisons, volumes were calculated using the following volume formulas:

Sweetgum: $V = 0.240 + 0.002186 * D^2 * H$ (Krinard 1988)

Sycamore: $V = 0.633 + 0.002221 * D^2 * H$ (Krinard 1988)

Green ash: $V = 0.175 + 0.002177 * D^2 * H$ (Krinard 1989)

Cherrybark oak: $V = -0.00567 + 0.0025769 * D^2 * H$ (Matney et al. 1985)

Yellow-poplar: $V = 1.798654 + 0.002060 * D^2 * H$ (Golden et al. 1982)

Loblolly pine: $\ln(V) = -5.731735 + 1.896449 * \ln(D) + 1.010252 * \ln(H)$

(Baldwin and Feduccia 1987)

Where: D = diameter at breast height outside bark (inches)

H = total height (feet)

V = total volume (cu. feet)

The volume formulas for green ash, sweetgum, and sycamore were for total stem volume, outside bark, above a one-foot stump. The formulas for cherrybark oak and loblolly pine were for total stem volume, outside bark, above a 0.5-foot stump. The yellow-poplar formula was based on total stem volume, outside bark, above a 0.5- to 2.0-foot stump.

For economic analyses, the following formulas for merchantable volume were used (stump heights were the same as for the total volume formulas):

Sweetgum: $V_m = -0.728 + 0.002271 * D^2 * H$ (Krinard 1988)

Sycamore: $V_m = -0.552 + 0.002250 * D^2 * H$ (Krinard 1988)

Green Ash: $V_m = V * Z$

$$\ln(V) = -5.502 + 0.91740 * \ln(D^2 * H)$$

$$Z = (1.0 + EXP[\{0.77188 + 11.26543 * (D\text{-}d/D)\} - \{73.62613 * (D\text{-}d/D)^2\} + \{111.38621 * (D\text{-}d/D)^3\} - \{59.39594 * (D\text{-}d/D)^4\}])^{-1}$$

(Schlaegel 1984b)

Cherrybark oak: $V_m = V * Z$

$$V = -0.00567 + 0.0025769 * D^2 * H$$

$$Z = 1.0 - (1.0 - EXP[-1.379237 * TAN\{0.788309 * (H^{0.089094}) * (d/D)\}])^{5.331156}$$

(Matney et al. 1985)

$$\text{Yellow-poplar: } V_m = V * Z$$

$$V = 1.798654 + 0.002060 * D^2 * H$$

$$Z = 1.0 + [0.663955 * (d^{3.392287}/D^{3.263456})]$$

(Golden et al. 1982)

$$\text{Loblolly pine: } V_m = V * Z$$

$$\ln(V) = -5.731735 + 1.896449 * \ln(D) + 1.010252 * \ln(H)$$

$$Z = \text{EXP}[-0.799015 * (d^{4.975752}/D^{4.686168})]$$

(Baldwin and Feduccia 1987)

d = top outside bark diameter of merchantable bole (4.0 inches)

V_m = volume of merchantable bole (cu. feet)

Z = ratio of merchantable bole volume to total bole volume

Naturally Regenerated Areas

Stratified random sampling was used to inventory the naturally regenerated stands. In Study A, each of the four natural stands was divided into five approximately equal sections. One circular, 0.01-acre plot was randomly placed within each of these five sections. To eliminate 'edge-effect', plots were not placed within one plot width of the stand boundary. A total of 20 plots were established for Study A.

Study B had only one naturally regenerated stand. Ten 0.01-acre circular plots were placed in this stand using stratified-random sampling as in Study A.

In both studies, the height, dbh and species of all trees in each plot over 4.5 feet in height were recorded.

Soils

The first soil analysis associated with this study was conducted in October, 1993. Soil samples were collected from the sycamore plots of Louisiana Gulf Coast seed origin in Study A. Two samples were taken at each of three depths (zero to two inches, three to five inches, and six to eight inches below the surface) on each sub-plot for a total of 144 samples. The bulk densities (grams/cc) of these samples were determined in laboratory analysis.[2] On April 1, 1999, a bucket auger was used to bore a hole in the center of each 50- by 100-foot sub-plot. Depth to first gray mottles and soil series were recorded for each of the 120 sub-plots. Depth to water table was measured after the water in the holes equilibrated.

Statistical Analysis

Survival and Growth Data

Survival was based on the total number of living study trees within each sub-plot divided by the total number of trees planted. Trees that received two different cultural treatments (e.g., trees that were disked on one side and mowed on the other side) were excluded from this calculation. Percent survival on each sub-plot was transformed with the arcsine-square root transformation after an initial analysis showed that the data did not meet the normality and homoscedasticity requirements for analysis of variance (ANOVA). The transformed data met the requirements.

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[2] Personal communication with Dr. Allan E. Houston and Dr. Donald D. Tyler, University of Tennessee.

Height, dbh and volume means for each sub-plot were calculated excluding the outer rows of border trees.

Statistical Models for Tree Growth and Survival

Growth and survival data were analyzed with ANOVA using the Mixed Procedure in SAS (SAS Institute 1997). Each sub-plot was treated as one experimental unit. After the data were analyzed with ANOVA, single degree of freedom (df) contrasts were used to compare means among significant fixed effects and among treatment combinations (e.g., fertilization and weed control combinations). All statistical analyses were conducted at the 95% confidence level.

A separate model was created for each species because some species contained an additional variable (seed source). Two models were then created ignoring the seed source variable: one contained all the species in Study A and one contained all the species in Study B. These composite models were used to detect significant survival and growth differences among species and to find significant species x treatment interactions.

Soils

ANOVA was used to detect differences among the bulk densities of the soil samples. Variations in soil bulk density due to depth and treatments were examined with Proc Mixed in SAS (SAS Institute 1997). Additionally, regressions were run using Proc Reg in an attempt to correlate the average tree height on each sub-plot with the bulk density of the soil on that plot. Since the soil samples were collected in 1993, height data collected in the closest available year were used. The data collected in February 1992 were selected.

For each of the Study A species, regression models in Proc Reg (SAS Institute 1997) were used to test for linear and quadratic relationships between tree survival, height, dbh and stem volume and depths to water table and mottles. Because the *x*-variables (i.e. depths to water table and mottles) were not fixed, these were Model II regressions. However, since the regression lines were fitted only for the purpose of predicting the *y*-variables, Model I regression techniques were considered acceptable (Sokol and Rohlf 1981). In cases where all treatment levels (e.g., control, disking and mowing for the weed control treatment) had significant survival- or growth-soil relationships, the Tukey-Kramer procedure was used to determined whether the regression slopes differed significantly. The purpose of this test was to find significant treatment-soil interactions.

Economic Analysis

An economic analysis was conducted to determine the annual rate of return for each treatment and species combination. The annual rate of return is "the rate of compound interest that is 'earned' by the capital invested; it is the average rate of capital appreciation during the life of the project" (Bullard and Straka 1993). Microsoft Excel was used to perform all calculations. Costs and revenues were in terms of constant dollars before taxes. Establishment and treatment costs used were averages given for the Southern Coastal Plain in the *Forest Landowner Manual Edition* (Dubois et al. 1997).

Revenues were calculated using merchantable volumes and the prices and product classes given by Timber Mart-South for the west Tennessee region (Norris 1997). A five-dollar annual management cost was assumed.

III. Results

Study A: 18-Year Growth of Sweetgum, American Sycamore and Green Ash

Survival

Overall Survival

The average survival rates were high for all species in Study A, but green ash (95%) and sweetgum (93%) had significantly higher survival than sycamore (88%) (Tables 1, A-1[3], A-2). There were no significant interactions between species and seed source, fertilization or cultural treatment. The only significant differences in survival between species on an individual treatment occurred between sycamore and green ash on mowed plots.

Survival by Species

Survival rates for sweetgum did not vary significantly with treatment or seed source (Tables A-3, A-4). Survival for all treatment combinations ranged from 91% to 96% with the exception of fertilized/mowed plots which had 88% survival.

Survival of sycamore also did not differ significantly by treatment or seed source (Tables A-5, A-6). Survival rates ranged from 80% on fertilized/mowed plots to 95% on fertilized disked plots.

Survival rates for green ash did not differ significantly with weed control or

[3] Tables with A- prefix appear in appendix.

Table 1. Survival after 18 years for three planted hardwood species. Study was located on a bottomland site in southwest Tennessee.

	Sweetgum	Sycamore	Green ash
		%	
All Treatments	93a[1]	88b	95a
Gulf	91a[2]	87a	-
Virginia	95a	88a	95
Unfertilized	94a	89a	94a
Fertilized	91a	87a	96a
Control	93a	87a	90a
Disk	95a	94a	97a
Mow	90a	82a	97a
Unfertilized/Control	95[3]	88	88
Unfertilized/Disk	96	94	96
Unfertilized/Mow	92	84	98
Fertilized/Control	91	87	92
Fertilized/Disk	94	95	99
Fertilized/Mow	88	80	95

1/ Mean separation was conducted among the three species means using single df contrasts (alpha=0.05).

2/ Means within each group and species followed by the same letter do not differ at alpha=0.05.

3/ Mean separation contrasts for treatment combinations appear in tables A-4, A-6, and A-8.

fertilization, but a significant difference did occur among treatment combinations (Tables A-7, A-8). The survival rate on unfertilized/mowed plots (98%) was significantly higher than survival than on unfertilized/control plots (88%).

There were no statistically significant interactions between fertilization, weed control, or seed source in any of the three species.

Sweetgum

Height

Total height of sweetgum was significantly affected by weed control but not by fertilization or seed source (Table A-9). Trees on disked plots, averaging 59.1 feet in height, were significantly taller than trees on control plots (52.1 feet) (Table A-10). Trees on mowed plots (56.5 feet) were not significantly taller than control plots.

Although fertilization did not affect tree height, there was a significant interaction between fertilization and weed control due to the fact that heights of trees on both disked and mowed plots were similar under fertilized and unfertilized conditions, while on control plots unfertilized trees (48.7 feet) were significantly smaller than fertilized trees (55.6 feet) (Figure 5, Table A-4). Mowing and disking provided significant height increases on unfertilized plots but not on fertilized plots.

With the exception of year two, the height response to fertilization was uniformly insignificant over 18 years (Table A-11). The height difference between disked plots and control plots was significant from years two through 18, but mowed

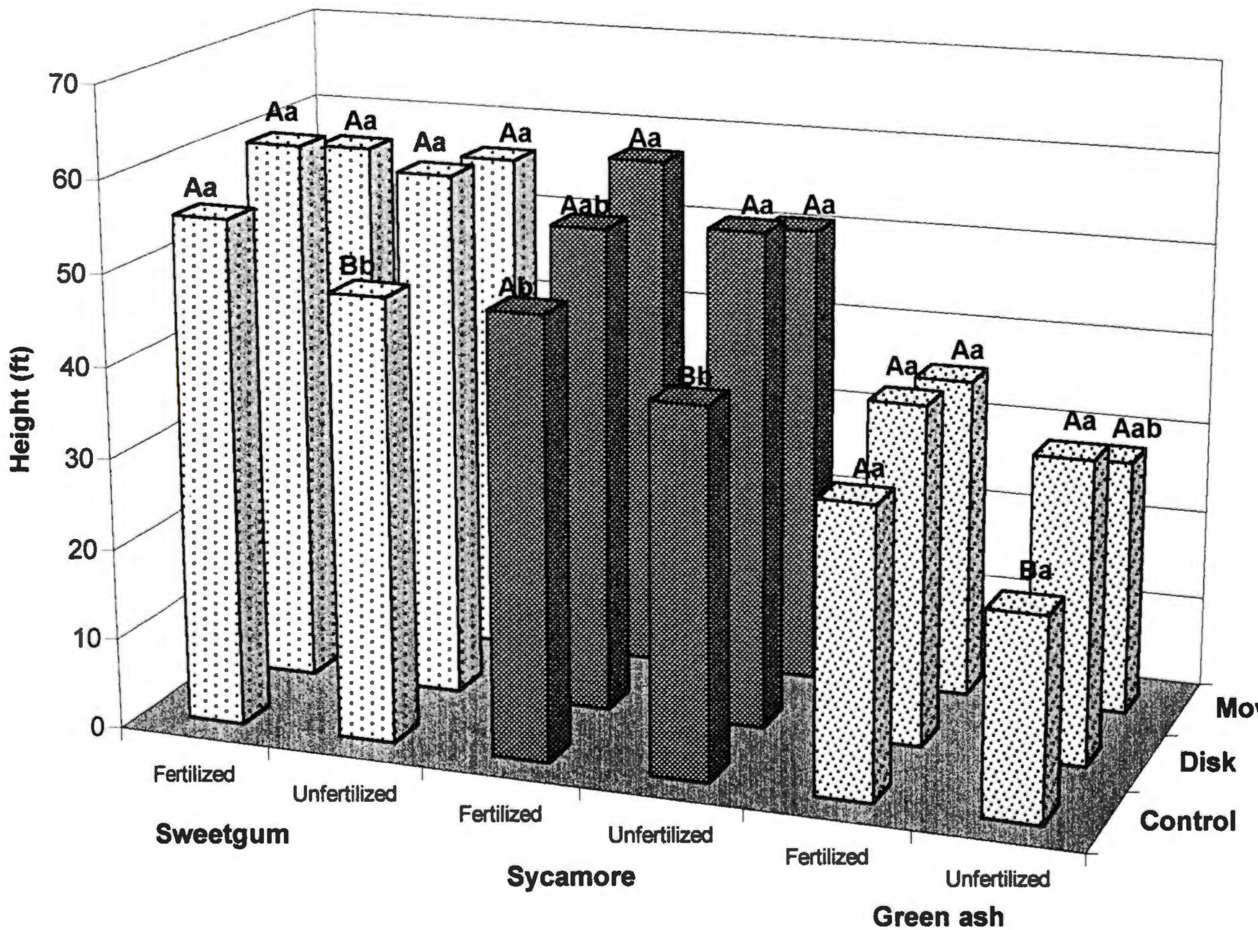

Figure 5. Eighteen-year height growth under various cultural treatment combinations for species planted on a bottomland site in southwest Tennessee.

***Note:* Same capital letters denote no significant difference (alpha=0.05) within same weed control and species; same lowercase letters denote no significant difference within same fertilization and species.**

plots never differed significantly from control plots. Trees on disked plots were significantly taller than those on mowed plots until year 18, when they were equal.

Dbh

Fertilization and weed control both resulted in significant increases in dbh of sweetgum, but seed source had no effect (Table A-12). Fertilized plots averaged 6.99 inches dbh; unfertilized plots averaged 6.29 inches (Table A-13). Trees on disked plots had an average dbh of 7.12 inches, while trees on mowed plots averaged 6.72 inches dbh. Both of these were significantly greater than control plots where dbh averaged 6.09 inches. On unfertilized plots, both mowing and disking significantly increased diameter, but on fertilized plots only disking was effective (Figure 6, Table A-4). Fertilization provided a significant diameter increase on control and disked plots but not on mowed plots. There were no interactions between fertilization, weed control, or seed source.

Stem Volume

Both fertilization and weed control had significant effects on stem volume, but there was no significant interaction between the two treatments (Table A-14). Fertilized trees averaged 7.00 cu. feet, while unfertilized trees averaged 5.66 cu. feet (Table A-15). Trees on disked plots (7.42 cu. feet) were significantly larger than those on mowed plots (6.42 cu. feet), which were significantly larger than trees on control plots (5.15 cu. feet). On unfertilized plots, both mowing and disking increased stem volume significantly, but on fertilized plots only disking made a significant difference in

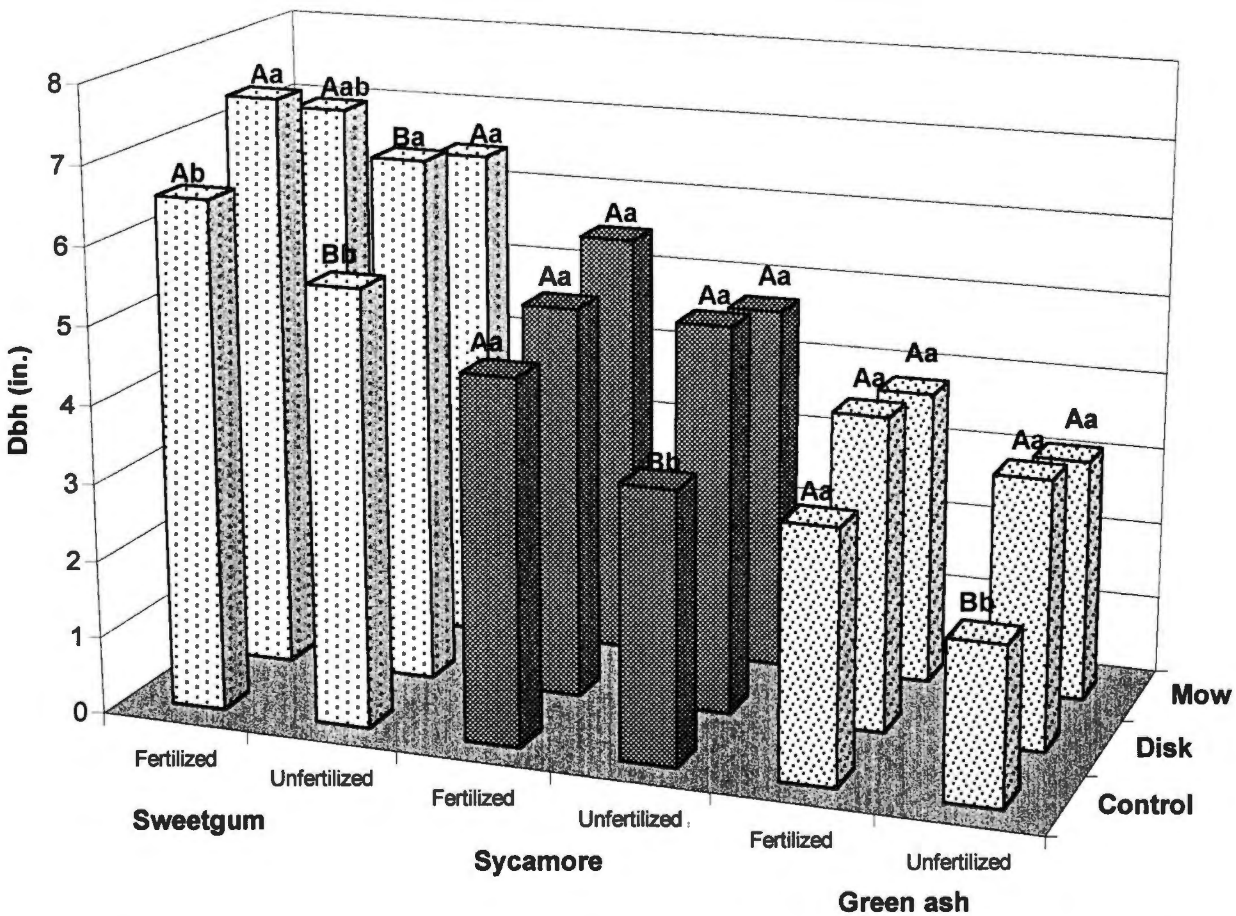

Figure 6. Eighteen-year dbh growth under various cultural treatment combinations for species planted on a bottomland site in southwest Tennessee.
Note: **Same capital letters denote no significant difference (alpha=0.05) within same weed control and species; same lowercase letters denote no significant difference within same fertilization and species.**

volume (Figure 7, Table A-4). Fertilization significantly increased volume on control and disked plots but not on mowed plots.

American Sycamore

Height

The height of sycamore was not significantly affected by fertilization or weed control, but there was a significant interaction between the two treatments (Table A-16). The height response to fertilization was significantly different on plots of different cultural treatments (Figure 5, Table A-10). Fertilization significantly increased tree heights on control plots but not on disked or mowed plots. On unfertilized plots, both mowing and disking significantly increased height, but on fertilized plots height was increased only by mowing (Table A-6).

Throughout the study, the only period when fertilization had a significant effect on height was during the second and third growing seasons (Table A-17). Disked trees had height growth superior to those on mowed and control plots through the fifth growing season, but from the ninth to the twelfth growing seasons, trees on disked plots were significantly taller than those on control plots but not those on mowed plots. After 18 years, mowing and disking were no longer superior to no weed control.

Dbh

Fertilization significantly increased dbh in sycamore (Table A-18). Trees on fertilized plots averaged 5.08 inches dbh, while unfertilized plots averaged 4.41 inches

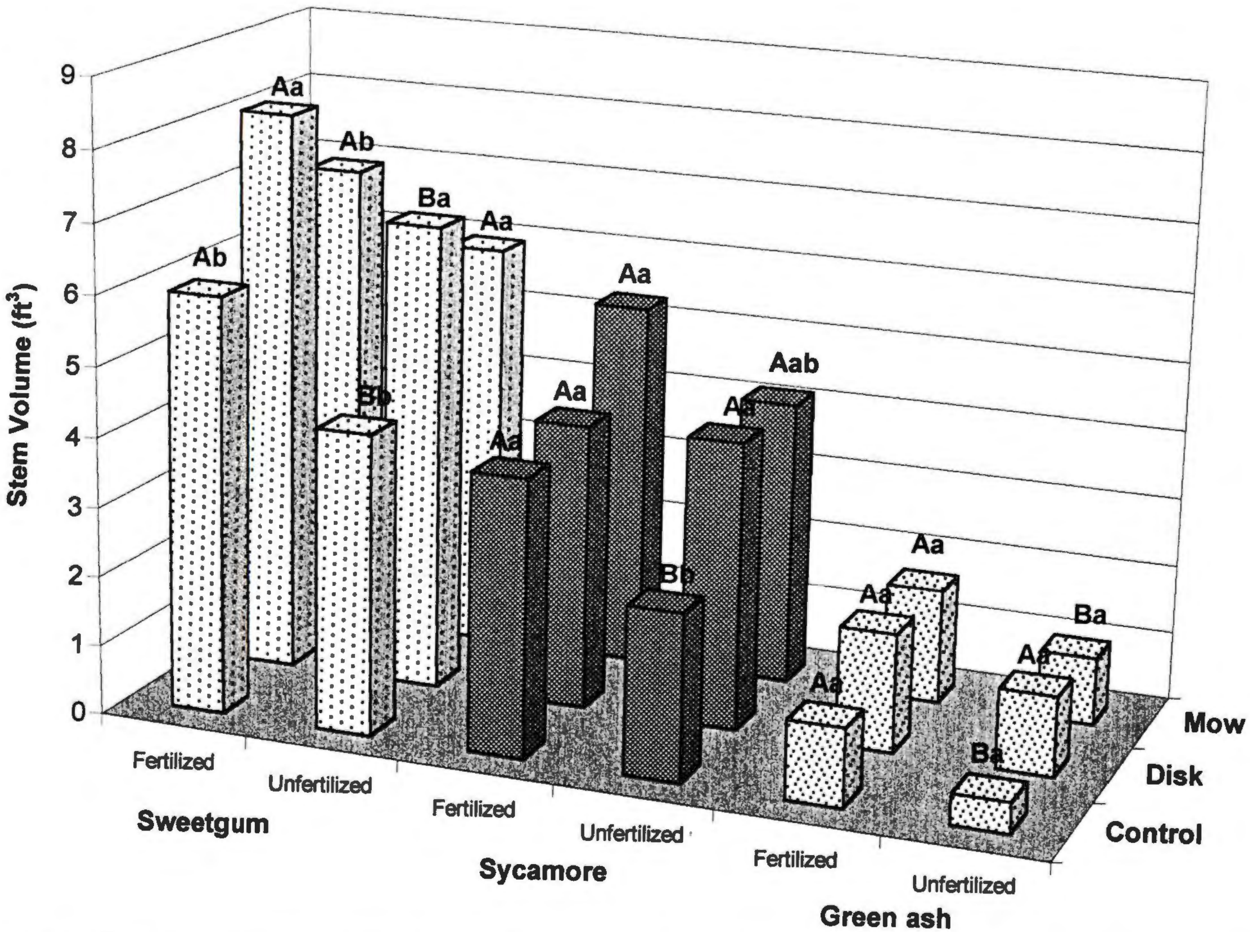

Figure 7. Eighteen-year stem volume growth under various cultural treatment combinations for species planted on a bottomland site in southwest Tennessee.
Note: **Same capital letters denote no significant difference (alpha=0.05) within same weed control and species; same lowercase letters denote no significant difference within same fertilization and species.**

dbh (Table A-13). There was also a significant interaction between fertilization and weed control. Fertilization significantly increased sycamore diameter on control plots but not on disked or mowed plots (Figure 6). Diameter was significantly increased by mowing and disking on unfertilized plots but not on fertilized plots (Table A-6).

Stem Volume

Sycamore did not show a significant change in stem volume due to the main treatments of fertilization, weed control, or seed source (Table A-19). However, there was a significant interaction between fertilization and weed control. On control plots, fertilization increased the average volume per tree by 1.58 cu. feet, but on disked and mowed plots fertilization did not significantly increase stem volume (Figure 7, Tables A-6, A-15). On unfertilized plots, volume was significantly greater for disked trees (4.15 cu. feet) than for control trees (2.39 cu. feet). Disking and mowing did not increase volume on fertilized plots, and mowing did not significantly increase volume on unfertilized plots.

Green Ash

Height

Green ash height did not vary significantly with weed control or fertilization (Table A-20). Trees on fertilized plots averaged 34.9 feet in height, while those on unfertilized plots averaged 27.8 feet in height (Table A-10). On unfertilized plots, disking, but not mowing, significantly increased height (Figure 5, Table A-8).

Fertilization significantly increased height growth on control plots but not on disked or mowed plots. No significant interaction existed between fertilization and weed control.

Height response to fertilization was significant only at years three and ten (Table A-21). Trees on disked plots were superior in height throughout the duration of the study, but at year 18, trees on disked and mowed plots were no longer superior to trees on control plots.

Dbh

Both fertilization and weed control had significant effects on the dbh of green ash (Table A-22). Trees on unfertilized plots averaged 2.87 inches dbh, while those on fertilized plots averaged 3.70 inches (Table A-13). When compared to the control plots, disking, but not mowing, significantly increased tree diameter. Control plots averaged 2.64 inches dbh; disked and mowed plots averaged 3.74 and 3.47 inches dbh, respectively. There was no interaction between fertilization and weed control.

Among the six fertilization/weed control combinations, dbh ranged from 2.03 inches to 4.04 inches. Mowing and disking increased tree diameter on unfertilized plots, but on fertilized plots neither weed control method was effective (Figure 6, Table A-8). Fertilization increased diameter significantly on control plots but not on plots that were mowed or disked.

Stem Volume

There were no significant (alpha=0.05) increases in stem volume of green ash due to fertilization or weed control (Table A-23). Trees on fertilized plots averaged 1.50 cu. feet, and trees on unfertilized plots averaged 0.86 cu. feet (Table A-15). There were two significant differences among treatment combinations: on control and mowed plots, fertilization significantly increased volume (Figure 7, Table A-8).

Species Comparisons

In the growth analyses done on this study by Waldrop et al. (1983) and Houston and Buckner (1989), the data from the Louisiana Gulf Coast and Virginia Coastal Plain seed sources were combined for sweetgum and sycamore. These data also were combined in the current analysis because no significant differences were detected in height, dbh, volume or survival due to seed source for sweetgum or sycamore. Furthermore, there were no significant interactions involving seed source.

Height

Through the tenth growing season, sycamore was significantly taller than both of the other species, but by year 12 sweetgum had equaled sycamore in height (Figure 8, Table A-24). After 18 years of growth, the mean height of sweetgum (55.9 feet) was greater than that of sycamore (50.8 feet), which was greater than that of green ash (31.4 feet).

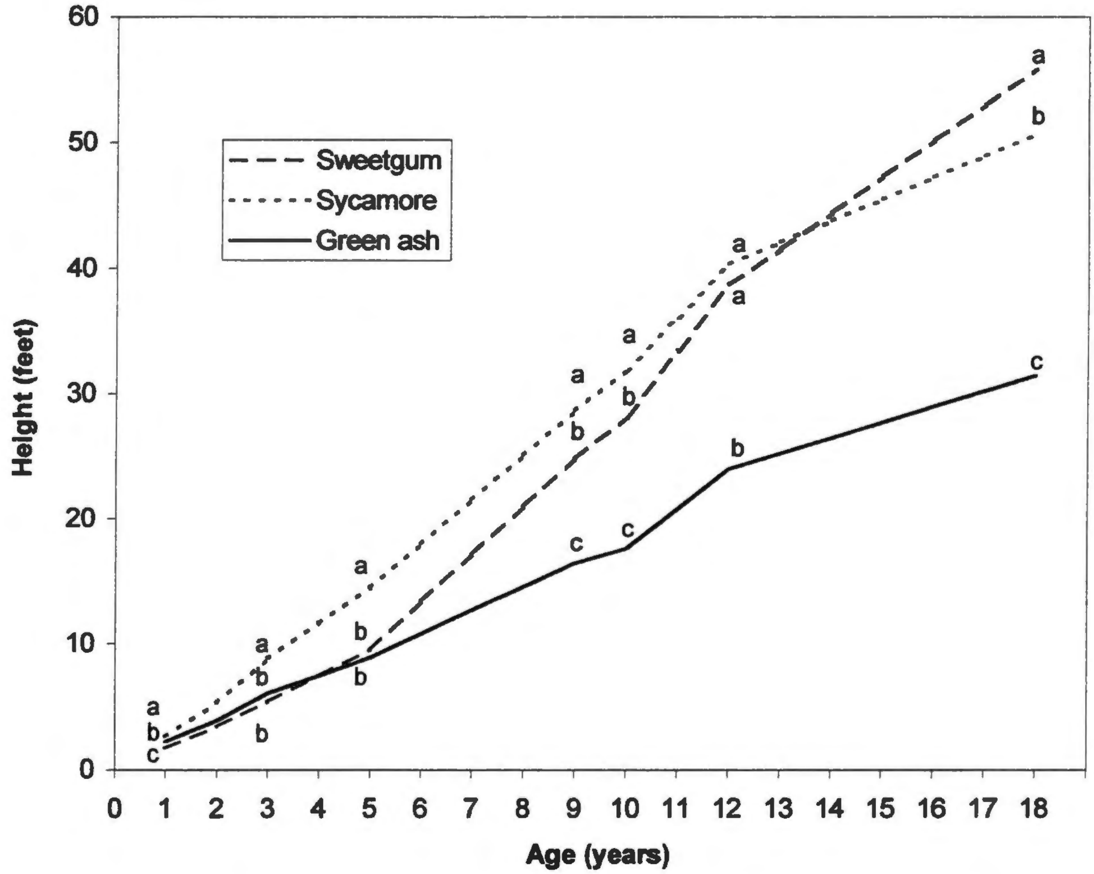

Figure 8. Mean heights across all treatments for three species planted on a bottomland site in southwest Tennessee.
Note: **Heights followed by the same letter within each year do not differ at alpha=0.05.**

At age 18, this pattern (sweetgum > sycamore > green ash) occurred under five of the six weed control/fertilization treatment combinations (Tables A-2, A-25). The exception was the unfertilized/control combination in which sweetgum was not significantly taller than sycamore.

Dbh

The average diameter of sweetgum (6.64 inches) was significantly larger than sycamore (4.74 inches), which was significantly larger than green ash (3.28 inches) (Tables A-2, A-26). This same pattern was significant under all six treatment combinations.

Stem Volume

The average volume of sweetgum (6.33 cu. feet) was significantly greater than that of sycamore (4.01 cu. feet) (Tables A-2, A-27). Sycamore was significantly greater in volume than green ash (1.18 cu. feet). This ranking occurred in all treatment combinations except on fertilized/mowed plots where sweetgum was not significantly greater in volume than sycamore.

Natural Regeneration

After 18 years, stocking on the naturally regenerated areas was predominated by sweetgum (72%), sycamore (9%), and red maple (*Acer rubrum* L.) (9%), and averaged 3,445 trees/ac (TPA) with height over 4.5 feet (Tables 2, 3). On average, only 95 TPA

Table 2. Number of trees (>4.5 feet in height) in the 18-year old naturally regenerated stands adjacent to Study A. Study was located on a bottomland site in southwest Tennessee.

		stems/acre by dbh class		
Species	% of total stems	<1 inch	1-4.9 inches	>5 inches
Sweetgum	71.8	650	1,770	55
Sycamore	9.4	115	200	10
Red maple	9.3	165	155	0
River birch	3.2	0	105	0
Boxelder	1.5	15	30	5
Yellow-poplar	1.5	15	35	0
Loblolly pine	1.3	0	20	25
Cherrybark oak	1.2	20	20	0
Eastern redcedar	1.0	5	30	0
Total		985	2,365	95

Note: Estimates were based on twenty 0.01 acre plots.

Table 3. Average total height and dbh of trees in the 18-year old naturally regenerated stands adjacent to Study A. Study was located on a bottomland site in southwest Tennessee.

Species	Height (feet)	Dbh (inches)
Sweetgum	22.2	1.81
Sycamore	23.3	1.46
Red maple	17.0	1.11
River birch	42.5	3.26
Boxelder	21.8	2.05
Yellow-poplar	21.7	1.88
Loblolly pine	31.1	5.41
Cherrybark oak	19.3	1.46
Eastern redcedar	13.6	1.97

Note: Estimates were based on twenty 0.01 acre plots.

were larger than 5.0 inches dbh. The majority of these were loblolly pine (25 TPA), which also had the largest mean diameter (5.41 in), and sweetgum (55 TPA). The average basal area of the natural regeneration was 92.5 $feet^2$/ac.

Study B: 17-Year Growth of Cherrybark Oak, Loblolly Pine and Yellow-poplar

Survival

Overall Survival

The overall survival in Study B averaged 80% and 74% after the first and second growing seasons, respectively (Table A-28). After 17 years, cherrybark oak averaged 64% survival and loblolly pine averaged 63% survival (Table 4). There were no significant differences in survival between these two species, nor were there any significant treatment interactions (Tables A-29).

Yellow-poplar could not be statistically analyzed for survival because two of the four blocks suffered complete mortality. This occurred early in the study when an invasion of sycamore caused severe competition problems on two of the blocks of yellow-poplar. The sycamores were felled and the herbicide Tordon was applied to the stumps. Subsequent flooding apparently spread herbicide that remained in the soil to the planted yellow-poplar, killing nearly all of them. With only two blocks left, there was not enough statistical power for analyses. Instead, the mean survival rate was calculated for each treatment.

Survival by Species

During years one and two, cherrybark oak survival was 89% and 77%, respectively. After 1, 2 and 17 years, cherrybark oak showed no significant variation in survival due to weed control, fertilization, or combination thereof (Tables 4, A-28, A-30, A-31). There were no interactions between fertilization and weed control.

Table 4. Survival after 17 years for three planted tree species. Study was located on a bottomland site in southwest Tennessee.

	Loblolly Pine	Cherrybark Oak	Yellow-poplar[1]
		%	
All Treatments	63a[2]	64a	92
Unfertilized	61a[3]	67a	95
Fertilized	65a	61a	89
Control	50a	64a	84
Disk	69a	66a	97
Mow	71a	61a	96
Unfertilized/Control	45[4]	62	93
Unfertilized/Disk	72	72	95
Unfertilized/Mow	66	66	98
Fertilized/Control	54	66	76
Fertilized/Disk	66	60	99
Fertilized/Mow	76	57	93

1/ Statistical analyses were not performed on yellow-poplar because 2 of the 4 blocks were destroyed.

2/ Mean separation was conducted between the two species means using single df contrasts (alpha=0.05).

3/ Percentages within each group and species followed by the same letter do not differ at alpha=0.05.

4/ Mean separation contrasts for treatment combinations appear in tables A-31 and A-33.

Loblolly pine survival averaged 80%, 74% and 63% after 1, 2 and 17 years, respectively. Survival of loblolly pine did not differ among treatment combinations except at year two (Tables A-28, A-32, A-33). After 17 years, there was no significant interaction between fertilization and weed control. Loblolly pine survival rates ranged from 45% on unfertilized/control plots to 76% on fertilized/mowed plots. Poor survival of the unfertilized/control treatment was partially due to the fact that one plot suffered complete mortality.

Yellow-poplar survival on all four blocks was 71% after one growing season and 65% after two growing seasons. After 17 years, survival was high on the two remaining blocks of yellow-poplar. On all but one of the treatment combinations, survival was 93% or greater. The only exception to yellow-poplar's uniformly high survival occurred on the fertilized/control plots (76%) (Table 4).

<u>Cherrybark Oak</u>

Height

There were no significant differences in height by fertilization, weed control, or any combination thereof (Figure 9, Tables A-31, A-34). Mean heights for the six treatment combinations ranged from 30.4 feet (unfertilized/control) to 37.1 feet (unfertilized/disked) (Table A-35).

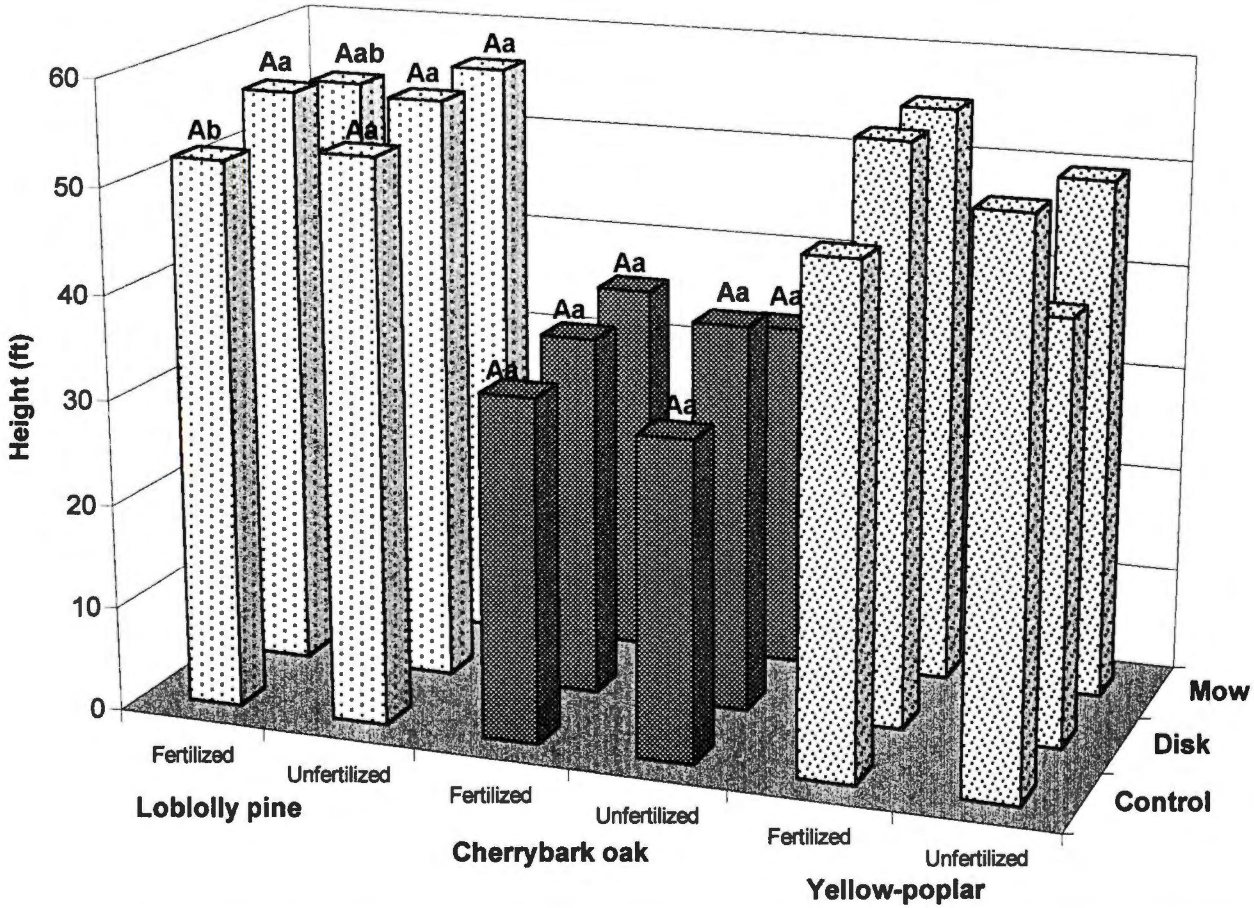

Figure 9. Seventeen-year height growth under various cultural treatment combinations for species planted on a bottomland site in southwest Tennessee.
Note: **Same capital letters denote no significant difference (alpha=0.05) within same weed control and species; same lowercase letters denote no significant difference within same fertilization and species.**

Dbh

Fertilization had no significant effect on the dbh of cherrybark oak (Figure 10, Table A-36). Among weed control treatments, dbh ranged from 3.60 inches (control plots) to 4.54 inches (disked plots), but these were not significantly different (Table A-37). There were no interactions between weed control and fertilization, nor were there any significant differences in dbh among treatment combinations (Table A-31).

Stem Volume

There were no significant differences in stem volume due to fertilization or weed control (Figure 11, Tables A-31, A-38). Trees on disked plots averaged 2.57 cu. feet, while those on mowed plots averaged 2.33 cu. feet, and those on control plots averaged 1.71 cu. feet (Table A-39). Average volumes of the fertilization/weed control combinations ranged from 1.60 cu. feet for trees on unfertilized/control plots to 2.88 cu. feet per tree for trees on unfertilized/disked plots. There was no significant interaction between fertilization and weed control.

<u>Loblolly Pine</u>

Height

There were no significant differences in height due to fertilization or weed control, nor was there a significant interaction between the two (Figure 9, Table A-40). There was only one significant difference among treatment combinations: trees on

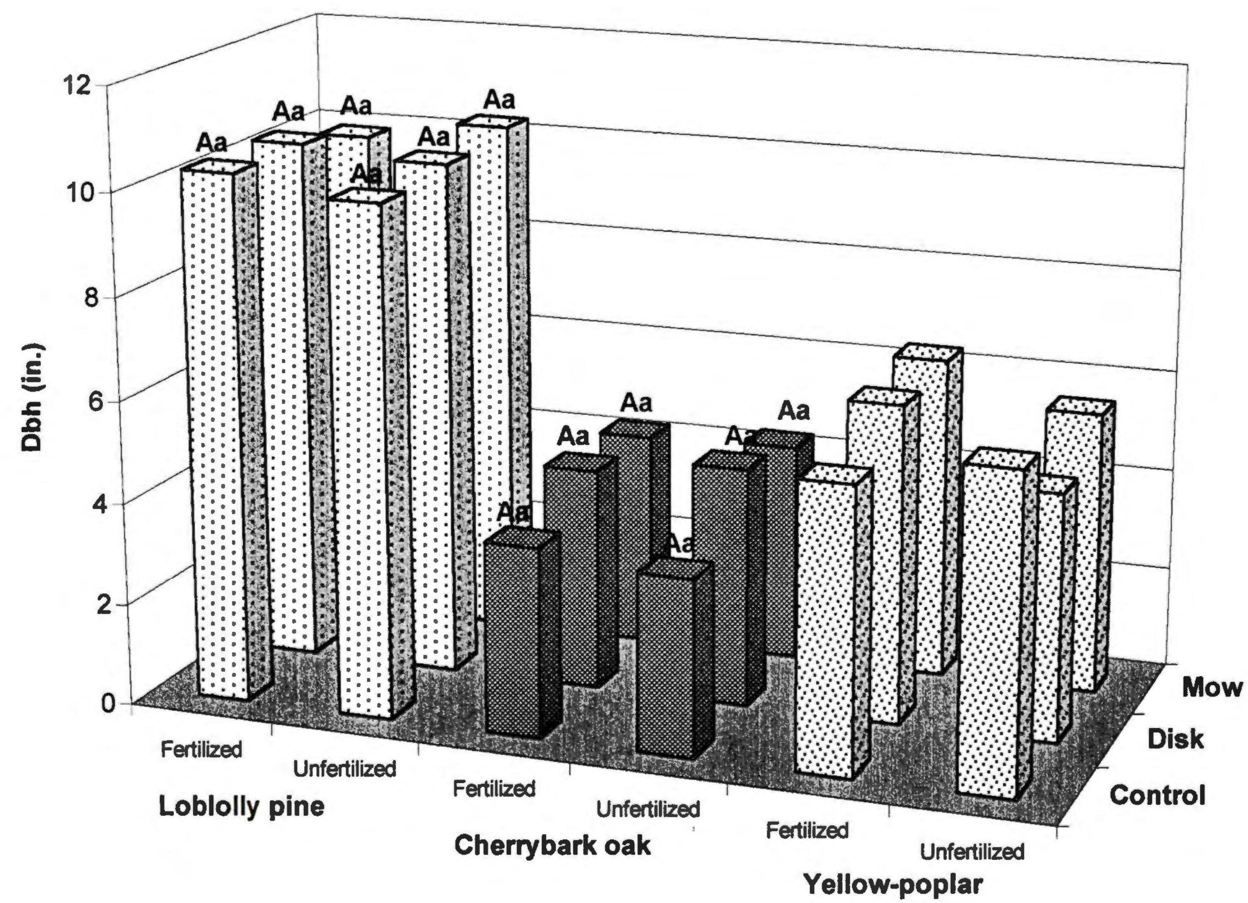

Figure 10. Seventeen-year dbh growth under various cultural treatment combinations for species planted on a bottomland site in southwest Tennessee.

***Note:* Same capital letters denote no significant difference (alpha=0.05) within same weed control and species; same lowercase letters denote no significant difference within same fertilization and species.**

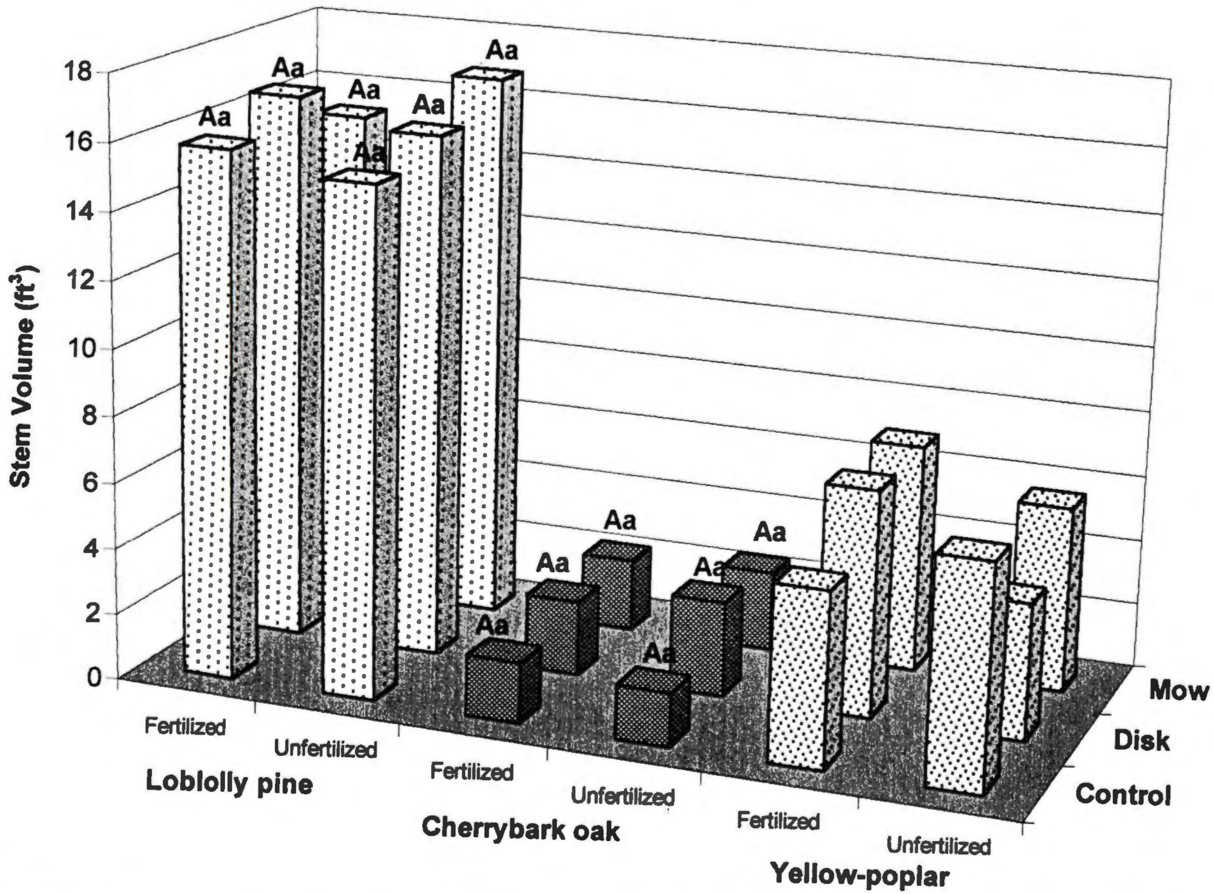

Figure 11. Seventeen-year stem volume growth under various cultural treatment combinations for species planted on a bottomland site in southwest Tennessee.
Note: **Same capital letters denote no significant difference (alpha=0.05) within same weed control and species; same lowercase letters denote no significant difference within same fertilization and species.**

fertilized/disked plots were significantly taller than trees on fertilized/control plots (Table A-33).

Dbh

Loblolly pine dbh ranged from 9.92 inches (fertilized/mowed plots) to 10.33 inches (fertilized/control and fertilized/disked plots) (Table A-37). There were no significant differences by fertilization or weed control treatment, nor were there any significant interactions (Figure 10, Tables A-33, A-41).

Stem Volume

Weed control and fertilization had no significant effect on loblolly pine stem volume (Figure 11, Tables A-33, A-42). Unfertilized trees averaged 15.99 cu. feet, and fertilized trees averaged 15.91 cu. feet (Table A-39). Volumes among treatment combinations ranged from 15.26 cu. feet (fertilized/mowed) to 16.82 cu. feet (unfertilized/mowed).

Yellow-poplar

Because two of the four blocks of yellow-poplar suffered complete mortality, it was not possible to analyze the growth data using the same statistical procedures as the other species. However, mean values for height, dbh and volume on the two surviving blocks were reported.

Height

Yellow-poplar growing on fertilized plots averaged 52.9 feet, and trees on unfertilized plots averaged 47.7 feet in height (Table A-35). The average height on mowed plots was 52.6 feet, while disked plots averaged 47.9 feet. Heights among treatment combinations ranged from 40.4 feet (unfertilized/disked plots) to 55.5 feet (fertilized/mowed plots) (Figure 9).

Dbh

On fertilized plots, yellow-poplar averaged 6.05 inches in dbh, and on unfertilized plots it averaged 5.52 inches (Table A-37). Dbh among fertilization/weed control combinations ranged from to 4.85 inches on unfertilized/disked plots to 6.36 inches on fertilized/mowed plots (Figure 10).

Stem Volume

The average volume per tree of yellow-poplar was 5.93 cu. feet (Table A-39). Trees on disked plots had an average stem volume of 5.50 cu. feet per tree. Control plots yielded 5.99 cu. feet per tree, and mowed plots averaged 6.31 cu. feet (Figure 11).

Species Comparisons

Yellow-poplar was not included in the species comparison model because it lacked data from two of the four blocks. Instead, only cherrybark oak and loblolly pine were analyzed for differences in height, dbh, and volume, and for species/treatment interactions.

Height

Loblolly pine was significantly taller than cherrybark oak under all treatment combinations (Tables A-43, A-44). No interactions between species and treatment occurred.

Dbh

Loblolly pine had a significantly larger mean dbh (10.16 inches) than cherrybark oak (4.14 inches) (Tables A-44, A-45). This pattern occurred among all treatment combinations. Because there was no significant dbh response to fertilization in either species, there was also no fertilization x species interaction. Weed control also did not interact with species.

Stem Volume

For all treatment combinations, the average stem volume per tree of loblolly pine was significantly greater than that of cherrybark oak (Tables A-44, A-46). There were no species x treatment interactions.

Natural Regeneration

The naturally regenerated stand was densely overstocked and contained few dominant trees. The majority of the trees in this stand were sweetgum (74%), followed by boxelder (*A. negundo* L.) (12%) and red maple (11%) (Table 5). The stand contained 4,340 stems per acre; however, only 30 trees per acre were more than 5 inches in dbh. Nearly half of the stems in this 17-year old stand were less than one inch in dbh. The species with the largest average diameter was cherrybark oak (2.55 inches) (Table 6). The basal area of this stand was 81.7 feet^2/acre.

Stand Level Comparisons

Sweetgum had the highest basal area in Study A (102.4 feet^2/acre). Sycamore and green ash had approximately ½ and ¼ of the basal area of sweetgum, respectively (Table A-47). Loblolly pine had the highest basal area (160.9 feet^2/acre) of any species in Study B (Table A-48). Yellow-poplar (84.3 feet^2/acre) and cherrybark oak (32.8 feet^2/acre) were notably less.

Total stem volume on a stand basis followed a pattern very similar to basal area (Figure 12, Tables A-49, A-50). In Study A, sweetgum was significantly greater than sycamore. Green ash had less than one third of the stand volume of sycamore and less than one fifth of the stand volume of sweetgum. Of the three species, green ash was the only one with no significant variation among cultural treatments. In Study B, loblolly pine had the greatest total stand volume. Considering only the two surviving blocks,

Table 5. Number of trees (>4.5 feet in height) in the 17-year old naturally regenerated stand adjacent to Study B. Study was located on a bottomland site in southwest Tennessee.

Species	% of total stems	stems/acre by dbh class		
		<1 inch	1-4.9 inches	>5 inches
Sweetgum	74.1	1,210	1,980	20
Boxelder	11.7	370	140	0
Red maple	10.8	300	170	0
Winged elm	1.6	60	10	0
Eastern redcedar	0.7	20	0	10
Cherrybark oak	0.4	0	20	0
Yellow-poplar	0.2	10	0	0
Ironwood	0.2	10	0	0
Sycamore	0.2	0	10	0
Total		1,980	2,330	30

Note: Estimates were based on twenty 0.01 acre plots.

Table 6. Average total height and dbh of trees in the 17-year old naturally regenerated stand adjacent to Study B. Study was located on a bottomland site in southwest Tennessee.

Species	Height (feet)	Dbh (inches)
Sweetgum	20.4	1.64
Boxelder	14.1	0.84
Red maple	14.9	0.90
Winged elm	12.7	0.74
Eastern redcedar	13.7	2.30
Cherrybark oak	22.0	2.55
Yellow-poplar	15.0	0.90
Ironwood	14.0	0.80
Sycamore	20.0	1.00

Note: Estimates were based on twenty 0.01 acre plots.

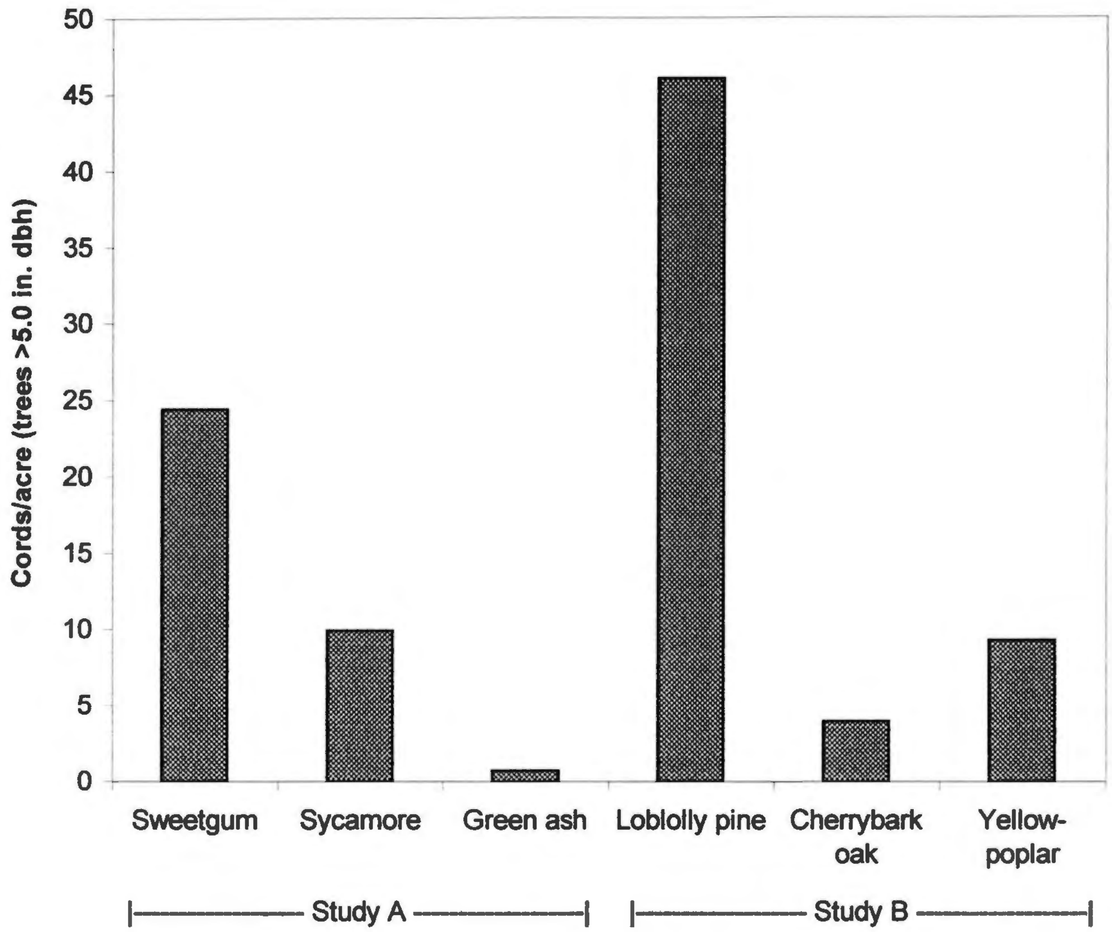

Figure 12. Merchantable volume per acre for six planted tree species. Study A volumes reflect 18 years of growth; Study B volumes reflect 17 years of growth. Study was located on a bottomland site in southwest Tennessee.

yellow-poplar ranked second. Cherrybark oak had much less stand volume than the other two species.

Merchantable stem volume (pulpwood) showed even greater differences between species (Table A-51). Loblolly pine and sweetgum again ranked highest in their respective studies while green ash had virtually no merchantable volume.

Soils

Treatment Effects on Bulk Density

Fourteen years after planting, soil bulk density on sycamore plots varied significantly by depth and among treatment combinations (Tables A-52, A-53). The mean bulk density from zero to two inches below the surface was significantly lower (1.30) than at three to five inches (1.52) or at six to eight inches (1.54). Bulk density also was significantly affected by weed control practices. At a depth of zero to two inches on fertilized plots, disking resulted in a significantly higher soil bulk density than no weed control. From three to five inches below the surface, mowing and fertilization resulted in a significantly higher soil bulk density than disking or no weed control in conjunction with fertilization. At a depth of six to eight inches on fertilized plots, bulk density also was higher on mowed plots than on disked plots. Regressions between tree height growth and soil bulk density did not provide evidence that any relationship existed between the two.

Natural Variation

Classification of soil on individual sub-plots in Study A revealed that the study site contained four soil series. Thirty-four subplots were classified as the moderately well drained Collins series, 55 contained the somewhat poorly drained Falaya series (coarse-silty, mixed, active, acid, thermic Aeric Fluvaquents), 30 contained the poorly drained Waverly series (coarse-silty, mixed, acid, thermic Typic Fluvaquents), and one was classified as the well drained Vicksburg series (coarse-silty, mixed, acid, thermic Typic Fluvaquents).

Significant relationships between tree survival and depth to the water table were observed in all three species (Tables A-54, A-55). Sycamore had a negative linear relationship with water table depth: higher survival rates occurred where the water table was closer to the surface. Polynomial regression revealed that green ash had a positive linear and a negative quadratic relationship between survival and depth to the water table (Figure 13). High survival rates occurred at water table depths from 6 to 36 inches, but survival decreased above and below this range. Sweetgum survival had a negative linear and a positive quadratic relationship with depth to water table. At depths less than 30 inches, higher survival occurred with a shallower water table, but at depths greater than 30 inches, this trend was absent.

In contrast to survival, all growth-water table and growth-mottle relationships were positive (Tables A-54, A-55). R-square values were low, but sweetgum showed significant evidence linking increased growth with greater depths to both water table and mottles (Figure 14). Sycamore showed a similar trend between stem volume and

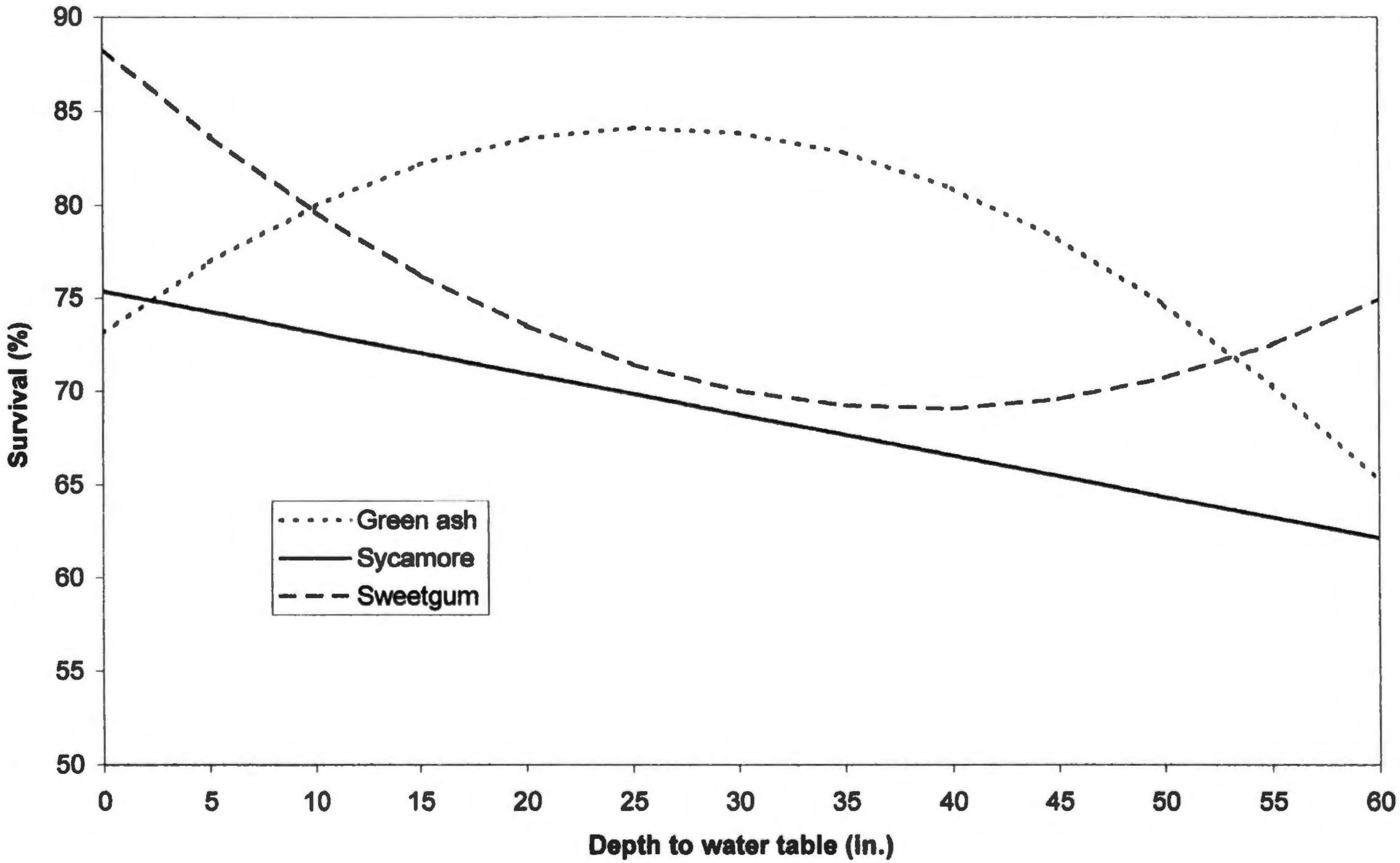

Figure 13. Relationships between survival rate and depth to water table for three tree species 18 years after planting on a bottomland site in southwest Tennessee.
Note: **Survival is arcsine-square root transformed.**

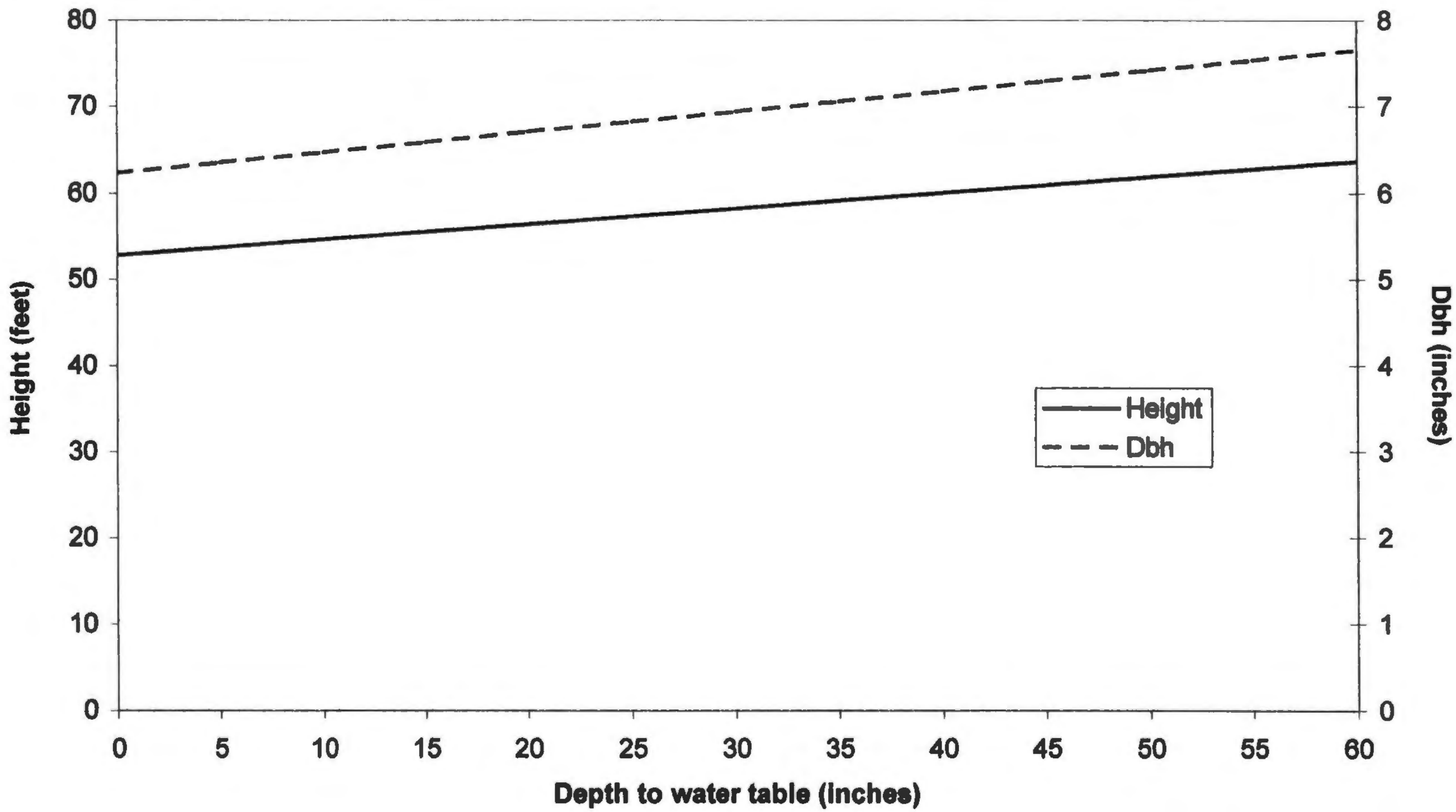

Figure 14. Relationships between height and dbh and depth to water table for sweetgum 18 years after planting on a bottomland site in southwest Tennessee.

depth to gray mottles (Figure 15).

There were no significant interactions between water table or mottling depths and cultural treatments. Thus, fertilization and weed control practices did not affect the response of trees to ground water.

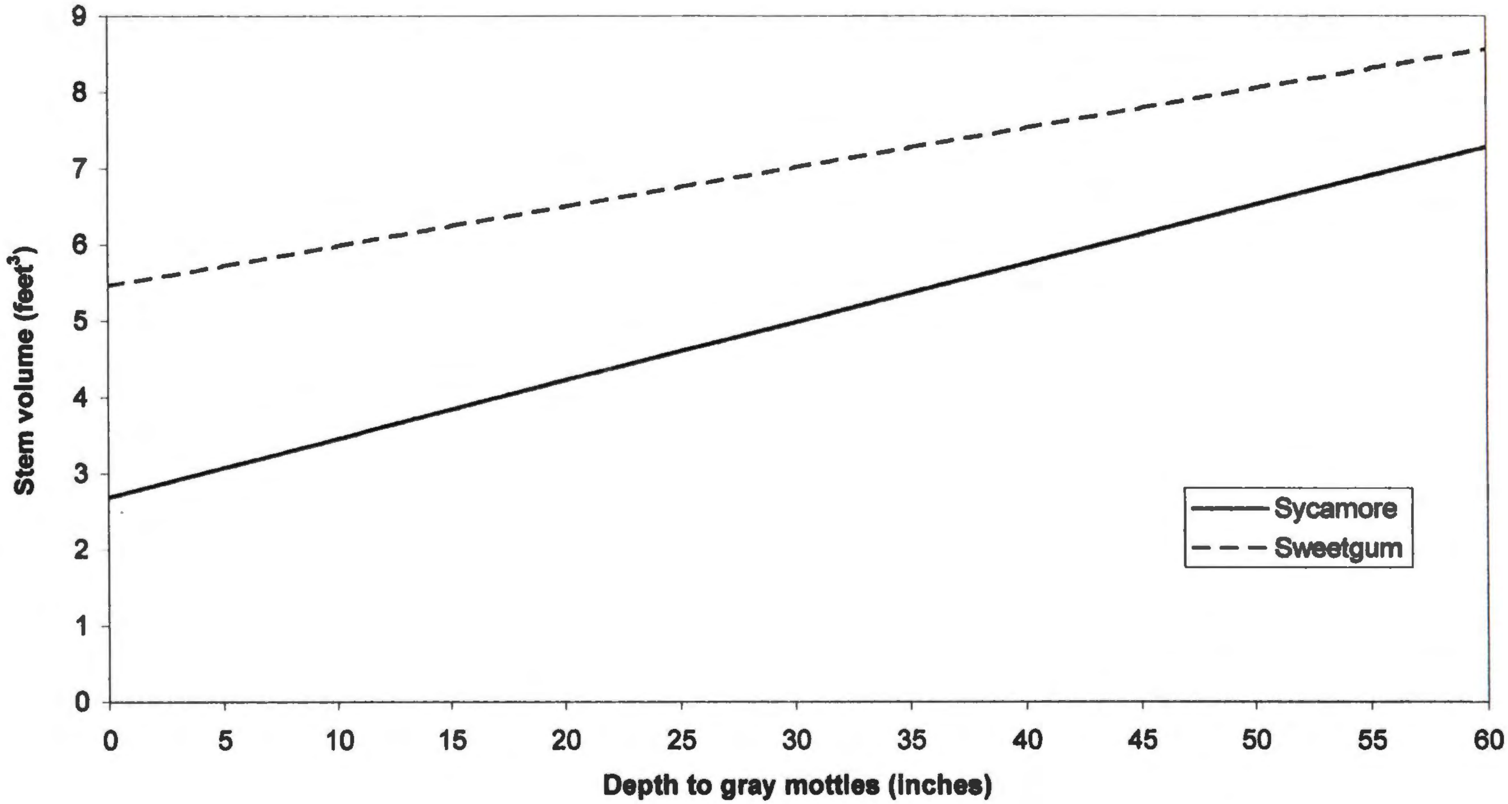

Figure 15. Relationships between stem volume and depth to gray mottles for two tree species 18 years after planting on a bottomland site in southwest Tennessee.

IV. Discussion

Survival

After 18 years, the mean survival rate in Study A for all species and treatments was 91%. High survival rates occurred despite "harsh, droughty summertime conditions" during three of the first five years after planting (Houston and Buckner 1989). The first growing season was exceptionally hot and dry (Waldrop et al. 1983). During the period from the third to the 18th growing season, mortality increased by only five percentage points in sycamore, three percentage points in green ash, and remained virtually unchanged in sweetgum.

In Study B, loblolly pine and cherrybark oak had slightly less than two thirds survival after 17 years while yellow-poplar averaged over 90% survival on two blocks. Cherrybark oak is known to be less flood-tolerant than most other bottomland hardwoods (Barrett 1995), and mortality here may have resulted from occasionally saturated soils. For unknown reasons, one sub-plot of loblolly pine suffered complete mortality, and the wide variation in survival rates among experimental blocks in Study B made treatment effects less detectable. None of the species in Study B showed a change in survival due to cultural treatments.

Hopper et al. (1993) reported lower survival when weed control was not applied to green ash, sweetgum and loblolly pine planted on wet and dry sites in west Tennessee. On our previously farmed bottomland site, weed competition on control plots was not severe enough to cause significant mortality. Sweetgum, sycamore and green ash had high survival rates on plots where no weed control was applied.

Seed Source

Seed source was not a factor in the survival and growth of sweetgum or sycamore. Similar studies relating the growth of sweetgum and sycamore to the geographic origin of the seed have, in sum, been inconclusive.

Fertilization

After 18 years, fertilization significantly increased growth on plots without weed control for all species in Study A. Fertilization on control plots increased the average stem volume per tree of green ash, sycamore, and sweetgum by 155%, 66%, and 39%, respectively, suggesting that N or P was a limiting factor on the study site. The only significant growth increase from fertilization on plots with weed control was in the case of disked sweetgum. None of the species in Study B showed significant growth increases from fertilization, perhaps because they were fertilized only once instead of three times as in Study A.

The growth increase of sweetgum under N fertilization has been demonstrated in other studies in which fertilization took place after the initial growing season. Nitrogen fertilization resulted in significant growth increases when applied to sweetgum stands at year four (Ku et al. 1981), year nine (Nelson and Switzer 1992), and annually from year 20 to year 25 (Broadfoot 1966). Guo et al. (1998) reported that growth increases in the study fertilized at year four were still significant ten years later. However, Francis (1985) found no significant height response to N and P fertilization in a 6-year old sweetgum stand. Studies conducted in the 1970s at the Southern Hardwoods Laboratory, Stoneville, Mississippi, reported inconsistent growth responses of planted sycamore to N and P fertilization (Francis 1985).

Disking and Mowing

Disking and mowing increased growth of all three species in Study A where there was no fertilization. Sweetgum and sycamore also showed some significant responses to weed control on fertilized plots.

The height growth of unfertilized sycamore on mowed and disked plots followed a pattern similar to one described by Krinard and Kennedy (1987). In that study, trees on disked plots put on most of their height growth in the early years while trees on mowed plots had a more uniform growth rate. In our study, the same pattern was demonstrated as trees on disked plots eventually lost their height advantage to trees on mowed plots. Disked sycamore were an average of 78% taller than mowed sycamore after 5 years, 21% taller after 12 years, and 10% taller at age 18. Sweetgum and green ash also showed less height difference between mowed and disked trees as time elapsed. After five years, disked sweetgum were 43% taller than mowed sweetgum; after 12 years, they were 15% taller, and after 18 years, they were only 3% taller. Green ash on disked plots maintained a 51%, 25%, and 18% height advantage over mowed plots in the same years. If these trends continue, the height differences between mowing and disking will diverge in favor of mowed plots. In all three species, trees on mowed and disked plots remained consistently taller than trees on control plots throughout the 18-year study. Control treatments showed parallel development but no trend to indicate that they will catch up with plots that underwent weed control.

The early and dramatic growth response to disking observed in this study (Houston and Buckner 1989, Waldrop et al. 1983) has been found in similar studies (Kennedy 1984, Krinard and Kennedy 1981, Hunt and Cleveland 1978). Although both mowing and disking control above-ground weed competition, disking also controls below-ground competition, thus increasing nutrient availability and reducing the amount of soil moisture consumed by weeds relative to mowing (Kennedy 1981b). In this study, improved nutrient and moisture availability likely caused the growth response during the first five years when disking took place. In a study where mowing and disking were continued through year 10, disking showed no growth advantage over mowing during the sixth through tenth years (Krinard and Kennedy 1983). Disking in the early years of a rotation enhances some soil properties, but the advantage of disking appears to decrease with time.

Krinard and Kennedy (1987) speculated that sycamore planted on disked plots eventually lost its height superiority to mowed plots because trees on mowed plots had developed deeper, more sustaining, root systems beneath the roots of competing vegetation. When disked, this competing vegetation was not permitted to develop root systems of consequence. In the Ames study, there are other possible explanations why trees on disked plots did not maintain their height superiority over mowed plots after weed control was ceased. Disked plots, unlike mowed or control plots, suffered compaction and possibly erosion which resulted in six to twelve inch deep troughs between the tree rows that were still present 13 years after disking was ceased. Soil heaved into ridges in the disking process may have exaggerated these troughs. During wet periods, many of these troughs contained standing water. This is evidenced by frequent and distinct gray mottles in the upper layers of the soil. Saturation of the soil in these troughs may have restricted tree roots on disked plots to the narrow ridges in line with the tree rows. In contrast, the soil on mowed and control plots was not compacted or eroded, and may have benefited structurally from the root systems of competing vegetation.

In terms of their effects on soils, comparisons may be made between disking and conventional tillage agriculture and between mowing and a no-till system. The increased rooting activity and available soil moisture typical of no-till systems (Wells and Touchton 1985) likely occurred on mowed plots in this study. On disked plots, and in conventional tillage agriculture, below-ground competition is destroyed. However, soil structure is also impacted by tillage, and lower infiltration rates and greater surface runoff are a common result. A no-till agricultural system often has a lower initial yield, but productivity has been shown to surpass that of traditional tillage after several years (Bandel 1984). Hill (1990) speculated that this trend is due to changes that gradually take place in soil physical properties under no-till systems. In the Ames study, soil changes on mowed plots likely included the development of a rich underground system of decomposing roots leading to a generally improved soil structure with increased organic matter and water channels. If this is the case, it may explain why mowing, in the long term, appears to result in a more productive site.

Tree growth of the species in Study B was not significantly improved by weed control. However, cherrybark oak growth varied greatly among blocks; any response to weed control treatments would have been lost in the large standard errors of the treatment mean estimates. Alternatively, loblolly pine growth was consistent among blocks and still showed no significant growth response to weed control treatments. This indicates that weed control may not be necessary for a competitive, early-succession species such as loblolly pine when planted on a former agricultural bottomland site.

Interactions

Sweetgum and sycamore both had significant fertilization x weed control interactions involving height, and sycamore also had interactions affecting diameter and stem volume. All four of these interactions resulted from the same growth pattern: on plots without weed control, fertilization significantly increased growth, but on plots with weed control, trees did not benefit from fertilization. The growth increases from fertilization alone were similar to those from weed control alone in all species in Study A. It appears that the addition of N and P through fertilization had approximately the same effect on tree growth as the removal of competition during the first five years. However, competing vegetation would have consumed not only N and P, but other nutrients as well as soil moisture and light. Clearly there are many unquantified and unmeasured variables, such as the effects of disking and/or competitors' roots on soil structure, which affect tree growth.

Species Comparisons

Green ash and sycamore exhibited much greater growth variation among replications than sweetgum, making statistical inferences for these two species less attainable. For stand volume, the average coefficient of variation for the six cultural treatments combinations was 37% for green ash, 35% for sycamore, and 17% for sweetgum, suggesting that natural site variations occurred among the four replications.

In terms of total height, sweetgum, sycamore, loblolly pine and yellow-poplar clearly performed better than green ash and cherrybark oak. Each of the former averaged more than 2.8 feet of height growth annually while the latter averaged 2.0 feet or less annually. Sweetgum and sycamore achieved heights that might have been expected from previous plantation research (Carlson and Goelz 1998, Guo et al. 1998, Krinard 1988), but green ash growth was surprisingly poor when compared to previous plantation studies (Krinard and Kennedy 1987, Krinard 1989). Additional soil testing would be required to determine whether nutrient deficiencies in the soil were the cause of the relatively poor performance of green ash.

Sycamore's rapid height growth began to decline after about 12 years. Carlson and Goelz (1998) reported a decrease in height growth of sycamore, possibly due to low soil nutrients, beginning around age five for a plantation on a minor stream bottom.

Hunt and Cleveland (1978) reported that growth of planted sycamore had already begun to taper off at age three.

Kennedy (1981a) found that the nutrient requirements of sycamore were generally lower than those of green ash and sweetgum; thus, it does not seem likely that the decline of sycamore growth in the present study was due to depleted fertility of the site. If the decline in growth over time proves common for plantation-grown sycamore, then this species would be better suited to short-rotation plantations.

Yellow-poplar and cherrybark oak are well suited to soils of the Collins series (Broadfoot 1976). In Study B, yellow-poplar grew rapidly, but it is difficult to predict site index before the age of 20 due to variability in the early growth of this species (Beck and Della-Bianca 1981). Cherrybark oak in this study was somewhat below average in height growth when compared to other even-aged stands (Clatterbuck 1987). However, since the Ames study was initiated, tree improvement programs have developed oak seedlings superior in growth rate and form to those available in 1981. Loblolly pine grew quite well, and appears to be capable of a much shorter economically viable rotation than the five planted hardwood species in this study.

Some practical methods to compare species included use of stand basal area and stand volume. Basal area, used in management techniques such as thinning, was calculated to compare stand densities. After 18 years, the moderate growth and high survival rate of sweetgum resulted in an over-stocked stand according to the stocking guide developed by Goelz (1995). Loblolly pine's rapid growth and moderate survival rate produced an over-stocked stand with a basal area of 160 feet/acre. Sycamore and yellow-poplar, due to their smaller diameters, were both within the 'fully-stocked' range based on Goelz' stocking guide. Cherrybark oak and green ash were still under-stocked due to poor growth in both species and only moderate survival in cherrybark oak.

Another method used to compare the growth of each species and treatment was total stand stem volume. Differences in stand volume were proportionately similar to those found in the basal area analysis because this parameter was calculated using only one additional variable (tree height). Green ash and cherrybark oak again performed poorly relative to the other species. Sweetgum and sycamore benefited significantly from cultural treatments.

The amount of merchantable wood per acre (trees greater than five inches in diameter) further exaggerated the superiority of those species which ranked high in total stand volume. Loblolly pine produced the most merchantable wood per acre since nearly every surviving trees was of merchantable size. However, at this point in the rotation, merchantable volumes for the hardwood species are not as meaningful as they will be at final harvest when the trees have reached different product classes.

Natural Regeneration

Because the naturally regenerated stands were entirely of seed origin, species composition was greatly impacted by the composition of neighboring stands. After 17 and 18 years, natural regeneration resulted in consistently dense stands of saplings dominated by sweetgum followed by sycamore, red maple and boxelder. The species with the largest average height and diameter were loblolly pine and, in Study A, river birch. These species were probably among the first to become established in the stand, thus gaining an early height advantage. Although the basal area of the natural stands was similar to that of the planted stands, the average diameter of the trees in the natural stands was far inferior in terms of merchantability. The naturally regenerated stands in Study A produced 4.4 cords per acre after 18 years, and the naturally regenerated stand in Study B produced only 0.6 cords per acre in 17 years.

Soils

The increased soil bulk density on plots that received both fertilization and mowing was likely caused by the heavy equipment operating on high-moisture soils during the early spring. Disked plots did not suffer increased bulk density as did mowed plots because disking performed on drier soils in the summer loosened the soil.

The Study A site was previously mapped entirely as the Collins series by the SCS (Flowers 1964), but the present study revealed four soil series. In addition to the variations in series, depth to water table, and depth to mottles, numerous variations in texture and horizonation also were observed. County soil maps may not be accurate enough for correct species-site matching in reforestation of flood plains.

Slight changes in topography were present on the study site. In blocks three and four, many of the plots located closest to the perennial drainage were visibly higher in elevation than plots elsewhere within the same blocks. These slightly elevated regions contained the moderately well drained and well-drained soils of the Collins and Vicksburg series. The only other signs of variation in soil series visible from the surface were areas of shallow standing water during winter indicating the poorly drained Waverly series.

Because most of the mortality occurred during the first three growing seasons, it is likely that seedlings planted above a deeper water table suffered more moisture-related stress during the first summers. This explains the negative relationships between survival rate and water table depth for sycamore and sweetgum. Green ash, however, suffered its highest mortality rates at the shallowest water table depths. In light of the superior flood tolerance of green ash seedlings (Baker 1977, Dickson et al. 1965, Hosner 1959), it is unlikely that saturated soils or flooding caused this mortality. Since the lowest survival rate for a green ash sub-plot after 18 year was 85%, variations in survival rate for this species were not meaningful from a practical standpoint.

Phillips and Markley (1963) concluded that natural sweetgum stands on a variety of wet soils in New Jersey had the highest site index when the water table remained around 20 inches below the surface for the duration of the growing season. The study also found that, although soil mottling was not correlated with site index, on younger alluvial soils water table was the primary cause of variation in site index. In the Ames study, the fact that water table depth was a better predictor of sweetgum growth than mottling depth may have resulted from the latter being more difficult to measure precisely.

Gray mottles not only provide evidence of poorly drained or periodically saturated soils; they also show exactly where anaerobic conditions have occurred. Better soil drainage reduces the amount of pore space occupied by water and increases the quantity of air in the soil. Aeration facilitates aerobic root respiration and improves the availability of nutrients (Brady 1974). Although the growth of sweetgum and sycamore increased on better-drained and aerated soils, green ash growth did not follow this trend. Green ash roots are capable of several morphological and physiological adaptations which allow transpiration and growth to continue on saturated soils (Hook and Brown 1973, Sena Gomes and Kozlowski 1980).

Economic Analysis

A financial evaluation of these plantations may be premature because they have not yet reached their intended rotation age. Currently, many of the hardwoods have not even reached pulpwood size (five inches dbh). The annual rates of return (ROR) will increase for these trees when they achieve sawtimber size (eleven inches dbh). At that point, the prospect of planting hardwoods, as opposed to alternative investments such as agriculture, will become more attractive.

An 18-year analysis of Study A revealed that the only positive ROR were from sweetgum grown without weed control, or disked without fertilization (Table A-56). Weed control in conjunction with fertilization did not provide a profit due to the costs associated with these two cultural treatments. In Study B, the only positive ROR from yellow-poplar occurred when no cultural treatments were applied (Table A-57). Loblolly pine had the highest ROR of any species. Loblolly pine without fertilization or weed control was most profitable at a 20% annual ROR. Weed control applied to loblolly pine reduced profitability on both fertilized and unfertilized plots.

V. Conclusions and Recommendations

Sweetgum, sycamore, green ash and yellow-poplar had high survival when planted without site preparation on a recently farmed flood plain. Cherrybark oak and loblolly pine had somewhat lower survival, but loblolly pine produced 46 cords per acre of merchantable wood, more than any of the hardwood species planted, after 17 years. Sycamore showed superior height growth through the tenth year, but after 18 years, sweetgum was significantly taller. Growth of green ash and cherrybark oak was slower than that of the other species. Natural regeneration produced a dense stand of low merchantability predominated by sweetgum.

Seed source had no effect on growth or survival, but either fertilization, mowing, or disking can be used to significantly increase tree growth in sweetgum, sycamore, and green ash. Loblolly pine and cherrybark oak were not affected by cultural treatments. After 18 years, the benefits of combining fertilization and weed control were significant only for disked sweetgum. The growth advantage of disking over mowing was prominent in early years for sweetgum, sycamore and green ash, but by age 18, no growth differences existed between the treatments. If the current trends continue, mowing will prove to be the superior weed control treatment for sawtimber-length rotations. Disking resulted in soil compaction and degradation of soil structure.

Soil bulk density was increased on plots undergoing both fertilization and mowing, but there was no correlation between soil bulk density and tree growth. Soil series as well as drainage and water table depth were quite variable within the flood plain, and although a shallower water table increased survival slightly, better-drained soils provided superior growth for sweetgum and sycamore. Mapping units on county soil maps may be too crude for adequate species-soil matching or for predicting tree growth on a flood plain site. Soil maps should be verified and flood plains should be mapped as precisely as possible prior to reforestation.

Loblolly pine is the only species in this study capable of producing enough merchantable wood (pulpwood or sawtimber) to be an economically viable investment at a rotation length of 18 years or less. The economic appeal of the hardwood species will likely improve when they reach sawtimber size, given the average costs incurred for a forest plantation in the southern United States.

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Appendix

Table A-1. Analysis of Variance for survival of all species in Study A. Study was located on a bottomland site in southwest Tennessee.

Source	df	F	Pr > F
Species	2	4.79	0.0247*
Fertilization	1	0.11	0.7392
Species x Fertilization	2	0.56	0.5829
Treatment	2	1.62	0.2730
Species x Treatment	4	1.38	0.2482
Fertilization x Treatment	2	0.53	0.5893
Species x Fertilization x Treatment	4	0.30	0.8778
Depth to Water Table (covariate)	1	8.66	0.0043

Note: Data were transformed with the arcsine-square root transformation.

* Significant at the alpha=0.05 level.

Table A-2. Pr > F values for species comparison contrasts for species in Study A. Study was located on a bottomland site in southwest Tennessee.

Treatment	Species Contrast	Survival	Height	Dbh	Stem Volume
All Treatments	Green ash vs. sycamore	0.0207*	0.0001***	0.0001***	0.0001***
All Treatments	Green ash vs. sweetgum	n.s.	0.0001***	0.0001***	0.0001***
All Treatments	Sycamore vs. sweetgum	0.0180*	0.0474*	0.0001***	0.0001***
Unfertilized/control	Green ash vs. sycamore	n.s.	0.0001***	0.0001**	0.0051**
Unfertilized/control	Green ash vs. sweetgum	n.s.	0.0001***	0.0001***	0.0001***
Unfertilized/control	Sycamore vs. sweetgum	n.s.	0.0364*	0.0001***	0.0063**
Unfertilized/disk	Green ash vs. sycamore	n.s.	0.0001***	0.0002***	0.0004***
Unfertilized/disk	Green ash vs. sweetgum	n.s.	0.0001***	0.0001***	0.0001***
Unfertilized/disk	Sycamore vs. sweetgum	n.s.	n.s.	0.0001***	0.0010**
Unfertilized/mow	Green ash vs. sycamore	0.0323*	0.0001***	0.0001***	0.0002***
Unfertilized/mow	Green ash vs. sweetgum	n.s.	0.0001***	0.0001***	0.0001***
Unfertilized/mow	Sycamore vs. sweetgum	n.s.	n.s.	0.0001***	0.0024**
Fertilized/control	Green ash vs. sycamore	n.s.	0.0002***	0.0003***	0.0004***
Fertilized/control	Green ash vs. sweetgum	n.s.	0.0001***	0.0001***	0.0001***
Fertilized/control	Sycamore vs. sweetgum	n.s.	n.s.	0.0001***	0.0017**
Fertilized/disk	Green ash vs. sycamore	n.s.	0.0001***	0.0038**	0.0010**
Fertilized/disk	Green ash vs. sweetgum	n.s.	0.0001***	0.0001***	0.0001***
Fertilized/disk	Sycamore vs. sweetgum	n.s.	n.s.	0.0001***	0.0001***
Fertilized/mow	Green ash vs. sycamore	0.0123*	0.0001***	0.0001***	0.0001***
Fertilized/mow	Green ash vs. sweetgum	n.s.	0.0001***	0.0001***	0.0001***
Fertilized/mow	Sycamore vs. sweetgum	n.s.	n.s.	0.0009***	n.s.

* Significant at the alpha=0.05 level.
** Significant at the alpha=0.01 level.
*** Significant at the alpha=0.001 level.

Table A-3. Analysis of Variance for survival of sweetgum. Study was located on a bottomland site in southwest Tennessee.

Source	df	F	Pr > F
Seed Source	1	2.69	0.1351
Fertilization	1	0.86	0.3788
Seed Source x Fertilization	1	0.65	0.4425
Treatment	2	1.75	0.2518
Seed Source x Treatment	2	1.85	0.1865
Fertilization x Treatment	2	0.20	0.8225
Seed Source x Fertilization x Treatment	2	1.95	0.1706

Note: Data were transformed with the arcsine-square root transformation.

Table A-4. Pr > F values for sweetgum contrasts. Study was located on a bottomland site in southwest Tennessee.

Contrast	Survival	Height	D.b.h.	Stem Volume
Control: fertilized vs. unfertilized	n.s.	0.0162*	0.0013**	0.0080**
Disk: fertilized vs. unfertilized	n.s.	n.s.	0.0141*	0.0205*
Mow: fertilized vs. unfertilized	n.s.	n.s.	n.s.	n.s.
Unfertilized: mow vs. control	n.s.	0.0028**	0.0029**	0.0092**
Unfertilized: disk vs. control	n.s.	0.0005***	0.0002***	0.0004***
Unfertilized: disk vs. mow	n.s.	n.s.	n.s.	n.s.
Fertilized: mow vs. control	n.s.	n.s.	n.s.	n.s.
Fertilized: disk vs. control	n.s.	n.s.	0.0027**	0.0015**
Fertilized: disk vs. mow	n.s.	n.s.	n.s.	0.0438*

* Significant at the alpha=0.05 level.

** Significant at the alpha=0.01 level.

*** Significant at the alpha=0.001 level.

Table A-5. Analysis of Variance for survival of sycamore. Study was located on a bottomland site in southwest Tennessee.

Source	df	F	Pr > F
Seed Source	1	0.22	0.6527
Fertilization	1	0.03	0.8745
Seed Source x Fertilization	1	0.22	0.6539
Treatment	2	2.13	0.2002
Seed Source x Treatment	2	0.92	0.4184
Fertilization x Treatment	2	0.45	0.6465
Seed Source x Fertilization x Treatment	2	1.30	0.2974

Note: Data were transformed with the arcsine-square root transformation.

Table A-6. Pr > F values for sycamore contrasts. Study was located on a bottomland site in southwest Tennessee.

Contrast	Survival	Height	Dbh	Stem Volume
Control: fertilized vs. unfertilized	n.s.	0.0492*	0.0001***	0.0041**
Disk: fertilized vs. unfertilized	n.s.	n.s.	n.s.	n.s.
Mow: fertilized vs. unfertilized	n.s.	n.s.	n.s.	n.s.
Unfertilized: mow vs. control	n.s.	0.0193*	0.0195*	n.s.
Unfertilized: disk vs. control	n.s.	0.0031**	0.0011**	0.0234*
Unfertilized: disk vs. mow	n.s.	n.s.	n.s.	n.s.
Fertilized: mow vs. control	n.s.	0.0409*	n.s.	n.s.
Fertilized: disk vs. control	n.s.	n.s.	n.s.	n.s.
Fertilized: disk vs. mow	n.s.	n.s.	n.s.	n.s.

* Significant at the alpha=0.05 level.

** Significant at the alpha=0.01 level.

*** Significant at the alpha=0.001 level.

Table A-7. Analysis of Variance for survival of green ash. Study was located on a bottomland site in southwest Tennessee.

Source	df	F	Pr > F
Fertilization	1	0.97	0.3978
Treatment	2	4.16	0.0734
Fertilization x Treatment	2	3.65	0.0918

Note: Data were transformed with the arcsine-square root transformation.

Table A-8. Pr > F values for green ash contrasts. Study was located on a bottomland site in southwest Tennessee.

Contrast	Survival	Height	Dbh	Stem Volume
Control: fertilized vs. unfertilized	n.s.	0.0258*	0.0058**	0.0483*
Disk: fertilized vs. unfertilized	n.s.	n.s.	n.s.	n.s.
Mow: fertilized vs. unfertilized	n.s.	n.s.	n.s.	0.0477*
Unfertilized: mow vs. control	0.0193*	n.s.	0.0215*	n.s.
Unfertilized: disk vs. control	n.s.	0.0207*	0.0072**	n.s.
Unfertilized: disk vs. mow	n.s.	n.s.	n.s.	n.s.
Fertilized: mow vs. control	n.s.	n.s.	n.s.	n.s.
Fertilized: disk vs. control	n.s.	n.s.	n.s.	n.s.
Fertilized: disk vs. mow	n.s.	n.s.	n.s.	n.s.

* Significant at the alpha=0.05 level.

** Significant at the alpha=0.01 level.

Table A-9. Analysis of Variance for height of sweetgum. Study was located on a bottomland site in southwest Tennessee.

Source	df	F	Pr > F
Seed Source	1	2.17	0.1747
Fertilization	1	1.86	0.2058
Seed Source x Fertilization	1	0.33	0.5775
Treatment	2	6.66	0.0299*
Seed Source x Treatment	2	0.75	0.4846
Fertilization x Treatment	2	4.73	0.0223*
Seed Source x Fertilization x Treatment	2	0.34	0.7165

* Significant at the alpha=0.05 level.

Table A-10. Total height after 18 years for three planted hardwood species. Study was located on a bottomland site in southwest Tennesseee.

	Sweetgum	Sycamore	Green ash
		feet	
All Treatments	55.9a[1]	50.8b	31.4c
Gulf	57.6a[2]	50.3a	-
Virginia	54.2a	51.3a	-
Unfertilized	54.4a	48.5a	27.8a
Fertilized	57.5a	53.1a	34.9a
Control	52.1b	44.3a	26.9a
Disk	59.1a	54.0a	35.3a
Mow	56.5ab	54.2a	31.9a
Unfertilized/Control	48.7[3]	40.3	22.1
Unfertilized/Disk	58.0	54.4	33.2
Unfertilized/Mow	56.4	50.9	28.2
Fertilized/Control	55.6	48.3	31.7
Fertilized/Disk	60.1	53.5	37.4
Fertilized/Mow	56.6	57.4	35.6

1/ Mean separation was conducted among the three species means using single df contrasts (alpha=0.05).

2/ Means within each group and species followed by the same letter do not differ at alpha=0.05.

3/ Mean separation contrasts for treatment combinations appear in tables A-4, A-6, and A-8.

Table A-11. Height response over time of planted sweetgum to cultural treatments. Study was located on a bottomland site in southwest Tennessee.

	Year after planting							
	1	2	3	5	9	10	12	18
	feet							
Unfertilized	1.7a	3.0b	4.9a	9.0a	24.1a	26.9a	36.9a	54.4a
Fertilized	1.7a	3.8a	5.9a	10.3a	25.7a	29.4a	40.7a	57.5a
Control	1.7a	3.4b	5.0b	8.3b	21.8b	24.8b	34.8b	52.1b
Disk	1.7a	3.9a	6.5a	12.6a	29.6a	33.1a	43.6a	59.1a
Mow	1.6a	2.9b	4.6b	8.0b	23.3b	26.7b	37.8b	56.5ab

Note: Height means within each column followed by the same letter do not differ at alpha=0.05. Mean separations were conducted with single df contrasts.

Table A-12. Analysis of Variance for dbh of sweetgum. Study was located on a bottomland site in southwest Tennessee.

Source	df	F	Pr > F
Seed Source	1	0.04	0.8478
Fertilization	1	25.27	0.0007***
Seed Source x Fertilization	1	2.46	0.1512
Treatment	2	17.75	0.0030**
Seed Source x Treatment	2	0.47	0.6319
Fertilization x Treatment	2	0.92	0.4199
Seed Source x Fertilization x Treatment	2	0.35	0.7070
Depth to Water (covariate)	1	20.18	0.0004
Depth to Water^2 (covariate)	1	11.72	0.0035

** Significant at the alpha=0.01 level.
*** Significant at the alpha=0.001 level.

Table A-13. Dbh after 18 years for three planted hardwood species. Study was located on a bottomland site in southwest Tennesseee.

	Sweetgum	Sycamore	Green ash
		inches	
All Treatments	6.64a[1]	4.74b	3.28c
Gulf	6.66a[2]	4.66a	-
Virginia	6.63a	4.83a	-
Unfertilized	6.29b	4.41b	2.87b
Fertilized	6.99a	5.08a	3.70a
Control	6.09b	4.09a	2.64b
Disk	7.12a	5.03a	3.74a
Mow	6.72a	5.12a	3.47ab
Unfertilized/Control	5.61[3]	3.49	2.03
Unfertilized/Disk	6.79	5.00	3.45
Unfertilized/Mow	6.47	4.73	3.13
Fertilized/Control	6.56	4.68	3.24
Fertilized/Disk	7.45	5.06	4.04
Fertilized/Mow	6.96	5.51	3.82

1/ Mean separation was conducted among the three species means using single df contrasts (alpha=0.05).

2/ Means within each group and species followed by the same letter do not differ at alpha=0.05.

3/ Mean separation contrasts for treatment combinations appear in tables A-4, A-6, and A-8.

Table A-14. Analysis of Variance for stem volume of sweetgum. Study was located on a bottomland site in southwest Tennessee.

Source	df	F	Pr > F
Seed Source	1	0.17	0.6895
Fertilization	1	18.29	0.0021**
Seed Source x Fertilization	1	2.27	0.1661
Treatment	2	16.87	0.0034**
Seed Source x Treatment	2	0.06	0.9397
Fertilization x Treatment	2	0.42	0.6612
Seed Source x Fertilization x Treatment	2	0.62	0.5506
Depth to Water (covariate)	1	15.56	0.0012
Depth to Water^2 (covariate)	1	7.41	0.0151

** Significant at the alpha=0.01 level.

Table A-15. Average stem volume after 18 years for three planted hardwood species. Study was located on a bottomland site in southwest Tennesseee.

	Sweetgum	Sycamore	Green ash
		cubic feet	
All Treatments	6.33a[1]	4.01b	1.18c
Gulf	6.40a[2]	3.84a	-
Virginia	6.26a	4.19a	-
Unfertilized	5.66b	3.56a	0.86a
Fertilized	7.00a	4.47a	1.50a
Control	5.15c	3.18a	0.78a
Disk	7.42a	4.13a	1.43a
Mow	6.42b	4.73a	1.32a
Unfertilized/Control	4.31[3]	2.39	0.44
Unfertilized/Disk	6.73	4.15	1.15
Unfertilized/Mow	5.94	4.14	0.98
Fertilized/Control	5.99	3.97	1.12
Fertilized/Disk	8.12	4.12	1.72
Fertilized/Mow	6.90	5.31	1.67

1/ Mean separation was conducted among the three species means using single df contrasts (alpha=0.05).

2/ Means within each group and species followed by the same letter do not differ at alpha=0.05.

3/ Mean separation contrasts for treatment combinations appear in tables A-4, A-6, and A-8.

Table A-16. Analysis of Variance for height of sycamore. Study was located on a bottomland site in southwest Tennessee.

Source	df	F	Pr > F
Seed Source	1	0.10	0.7541
Fertilization	1	1.85	0.2066
Seed Source x Fertilization	1	0.14	0.7212
Treatment	2	4.34	0.0684
Seed Source x Treatment	2	2.28	0.1305
Fertilization x Treatment	2	4.61	0.0241*
Seed Source x Fertilization x Treatment	2	0.96	0.4016

* Significant at the alpha=0.05 level.

Table A-17. Height response over time of planted sycamore to cultural treatments. Study was located on a bottomland site in southwest Tennessee.

	Year after planting							
	1	2	3	5	9	10	12	18
	feet							
Unfertilized	2.6a	4.9b	8.1b	13.4a	27.8a	29.9a	37.8a	48.5a
Fertilized	2.6a	5.8a	9.7a	15.5a	29.5a	33.9a	43.1a	53.1a
Control	2.5b	4.6b	7.7b	12.4b	23.6b	26.2b	33.9b	44.3a
Disk	2.9a	7.0a	11.9a	18.5a	34.1a	37.2a	45.6a	54.0a
Mow	2.4b	4.4b	7.1b	12.4b	28.3ab	32.4ab	41.9ab	54.2a

Note: Height means within each column followed by the same letter do not differ at alpha=0.05. Mean separations were conducted with single df contrasts.

Table A-18. Analysis of Variance for dbh of sycamore. Study was located on a bottomland site in southwest Tennessee.

Source	df	F	Pr > F
Seed Source	1	0.47	0.5117
Fertilization	1	7.85	0.0206*
Seed Source x Fertilization	1	0.08	0.7831
Treatment	2	4.06	0.0768
Seed Source x Treatment	2	1.21	0.3227
Fertilization x Treatment	2	43.38	0.0001***
Seed Source x Fertilization x Treatment	2	4.36	0.0286*

* Significant at the alpha=0.05 level.
*** Significant at the alpha=0.001 level.

Appendix A-19. Analysis of Variance for stem volume of sycamore. Study was located on a bottomland site in southwest Tennessee.

Source	df	F	Pr > F
Seed Source	1	0.56	0.4720
Fertilization	1	3.77	0.0841
Seed Source x Fertilization	1	0.00	0.9613
Treatment	2	2.14	0.1986
Seed Source x Treatment	2	1.61	0.2269
Fertilization x Treatment	2	8.43	0.0026**
Seed Source x Fertilization x Treatment	2	1.71	0.2097

** Significant at the alpha=0.01 level.

Table A-20. Analysis of Variance for height of green ash. Study was located on a bottomland site in southwest Tennessee.

Source	df	F	Pr > F
Fertilization	1	8.42	0.0624
Treatment	2	3.91	0.0819
Fertilization x Treatment	2	1.04	0.4083

Table A-21. Height response over time of planted green ash to cultural treatments. Study was located on a bottomland site in southwest Tennessee.

	Year after planting							
	1	2	3	5	9	10	12	18
	feet							
Unfertilized	2.1a	3.4a	5.3b	7.9a	15.2a	15.8b	21.1a	27.8a
Fertilized	2.3a	4.3a	6.8a	9.9a	17.7a	19.4a	26.8a	34.9a
Control	2.1a	3.4b	5.2b	7.2b	13.1c	13.8c	19.6c	26.9a
Disk	2.4a	5.0a	7.9a	11.4a	20.1a	21.3a	28.6a	35.3a
Mow	2.2a	3.2b	5.0b	8.1b	16.2b	17.7b	23.5b	31.9a

Note: Height means within each column followed by the same letter do not differ at alpha=0.05. Mean separations were conducted with single df contrasts.

Table A-22. Analysis of Variance for dbh of green ash. Study was located on a bottomland site in southwest Tennessee.

Source	df	F	Pr > F
Fertilization	1	15.24	0.0298*
Treatment	2	6.83	0.0284*
Fertilization x Treatment	2	1.91	0.2280

* Significant at the alpha=0.05 level.

Appendix A-23. Analysis of Variance for stem volume of green ash. Study was located on a bottomland site in southwest Tennessee.

Source	df	F	Pr > F
Fertilization	1	10.07	0.0504
Treatment	2	3.31	0.1074
Fertilization x Treatment	2	0.07	0.9288

Table A-24. Mean heights for three species planted on a bottomland site in southwest Tennessee.

	Year after planting							
	1	2	3	5	9	10	12	18
	feet							
Green ash	2.2b	3.9b	6.0b	8.9b	16.5c	17.6c	23.9b	31.4c
Sycamore	2.6a	5.3a	8.9a	14.4a	28.6a	31.9a	40.5a	50.8b
Sweetgum	1.7c	3.4c	5.4b	9.6b	24.9b	28.2b	38.8a	55.9a

Note: Height means within the same year followed by the same letter do not differ at alpha=0.05. Mean separations were conducted with single df contrasts.

Table A-25. Analysis of Variance for height of all species in Study A. Study was located on a bottomland site in southwest Tennessee.

Source	df	F	Pr > F
Species	2	60.79	0.0001***
Fertilization	1	7.47	0.0154*
Species x Fertilization	2	0.54	0.5930
Treatment	2	5.85	0.0389*
Species x Treatment	4	1.36	0.2541
Fertilization x Treatment	2	3.53	0.0340*
Species x Fertilization x Treatment	4	1.17	0.3319
Depth to Mottles (covariate)	1	9.36	0.0031

* Significant at the alpha=0.05 level.
*** Significant at the alpha=0.001 level.

Table A-26. Analysis of Variance for dbh of all species in Study A. Study was located on a bottomland site in southwest Tennessee.

Source	df	F	Pr > F
Species	2	151.10	0.0001***
Fertilization	1	23.68	0.0002***
Species x Fertilization	2	0.23	0.7988
Treatment	2	10.57	0.0108*
Species x Treatment	4	1.13	0.3503
Fertilization x Treatment	2	4.46	0.0147*
Species x Fertilization x Treatment	4	1.17	0.3293
Depth to Mottles (covariate)	1	20.86	0.0001

* Significant at the alpha=0.05 level.
*** Significant at the alpha=0.001 level.

Table A-27. Analysis of Variance for stem volume of all species in Study A. Study was located on a bottomland site in southwest Tennessee.

Source	df	F	Pr > F
Species	2	81.46	0.0001***
Fertilization	1	9.96	0.0065**
Species x Fertilization	2	0.16	0.8562
Treatment	2	3.58	0.0947
Species x Treatment	4	1.81	0.1364
Fertilization x Treatment	2	1.37	0.2598
Species x Fertilization x Treatment	4	1.16	0.3344
Depth to Mottles (covariate)	1	22.42	0.0001

** Significant at the alpha=0.01 level.

*** Significant at the alpha=0.001 level.

Table A-28. Survival after one and two growing seasons for species in Study B. Study was conducted on a bottomland site in southwest Tennessee.

		Cherrybark oak		Loblolly pine		Yellow-poplar[1]	
		Unfertilized	Fertilized	Unfertilized	Fertilized	Unfertilized	Fertilized
				%			
Year 1	All Treatments	89a[2]		80a		71a	
	Control	88aA[3]	91aA	73aA	79aA	82aA	73aA
	Disk	88aA	94aA	86aA	81aA	70aA	66aA
	Mow	88aA	89aA	79aA	83aA	61aA	76aA
Year 2	All Treatments	77a		74a		65a	
	Control	73aA	81aA	68bA	73aA	71aA	70aA
	Disk	78aA	80aA	74abA	77aA	64aA	58aA
	Mow	70aA	79aA	80aA	72aA	57aA	73aA

1/ Survival rates based on all four blocks.

2/ Means for all treatments were compared among the three species using single df contrasts. Means followed by the same letter do not differ (alpha=0.05).

3/ Means within the same species and weed control that are followed by the same uppercase letter do not differ at alpha=0.05; means within the same species and fertilization regime that are followed by the same lowercaseletter do not differ at alpha=0.05.

Table A-29. Analysis of Variance for survival of species in Study B. Study was located on a bottomland site in southwest Tennessee.

Source	df	F	Pr > F
Species	1	0.09	0.7276
Fertilization	1	0.00	0.9770
Species x Fertilization	1	1.61	0.2910
Treatment	2	1.17	0.3713
Species x Treatment	2	1.69	0.0777
Fertilization x Treatment	2	2.53	0.2551
Species x Fertilization x Treatment	2	0.36	0.8332

Note: Data were transformed with the arcsine-square root transformation.

Table A-30. Analysis of Variance for survival of cherrybark oak. Study was located on a bottomland site in southwest Tennessee.

Source	df	F	Pr > F
Fertilization	1	0.48	0.5382
Treatment	2	0.07	0.9301
Fertilization x Treatment	2	1.72	0.2569

Note: Data were transformed with the arcsine-square root transformation.

Table A-31. Pr > F values for cherrybark oak contrasts. Study was located on a bottomland site in southwest Tennessee.

Contrast	Survival	Height	Dbh	Stem Volume
Control: fertilized vs. unfertilized	n.s	n.s.	n.s.	n.s.
Disk: fertilized vs. unfertilized	n.s	n.s.	n.s.	n.s.
Mow: fertilized vs. unfertilized	n.s	n.s.	n.s.	n.s.
Unfertilized: mow vs. control	n.s	n.s.	n.s.	n.s.
Unfertilized: disk vs. control	n.s	n.s.	n.s.	n.s.
Unfertilized: disk vs. mow	n.s	n.s.	n.s.	n.s.
Fertilized: mow vs. control	n.s	n.s.	n.s.	n.s.
Fertilized: disk vs. control	n.s	n.s.	n.s.	n.s.
Fertilized: disk vs. mow	n.s	n.s.	n.s.	n.s.

Table A-32. Analysis of Variance for survival of loblolly pine. Study was located on a bottomland site in southwest Tennessee.

Source	df	F	Pr > F
Fertilization	1	0.94	0.4045
Treatment	2	2.32	0.1790
Fertilization x Treatment	2	1.43	0.3099

Note: Data were transformed with the arcsine-square root transformation.

Table A-33. Pr > F values for loblolly pine contrasts. Study was located on a bottomland site in southwest Tennessee.

Contrast	Survival	Height	Dbh	Stem Volume
Control: fertilized vs. unfertilized	n.s.	n.s.	n.s.	n.s.
Disk: fertilized vs. unfertilized	n.s.	n.s.	n.s.	n.s.
Mow: fertilized vs. unfertilized	n.s.	n.s.	n.s.	n.s.
Unfertilized: mow vs. control	n.s.	n.s.	n.s.	n.s.
Unfertilized: disk vs. control	n.s.	n.s.	n.s.	n.s.
Unfertilized: disk vs. mow	n.s.	n.s.	n.s.	n.s.
Fertilized: mow vs. control	n.s.	n.s.	n.s.	n.s.
Fertilized: disk vs. control	n.s.	0.0390*	n.s.	n.s.
Fertilized: disk vs. mow	n.s.	n.s.	n.s.	n.s.

* Significant at the alpha=0.05 level.

Table A-34. Analysis of Variance for height of cherrybark oak. Study was located on a bottomland site in southwest Tennessee.

Source	df	F	Pr > F
Fertilization	1	0.07	0.8086
Treatment	2	0.90	0.4557
Fertilization x Treatment	2	0.38	0.7003

Table A-35. Total height after 17 years for three species planted on a bottomland site in southwest Tennessee.

	Loblolly pine	Cherrybark oak	Yellow-poplar[1]
	feet		
All Treatments	55.0a[2]	34.0b	50.3
Unfertilized	55.4a[3]	33.6a	47.7
Fertilized	54.2a	34.4a	52.9
Control	53.0a	31.6a	50.5
Disk	56.1a	35.9a	47.9
Mow	55.4a	34.6a	52.6
Unfertilized/Control	53.7[4]	30.4	53.0
Unfertilized/Disk	56.1	37.1	40.4
Unfertilized/Mow	56.5	33.3	49.8
Fertilized/Control	52.3	32.8	47.9
Fertilized/Disk	56.0	34.6	55.3
Fertilized/Mow	54.3	35.8	55.5

1/ Statistical analyses were not performed on yellow-poplar because 2 of the 4 blocks were destroyed.

2/ Mean separation was conducted between the two species means using single df contrasts (alpha=0.05).

3/ Percentages within each group and species followed by the same letter do not differ at alpha=0.05.

4/ Mean separation contrasts for treatment combinations appear in tables A-31 and A-33.

Table A-36. Analysis of Variance for dbh of cherrybark oak. Study was located on a bottomland site in southwest Tennessee.

Source	df	F	Pr > F
Fertilization	1	0.02	0.8865
Treatment	2	2.99	0.1254
Fertilization x Treatment	2	0.29	0.7614

Table A-37. Dbh after 17 years for three species planted on a bottomland site in southwest Tennessee.

	Loblolly pine	Cherrybark oak	Yellow-poplar[1]
	inches		
All Treatments	10.16a[2]	4.14b	5.79
Unfertilized	10.15a[3]	4.16a	5.52
Fertilized	10.19a	4.11a	6.05
Control	10.16a	3.60a	5.85
Disk	10.24a	4.54a	5.55
Mow	10.11a	4.28a	5.96
Unfertilized/Control	9.99[4]	3.47	6.14
Unfertilized/Disk	10.14	4.70	4.85
Unfertilized/Mow	10.31	4.32	5.56
Fertilized/Control	10.33	3.73	5.56
Fertilized/Disk	10.33	4.37	6.24
Fertilized/Mow	9.92	4.24	6.36

1/ Statistical analyses were not performed on yellow-poplar because 2 of the 4 blocks were destroyed.

2/ Mean separation was conducted between the two species means using single df contrasts (alpha=0.05).

3/ Percentages within each group and species followed by the same letter do not differ at alpha=0.05.

4/ Mean separation contrasts for treatment combinations appear in tables A-31 and A-33.

Table A-38. Analysis of Variance for stem volume of cherrybark oak. Study was located on a bottomland site in southwest Tennessee.

Source	df	F	Pr > F
Fertilization	1	0.28	0.6342
Treatment	2	1.71	0.2591
Fertilization x Treatment	2	0.38	0.6976

Table A-39. Stem volume after 17 years for three species planted on a bottomland site in southwest Tennessee.

	Loblolly pine	Cherrybark oak	Yellow-poplar[1]
	----------	cubic feet	----------
All Treatments	15.94a[2]	2.20b	5.93
Unfertilized	15.99a[3]	2.31a	5.42
Fertilized	15.91a	2.10a	6.45
Control	15.56a	1.71a	5.99
Disk	16.25a	2.57a	5.50
Mow	16.04a	2.33a	6.31
Unfertilized/Control	15.28[4]	1.60	6.73
Unfertilized/Disk	15.87	2.88	4.12
Unfertilized/Mow	16.82	2.45	5.67
Fertilized/Control	15.84	1.82	5.26
Fertilized/Disk	16.63	2.26	6.88
Fertilized/Mow	15.26	2.22	6.96

1/ Statistical analyses were not performed on yellow-poplar because 2 of the 4 blocks were destroyed.

2/ Mean separation was conducted between the two species means using single df contrasts (alpha=0.05).

3/ Percentages within each group and species followed by the same letter do not differ at alpha=0.05.

4/ Mean separation contrasts for treatment combinations appear in tables A-31 and A-33.

Table A-40. Analysis of Variance for height of loblolly pine. Study was located on a bottomland site in southwest Tennessee.

Source	df	F	Pr > F
Fertilization	1	3.73	0.1488
Treatment	2	3.88	0.0830
Fertilization x Treatment	2	0.98	0.4388

Table A-41. Analysis of Variance for dbh of loblolly pine. Study was located on a bottomland site in southwest Tennessee.

Source	df	F	Pr > F
Fertilization	1	0.02	0.8889
Treatment	2	0.16	0.8565
Fertilization x Treatment	2	2.11	0.2161

Table A-42. Analysis of Variance for stem volume of loblolly pine. Study was located on a bottomland site in southwest Tennessee.

Source	df	F	Pr > F
Fertilization	1	0.01	0.9232
Treatment	2	0.37	0.7053
Fertilization x Treatment	2	1.86	0.2493

Table A-43. Analysis of Variance for height of species in Study B. Study was located on a bottomland site in southwest Tennessee.

Source	df	F	Pr > F
Species	1	188.97	0.0001***
Fertilization	1	0.04	0.8864
Species x Fertilization	1	0.61	0.5200
Treatment	2	1.57	0.2535
Species x Treatment	2	0.16	0.9384
Fertilization x Treatment	2	0.08	0.8580
Species x Fertilization x Treatment	2	1.06	0.5127

*** Significant at the alpha=0.001 level.

Table A-44. Pr > F values for contrasts between Study B species. Study was located on a bottomland site in southwest Tennessee.

Treatment	Species Contrast	Survival	Height	Dbh	Stem Volume
All Treatments	Loblolly pine vs. cherrybark oak	n.s.	0.0001***	0.0001***	0.0001***
Unfertilized/control	Loblolly pine vs. cherrybark oak	n.s.	0.0001***	0.0001***	0.0001***
Unfertilized/disk	Loblolly pine vs. cherrybark oak	n.s.	0.0001***	0.0001***	0.0001***
Unfertilized/mow	Loblolly pine vs. cherrybark oak	n.s.	0.0001***	0.0001***	0.0001***
Fertilized/control	Loblolly pine vs. cherrybark oak	n.s.	0.0001***	0.0001***	0.0001***
Fertilized/disk	Loblolly pine vs. cherrybark oak	n.s.	0.0001***	0.0001***	0.0001***
Fertilized/mow	Loblolly pine vs. cherrybark oak	n.s.	0.0001***	0.0001***	0.0001***

*** Significant at the alpha=0.001 level.

Table A-45. Analysis of Variance for dbh of species in Study B. Study was located on a bottomland site in southwest Tennessee.

Source	df	F	Pr > F
Species	1	403.67	0.0001***
Fertilization	1	0.00	0.9987
Species x Fertilization	1	0.08	0.8485
Treatment	2	2.61	0.1695
Species x Treatment	2	1.96	0.1798
Fertilization x Treatment	2	0.76	0.5143
Species x Fertilization x Treatment	2	0.44	0.6668

*** Significant at the alpha=0.001 level.

Table A-46. Analysis of Variance for stem volume of species in Study B. Study was located on a bottomland site in southwest Tennessee.

Source	df	F	Pr > F
Species	1	554.80	0.0001***
Fertilization	1	0.09	0.7700
Species x Fertilization	1	0.04	0.9056
Treatment	2	1.64	0.2870
Species x Treatment	2	0.01	0.9761
Fertilization x Treatment	2	1.18	0.3454
Species x Fertilization x Treatment	2	1.23	0.3200

*** Significant at the alpha=0.001 level.

Table A-47. Basal area after 18 years for three planted tree species. Study was located in southwest Tennessee.

	Sweetgum		Sycamore		Green ash	
	Unfertilized	Fertilized	Unfertilized	Fertilized	Unfertilized	Fertilized
	square feet/acre					
All Treatments	102.4a[1]		52.6b		28.4c	
Control	78.6bB[2]	99.4bA	30.8bB	52.1aA	9.9bB	26.2bA
Disked	106.3aB	125.0aA	59.4aA	61.3aA	28.8aA	40.9aA
Mowed	97.3aA	107.6bA	48.9aA	63.1aA	26.3abA	38.2abA

1/ Means for all treatments were compared among the three species; means followed by the same letter do not differ at alpha=0.05. Mean separations were performed with single df contrasts.

2/ Means within the same species and weed control that are followed by the same uppercase letter do not differ at alpha=0.05; means within the same species and fertilization regime that are followed by the same lowercase letter do not differ at alpha=0.05.

Table A-48. Basal area after 17 years for three planted tree species. Study was located in southwest Tennessee.

	Cherrybark oak		Loblolly Pine		Yellow-poplar[1]	
	Unfertilized	Fertilized	Unfertilized	Fertilized	Unfertilized	Fertilized
			square feet/acre			
All Treatments	32.8b[2]		160.9a		84.3	
Control	25.0aA[3]	23.1aA	110.2bA	142.3aA	92.4	60.2
Disked	42.8aA	32.5aA	179.7aA	170.7aA	57.9	98.8
Mowed	41.7aA	31.4aA	171.2abA	183.2aA	78.9	95.2

1/ Basal area was calculated from two surviving blocks but statistical analyses were not performed.

2/ Means for all treatments were compared among the three species; means followed by the same letter do not differ at alpha=0.05. Mean separations were performed with single df contrasts.

3/ Means within the same species and weed control that are followed by the same uppercase letter do not differ at alpha=0.05; means within the same species and fertilization regime that are followed by the same lowercase

Table A-49. Total stand volume after 18 years for three planted tree species. Study was located in southwest Tennessee.

	Sweetgum		Sycamore		Green ash	
	Unfertilized	Fertilized	Unfertilized	Fertilized	Unfertilized	Fertilized
	cubic feet/acre					
All Treatments	2,567.0a[1]		1,539.5b		489.4c	
Control	1,792.6bB[2]	2,389.5bA	903.8bB	1,470.2aA	169.3aA	455.5aA
Disked	2,772.7aB	3,303.3aA	1,689.9aA	1,696.7aA	479.0aA	737.3aA
Mowed	2,386.0aA	2,637.9bA	1,417.1abA	1,843.5aA	420.5aA	704.8aA

1/ Means for all treatments were compared among the three species; means followed by the same letter do not differ at alpha=0.05. Mean separations were performed with single df contrasts.

2/ Means within the same species and weed control that are followed by the same uppercase letter do not differ at alpha=0.05; means within the same species and fertilization regime that are followed by the same lowercase letter do not differ at alpha=0.05.

Table A-50. Total stand volume after 17 years for three planted tree species. Study was located in southwest Tennessee.

	Cherrybark oak		Loblolly pine		Yellow-poplar[1]	
	Unfertilized	Fertilized	Unfertilized	Fertilized	Unfertilized	Fertilized
	cubic feet/acre					
All Treatments	653.2b[2]		4,315.7a		2,375.5	
Control	468.6aA[3]	553.1aA	2,953.4aA	3,454.6aA	2,726.4	1,741.4
Disked	895.0aA	628.7aA	4,964.5aA	4,725.6aA	1,704.9	2,967.0
Mowed	743.6aA	630.3aA	4,788.4aA	5,007.5aA	2,420.5	2,819.6

1/ Means were calculated from two surviving blocks but statistical analyses were not performed.

2/ Means for all treatments were compared among the three species; means followed by the same letter do not differ at alpha=0.05. Mean separations were performed with single df contrasts.

3/ Means within the same species and weed control that are followed by the same uppercase letter do not differ at alpha=0.05; means within the same species and fertilization regime that are followed by the same lowercase letter do not differ at alpha=0.05.

Table A-51. Merchantable stand volume for six planted tree species[1]. Study was located on a bottomland site in southwest Tennessee.

	Study A			Study B		
	Sweetgum	Sycamore	Green ash	Cherrybark oak	Loblolly pine[2]	Yellow-poplar[3]
	cords/acre to 4 inch top					
Average	24.4	9.9	0.7	46.0	4.0	9.3
Unfertilized/Control	15.1	3.6	0.0	31.2	2.6	11.1
Unfertilized/Disk	26.5	10.6	0.0	53.3	6.2	4.1
Unfertilized/Mow	23.2	9.7	0.4	47.0	5.7	8.6
Fertilized/Control	23.3	9.6	0.5	39.7	3.4	6.8
Fertilized/Disk	32.3	10.9	1.4	51.9	4.2	12.7
Fertilized/Mow	26.1	14.8	2.0	53.0	4.5	12.5

1/ Study A represents 18 years of growth and Study B represents 17 years of growth.

2/ Some trees included here were in the chip-n-saw size class in the financial analysis.

3/ Volume was calculated with survival and growth data from only the two blocks that did not suffer complete mortality.

Table A-52. Soil bulk density after 14 years on a sycamore plantation in southwest Tennessee.

	Depth below surface (in.)		
	0 to 2	3 to 5	6 to 8
	grams/cc		
All Treatments	1.30b[1]	1.52a	1.54a
Unfertilized/Control	1.25ab[2]	1.55ab	1.54ab
Unfertilized/Disk	1.32ab	1.53abc	1.52ab
Unfertilized/Mow	1.30ab	1.51abc	1.52ab
Fertilized/Control	1.23b	1.49bc	1.55ab
Fertilized/Disk	1.35a	1.46c	1.48b
Fertilized/Mow	1.33ab	1.60a	1.60a

1/ Mean separation was conducted among the three depth means using single df contrasts (alpha=0.05).

2/ Bulk densities at the same depth followed by the same letter do not differ at alpha=0.05.

Table A-53. Analysis of Variance for soil bulk density on sycamore plots of Louisiana Gulf Coast origin. Study was located on a bottomland site in southwest Tennessee.

Source	df	F	Pr > F
Depth	2	74.51	0.0001***
Fertilization	1	0.04	0.8633
Depth x Fertilization	2	0.81	0.4891
Treatment	2	0.86	0.4694
Depth x Treatment	4	2.42	0.1060
Fertilization x Treatment	2	1.28	0.3456
Depth x Fertilization x Treatment	4	1.26	0.2938

*** Significant at the alpha=0.001 level.

Table A-54. Relationships between tree survival and growth and soil properties 18 years after planting on a bottomland site in southwest Tennessee.

		Green ash		Sycamore		Sweetgum	
		Depth to Water	Depth to Mottles	Depth to Water	Depth to Mottles	Depth to Water	Depth to Mottles
Survival	Prob>F	0.0056**	n.s.	0.0152*	n.s.	0.0009***	n.s.
	R-square	0.3895		0.1214		0.2696	
Height	Prob>F	n.s.	n.s.	n.s.	n.s.	0.0228*	n.s.
	R-square					0.1076	
Dbh	Prob>F	n.s.	n.s.	n.s.	n.s.	0.0133*	0.0206*
	R-square					0.1261	0.1112
Stem volume	Prob>F	n.s.	n.s.	n.s.	0.0064**	0.0069**	0.0291*
	R-square				0.1506	0.1484	0.0993

* Significant at alpha=0.05.
** Significant at alpha=0.01.
*** Significant at alpha=0.001.

Table A-55. Parameters (standard errors in parentheses) from significant survival- and growth-soil regressions for an 18-year old bottomland hardwood plantation in Fayette County, Tennessee.

Species	*x*-variable	*y*-variable	Parameters		
			a	b_1	b_2
Green ash	depth to water table	survival[1]	73.1359	0.8455	-0.01629
			(2.3001)	(0.0248)	(0.0044)
Sycamore	depth to water table	survival	75.3865	-0.2210	-
			(1.9521)	(0.0877)	-
Sycamore	depth to mottles	stem volume	2.6901	0.0766	-
			(0.4957)	(0.0268)	-
Sweetgum	depth to water table	survival	88.3349	-0.9974	0.0129
			(3.0000)	(0.2802)	(0.0047)
Sweetgum	depth to water table	height	52.7894	0.1815	-
			(1.7036)	(0.0771)	-
Sweetgum	depth to water table	dbh	6.2326	0.0237	-
			(0.2036)	(0.0092)	-
Sweetgum	depth to mottles	dbh	6.2269	0.0247	-
			(0.2154)	(0.0103)	-
Sweetgum	depth to water table	stem volume	5.3296	0.0588	-
			(0.4588)	(0.0208)	-
Sweetgum	depth to mottles	stem volume	5.4626	0.0518	-
			(0.4814)	(0.0230)	-

Note: Model: $y$hat = $a + b_1 x + b_2{}^2 x$ where $y$hat is predicted growth or survival, a, b_1 and b_2 are parameters estimated from the data, and x is the variable specified in the table.

1/ Survival is an arcsine-square root transformed percent.

Table A-56. Financial analysis in constant dollars, before taxes, on a per acre basis for 18 years of growth in Study A. Study was located in southwest Tennessee.

			Costs[1] ($)				Revenue[2] ($)	Annual Rate
Species	Fertilization	Treatment	Establishment	Fertilization	Treatment	Annual costs		of Return (%)
Sweetgum	unfertilized	control	68.02	0.00	0.00	5.00	242.66	3
Sweetgum	unfertilized	disked	68.02	0.00	200.00	5.00	425.86	1
Sweetgum	unfertilized	mowed	68.02	0.00	200.00	5.00	372.82	0
Sweetgum	fertilized	control	68.02	164.85	0.00	5.00	374.43	1
Sweetgum	fertilized	disked	68.02	164.85	200.00	5.00	519.06	0
Sweetgum	fertilized	mowed	68.02	164.85	200.00	5.00	419.43	-2
Sycamore	unfertilized	control	68.02	0.00	0.00	5.00	57.85	-9
Sycamore	unfertilized	disked	68.02	0.00	200.00	5.00	170.34	-5
Sycamore	unfertilized	mowed	68.02	0.00	200.00	5.00	155.88	-6
Sycamore	fertilized	control	68.02	164.85	0.00	5.00	154.27	-6
Sycamore	fertilized	disked	68.02	164.85	200.00	5.00	175.16	-8
Sycamore	fertilized	mowed	68.02	164.85	200.00	5.00	237.84	-6
Green ash	unfertilized	control	76.74	0.00	0.00	5.00	0.00	N/A
Green ash	unfertilized	disked	76.74	0.00	200.00	5.00	0.00	N/A
Green ash	unfertilized	mowed	76.74	0.00	200.00	5.00	6.43	-78
Green ash	fertilized	control	76.74	164.85	0.00	5.00	8.04	-62
Green ash	fertilized	disked	76.74	164.85	200.00	5.00	22.50	-29
Green ash	fertilized	mowed	76.74	164.85	200.00	5.00	32.14	-24

1/ Establishment costs include planting and seedling costs with 50% federal cost share. Other costs are averages for forest plantations in the southern United States.

2/ Revenues are based on merchantable pulpwood. Prices and product classes are those given in Timber Mart-South.

Table A-57. Financial analysis in constant dollars, before taxes, on a per acre basis for 17 years of growth in Study B. Study was located in southwest Tennessee.

Species	Fertilization	Treatment	Costs[1] ($) Establishment	Fertilization	Treatment	Annual costs	Revenue[2] ($)	Annual Rate of Return (%)
Cherrybark oak	unfertilized	control	81.10	0.00	0.00	5.00	43.39	-14
Cherrybark oak	unfertilized	disked	81.10	0.00	200.00	5.00	104.46	-10
Cherrybark oak	unfertilized	mowed	81.10	0.00	200.00	5.00	83.56	-11
Cherrybark oak	fertilized	control	81.10	54.95	0.00	5.00	59.46	-12
Cherrybark oak	fertilized	disked	81.10	54.95	200.00	5.00	70.71	-15
Cherrybark oak	fertilized	mowed	81.10	54.95	200.00	5.00	70.71	-14
Yellow-poplar[3]	unfertilized	control	72.38	0.00	0.00	5.00	204.09	1
Yellow-poplar	unfertilized	disked	72.38	0.00	200.00	5.00	406.57	-14
Yellow-poplar	unfertilized	mowed	72.38	0.00	200.00	5.00	390.50	-7
Yellow-poplar	fertilized	control	72.38	54.95	0.00	5.00	368.00	-6
Yellow-poplar	fertilized	disked	72.38	54.95	200.00	5.00	133.38	-5
Yellow-poplar	fertilized	mowed	72.38	54.95	200.00	5.00	281.23	-6
Loblolly pine	unfertilized	control	49.42	0.00	0.00	5.00	1,400.90	20
Loblolly pine	unfertilized	disked	49.42	0.00	200.00	5.00	2,333.08	15
Loblolly pine	unfertilized	mowed	49.42	0.00	200.00	5.00	2,144.16	15
Loblolly pine	fertilized	control	49.42	54.95	0.00	5.00	1,809.47	19
Loblolly pine	fertilized	disked	49.42	54.95	200.00	5.00	2,234.85	14
Loblolly pine	fertilized	mowed	49.42	54.95	200.00	5.00	2,418.06	14

1/ Establishment costs include planting and seedling costs with 50% federal cost share. Other costs are averages for forest plantations in the southern United States.

2/ Revenues are based on merchantable pulpwood for hardwood species and both pulpwood and chip-n-saw for loblolly pine. Prices and product classes are those given in Timber Mart-South.

3/ Based on the two surviving blocks only.

VITA

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