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THE EFFECTS OF FERTILIZATION, IRRIGATION, AND SITE FACTORS ON GROWTH OF FOREST TREE SPECIES

A Thesis

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ABSTRACT

Two south-facing slope positions were planted with sweetgum (*Liquidambar styraciflua* L.), yellow-poplar (*Liriodendron tulipifera* L.), loblolly pine (*Pinus taeda* L.), and northern red oak (*Quercus rubra* L.). The upper slope position was originally an undisturbed oak-hickory forest; the lower slope position was an old field with a 20-year-old stand of shortleaf and Virginia pines. Soils in the area are Typic Paleudults. Four treatments were tested on each of the four species as follows: 1) fertilizer applied at planting time, 2) irrigation applied the first 7 years after planting, 3) the combination of fertilization and irrigation, and 4) control.

At age 7, yellow-poplar appeared to be highly sensitive to treatments on both slope positions. Fertilized trees were taller on both slope positions while irrigated trees were taller only on the upper slope. The tallest trees in the study were in fertilized and irrigated plots on the upper slope. After 22 years, trees receiving fertilization and/or irrigation were still taller and relative plot volume was greater than untreated trees. The relative height advantage was much less at age 22 than at age 7.

Sweetgum appeared to be somewhat less responsive than yellow-poplar to treatments. At age 7, fertilized trees were taller on both slope positions. Irrigation had little apparent influence on height growth of sweetgum. At age 22, irrigated trees were shorter

than non-irrigated trees and the height of fertilized and unfertilized trees was essentially equal. Fertilization and irrigation had little apparent influence on relative plot volume at age 22.

There were no apparent treatment or planting site effects on the survival and height growth of northern red oak. Both survival and height growth were the poorest of the four test species. For this reason, it was not included in further analysis.

At age 7 loblolly pine was the tallest of the four species for all site and treatment conditions except yellow-poplar growing on the upper slope with fertilization and irrigation. Unlike yellow-poplar or sweetgum, the best growth was on the lower slope. Apparently loblolly pine was less sensitive to soil/site conditions than either of the hardwoods.

While initial survival and height growth of loblolly pine were adequate, by age 22, mortality of the pine had increased in some plots to such an extent that there were not enough trees present for statistical analyses. It was no longer included as a test species in the study.

Changes in growing conditions following the cessation of irrigation treatments and the small quantity of fertilizer applied seemed to have had adverse effects on height growth during the second growth interval during which the best growth of sweetgum and yellow-poplar was better on untreated plots. A trend that appeared to be consistent was the more intensive the treatment applied during the first growth interval, the worse the growth during the second growth interval.

The reason for this anomaly was not clear. It may have been related to changes in the soil environment which affected the concentration and distribution of tree roots and micro-organisms once the fertilizer was utilized and irrigation was discontinued.

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INTRODUCTION

A primary objective in most intensive forestry efforts is to increase the volume production of wood on forest land. Success usually depends on the ability of forest managers to either manage for species whose silvical characteristics match the growth potential of the forest site or manipulate site factors to match the requirements of desirable species. The tree species best suited to available sites are commonly not those in demand. Fertilization and irrigation are widely used agricultural practices that have the potential for altering site conditions of intensively managed forest lands. These management practices are already used in forest nurseries and seed orchards, but possible gains from their use in conventional stand management have not been determined.

The productive potential of a forest site depends on its ability to supply water and nutrients. Soil physical properties affect tree growth potential through their effects on both retention and availability of soil moisture and nutrients. The available water-holding capacity of a soil is determined by soil texture and structure of each soil horizon and the depth from the soil surface to a restrictive horizon. These properties also control the effective rooting depth and the manner in which roots grow (Pritchett, 1987; Spurr and Barnes, 1973). Nutrient retention and availability are influenced by soil texture. Cation exchange capacity (CEC) varies widely with the mix of clay minerals and the amount of organic matter present in each horizon (Brady, 1974). These factors interact to determine the productive potential of a site.

In the spring of 1965 a study was initiated on two different sites near Oak Ridge, Tennessee (Buckner, 1972). The purpose of this experiment was to identify the extent to which tree growth was limited by native levels of soil moisture and nutrients. Four species were planted:

yellow-poplar (*Liriodendron tulipifera* L.)

sweetgum (*Liquidambar styraciflua* L.)

loblolly pine (*Pinus taeda* L.)

northern red oak (*Quercus rubra* L.).

The seedlings were subjected to four cultural treatments:

1. fertilization,
2. irrigation,
3. fertilization with irrigation,
4. no fertilization or irrigation (control).

The four test species varied widely in response to treatments. Wide growth differences to identical treatments within a species appeared to be related to natural variation in site conditions.

Increases in height growth were demonstrated using fertilization and irrigation during stand establishment and early growth period. Significant differences in tree height were still evident at age 7. However, the long-term effects of these treatments are not known. The feasibility of these practices in forest management will be determined by application costs and the duration and degree of growth response.

Growth measurements made in 1971 were reported by Buckner and Maki (1977). Crown closure had not occurred and all trees were essentially free to grow. By 1986, crown closure had occurred making competition among trees an additional factor affecting individual tree growth. The effects of competition are confounded with soil-site factors.

Sweetgum and yellow-poplar were the only species surviving in sufficient numbers in 1986 to allow statistical analyses. While initial survival of loblolly pine was good, mortality over the years has been severe for reasons that are not readily apparent. Of the four species, loblolly pine was the least sensitive to soil/site conditions and it was badly damaged or weakened by climatic factors resulting in high mortality after the seventh growing season. Growth and survival of northern red oak was so poor that it was not analyzed in the original report (Buckner, 1972).

This study was undertaken to address the question of duration of treatment effects and the influence of site variability on species responses. Specific objectives were:

1. To determine and evaluate the effects of fertilization and irrigation treatments applied at planting and during the establishment years on height growth after 22 years.
2. To determine how differences in site conditions may have influenced tree growth and response to treatments.

CHAPTER I

LITERATURE REVIEW

Previous Work

The present study is a continuation of an experiment initiated by Buckner (1972). This study was established in the Ridge and Valley Province of East Tennessee in 1965 to determine the extent to which deficiencies of soil moisture and nutrients influenced growth of forest species. The study area included two sites representing different topographic positions. Site 1 was a lower slope site that had previously been used for agricultural purposes but had not been cultivated for approximately 20 years. Following abandonment a mixed Virginia (*Pinus virginiana* Mill.) and shortleaf (*Pinus echinata* Mill.) pine stand had become established and stabilized this area. Site 2 was an upper slope site which supported a mature oak (*Quercus* spp.) and hickory (*Carya* spp.) forest and did not show evidence of recent disturbance.

Four commercially important tree species were planted: yellow-poplar, sweetgum, northern red oak, and loblolly pine. The three hardwoods are native to this region while the pine has become naturalized through widespread planting. The four species were selected for their commercial value and the wide range of site sensitivities they represent. Yellow-poplar is a highly site-demanding species exhibiting excellent growth and form on good sites and inferior growth on poor sites. Sweetgum and northern red oak are not as demanding in their requirements for satisfactory growth although both are somewhat sensitive to site conditions. Generally, loblolly pine is less sensitive to site factors, exhibiting adequate growth across a wide range of site conditions. Loblolly pine was used in this study as the standard to which the performance of the other three species were compared. All four species are intolerant of shade and competition.

The treatments were fertilization, irrigation, and fertilization and irrigation applied together. Untreated plots served as controls. The fertilization application consisted of 33 lbs nitrogen (N), 50 lbs phosphorus (P), and 4 lbs magnesium (Mg)/acre and was applied as trees were planted. The nutrients were supplied in the form of MagAmp (7-45-0 with 5 Mg) and Ureaform N (45-0-0). The fertilizer was placed approximately 2 inches from the seedlings in the closing hole. This treatment was intended only to eliminate nutrient deficiencies for the first few years and were not considered optimum rates.

On irrigated plots, water was administered for 7 years only during the growing season. The intent was to keep soil moisture levels near field capacity. Plots were irrigated when soil moisture tension approached two atmospheres as monitored with a neutron moisture meter. Tree growth was evaluated by analysis of average annual height growth over the 7-year study period, analysis of height growth within each growing season, and analysis of total height at the end of each growing season (Buckner, 1972) to evaluate cumulative growth effects over the study period.

Buckner concluded after 7 years that yellow-poplar seedlings growing on the undisturbed forest soil of the upper slope were highly sensitive to both fertilization and irrigation treatments. Trees growing on plots receiving both treatments were nearly twice as tall as trees on control plots. When either treatment was applied separately, the increase in growth represented a gain of approximately 50% over controls. The response to fertilization treatments decreased over 7 years while the response to irrigation increased. Irrigation had little influence during the early seedling stage. Average annual height growth of fertilized trees was 55% greater than that of unfertilized trees, while the average annual height growth of irrigated trees was 22% greater than non-irrigated trees.

On the lower slope, yellow-poplar growth was poorer. This was a reflection of the site-sensitivity of this species and an example of how old degraded fields are poor sites on which to plant yellow-poplar. Yellow-poplar exhibited little response to irrigation while the relative response to fertilization was greater than on the upper slope. Height growth was approximately doubled where both treatments were applied together. The effects of these two treatments appeared to be additive on both slope positions.

Survival of yellow-poplar was significantly less on fertilized plots. However, survival of fertilized yellow-poplar was better on the lower slope and when applied in conjunction with irrigation.

This suggests that moist soils ameliorate the damaging influence of fertilizer salts.

Sweetgum exhibited a response pattern of height growth similar to that of yellow-poplar although of smaller magnitude. Growth was better on fertilized plots on both slope positions. Irrigation was more effective on the upper slope. Where both treatments were combined, the height growth advantage was essentially the sum of the influence of either applied separately. The survival pattern among treatments was similar to that for yellow-poplar. Growth was generally better on the upper slope site.

The survival and height growth of northern red oak was not satisfactory under any treatment or site. Red oak did not grow well on the undisturbed forest soil or the old field using planting techniques that are adequate for other more widely planted species in this region. Height growth and survival were the poorest of the four species tested in this study (Buckner and Maki, 1977).

Loblolly pine had the largest average growth of all species. It generally outgrew all other species under both sites and treatments encountered with the exception of yellow-poplar growing under the best combination of conditions (upper slope forest soil with fertilizer and irrigation). Growth was better on irrigated plots on the upper slope; however, irrigation appeared to decrease growth on the lower slope. Overall growth was better on the lower slope each year except during a prolonged early season drought. Tree height was greater on fertilized plots early in the study but these effects were not noticeable in later years. Apparently the insensitivity of this species makes it incapable of fully utilizing the growth potential of the better site conditions.

Five factors--fertilization, irrigation, slope position, the old field condition, and soil site variability--emerge from Buckner's (1972) report as influencing tree growth.

Fertilization

The role of nutrient deficiencies in agricultural systems has long been recognized (Follett, et al., 1981). Fertilization has become an important cultural technique to correct nutrient imbalances and increase crop production (Tisdale, et al., 1985).

The application of fertilizer on forest lands was not recognized as a viable silvicultural tool until recently. The use of this practice became more widespread as research methodologies and analytical techniques were developed which allowed investigators to diagnose nutrient deficiencies in soils and relate these growth responses in trees (Pritchett and Fisher, 1987).

Early research with forest fertilization identified N deficiency as a growth-limiting factor in forests throughout the United States (Gessel and Walker, 1956; Zahner, 1959; McAlpine, 1959). Phosphorus deficiency has been identified in pine plantations in sterile, sandy soils of the southeastern coastal plain (Barnes and Ralston, 1953; Pritchett and Swinford, 1961). In the sandy glacial outwash soils of the northeast, potassium (K) deficiency was identified in red pine (*Pinus resinosa* Ait.), eastern white pine (*Pinus strobus* L.), and Norway spruce (*Picea abies* (L.) Karat.) (Keiberg and White, 1951). Since that time many other species throughout the United States have been shown to respond to fertilization. Comprehensive surveys concerning fertilization research were compiled by White and Leaf (1956), Arneman (1960), Walker and Beacher (1963), Mustanoja and Leaf (1965). The proceedings of three symposia on forest fertilization (Ralston, *et al*., 1959; Bengston, *et al*., 1967; and Leaf and Leonard, 1976) also contribute much relevant information regarding forest fertilization research in the United States. Forest fertilization has been successful enough in the southeastern United States for industry to join with the University of Florida to form the Cooperative Research in Forest Fertilization (CRIFF, 1972) and the North Carolina State Forest Fertilization Cooperative (Anonymous, 1983). The goal of both cooperatives is to develop fertilizer technologies and enhance forest productivity.

Fertilization of Yellow-Poplar

Yellow-poplar has responded to fertilization in many experiments. The most consistent and largest response has been to N fertilizers with an added response to P in combination with N. Gains in height growth of fertilized trees are often demonstrated although the largest response is on the poorest sites. Effects of fertilizers on growth are usually of short duration with major growth effects occurring within 3 to 5 years after application (Beck and Della-Bianca, 1981).

McAlpine (1959) applied diammonium phosphate (20-52-0) at rates of 0, 250, 500, and 1,000 lbs/acre to yellow-poplar seedlings on a site found to be low in N, P, K, and Calcium (Ca) by agricultural standards. After one growing season, fertilized trees were significantly taller than unfertilized trees. Trees receiving applications of 500 and 1,000 lbs/acre exhibited greater response than 250 lbs/acre but no significant differences were detected between the 500 and 1,000 lbs/acre treatments. Fertilizer treatments did not affect survival.

Ike (1962) remeasured these trees after four growing seasons and reported that fertilized trees not only maintained their growth advantage but were actually showing increases in height each year over unfertilized trees. This trend was also apparent among the different rates of application. The two highest rates gave greater responses than the 250-pound rate, and there were still no significant differences detected between the 500 and 1,000 pound treatment rates.

Whipple and Moeck (1968) fertilized yellow-poplar by spreading 100 lbs P/acre applied as super phosphate (0-20-0) 1 month after planting. Two months later, trees were sidedressed with 100 lbs N/acre applied as ammonium nitrate (33.5-0-0). After 1 year, height of fertilized yellow-poplar seedlings was 217% taller than unfertilized plots. Survival and growth response varied with topographic position. Survival of fertilized trees was best on the lower slope position while height growth was tallest on an upper slope site.

In West Tennessee, van de Werken and Warmbrod (1969) fertilized 8-10 feet tall yellow-poplar trees with 60 and 120 lbs N/acre annually for 8 years. Trees receiving annual applications of 120 lbs of N rate averaged 24.4 feet tall compared to 14.3 feet for unfertilized controls. Average tree height was 19.5 feet for trees receiving annual applications of 60 lbs N/acre.

Farmer, Snow & Curlin (1970) reported 5 year results of fertilizing on growth of yellow-poplar seedlings on an eroded site in the Tennessee Valley considered marginal for yellow-poplar. Three levels of N (0, 300, 600 lbs/ac) and P (0, 150, 300 lbs/ac) were applied as trees were planted. Nitrogen significantly increased growth for 2 years and P was effective only in combination with N. After 5 years, only the N treatments remained effective in increasing growth. Trees receiving 600 lbs/acre of nitrogen exhibited the greatest height growth; 80% higher when compared to control trees. Growth differences were still evident after 9 years (Buckley and Farmer, 1974). Mean height for low and high N applications were 16% and 44% taller, respectively, over untreated plots. There was a large amount of variation in plot means relating to degree of erosion.

Farmer, Bengston & Curlin (1970) reported the results of a single N and P application to pole or small sawlog sized stands of pine and mixed hardwood stands at sites throughout the Tennessee River Valley. Fertilizer treatments were 300 lbs N/acre and 300 lbs N/acre plus 66 lbs P/acre. Results varied widely with location, but N effects were consistently positive. Yellow-poplar was the most responsive species to treatments.

Buckner (1972) applied a complete fertilizer (1,000 lbs/acre) of 15-15-15 (150 lbs N/acre, 66 lbs P/acre, 75 lbs K/acre) to an uneven-aged natural stand of mature yellow-poplar. Height and diameter growth was significantly greater on fertilized plots for 2 years following application. However, significant growth effects were not apparent after that time.

Farmer, Buckley & Potts (1978) conducted an economic analysis to determine the profitability of N fertilization of sawtimber sized yellow-poplar. These stands received 300 lbs N/acre. The studies determined that fertilization may not be economically feasible. To be profitable, the value increment of treated stands would have to increase two to three times that of actual value increase in order to become profitable. They expressed doubts that such an increase in value was achievable utilizing current techniques.

Fertilization of Sweetgum

Most research to evaluate the effects of fertilization on growth of sweetgum has been conducted outside the Ridge and Valley province of Tennessee. On the Fayette Experiment Forest, Whipple and Moeck (1968) fertilized sweetgum seedlings 1 month after planting with 100 lbs P/acre and 2 months later with 100 lbs N/acre. After 1 year, fertilized seedlings were 110% taller than untreated seedlings. Height means varied with topographic position--tallest trees were on lower north slopes.

Broadfoot and Ike (1968) summarized responses to surface application of fertilizer measured in a 20-year-old natural sweetgum stand in Louisiana (Broadfoot, 1966). Trees were topdressed annually for 5 years with fertilizer at five rates per acre: 0, 75, 150, 300 and 150 lbs N plus 35 lbs each P and K/acre. The N source was ammonium nitrate (33.5-0-0) and the P and K were from a mixed fertilizer (0-20-20). All treatments increased diameter and height growth. Nitrogen at 300 lbs N/acre increased diameter the most while the combination rate of 150 lbs N plus 35 lbs each of P and K/acre increased height the most.

On an abandoned field in southern Illinois, sweetgum growth was best in 1976 on areas receiving additions of amendments rich in P. Trees growing on P fertilized plots were taller than those on unfertilized plots after 21 years (Gilmore and Rolfe, 1984). However, differences between fertilized and unfertilized areas were less at age 21 than at age 10. Gilmore and Rolfe attributed part of the decrease in growth in some areas to allelopathic interference by fescue (*Festuca arundinacea* Schreb.).

In studies near Stoneville, Mississippi, Francis (1985) reported that sweetgum responded to fertilizer treatments of N alone, N + P, and N + P + K. Trees were tallest on areas fertilized at rates of 200-300 lbs N/acre, 100-150 lbs P/acre, and 250 lbs K/acre. He concluded that fertilizer treatments could be recommended as a silvicultural practice only in special cases and best results from these treatments would probably be realized on disturbed sites such as abandoned agricultural lands that are low in fertility.

Irrigation

Soil moisture deficits are one of the most important factors affecting tree growth (Spurr and Barnes, 1973). The distribution of forests throughout the world are controlled to a large extent by the availability of soil moisture. The affects of moisture stress on apical, radial, and reproductive growth have been reviewed by Zahner (1968). Reviews by Kozlowski (1968) and Kramer (1969) have summarized most of the research about the relationship of tree growth and soil moisture.

Irrigation has been widely used to increase agricultural productivity in areas where soil moisture is the principal limiting factor (Brady, 1974). Most of the irrigated agricultural land in the United States was in the arid western states but irrigation is now being utilized frequently in the eastern United States (Troeh, et al., 1980).

Interest in alleviating soil moisture deficits with irrigation to increase forest productivity in the United States began with Paul and Marts' (1931) investigation of springwood-summerwood transition in longleaf pine (Pinus palustris Mill.). Many research endeavors have investigated the feasibility of irrigation practices as a silvucultural technique. Hansen (1977) reviewed most of the research concerning effects of irrigation on productivity of forested lands.

Kraus and Bengston (1959) summarized some of the potential applications of irrigation in forestry. They concluded that widespread use of irrigation is unlikely in commercial forestry. However, irrigation can be a valuable research technique to investigate the effects of soil moisture on tree growth, e.g., photosynthate conversion and soil moisture/fertilizer interactions. They cite a study by Black (1957) where both root and shoot yields were increased by irrigation on sites where soil moisture was deficient. The shoot:root ratio increased with increasing moisture levels and reached an optimum point where no further increases in this ratio were observed.

Kraus and Bengston (1959) also cited an experiment in Idaho (c.f. Anonymous, 1958) designed to investigate soil moisture/fertilizer interactions. Treatments were fertilization, and/or cultivation, and/or irrigation. Modest increases in height occurred on fertilized plots but when fertilization was combined with either irrigation or cultivation, tree height was three times greater than those on the untreated area after 2 years. The response to cultivation was attributed to decreased competition for available moisture.

Kraus and Bengston (1959) conclude that practical uses of irrigation are best suited to small areas of intensively managed tree crops in regions where annual rainfall is generally adequate but sometimes lacking during the growing season. Even then, application costs are high enough only to warrant the use of irrigation for specialty uses such as forest nurseries, seed orchards, or plantations having important genetic or research value. The view that use of irrigation is only justifiable for high value crops is shared by Armson (1977), Hansen (1983), and Pritchett and Fisher (1987).

One potential use of irrigation in forested areas is using municipal sewage effluent to supplement soil moisture (Sopper and Kerr, 1979; Sopper, et al., 1982). This method has the greatest chance for success because it provides low rates of nutrients as well as water. This practice would be restricted to sites where soil properties were capable of utilizing effluent without degrading water quality in adjacent watersheds.

Topographic Influences

Topographic influences which affect site quality include topographic position, slope gradient, slope aspect, the type of landform, and its surface shape. These factors are highly correlated with soil moisture and soil development (Spurr and Barnes, 1973; Birkeland, 1974; Bloom, 1978).

Both yellow-poplar and sweetgum are dependent on these factors but yellow-poplar is more sensitive than sweetgum to site conditions (Harlow and Harrar, 1969; Fowells, 1962). Smalley (1961, 1964, 1969) reported that topographic position and aspect were closely linked with growth of yellow-poplar in northern Alabama. Height of yellow-poplar increased from an upper slope position down the slope to a stream bottom. Growth was better on north slopes than on south slopes.

In the North Carolina Piedmont, sites favored for planting yellow-poplar are bottomlands, coves or draws, and on lower north and east slopes (Boyette and Brenneman, 1982). Yellow-poplar grows well on these areas where soils are moderately moist, well-drained, and loose-textured. A moist, but well-drained soil is recommended when planting this species on slopes. Sweetgum is recommended for planting on bottomlands, coves or draws, and lower slopes on sites with fertile, moist clay and loamy soils (Boyette and Brenneman, 1982).

In the mountains of North Carolina, yellow-poplar is or should be favored on bottoms and coves on north and east slopes, and on the lower third of some sheltered south and west slopes (Boyette and Brenneman, 1982). Desirable mountain soils should have the same characteristics as for the Piedmont. Bottomland soils in the mountains need to have a loamy soil at least 2-3 feet in depth to mottling. Growth on upland sites is improved with moister aspects, lower slope position, and increased annual rainfall.

In southern Ohio, site index of yellow-poplar was highest on northeast aspects and lowest on southwest aspects. Site index increased from upper slope sites down the slope (Munn and Vimmerstedt, 1981). In the New Jersey Coastal Plain, site index of yellow-poplar was highest on lower portions of stream-cut slopes and bottomland sites with good surface drainage (Philips, 1962).

McNab (1984) reported that height of yellow-poplar was most responsive to plot surface shape in the Southern Appalachian Mountains. Tallest trees grew on plots which were doubly concave in shape perpendicular and parallel to the contour. Surface shape concentrates drainage water on concave landforms. Site index of yellow-poplar was highest on concave landforms of northeastern aspect, and steeper slope gradient. He associated aspect with evapotranspirational stress and gradient with soil drainage characteristics.

In the Loessial hills in West Tennessee, Hebb (1962) found site index of yellow-poplar was highest on northern and eastern slopes. Site index increased from ridgetops to bottoms as long as soils were well-drained. Site index of sweetgum was highest in bottoms with poor apparent internal drainage and lowest on ridgetops with excessive drainage.

Old Field Soil Condition

Growth of yellow-poplar has consistently been correlated with soil properties that affect rooting depth and available water supply of soils. Specific variables are the relative content of sand, silt, and clay (soil texture); thickness of forest floor; organic matter content; thickness of various horizons; available water; and depth to impermeable or inhibiting layers (Beck and Della-Bianca, 1981).

Generally, old fields are recognized as poor sites for planting hardwood species, in particular yellow-poplar (Russell, 1977). Old-fields usually have sustained some degree of erosion, soils are compacted, depleted of nutrient supply due to crop removals, and have heavy sod or weed growth. The A horizon of old fields is typically thin or absent and composed of clayey material from subsoil horizons. Soil structure is destroyed by frequent cultivation. Increased clay content and poor structure would decrease infiltration capacity, permeability, and moisture storage capacity of surface horizons (Brady, 1974). Bulk density is often higher and may restrict root development (Loftus, 1971; Francis, 1979).

Organic matter content is lower on agricultural soils than forest soils (Rolfe and Boggess, 1973). This would adversely affect soil structure, nutrient supply, availability, and biological properties of these soils. Clark (1964) found that soil structure was poor on old fields and that populations of soil organisms, particularly endotropic mycorrhizae, were reduced under old field conditions. Both yellow-poplar and sweetgum are known to have symbiotic relationships with these fungi resulting in improved survival and availability of soil nutrients. Clark (1964) found that yellow-poplar grew better in soils from old fields which had been previously planted with pine, nitrogen-fixing tree species (in this case black locust, Robinia pseudoacocia L.), or natural tree cover. He attributed this to improved soil structure and increased populations of soil micro-organisms.

Carmean, et al. (1976) found in a companion study on the same site that growth and survival of yellow-poplar and sweetgum were adversely affected on the old field site. Height growth of both species was greater on the plots clearcut from fully stocked areas of planted pine or natural hardwood regeneration. Height growth was best on the plot clearcut from the black locust plantation. They attributed the better growth on previously forested areas to several factors. They reported differences in soil porosity, bulk density, and organic matter content which resulted from old field succession and planting trees on agricultural land.

Endomycorrhizae relations were also improved in plots on previously forested areas. Yellow-poplar seedlings grown in undisturbed cores from the hardwood forest and the pine, and locust plantation had well-developed endomycorrhizae while trees from the non-forested area showed weakly developed mycorrhizae (Clark, 1964). The physiological activity of endomycorrhizae was associated with soil physical properties and the ability of hardwood seedlings to obtain sufficient amounts of soil N and P.

Several species associated with old field succession have been shown to contain allelopathic compounds which inhibit nitrogen-fixing and nitrifying bacteria (Rice, 1964; 1972; 1974). Carmean, et al. (1976), hypothesized that allelopathy may have influenced tree growth by inhibiting soil micro-organisms and/or endomycorrhizal development.

Soil-Site Variability

Assessment of soil-site variation in the design and interpretation of field experiments in forestry and agronomy are important if treatment results are to be properly interpreted and understood. Failure to account for spatial variability in soil properties when establishing experimental plots can introduce effects into the experimental design which cannot be accounted for with statistical analysis (Wilding and Drees, 1984). This variation can mask treatment effects, negate the effectiveness of the statistical design and analysis, and result in erroneous interpretation of results.

Soil variation often has important effects on tree growth. Merz and Finn (1955) studied the effect of different methods of site preparation on growth of yellow-poplar on an old field in Ohio. They recognized differences in soil properties when the experiment was established and adjusted their analysis to reflect soil depth. They noted that height growth of yellow-poplar seedlings was correlated with soil depth and that failure to account for variation in soil depth might have led to misleading conclusions about growth response.

Gilmore, et al. (1968) showed that height and diameter of yellow-poplar was closely related to variation in effective soil depth and thickness of accumulation of organic matter. Best growth was on areas where depth to a fragipan and organic matter accumulation was deepest. They noted poor survival and growth on areas with shallow effective soil depth and little accumulation of organic matter. They attributed this poor growth and survival primarily to drought conditions.

Hay, et al. (1987) reported that significant differences in height of yellow-poplar seedlings due to nursery treatments had disappeared after 2 years in a test near Oak Ridge, Tennessee. Changes in seedling growth were caused by excessive soil variation of the test site. Soil-site differences had not been evaluated prior to outplanting. Five different soils were identified on the 1 acre site. Soil physical and chemical properties which affected the quantity and quality of the rooting environment were more influential on subsequent tree growth than nursery treatments.

Wright (1975) discussed how careful design of genetic research could increase the statistical precision of interpretation of results. Soil-site variability can be minimized by using smaller plots and many smaller blocks when establishing studies. Wright and Freeland (1960) and Conkle (1963) reported that the amount of information gained per tree is 20-30% less than four-tree than with one-tree plots, and 80-90% less with 100-tree than with one-tree plots. Evers, et al. (1984) reported that growth and survival of plantations of hybrid poplar (Populus spp.) clones were inconsistent due to lack of detailed information on soils, soil-growth relationships, and inadequate cultural treatments in Ontario.

In Louisiana, Slay, et al. (1986) illustrated how site variation can cause treatment effects to be obscured or misinterpreted. They demonstrated how differences between treatment means were detectable with adjusted (covariance) analysis of variance which were not apparent using ordinary analysis of variance. Failure to adjust analyses of variance with pretreatment soil chemical data would have resulted in misinterpretation of site preparation treatment effects on concentrations of soil N, P, K, Ca, and Mg concentrations.

Randomized, complete-block (RCB) designed field studies can mask treatment differences in the concentration of soil nutrients (Lloyd and McKee, 1983). Using soil N data as an example, they illustrated how compositing of samples and blocking can reduce natural variation among treatment plots. This makes the RCB design more efficient in that it increases the probability of detecting biologically meaningful treatment differences when they are present.

Wide variation in soil-site properties has been encountered in studies relating site index to soil mapping units. Carmean (1961) reported poor correlation between site index of black oak (Quercus velutina Lam.) and soil taxonomic units used prior to 1960; reclassification into new taxonomic units did not improve this relationship (Carmean, 1965). Soil survey information for black oak was refined by relating topographic features which indirectly express microclimate, soil moisture, and other soil features important to tree growth, e.g., soil texture and surface soil thickness (Carmean, 1967). Specific topographic variables identified were aspect, slope position, slope shape, and slope steepness.

Van Lear and Hosner (1967) found poor correlation between site index for yellow-poplar and soil mapping units in southwestern Virginia. Wide variation of site index was found within each mapping unit. Reasons for this variation were: 1) soil mapping units cannot be defined with respect to the specific site requirements for each species, 2) site index may vary considerably within the range of soil properties associated with each soil mapping unit, and 3) site index may not be a precise measure of site quality.

Munn and Vimmerstedt (1980) reported considerable variation within some soil mapping units in southeastern Ohio. They determined that more accurate predictions of tree height could be made by subdividing mapping units on the basis of soil chemical factors, e.g., soil pH, or physical factors such as slope position or aspect. Their investigation revealed that about 65% of the variability in height of yellow-poplar could be accounted for by soil chemical and physical properties and topographic features.

CHAPTER II

STUDY LOCATION AND METHODS

Location

The study area was located on The University of Tennessee Forest Experiment Station in Anderson County within the city limits of Oak Ridge, Tennessee. This area is in the Great Valley of East Tennessee, a part of the Ridge and Valley Physiographic Province which extends northeastward from northern Alabama and northwest Georgia to the Hudson River Valley in New York (Hunt, 1973). The region is characterized by faulted and folded beds of Paleozoic age dolomites, limestones, sandstones, and shales that have been shaped into long parallel ridges and valleys by erosion (Luther, 1977).

The study was conducted on a south-facing slope of an east-west oriented ridge underlain by dolomite. Two slope positions were cleared for planting in the spring of 1964, an upper slope site near the ridge crest and a lower slope site on the footslope. Prior to clearing, the upper slope site supported a mature oak-hickory stand that indicated a relatively undisturbed forest condition over the past century.

Past Use

The lower slope site had previously been cleared for agriculture, abandoned in the early 1940's, and now supported a 20-year-old mixed stand of shortleaf (*Pinus echinata* L.) and Virginia pine (*Pinus virginiana* Mill.). Upper slope sites are often less productive than sites on footslopes (Smalley, 1961, 1964, 1969). Ridges are more exposed to erosive forces and soils on ridges tend to be drier and thinner than on footslopes. Soils on footslopes are generally deeper and have the potential to supply more available water through sub-surface irrigation. Although the lower slope was potentially the better of the two sites, past agricultural practices on the lower slope had caused significant site degradation. Sheet erosion had apparently removed much of the original A horizon. The differences in the two sites attributable to past land-use were confounded with differences due to slope position.

Climate

The climate of the area is typical of the Southern Appalachian region (Peters, *et al*., 1970). For the summer months the average daily maximum temperature is 86°F, and in winter the average daily minimum temperature is 30°F. Temperature extremes range from approximately 105°F in summer to -17°F in winter (Moneymaker, 1981). Precipitation averages almost 55 inches per year with snowfall accounting for about 11 inches. On the average, precipitation is evenly distributed throughout the year with 45% falling from April to September. Prevailing winds are from the southwest. The effect of these regional winds combined with greater insolation on south-facing slopes makes evapotranspirational stresses greater on slopes of southern aspect than on north or east slopes. Periodic droughts are common and moisture stress commonly develops by mid-summer.

Soils

On the upper slope site the predominant soils on the upper slope site are Claiborne silt loam (Fine-loamy, siliceous, mesic, Typic Paleudults) and Fullerton cherty silt loam (Clayey, kaolinitic, thermic, Typic Paleudults) (Moneymaker, 1981). Claiborne soils are deep well-drained forest soils formed in the residuum of dolomite or old alluvium along broad ridgetops. The thick, dark-colored A horizon is rich in organic matter and has a silt loam texture; infiltration is rapid. This topsoil overlies a thick, permeable argillic (Bt) horizon. Fullerton soils have a thin A horizon overlying thick E and thick Bt horizons. The higher clay content of Fullerton soils makes these soils less permeable than Claiborne soils. These soils are characteristically found on ridgetops and hillsides in eastern Tennessee (Moneymaker, 1981).

Soils on the lower slope are mostly Fullerton and Minvale with inclusions of Claiborne soils. The morphology of the Fullerton soils on the lower slope is similar to the upper slope except a thin A horizon is forming in the old plow layer (Ap). Erosion has removed much of the original A horizon and the Ap is composed of material mixed from original A horizon and the upper Bt horizon. The Minvale cherty silt loam (Fine-loamy, siliceous, thermic, Typic Paleudults) is a colluvial soil on benches and footslopes formed from material washed from Claiborne and Fullerton soils. These soils are similar in morphology to the Fullerton series, but clay content is less.

The Claiborne series rates high for available water because of the combination of good texture and structure while the Fullerton and Minvale soils are rated low (Moneymaker, 1981). The low ratings are likely due to the pronounced chertiness of both soils as well as the high clay content of Fullerton soils. Based on agricultural standards, the natural fertility of the Claiborne soils is ranked medium while the Fullerton and Minvale soils are ranked low. Fullerton soils have a higher cation exchange capacity (CEC); however, the high organic matter content and good physical properties of the Claiborne soil make it potentially more productive.

Experimental Design

The original experimental design used was a randomized complete block with a factorial arrangement of treatments (Buckner and Maki, 1977). Four replications of four treatments were used on each area (Figure 1). The treatments were: 1) fertilization, 2) irrigation, 3) fertilization and irrigation combined, and 4) control plots. The fertilizer treatment consisted of 33 lbs N, 45 lbs P, and 4 lbs Mg/acre. Fertilizers were applied as 2 ounces of MagAmp (7-45-0 W/5 Mg) and 1 ounce of Ureaform N (45-0-0) placed in the closing hole approximately 2 inches from the seedling roots as seedlings were planted (Buckner and Maki, 1977). No further fertilizer applications were made. The fertilizer treatment was intended to

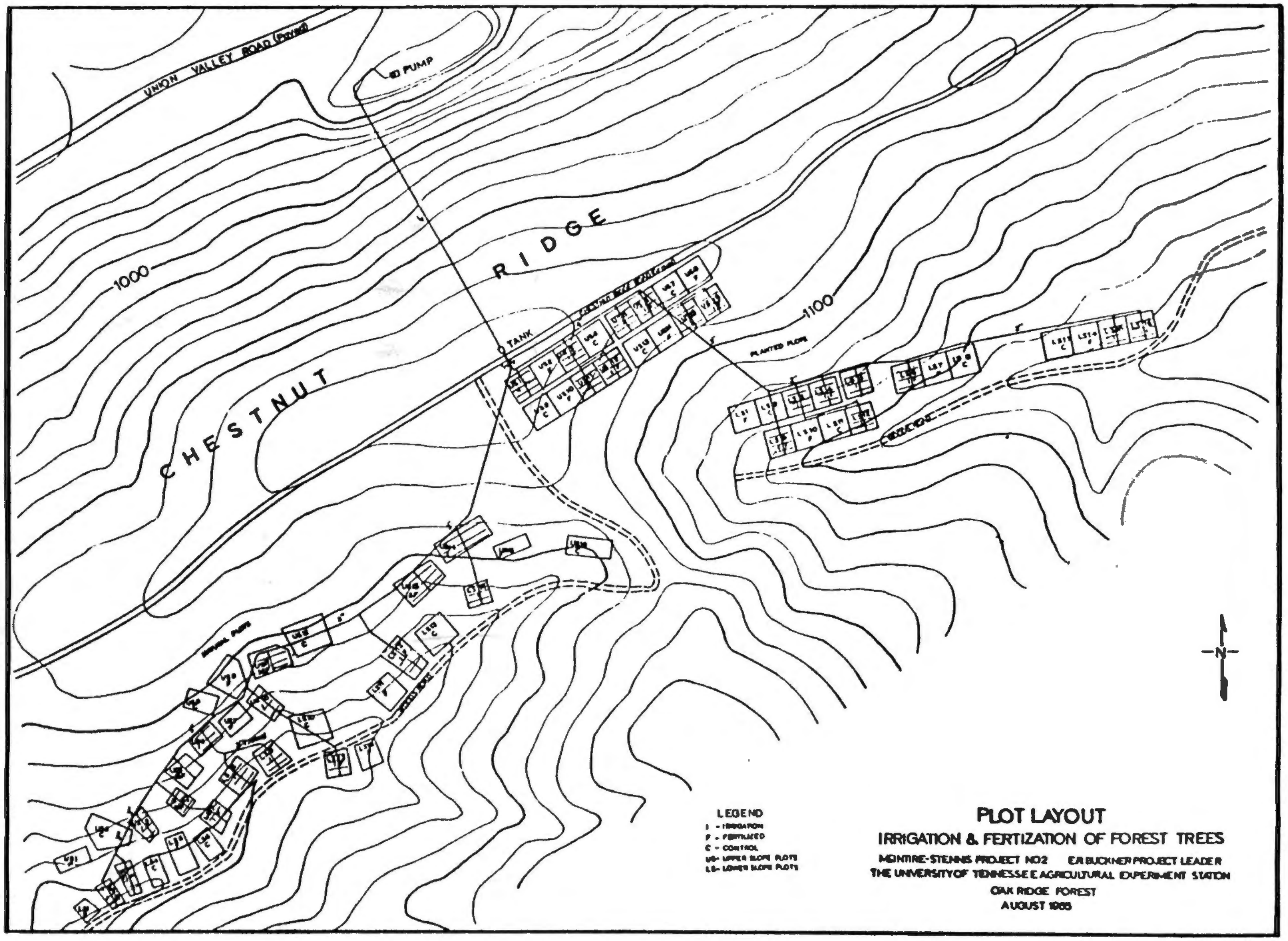

Figure 1. Location and arrangement of plots and treatments applied for both the natural yellow-poplar stand and the planted plots (from Buckner, 1972).

offset any nutrient deficiencies for the "establishment years." The irrigation treatment was applied periodically for the first 7 years during the summer months in an attempt to maintain soil moisture tension below two atmospheres.

Four species, loblolly pine, northern red oak, sweetgum, and yellow-poplar were represented in each treatment plot as 25-tree subplots. Trees were planted in five rows of five trees arrangement with spacing at 7 feet by 7 feet. Only the inner nine trees of each species subplot comprised the measurement plot; the 16 trees on the outside edges of each subplot were considered isolation trees and were not measured.

Data Collection and Analysis

Tree heights and diameters at breast height of crop trees were measured in December 1986 and January 1987 using a diameter tape and a Suunto clinometer. Suitable volume tables were not available for the test species in this area. Relative volume was calculated from height and diameter measurements and the formula for determining the volume of a cone:

Cubic Foot Volume = (0.005454*(DBH**2)*HT

Where: DBH = diameter at breast height (4.5 ft)

HT = total height of tree

This formula provides a conservative volume estimate and simplifies species comparisons (Husch, *et al.*, 1985).

The dates of collection defined three growth periods: 1) total height and relative stand volume at age 22, 2) height growth over the period from ages 7 to 22, and 3) total height growth at age 7 using Buckner's data. All reference to age indicates plantation age. Diameter growth was not analyzed because diameter growth is more strongly affected by stand density rather than environmental or genetic factors. Only dominant and co-dominant trees (Smith, 1962) were used in the height growth analyses as these classes contain only crop trees and are normally used in forest site quality assessment (Husch, et al., 1985). Volume estimates were based on all crop trees surviving on the plots regardless of crown class. All tests for significance of statistical effects were performed at 5% level (alpha - 0.05). Individual treatment effects for each species were tested for significance using linear contrasts in orthogonal sets. Relevant contrasts were:

1. fertilization versus no fertilization (F & IF vs C & I),
2. irrigation versus no irrigation (I & IF vs C & F),
3. interaction between fertilization and irrigation treatments (C & IF vs F & I).

Individual site X treatment interactions for each species were tested for significance using linear contrasts in orthogonal sets. Relevant contrasts were:

1. fertilization X site interaction (lower slope F & IF and upper slope C & I vs lower slope C & I and upper slope F & IF).

2. irrigation X site interaction (lower slope C & F and upper slope I & IF vs lower slope I & IF and upper slope C & F),
3. fertilization X irrigation X site interaction (lower slope C & IF and upper slope F & I vs lower slope F & I and upper slope C & IF).

In the analysis of variance, replication(site) is the error term to test for significance of the site effect and replication X treatment(site) is the error term to test the significance of treatment and the site X treatment interaction. Dr. William Sanders, the University of Tennessee Agricultural Experiment Station Statistician, suggested that replication(site) and replication X treatment(site) be pooled for the analysis of the height data if the difference between these two values were small. The new pooled error team could then be used to test the statistical significance of site, treatment, and the site X treatment interaction on height. This was done to allow for the large amount of missing data (i.e., dead or missing trees and trees not in the dominant or codominant crown classes) and the resulting imbalance in the statistical design. The analysis of variance for volume was performed with replication(site) as the error term for site and replication X treatment(site) as the error term for treatment and the site X treatment interaction because volume was calculated for each plot and there was no missing data.

Edaphic Features

Edaphic features of the study are identified primarily by visual observation of each plot. Soil information was observed by borings taken with a soil auger. Soil horizons were identified by changes in field texture of the soil, changes in soil color, and relative coarse fragment content. Landform types and surface shapes were based on inspection of each plot.

CHAPTER III

RESULTS

Survival

Yellow-Poplar

Survival counts are based on the number of live crop trees on each plot at the end of the first and second growth periods. On both lower and upper slopes survival of yellow-poplar varied among treatment plots (Table 1). The highest survival at age 7 on the lower slope was in fertilized plots where survival was 83% and in irrigated and fertilized plots with 86% survival. Survival was 78% in controls and 72% in irrigated plots.

On the upper slope at age 7 survival of yellow-poplar was highest in control plots where survival was 94%. The lowest survival was in fertilized plots averaging 67%. Survival in irrigated plots was 92% and 83% in irrigated and fertilized plots.

By age 22 survival had decreased slightly. The best survival on the lower slope was 83% in irrigated and fertilized plots and 81% in fertilized plots (Table 1). The lowest survival was 69% in controls and in irrigated plots.

On the upper slope the best survival at age 22 was still on control plots with 94% (Table 1), while 86% were alive in irrigated plots, and 81% in irrigated and fertilized plots. The lowest survival was 67% in fertilized plots.

Table 1. Survival (%) of yellow-poplar at ages 7 and 22.

Site	Treatment	Survival -(%)	
		Age 7	Age 22
Lower Slope	Control	78	69
	Fertilized	83	81
	Irrigated	72	69
	Irrigated & Fertilized	86	83
Upper Slope	Control	94	94
	Fertilized	67	67
	Irrigated	92	86
	Irrigated & Fertilized	83	81

Sweetgum

Survival of sweetgum at age 7 also appeared to be related to treatments. The best survival on the lower slope was 92% in control plots (Table 2). Survival was 83% in fertilized plots, 86% in irrigated plots, and 78% in irrigated and fertilized plots.

The best survival on the upper slope was 94% in irrigated plots at age 7. In control plots survival was 89%, in fertilized plots 83%, and 72% on irrigated and fertilized plots.

At age 22 survival of sweetgum on both lower and upper slopes had decreased. On the lower slope survival was 78% in irrigated plots, 75% in irrigated and fertilized plots, 69% in fertilized plots, and 64% in controls (Table 2).

The best survival on the upper slope at age 22 was 86% in irrigated plots (Table 2) and the lowest survival was 67% on irrigated and fertilized plots. By age 22, 78% of the fertilized trees and 72% of the controls were alive.

Loblolly Pine

Loblolly pine survival seemed to be related to treatments on both sites at age 7 (Table 3). The best survival on the lower slope was 81% in irrigated plots and lowest was 47% in fertilized plots. Survival was 72% in control and 64% in irrigated and fertilized plots.

The highest survival of loblolly pine on the upper slope at age 7 was 75% in control plots (Table 3). In fertilized, irrigated, and irrigated and fertilized plots survival was 56%, 58%, and 64%, respectively.

Table 2. Survival (%) of sweetgum at ages 7 and 22.

Site	Treatment	Survival -(%) Age 7	Survival -(%) Age 22
Lower Slope	Control	92	64
	Fertilized	83	69
	Irrigated	86	78
	Irrigated & Fertilized	78	75
Upper Slope	Control	89	72
	Fertilized	83	78
	Irrigated	94	86
	Irrigated & Fertilized	72	67

Table 3. Survival (%) of loblolly pine at ages 7 and 22.

Site	Treatment	Survival -(%) Age 7	Survival -(%) Age 22
Lower Slope	Control	72	50
	Fertilized	47	36
	Irrigated	81	47
	Irrigated & Fertilized	64	58
Upper Slope	Control	75	44
	Fertilized	56	36
	Irrigated	58	31
	Irrigated & Fertilized	64	31

At age 22 increased mortality was evident on both lower and upper slopes. Survival was 50% on controls, 58% in irrigated and fertilized plots, 47% in irrigated plots, and 36% in fertilized plots on the lower slope (Table 3).

Mortality of loblolly pine had increased substantially on the upper slope by age 22. Survival had decreased to 44% for controls, 36% for fertilized plots, and 31% for both irrigated and irrigated and fertilized plots (Table 3).

The reasons for the high mortality of loblolly pine by age 22 are not clear. This study is located approximately 70 miles north of the natural range of this pine, thus climatic factors may have influenced its survival. During the first growth period, several heavy snows and ice storms damaged many of these trees. The weight of snow and ice accumulation in the crowns bent many trees over so their tops were touching the ground. The trees may have been so weakened by these storms that they may have become more susceptible to disease or insect damage. By age 22 loblolly pine was dropped from consideration as a test species and was not included in the statistical analyses. The inclusion of growth data of the pine is intended for comparison with the two hardwoods.

Yellow-Poplar Height and Volume

Total Height Age 7 of Dominants and Codominants

There were significant height differences between the two slope positions at age 7 (Table 4). Tallest trees were on the upper

Table 4. Analysis of variance of total height of dominant and codominant yellow-poplar trees at age 7.

Source	df	Sum of Squares	F	Significance
Site	1	762.939	22.577	*
Trt	3	2,450.132	24.168	*
Fert. vs no fert.	1	1,841.240	54,486	*
Irr. vs no irr.	1	511.474	15.136	*
Fert. x Irr.	1	22,826	<1	NS
Site x Trt	3	346.371	3.417	*
Fert. x Site	1	59.046	<2	NS
Irr. x Site	1	297.282	8.797	*
Fert. x Irr. x Site	1	1,564	<1	NS
Error	24	811.032		

*=Significant at 0.05 level, NS=Not significant at 0.05 level.

slope. Mean height of trees on the upper slope was 22.9 feet compared to 17.7 feet for lower slope trees (Table 5).

Differences in height were observed between treatments (Table 4). Average height of fertilized trees was 24.3 feet and unfertilized trees averaged 16.3 feet. Fertilization appeared to be most effective on the lower slope where fertilized trees averaged 22.3 feet or 70% taller than unfertilized trees which averaged 13.1 feet (Table 5). Fertilized trees on the upper slope were also taller than unfertilized trees. Mean height of upper slope fertilized yellow-poplar was 26.3 feet compared with 19.6 feet for unfertilized trees, a difference of 34%.

Irrigated trees were significantly taller than non-irrigated trees (Table 4). Mean height of irrigated trees was 22.6 feet and non-irrigated trees averaged 18.1 feet. A significant interaction between site and irrigation (Table 4) indicated irrigation was most effective on the upper slope. Irrigated yellow-poplar on the upper slope averaged 26.7 feet compared to 19.2 feet for non-irrigated trees (Table 5), a difference of 39%. On the lower slope mean height of irrigated trees was 18.5 feet compared to 17.0 feet for non-irrigated trees.

Total Height Age 22 of Dominants and Codominants

Differences in tree height were apparent between the upper and lower slopes at age 22 (Table 6). Yellow-poplar was significantly taller on the upper slope than on the lower slope. Mean height was 62.7 feet on the upper slope and 58.3 feet on the lower slope.

Table 5. Total height (ft) of dominant and codominant yellow-poplar trees at age 7.

Treatments and Comparisons	Site	
	Lower Slope	Upper Slope
Treatments		
Control	11.7	15.9
Fertilized	22.3	22.6
Irrigated	14.6	23.3
Irrigated & Fertilized	22.4	30.1
Mean	17.7	22.9
Comparisons		
Fertilized	22.3	26.3
Unfertilized	13.1	19.6
Irrigated	18.5	26.7
Non-irrigated	17.0	19.2

Table 6. Analysis of variance of total height of dominant and codominant yellow-poplar trees at age 22.

Source	df	Sum of Squares	F	Significance
Site	1	487.868	5.189	*
Trt	3	653.385	2.316	NS
Fert. vs no fert.	1	646.158	6.872	*
Irr. vs no irr.	1	1.748	<1	NS
Fert. x Irr.	1	4.830	<1	NS
Site x Trt	3	957.426	3.394	*
Fert. x Site	1	93.615	<1	NS
Irr. x Site	1	847.618	9.015	*
Fert. x Irr. x Site	1	40.016	<1	NS
Error	24	2,256.599		

*=Significant at 0.05 level, NS=Not significant at 0.05 level.

Fertilized trees were significantly taller than unfertilized trees (Table 6). Mean height of fertilized trees on the lower slope was 61.8 feet and unfertilized trees averaged 54.8 feet (Table 7). On the upper slope fertilized trees were 64.5 feet compared to 60.8 feet for unfertilized trees, differences of 13% and 6%, respectively, on the lower and upper slopes.

A significant interaction between site and treatment was related to differences in height of irrigated trees on the two slope positions (Table 6) relative to non-irrigated trees. The mean height of irrigated yellow-poplar on the lower slope was 7% less than non-irrigated trees (56.2 ft vs 60.3 ft). Irrigated trees on the upper slope were 9% taller than non-irrigated trees (65.5 ft vs 59.8 ft, respectively).

Height Growth Ages 7 to 22 of Dominants and Codominants

Height growth of trees on the upper slope did not differ significantly from growth of trees on the lower slope during the second growth period (Table 8). Average growth was 40.5 feet on the lower slope and 39.8 feet on the upper slope (Table 9).

Fertilized trees grew significantly less than unfertilized trees on both slope positions (Table 9). Fertilized trees on the lower slope grew 39.4 feet while unfertilized trees grew 41.7 feet, a difference of 6%. On the upper slope height growth of fertilized trees was 38.2 feet compared to 41.3 feet for unfertilized trees, an 8% difference.

Also the height growth of irrigated trees was significantly less than non-irrigated trees. Lower slope irrigated trees (37.8 ft)

Table 7. Total height (ft) of dominant and codominant yellow-poplar trees at age 22.

Treatments and Comparisons	Site	
	Lower Slope	Upper Slope
Treatments		
Control	57.0	57.5
Fertilized	63.7	62.2
Irrigated	52.6	64.1
Irrigated & Fertilized	59.9	66.9
Mean	58.3	62.7
Comparisons		
Fertilized	61.8	64.5
Unfertilized	54.8	60.8
Irrigated	56.2	65.5
Non-irrigated	60.3	59.8

Table 8. Analysis of variance of height growth of dominant and codominant yellow-poplar trees between ages 7 and 22.

Source	df	Sum of Squares	F	Significance
Site	1	30.621	<1	NS
Trt	3	795.828	5.193	*
Fert. vs no fert.	1	305.901	5.988	*
Irr. vs no irr.	1	453.419	8.975	*
Fert. x Irr.	1	5.584	<1	NS
Site x Trt	3	198.938	1.298	NS
Fert. x Site	1	3.965	<1	NS
Irr. x Site	1	140.944	<3	NS
Fert. x Irr. x Site	1	57.403	<2	NS
Error	24	1,226.088		

*=Significant at 0.05 level, NS=Not significant at 0.05 level.

Table 9. Height growth (ft) of dominant and codominant yellow-poplar trees between ages 7 and 22.

Treatments and Comparisons	Site	
	Lower Slope	Upper Slope
Treatments		
Control	45.3	41.7
Fertilized	41.3	39.7
Irrigated	38.1	40.9
Irrigated & Fertilized	37.5	36.8
Mean	40.5	39.8
Comparisons		
Fertilized	39.4	38.2
Unfertilized	41.7	41.3
Irrigated	37.8	38.8
Non-irrigated	43.3	40.7

grew 15% less than non-irrigated trees (43.3 ft), while there was a 5% difference in growth of irrigated and non-irrigated trees (38.8 ft and 40.7 ft, respectively).

Relative Plot Volume Age 22

Relative volume per plot was converted to a "per acre" basis for convention. There were significant differences in volume of yellow-poplar between the upper and lower slopes (Table 10). Volume averaged 2,837 cubic feet per acre on the upper slope compared to 1,971 cubic feet per acre on the lower slope.

The volume in fertilized plots was significantly greater than in unfertilized plots. The volume on fertilized plots on the lower slope was 90% greater than unfertilized plots (2,850 and 1,361 cubic feet per acre for fertilized and unfertilized plots, respectively). On the upper slope, volume was 3,171 and 2,503 cubic feet per acre on fertilized plots and unfertilized plots, respectively, a difference of 27% (Table 11).

For relative volume there was a significant interaction between site and treatment (Table 10). This is attributable to differences in volume on irrigated plots on the lower and upper slopes (Table 11). On the lower slope the volume of yellow-poplar on irrigated plots was 42% less than non-irrigated plots while the volume of upper slope irrigated plots was 58% greater than non-irrigated plots. Lower slope irrigated plots averaged 1,630 cubic feet per acre compared to 2,311 cubic feet per acre on non-irrigated plots. On the upper slope the volume was 3,471 cubic feet per acre on irrigated plots compared with 2,203 cubic feet per acre on non-irrigated plots.

Table 10. Analysis of variance for relative plot volume of yellow-poplar trees at age 22.

Source	df	Sum of Squares	F	Significance
Site	1	6,000,703	45.66	*
Rep(Site) error 1	6	788,613	-	*
Trt	3	7,960,464	4.44	*
Fert. vs no fert.	1	7,125,356	11.93	*
Irr. vs no irr.	1	690,366	1.16	NS
Fert. x Irr.	1	144,742	0.24	NS
Site x Trt	3	8,853,541	4.94	*
Fert. x Site	1	609,903	1.02	NS
Irr. x Site	1	7,598,547	12.73	*
Fert. x Irr. x Site	1	644,991	1.08	NS
Error 2	18	10,746,256		

*=Significant at 0.05 level, NS=Not significant at 0.05 level.

Table 11. Relative plot volume (ft^3/ac) and survival (%) of yellow-poplar trees at age 22.

Treatments and Comparisons	Site			
	Lower Slope		Upper Slope	
	Volume	(%)	Volume	(%)
Treatments				
Control	1,492	(69)	1,944	(94)
Fertilized	3,130	(81)	2,462	(67)
Irrigated	1,230	(69)	3,063	(86)
Irrigated & Fertilized	2,031	(83)	3,880	(82)
Mean	1,971		2,837	
Comparisons				
Fertilized	2,580		3,171	
Unfertilized	1,361		2,503	
Irrigated	1,630		3,471	
Non-irrigated	2,311		2,203	

Sweetgum Height and Volume

Total Height Age 7 of Dominants and Codominants

Sweetgum did not appear to be as sensitive to site factors at age 7 as was yellow-poplar (Table 12). Tree height on the lower slope was 19.0 feet compared with 19.6 feet on the upper slope (Table 13).

Fertilized trees were significantly taller than unfertilized trees on both slope positions. On the lower slope, fertilized trees averaged 20.9 feet compared to 17.1 feet for unfertilized trees while on the upper slope fertilized trees were 20.6 feet and unfertilized sweetgum were 18.6 feet (Table 13). The difference between fertilized and unfertilized trees was greater on the lower slope (22%) than on the upper slope (11%).

There were no significant differences between height of irrigated and non-irrigated sweetgum on either slope position (Tables 12 and 13).

Total Height Age 22 of Dominants and Codominants

No significant differences in height were observed between the upper and lower slopes at age 22 (Table 14). Sweetgum averaged 53.6 feet on the lower slope and 52.5 feet on the upper slope (Table 15).

By age 22 fertilized trees were no longer significantly taller than unfertilized trees. Height of fertilized trees was 55.9 feet on the loewr slope compared to 51.3 feet for unfertilized trees

Table 12. Analysis of variance of total height of dominant and codominant sweetgum trees at age 7.

Source	df	Sum of Squares	F	Significance
Site	1	25.473	<1	NS
Trt	3	341.967	<2	NS
Fert. vs no fert.	1	329.352	4.861	*
Irr. vs no irr.	1	17.885	<1	NS
Fert. x Irr.	1	15,801	<1	NS
Site x Trt	3	122.178	<1	NS
Fert. x Site	1	30.375	<1	NS
Irr. x Site	1	57.821	<1	NS
Fert. x Irr. x Site	1	26.816	<1	NS
Error	24	1,626.096		

*=Significant at 0.05 level, NS=Not significant at 0.05 level.

Table 13. Total height (ft) of dominant and codominant sweetgum trees at age 7.

Treatments and Comparisons	Site	
	Lower Slope	Upper Slope
Treatments		
Control	16.4	17.3
Fertilized	21.8	19.6
Irrigated	17.8	19.8
Irrigated & Fertilized	20.0	21.6
Mean	19.0	19.6
Comparisons		
Fertilized	20.9	20.6
Unfertilized	17.1	18.6
Irrigated	18.9	20.7
Non-irrigated	19.1	18.4

Table 14. Analysis of variance of total height of dominant and codominant sweetgum trees at age 22.

Source	df	Sum of Squares	F	Significance
Site	1	15.489	<1	NS
Trt	3	921.342	2.711	NS
Fert. vs no fert.	1	86.106	<1	NS
Irr. vs no irr.	1	732.479	6.466	*
Fert. x Irr.	1	51.248	<1	NS
Site x Trt	3	393.310	<2	NS
Fert. x Site	1	241.325	<2	NS
Irr. x Site	1	110.378	<1	NS
Fert. x Irr. x Site	1	2.838	<1	NS
Error	24	339.843		

*=Significant at 0.05 level, NS=Not significant at 0.05 level.

Table 15. Total height (ft) of dominant and codominant sweetgum trees at age 22.

Treatments and Comparisons	Site	
	Lower Slope	Upper Slope
Treatments		
Control	54.7	55.1
Fertilized	58.8	52.5
Irrigated	48.0	51.4
Irrigated & Fertilized	53.0	51.2
Mean	53.6	52.5
Comparisons		
Fertilized	55.9	51.8
Unfertilized	51.3	53.2
Irrigated	50.5	51.3
Non-irrigated	56.7	53.8

(Table 15). There was little difference between height of fertilized and unfertilized sweetgums on the upper slope (51.8 and 53.2 ft for fertilized and unfertilized trees, respectively).

As was true at age 7, no significant irrigation effect was detected. Non-irrigated trees were actually taller than irrigated trees on both slope positions. The difference in height of irrigated and non-irrigated trees was most apparent on the lower slope where irrigated trees were 12% shorter than non-irrigated trees (50.5 ft vs 56.7 ft, respectively). Irrigated trees on the upper slope averaged 51.3 feet compared to 53.8 feet for non-irrigated trees

Height Growth Ages 7 to 22 of Dominants and Codominants

There was no significant difference in height growth of sweetgum on the lower and upper slopes during the second growth period (Table 16). Height growth was approximately equal on both slope positions (Table 17).

Irrigated trees on both the lower and upper slopes grew less than non-irrigated trees (Table 17). On the lower slope irrigated sweetgum grew 31.6 feet and non-irrigated trees grew 37.5 feet, a difference of 19%. Trees on the upper slope grew 30.6 feet on irrigated plots and 35.3 feet on non-irrigated plots, a difference of 16%.

No significant difference was observed between fertilized and unfertilized sweetgum on the lower slope during the second growth period (35.0 and 34.1 ft for fertilized and unfertilized trees, respectively). On the upper slope fertilized trees were 11% smaller than unfertilized trees.

Table 16. Analysis of variance of height growth of dominant and codominant sweetgum trees between ages 7 and 22.

Source	df	Sum of Squares	F	Significance
Site	1	64.766	<2	NS
Trt	3	1,021.619	6.264	*
Fert. vs no fert.	1	70.716	<2	NS
Irr. vs no irr.	1	921.948	16.957	*
Fert. x Irr.	1	104.152	<2	NS
Site x Trt	3	142.473	<1	NS
Fert. x Site	1	120.143	<2	NS
Irr. x Site	1	4.180	<1	NS
Fert. x Irr. x Site	1	6.544	<1	NS
Error	24	1,304.736		

*=Significant at 0.05 level, NS=Not significant at 0.05 level.

Table 17. Height growth (ft) of dominant and codominant sweetgum trees between ages 7 and 22.

Treatments and Comparisons	Site	
	Lower Slope	Upper Slope
Treatments		
Control	38.1	37.8
Fertilized	37.0	32.9
Irrigated	30.2	31.6
Irrigated & Fertilized	33.0	29.6
Mean	34.6	33.0
Comparisons		
Fertilized	35.0	31.2
Unfertilized	34.1	34.7
Irrigated	31.6	30.6
Non-irrigated	37.5	35.3

Total Volume Age 22

Site differences in plot volume for sweetgum were not significant (Table 18). However, the interaction of fertilization with site was significant at the 10% level. The volume of fertilized sweetgum on the lower slope was 38% greater than unfertilized trees (2,244 vs 1,625 cubic feet per acre). On the upper slope volume was greater on unfertilized plots (2,175 cubic feet per acre) than on unfertilized plots (2,027 cubic feet per acre) (Table 19).

Although not statistically significant, volume in irrigated plots was less than volume in non-irrigated plots on both slope positions.

Table 18. Analysis of variance for relative plot volume of sweetgum trees at age 22.

Source	df	Sum of Squares	F	Significance
Site	1	221,370	0.60	NS
Rep(Site) error 1	6	4,824,026	-	-
Trt	3	1,397,764	1.27	NS
Fert. vs no fert.	1	479,990	1.31	NS
Irr. vs no irr.	1	445,735	1.21	NS
Fert. x Irr.	1	472,037	1.29	NS
Site x Trt	3	1,279,219	1.16	NS
Fert. x Site	1	1,176,943	3.21	NS
Irr. x Site	1	101,037	0.28	NS
Fert. x Irr. x Site	1	1,238	0.00	NS
Error 2	18	6,605,424		

*=Significant at 0.05 level, NS=Not significant at 0.05 level.

Table 19. Relative plot volume (ft^3/ac) and survival (%) of sweetgum at age 22.

Treatments and Comparisons	Site			
	Lower Slope		Upper Slope	
	Volume	(%)	Volume	(%)
Treatments				
Control	1,674	(64)	2,124	(72)
Fertilized	2,551	(69)	2,209	(78)
Irrigated	1,576	(78)	2,226	(86)
Irrigated & Fertilized	1,938	(75)	1,846	(67)
Mean	1,935		2,101	
Comparisons				
Fertilized	2,244		2,027	
Unfertilized	1,625		2,175	
Irrigated	1,757		2,036	
Non-irrigated	2,112		2,166	

CHAPTER IV

DISCUSSION

Yellow-Poplar

Site

Yellow-poplar was taller on the upper slope than on the lower slope at age 7 (Figure 2A). The better growth on the upper slope is contrary to reports by Smalley (1961, 1964, 1969) who found that yellow-poplar grew best in stream bottoms and on lower slopes. Buckner and Maki (1977) attributed the differences in tree height on the two planting areas to past land use on the lower slope, a factor which was more important than anticipated when the experiment was designed.

Abandoned agricultural lands are considered to be poor sites for yellow-poplar (Russell, 1977). These sites are often low in nutrients and organic matter and soil properties are impaired by frequent cultivation and possibly erosion. The relatively undisturbed nature of the upper slope with well-developed forest soils made this the better of the two sites for yellow-poplar at age 7.

Differences in height of yellow-poplar on the upper and lower slopes were still apparent at age 22 (Figure 2B). Trees were taller on the upper slope. However, the relative difference in height is smaller at age 22 (8%) than at age 7 (30%).

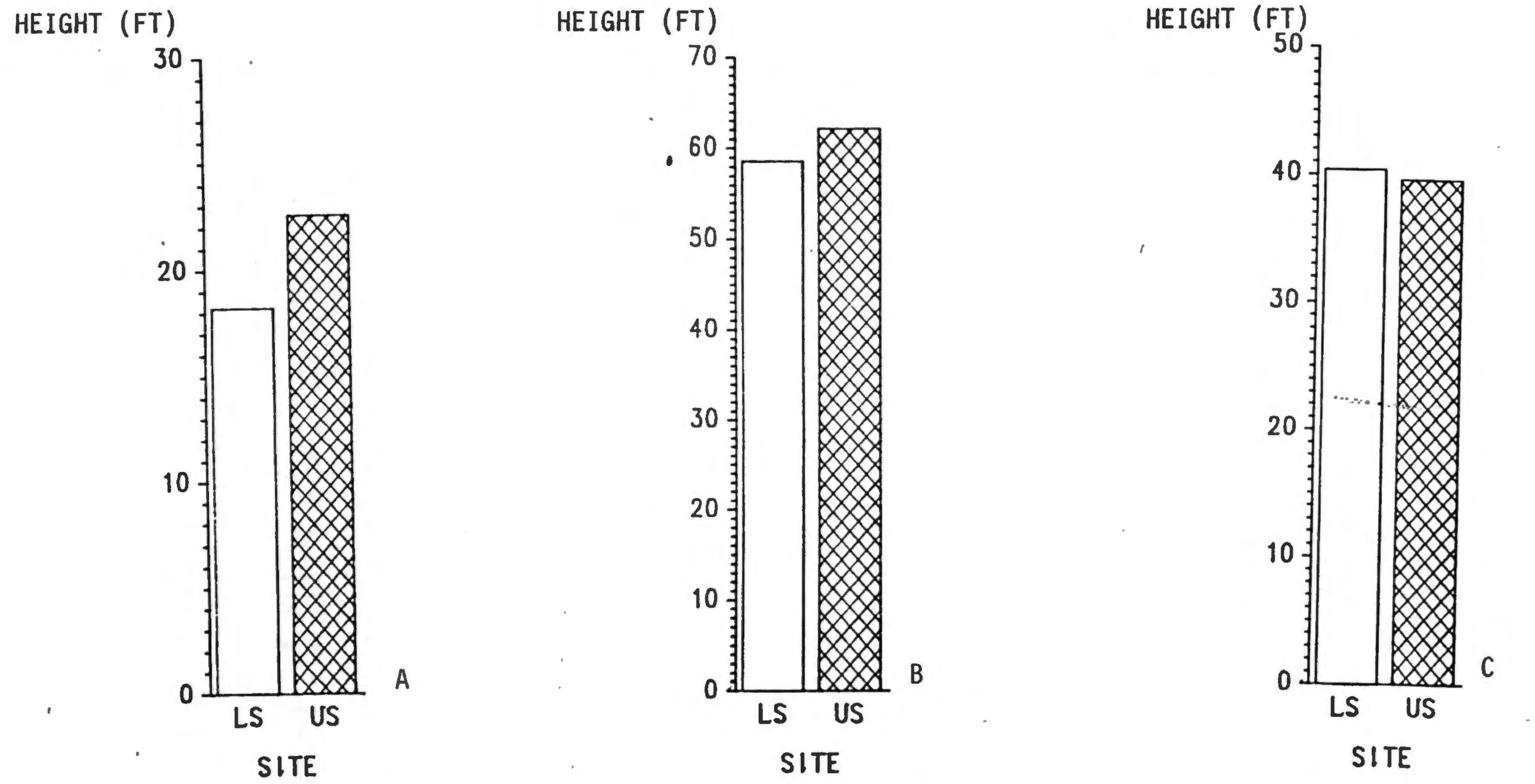

Figure 2. Height (ft) of dominant and codominant yellow-poplar trees on the lower and upper slopes. (LS=lower slope, US=upper slope).
A. Age 7
B. Age 22
C. Height growth between ages 7 and 22

The relative reduction in height differences between the two sites suggests that site quality may have changed over time. It is possible that the lower slope was recovering from the old field condition as trees continued to occupy the site and the time since cultivation increased (Clark, 1964). Carmean, et al. (1976) reported that growing conditions for planted hardwoods were improved on old fields after a rotation of pines or natural invasion of other tree species. Yellow-poplar grew taller when planted in a clearcut portion of a shortleaf pine plantation established on an old field in southern Illinois than on a portion of the old field not occupied by trees (Young, et al., 1969).

Height growth of yellow-poplar on the lower slope did not differ from growth of trees on the upper slope between ages 7 and 22 (Figure 2C). The fact that height growth during this growth period was the same on both sites indicated that productivity of the presumably poorer site (lower slope) was equal to the better site (upper slope). Therefore, productivity of the lower slope has improved with time.

Fertilization

At age 7 fertilized yellow-poplar was taller than unfertilized trees on both lower and upper slopes (Figure 3A). Fertilization appeared to be more effective on the lower slope than on the upper slope. Fertilized trees on the lower slope were 70% taller than unfertilized trees, while on the upper slope the difference in height of fertilized and unfertilized trees was 34%.

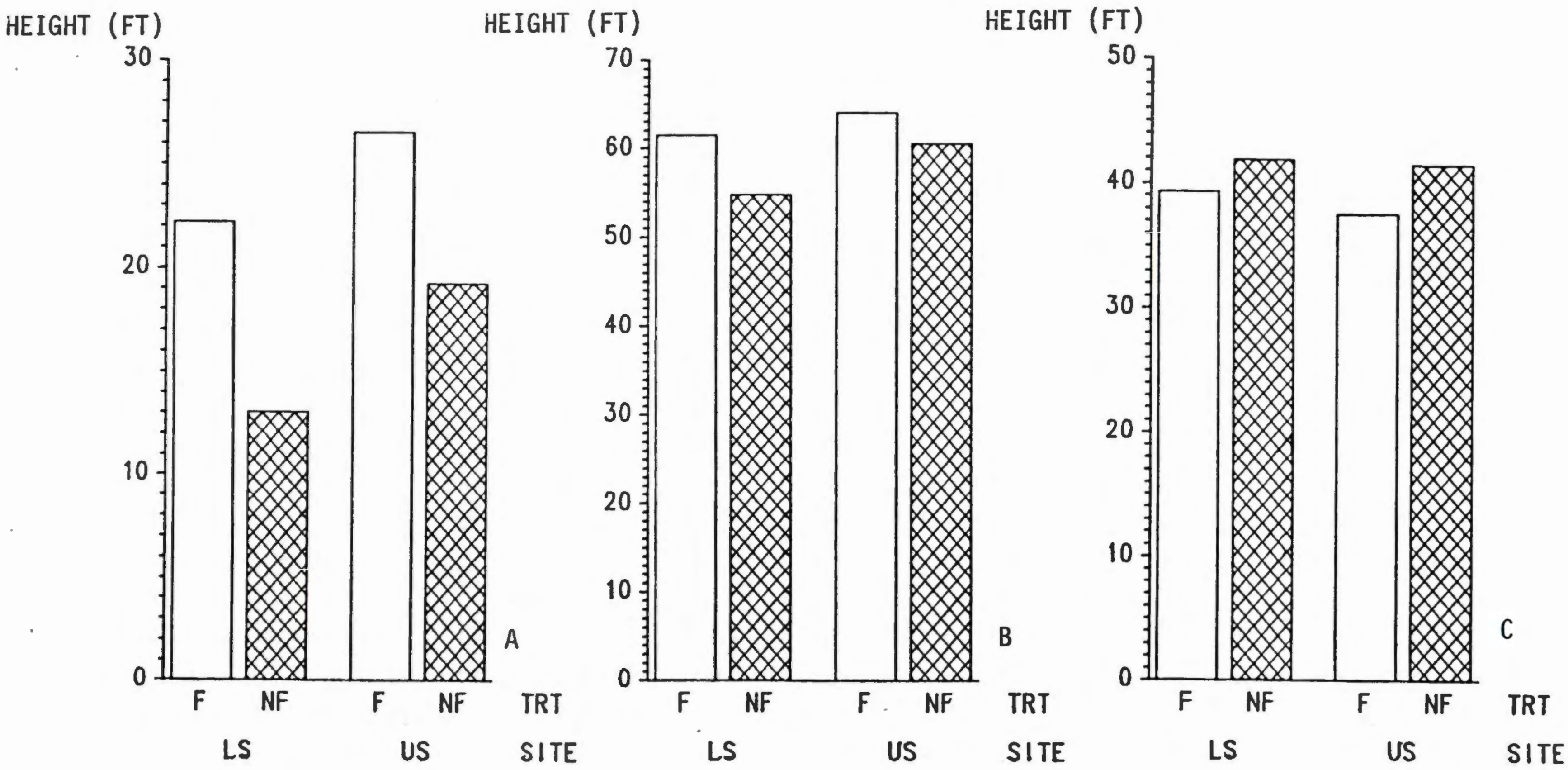

Figure 3. Height (ft) of fertilized and unfertilized dominant and codominant yellow-poplar trees on the lower and upper slopes. (LS=lower slope, US=upper slope, TRT=treatment, F=fertilized, NF=unfertilized)
A. Age 7
B. Age 22
C. Height growth between ages 7 and 22

The greater relative increase in height of fertilized trees on the lower slope could be a result of less fertile soils on the old field site. The greatest growth responses to fertilization have been realized on sites where soil nutrients are most deficient (Beck and Della-Bianca, 1981; Pritchett and Fisher, 1987). The difference in degree of response to fertilization could also be caused by an interaction between fertilizer and soil moisture levels on the two slope positions. Fertilization may have been more effective on the topographically moister lower slope than on the drier upper slope (Brady, 1974).

At age 22 fertilized trees were still taller than unfertilized trees (Figure 3B). The difference in height between fertilized and unfertilized trees decreased with time but was still greater on the lower slope (13%) than on the upper slope (6%). The greater height of fertilized trees at age 22 was due to the initial increase in growth during the first 7 years. The amounts of fertilizer were small and were only intended to last a few years. Fertilizer effects on height and diameter growth of yellow-poplar have generally been short-lived (Beck and Della-Bianca, 1981).

Fertilization did not increase the height growth in the second growth period (Figure 3C). Growth of fertilized trees on the lower slope was 6% less than unfertilized trees, while on the upper slope fertilized trees grew 8% less than unfertilized trees.

The early growth advantage attributable to fertilization had disappeared during the second growth period. Buckner (1972) noted that annual height growth of yellow-poplar was increased initially on fertilized plots but decreased each year through the first growth period. While fertilized trees on both lower and upper slopes were taller at age 22, it was apparent their height advantage at age 22 was the result of the initial increase in height evident at age 7 and not a continued growth response to fertilization.

Irrigation

No differences in height were observed on the lower slope between irrigated and non-irrigated yellow-poplar at age 7 (Figure 4A). The lack of response to irrigation treatments indicated that soil moisture shortages were not as important as other factors in affecting tree growth on the lower slope. Internal soil moisture recharge should have been adequate on this site because of its topographic position.

Irrigation treatments were discontinued after the seventh growing season. By age 22 trees on non-irrigated plots on the lower slope were 7% taller than trees on irrigated plots (Figure 4B). Although there were no significant differences in height related to irrigation on the lower slope at age 7, trees in irrigated plots grew 15% less than trees in non-irrigated plots between ages 7 and 22 (Figure 4C).

At age 7, irrigated trees were 39% taller than non-irrigated trees on the upper slope (Figure 4A). The increase in height of irrigated yellow-poplar suggested that deficiencies of soil moisture were an important factor affecting tree growth on this site. Soil

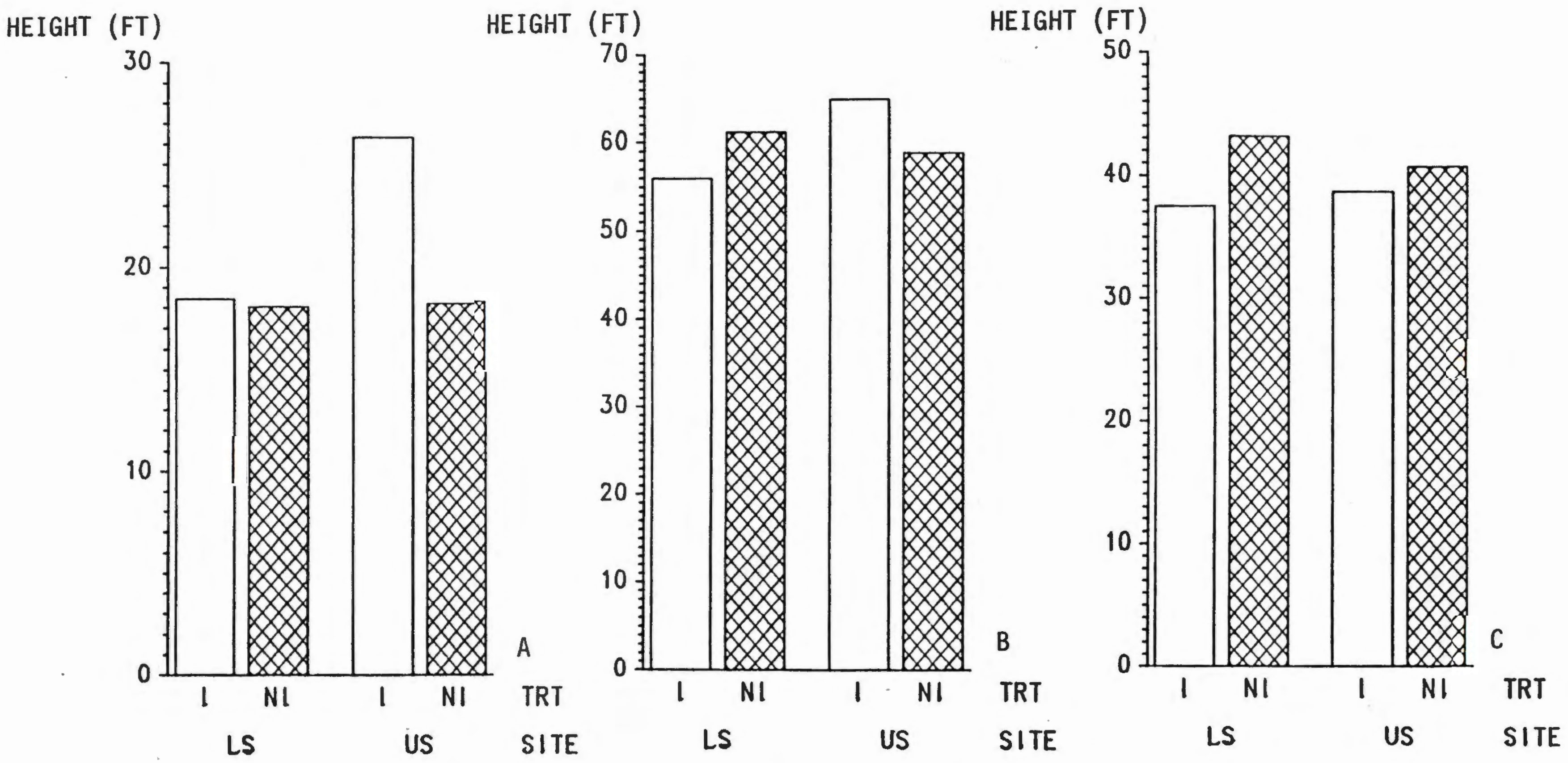

Figure 4. Height (ft) of irrigated and non-irrigated dominant and codominant yellow-poplar trees on the lower and upper slopes. (LS=lower slope, US=upper slope, TRT=treatment, I=irrigated, NI=non-irrigated)
A. Age 7
B. Age 22
C. Height growth between ages 7 and 22

moisture shortages should be expected on the drier upper slope position.

At age 22, irrigated trees on the upper slope were 9% taller than non-irrigated trees. The relative increase in height of irrigated trees decreased over time (39% at age 7). Between age 7 and age 22 height growth was slightly less on irrigated plots than on non-irrigated plots (Figure 4C). However, the initial increase in height was still evident after 22 years. Apparently the irrigated trees have maintained the initial increase in height from irrigation treatments measured at age 7.

During the second growth period trees in irrigated plots grew less than non-irrigated plots on both slope positions. The decrease in height growth of irrigated trees relative to non-irrigated trees indicated that irrigation had no continued positive influence on height growth of yellow-poplar in the second growth period. The effects of irrigation treatments could only be expected to improve growing conditions while these treatments were being applied. Any increases in growth rates associated with irrigation should not be expected once these treatments ceased.

It was not clear why trees on irrigated plots grew less than non-irrigated trees during the second growth period. Changes in the soil environment as a result of irrigation during the first growth period may have affected soil microbial populations including mycorrhizal fungi. The presence of mycorrhizae is essential to successful growth of yellow-poplar, especially on droughty or nutrient poor sites. If adequate mycorrhizal development was suppressed by irrigation during the first growth period, growth of yellow-poplar would have been adversely affected during the second growth period.

Tree roots tend to be concentrated in the soil profile where nutrients or adequate moisture are most available (Barber, 1984). Roots of irrigated trees may have been grown primarily in the upper part of the soil profile where water was readily available from irrigation lines while non-irrigated trees would have been forced to exploit a wider volume of soil to seek adequate moisture. When irrigation was discontinued, irrigated trees would have been at a disadvantage in their ability to obtain water from other parts of the soil profile. They would not have been able to maintain the growth rates they had while being irrigated.

Plot Volume at Age 22

Volume estimates were based on the sum of individual tree volumes of all living trees at age 22 on each plot regardless of their crown position. The volume of each tree was a function of both total height and diameter at breast height (DBH), as well as survival.

The volume in yellow-poplar plots was 44% greater on the upper slope than on the lower slope (Figure 5). The difference in plot volume on the two slope positions can be attributed to the influence of the old field condition on the lower slope in contrast to the forest soil on the upper slope on tree growth and survival.

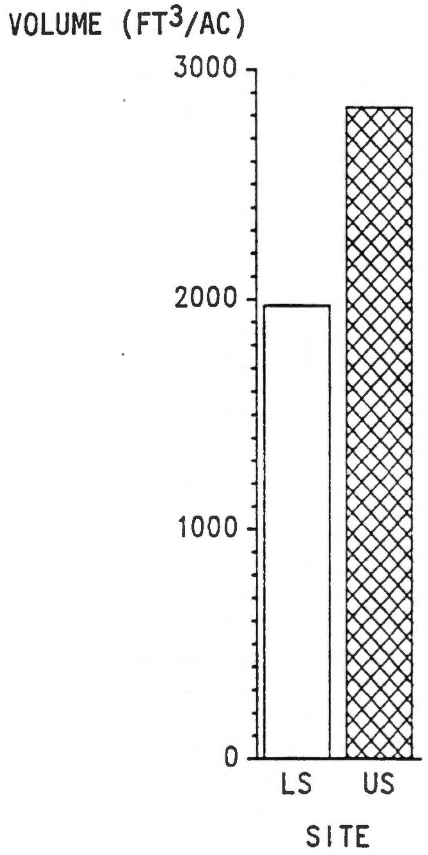

Figure 5. Plot volume (ft^3/ac) of yellow-poplar trees on the lower and upper slopes at age 22. (LS=lower slope, US=upper slope)

The volume in fertilized plots was larger than in unfertilized plots on both slope positions (Figure 6) with the largest difference on the lower slope where fertilized plots contained 90% greater volume than unfertilized plots. On the upper slope the volume in fertilized plots was 27% greater than unfertilized trees.

The increased volume in fertilized plots suggested that nutrient levels on both sites were at less than optimum levels. The greater apparent response to fertilization on the lower slope may have been influenced by an interaction between soil moisture levels on the two slope positions and the effectiveness of the fertilizer treatment. The lower slope site was in a topographic position which could have been inherently moister than the drier upper slope.

Also, survival was higher in fertilized plots on the lower slope (81% in fertilized plots and 83% in irrigated and fertilized plots) than unfertilized plots (69% both in control and in irrigated plots). The greater tree growth found in lower slope fertilized plots contributed to the larger volume on this site. Although survival was lower in fertilized plots on the upper slope (67% in fertilized plots and 81% in irrigated and fertilized plots) than unfertilized plots (44% in control plots and 86% in irrigated plots), the apparent increase in tree growth with fertilization was able to offset the low survival on this site.

The volume in irrigated plots on the lower slope was 42% less than non-irrigated plots (Figure 7). The smaller plot volume in the lower slope irrigated plots was attributable in part to poor

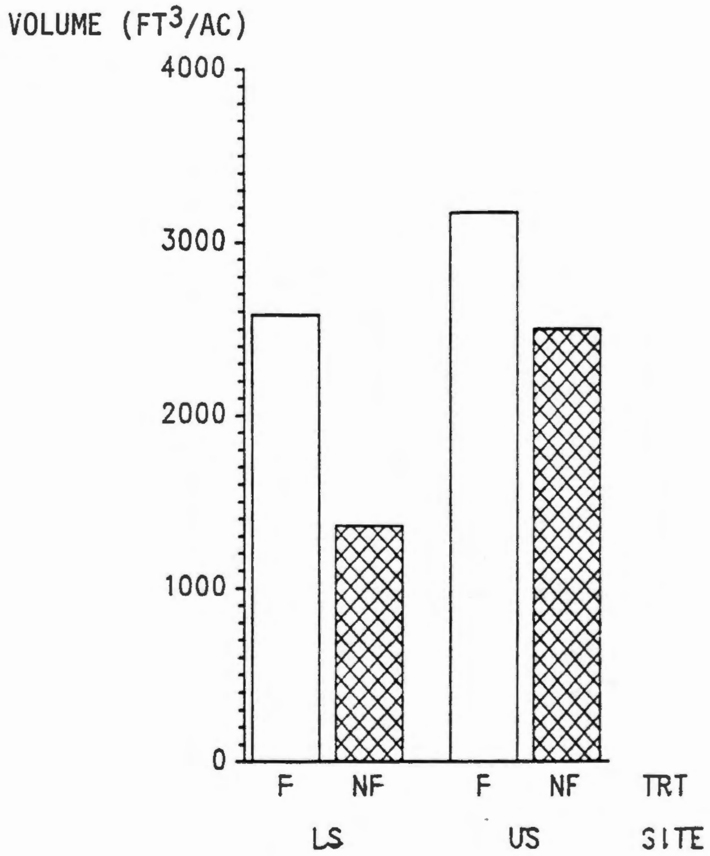

Figure 6. Plot volume (ft^3/ac) of fertilized and unfertilized yellow-poplar trees on the lower and upper slopes at age 22. (LS=lower slope, US=upper slope, TRT= treatment, F=fertilized, NF=unfertilized)

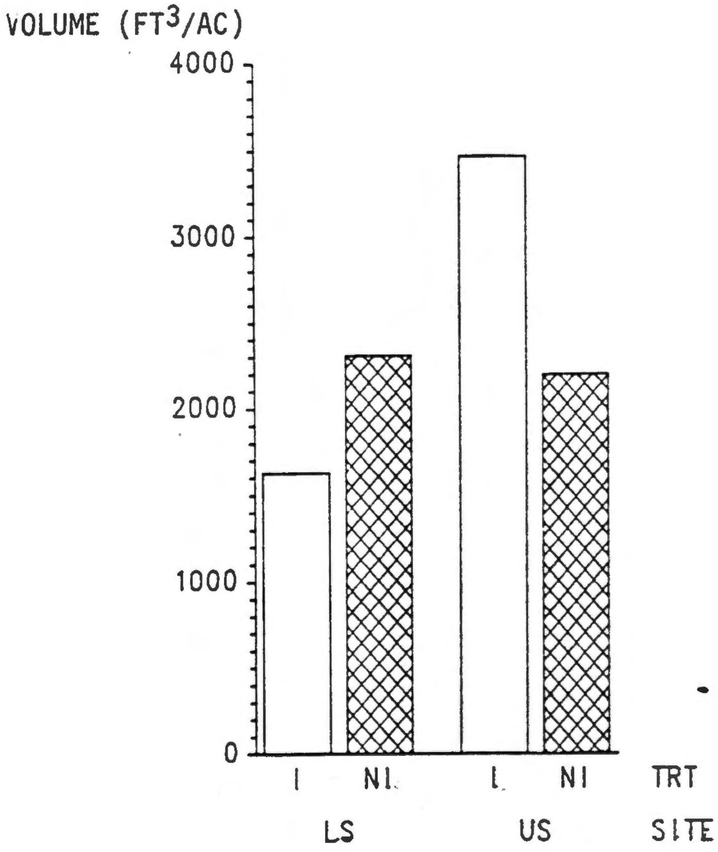

Figure 7. Plot volume (ft^3/ac) of irrigated and non-irrigated yellow-poplar trees on the lower and upper slopes at age 22. (LS=lower slope, US=upper slope, TRT=treatment, I=irrigated, NI=non-irrigated)

height growth in these plots during the first and second growth periods. Survival was also low in irrigated plots on the lower slope, especially on plots receiving only irrigation (69%). The combination of poor height growth and low survival indicated that irrigation was an ineffective treatment on the lower slope.

On the upper slope volume was 58% greater on irrigated plots compared to non-irrigated plots. The height advantage of irrigated trees on the upper slope was a factor influencing the higher volume on irrigated plots. Higher survival in irrigated plots (86% in irrigated plots and 82% in irrigated and fertilized plots) than non-irrigated plots (94% in controls and 67% in fertilized plots) also contributed to the greater volume in irrigated plots.

Sweetgum

Site

No significant differences in height growth of sweetgum between the two slope positions were observed for any of the growth intervals tested (Figure 8A,B,C). This demonstrated the relative insensitivity of this species to site factors and cultural treatments which apparently had an important influence on the growth of yellow-poplar.

Fertilization

At age 7, fertilized sweetgums were significantly taller than non-fertilized trees on both slope positions (Figure 9A). The largest apparent response to fertilization was on the lower slope where fertilized trees were 22% taller than unfertilized trees. On the

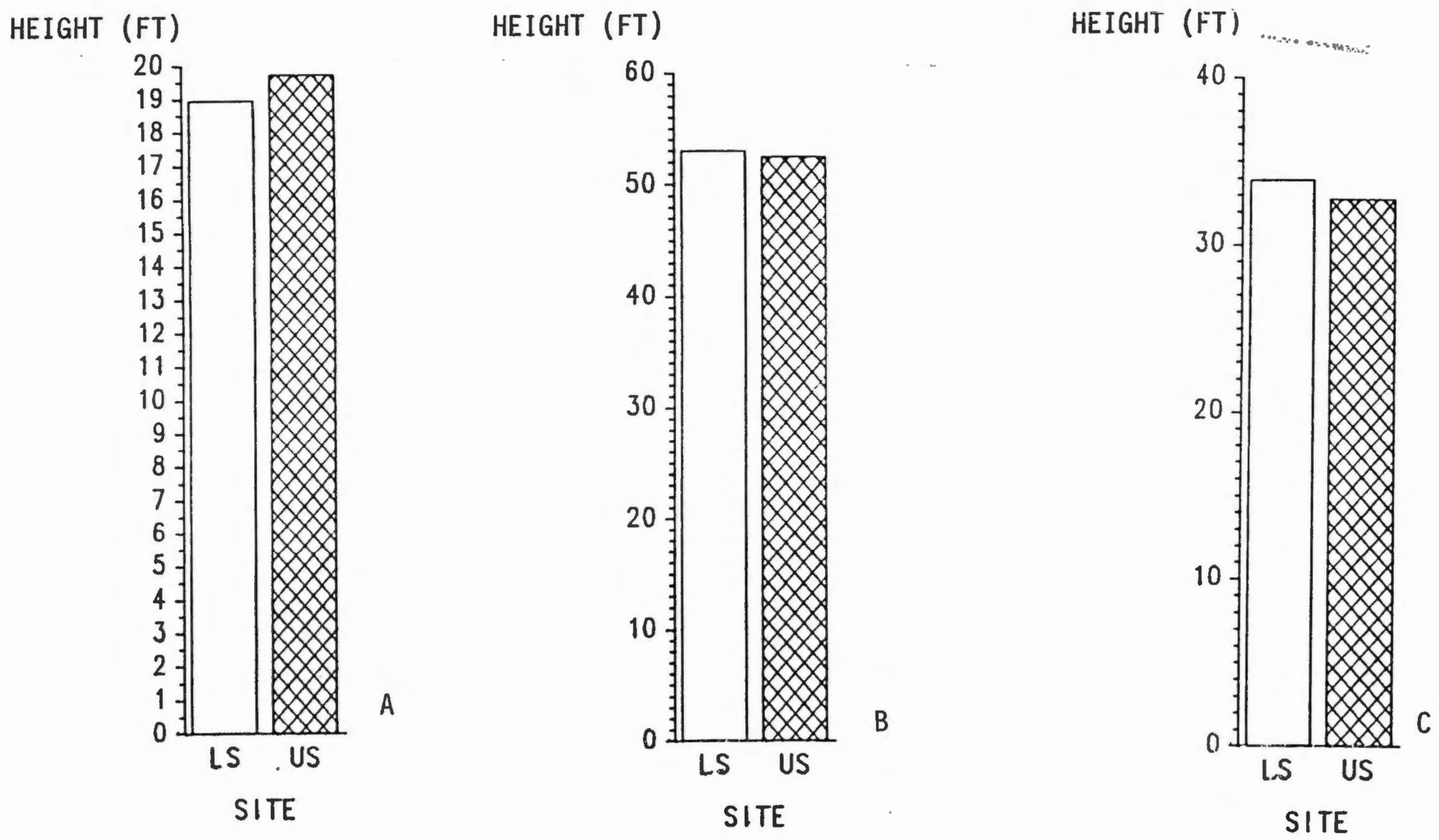

Figure 8. Height (ft) of dominant and codominant sweetgum trees on the lower and upper slopes. (LS=lower slope, US=upper slope)
A. Age 7
B. Age 22
C. Height growth between ages 7 and 22

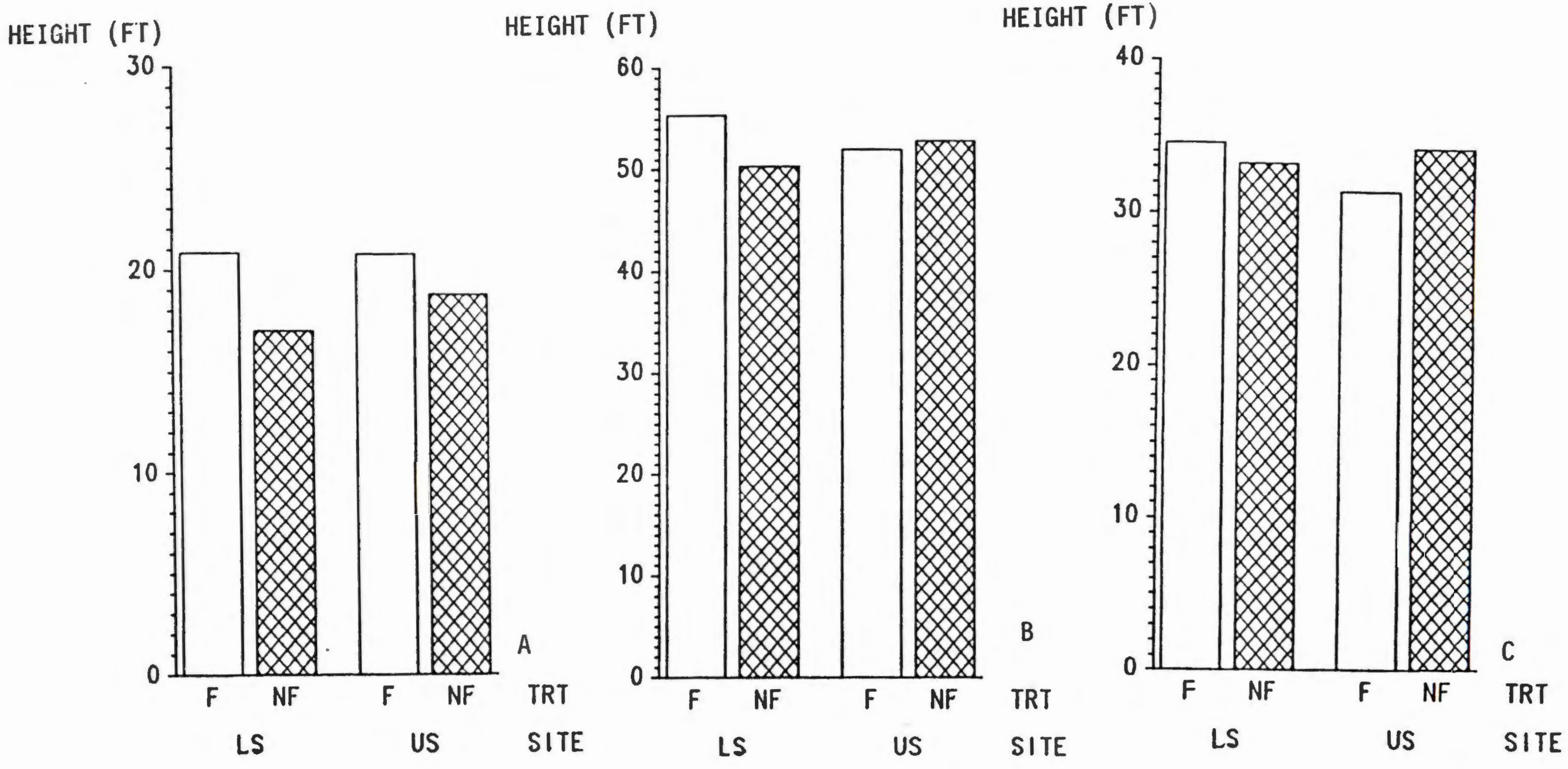

Figure 9. Height (ft) of fertilized and unfertilized dominant and codominant sweetgum trees on the lower and upper slopes. (LS=lower slope, US=upper slope, TRT=treatment, F=fertilized, NF=unfertilized)
A. Age 7
B. Age 22
C. Height growth between ages 7 and 22

upper slope fertilized sweetgums were 11% taller than unfertilized trees.

The larger difference in height of fertilized trees versus unfertilized trees on the lower slope was similar to that observed for yellow-poplar at age 7 although of smaller magnitude. The better apparent response of sweetgum to fertilization on the lower slope may have been related to better utilization of fertilizer by trees on a site where soil moisture was not as limiting to tree growth as on the drier upper slope (Brady, 1974). It also could be related to lower soil fertility on the old field site.

By age 22, no significant differences in height of fertilized and unfertilized sweetgum were observed (Figure 9B). However, fertilized trees on the lower slope were 9% taller than unfertilized trees. On the upper slope there was a difference of only 3% between fertilized and unfertilized trees. The small increases in height that were apparent at age 7 had all but disappeared by age 22. Though not significant, the difference between height of fertilized and unfertilized sweetgum was greater on the lower slope, a pattern similar to that demonstrated by yellow-poplar.

No significant differences in height growth of fertilized and unfertilized sweetgum were observed during the second growth period (Figure 9C). Growth of fertilized trees was only slightly higher (2%) than unfertilized trees on the lower slope. On the upper slope height growth of trees on fertilized plots was 11% less than on unfertilized plots. The decrease in height growth of sweetgum on fertilized plots reflected a slowdown in growth rate as the effect of fertilization diminished over time.

Irrigation

There were no significant differences between height of irrigated and non-irrigated sweetgum at age 7 on either slope position (Figure 10A). Height of irrigated trees on the lower slope was essentially equal to height of non-irrigated trees. However, on the upper slope tree height was 12% greater on irrigated plots compared to non-irrigated plots. Although not significant, the slight increase in height of irrigated trees on the upper slope may have been related to the drier site conditions on the upper slope.

By age 22 total height of irrigated trees was less than non-irrigated trees on both slope positions (Figure 10B). On the lower slope irrigated trees were 12% shorter compared to non-irrigated trees. Height of irrigated sweetgums on the upper slope was 5% less than non-irrigated trees.

It was apparent that height growth of irrigated sweetgum had slowed by age 22. Site conditions would have changed after irrigation was discontinued. The change in soil moisture levels during the second growth period could have had adverse effects on tree growth. It is not known why the difference in height of irrigated and non-irrigated trees was larger on the lower rather than on the upper slope. A similar pattern was observed with yellow-poplar.

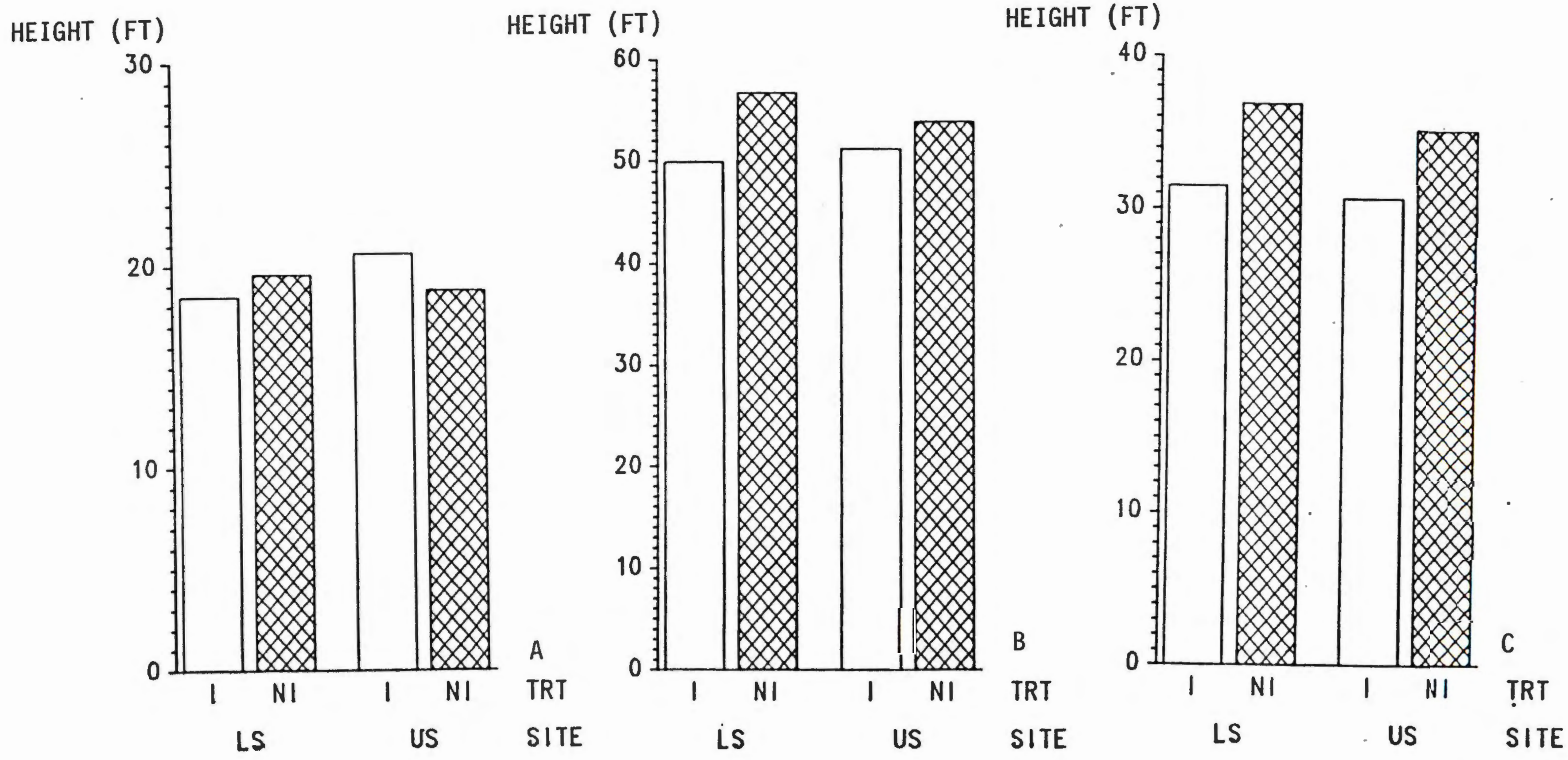

Figure 10. Height (ft) of irrigated and non-irrigated dominant and codominant sweetgum trees on the lower and upper slopes. (LS=lower slope, US=upper slope, TRT=treatment, I=irrigated, NI=non-irrigated)
A. Age 7
B. Age 22
C. Height growth between ages 7 and 22

Height growth of irrigated sweetgum was less than non-irrigated trees during the second growth period (Figure 10C). The difference in growth of irrigated and non-irrigated trees was 19% on the lower slope and 16% on the upper slope. This decrease in height growth of irrigated trees on both slope positions indicated that trees were adversely affected by changes in site conditions following the cessation of irrigation treatments on both slope positions.

Sweetgum also has symbiotic relationships with mycorrhizal fungi. Irrigation treatments may have repressed mycorrhizal development during the first growth period and this may have hindered growth during the second growth period when no irrigation was applied.

Root development was possibly affected by irrigation in other ways. Roots of irrigated sweetgum may have been concentrated in areas of the soil profile where irrigation water was readily available. When irrigation was stopped after age 7, tree roots of irrigated trees would not have been able to extract water from other parts of the soil and this would have caused growth to slow.

Plot Volume at Age 22

No significant differences in plot volume of sweetgum were observed between lower and upper slopes (Figure 11). Sweetgum was less sensitive to site conditions than yellow-poplar and grew well on both the old field soil on the lower slope as well as undisturbed forest soils on the upper slope.

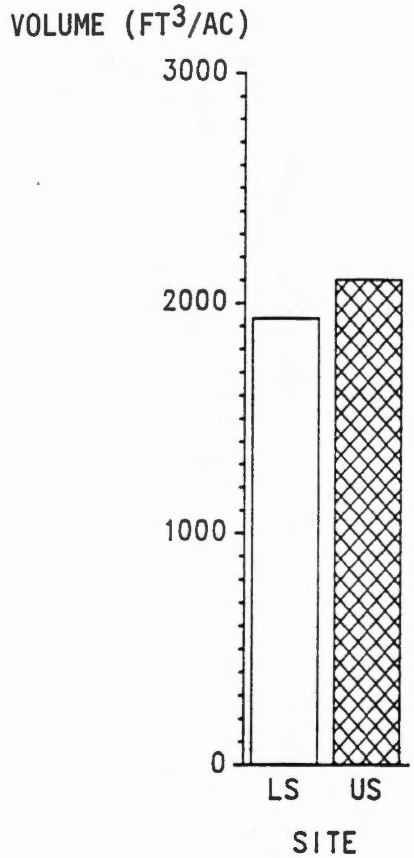

Figure 11. Plot volume (ft^3/ac) of sweetgum trees on the lower and upper slopes at age 22. (LS=lower slope, US=upper slope)

The differences between volume of fertilized and unfertilized sweetgum were not significant at the 5% level. However, there was a significant interaction between site and fertilization at the 10% level. The volume in fertilized plots on the lower slope was 38% greater than in unfertilized plots (Figure 12). On the upper slope fertilized plots had 7% less volume than unfertilized plots. The greater volume in fertilized plots on the lower slope was related more to better height growth of fertilized trees during both growth periods than survival. There was not much difference in survival in fertilized plots (69% in fertilized plots and 75% in irrigated and fertilized plots) than in unfertilized plots (64% in control plots and 78% in irrigated plots). Apparently fertilization was effective and had a positive influence on volume of sweetgum. This was also true with yellow-poplar.

The smaller volume of sweetgum in fertilized plots on the upper slope compared to unfertilized plots was the result of relatively poor height growth and survival in fertilized plots. Survival was less in fertilized plots (78% in fertilized and 86% in irrigated and fertilized plots) on the upper slope than in unfertilized plots (72% in control plots and 86% in irrigated plots). Height growth was better in fertilized plots than unfertilized plots at age 7 but during the second growth period trees grew taller in unfertilized plots than in fertilized plots.

Volume of sweetgum in irrigated plots was less than in non-irrigated plots on both slope positions (Figure 13). The difference

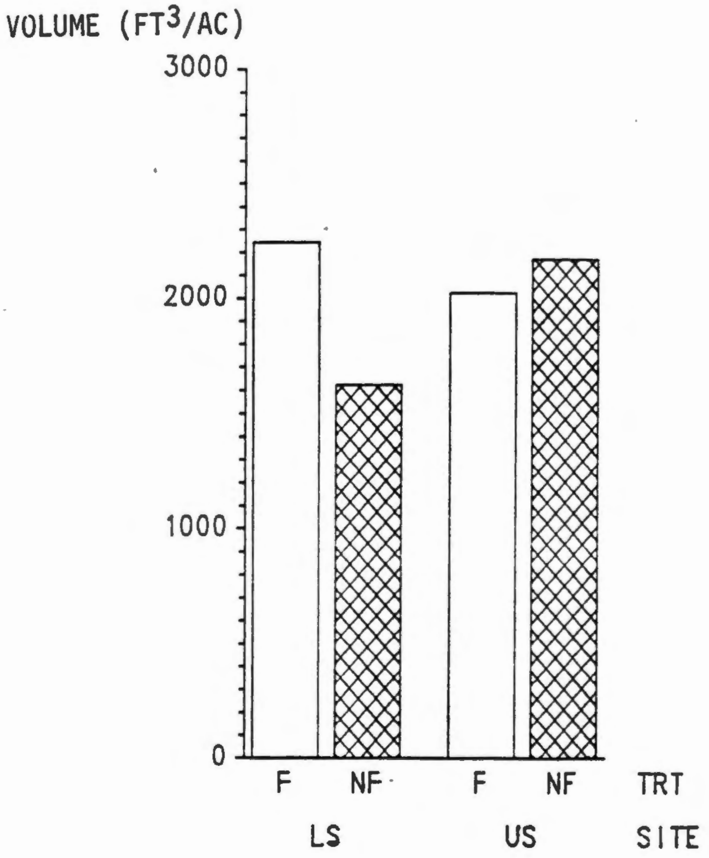

Figure 12. Plot volume (ft^3/ac) of fertilized and unfertilized sweetgum trees on the lower and upper slopes at age 22. (LS=lower slope, US=upper slope, TRT= treatment, F=fertilized, NF=unfertilized)

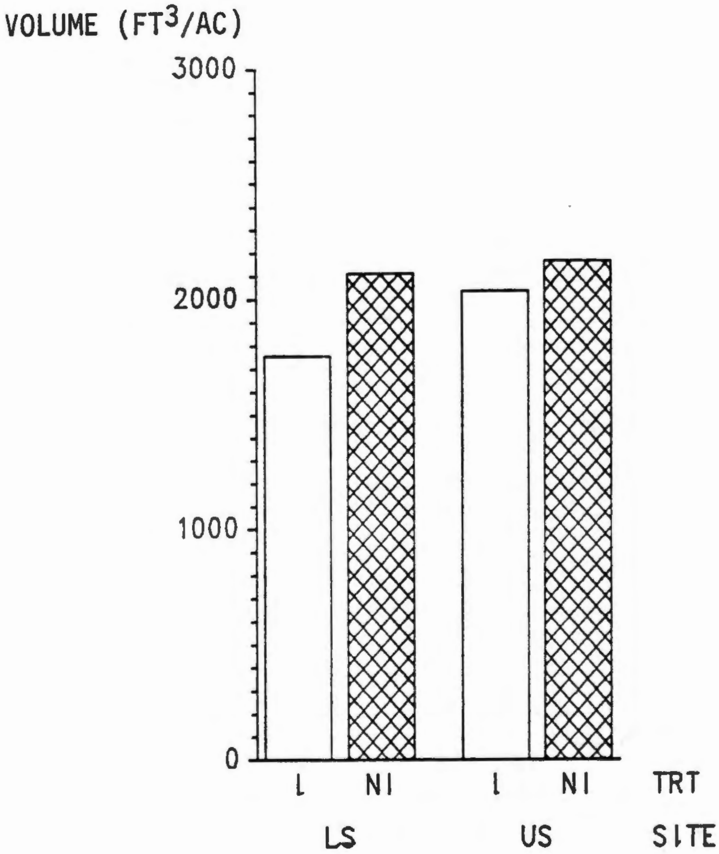

Figure 13. Plot volume (ft^3/ac) of irrigated and non-irrigated sweetgum trees on the lower and upper slopes at age 22. (LS=lower slope, US=upper slope, TRT= treatment, I-irrigated, NI=non-irrigated)

in volume of irrigated and non-irrigated sweetgum was greater on the lower slope (20%) than on the upper slope (6%). The low volume in irrigated plots on the lower slope was probably related more to poor height growth on irrigated plots during both growth periods than survival. Survival was higher in irrigated plots (78% in irrigated plots and 75% in irrigated and fertilized plots) than in non-irrigated plots (64% and 69% in control and in fertilized plots, respectively). Irrigation was not an effective treatment to increase volume of sweetgum on the lower slope.

Poor height growth during both growth periods was the major contributor to the low volume in irrigated plots on the upper slope. There was not much difference between survival in irrigated plots (86% in irrigated plots and 67% in irrigated and fertilized plots) and non-irrigated plots (72% in control plots and 78% in fertilized plots). Apparently, irrigation had no positive influence on volume of sweetgum at age 22 on the upper slope.

At age 22 the volume of sweetgum in fertilized plots was greater than in unfertilized plots only on the lower slope. On the upper slope volume in fertilized plots was less than in unfertilized plots. Irrigation appeared to have a negative influence on volume of sweetgum, especially on the lower slope. Sweetgum demonstrated little sensitivity to treatments which greatly affected the growth of yellow-poplar.

Edaphic Features and Tree Growth

Wide variation among tree heights on plots receiving the same treatments suggested that edaphic features of the two sites strongly influenced tree growth. During the first growth period of this study, it was acknowledged by Buckner and Maki that soil properties were more variable than they had originally anticipated. Variability in soil properties on both upper and lower slopes probably had a strong influence on species performance and possibly on response to treatments.

To simplify the discussion, height growth on untreated plots (controls) will be compared so treatment effects will be eliminated (Figure 14). Undoubtedly, growth responses in treatment plots reflect interactions among treatments and soil-site variables. Evaluation of these interactions is beyond the scope of this study.

Control Plots on Lower Slope, Old Field Site

The untreated plot in replication 1 on the lower slope site was near the upper edge of the old field. Topography was very steep and the plot is on a concave and linear surface (parallel and perpendicular to the contour). It was at the head of a small valley between side ridges. The soil was shallow with an A horizon less than 6 inches deep and overlying a clayey subsoil. Such an area would probably be subject to high rates of geologic erosion even with tree cover, and erosion was likely accelerated when this site was cultivated. The soil contains a high concentration of chert

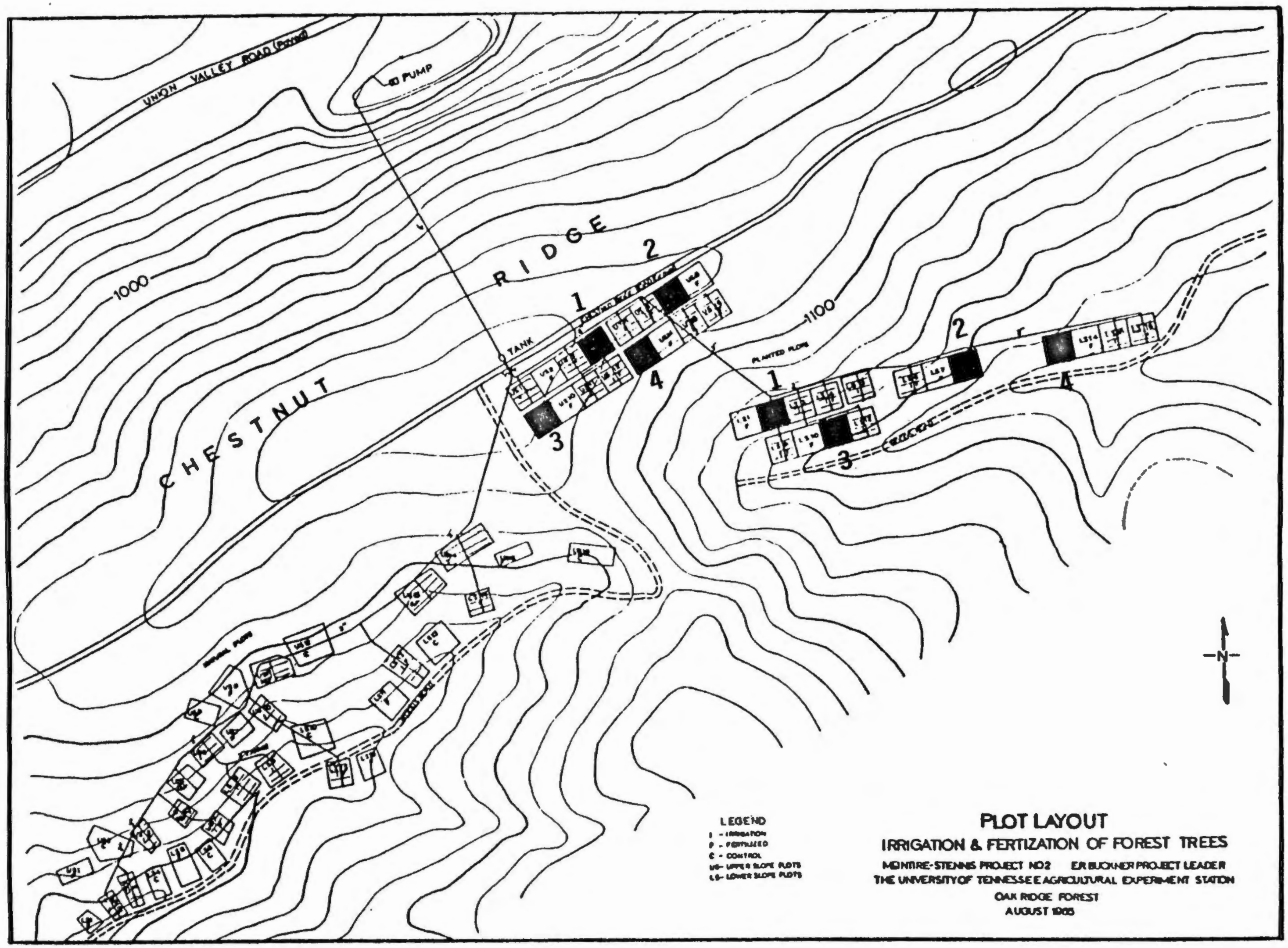

Figure 14. Location and arrangement of plots and treatments applied for both the natural yellow-poplar stand and the planted plots (from Buckner, 1972). (■ =control plots on planted plots; 1, 2, 3, 4=control plots replications 1-4 on the lower and upper slopes.)

fragments which would reduce the moisture storage capacity of this soil.

After 7 growing seasons, mean annual height growth of yellow-poplar, sweetgum, and loblolly pine on this plot were 1.5, 2.2, and 3.0 feet per year, respectively (Figure 15). These growth rates suggest this site was not suited to yellow-poplar but sweetgum and loblolly pine performed relatively well. The site factors associated with this plot support this. In the second growth interval (1971 to 1986), yellow-poplar grew an average of 2.8 feet, sweetgum 2.7 feet, and loblolly pine 2.5 feet per year (Figure 16). This relative increase in growth of yellow-poplar compared to sweetgum is probably related to better site conditions as the lower slope site recovered from the old field condition. Although the average annual growth rate of yellow-poplar was higher than that of loblolly pine during the second growth period, total height of yellow-poplar (52.5 ft) was less than that of the pine (58.6 ft) at age 22. The lower total growth of yellow-poplar relative to that of the pine still suggests this was not a superior site for yellow-poplar.

The control plot of replication 2 was located near the bottom of the slope. Topography was not as steep as in replication 1. The landform shape is linear-concave parallel and perpendicular to the contour. The soil here was deeper with a thicker A horizon. The subsoil was less clayey but still contains a large amount of chert fragments. This plot was in a portion of the landscape where soil material would accumulate from colluvial action and this was

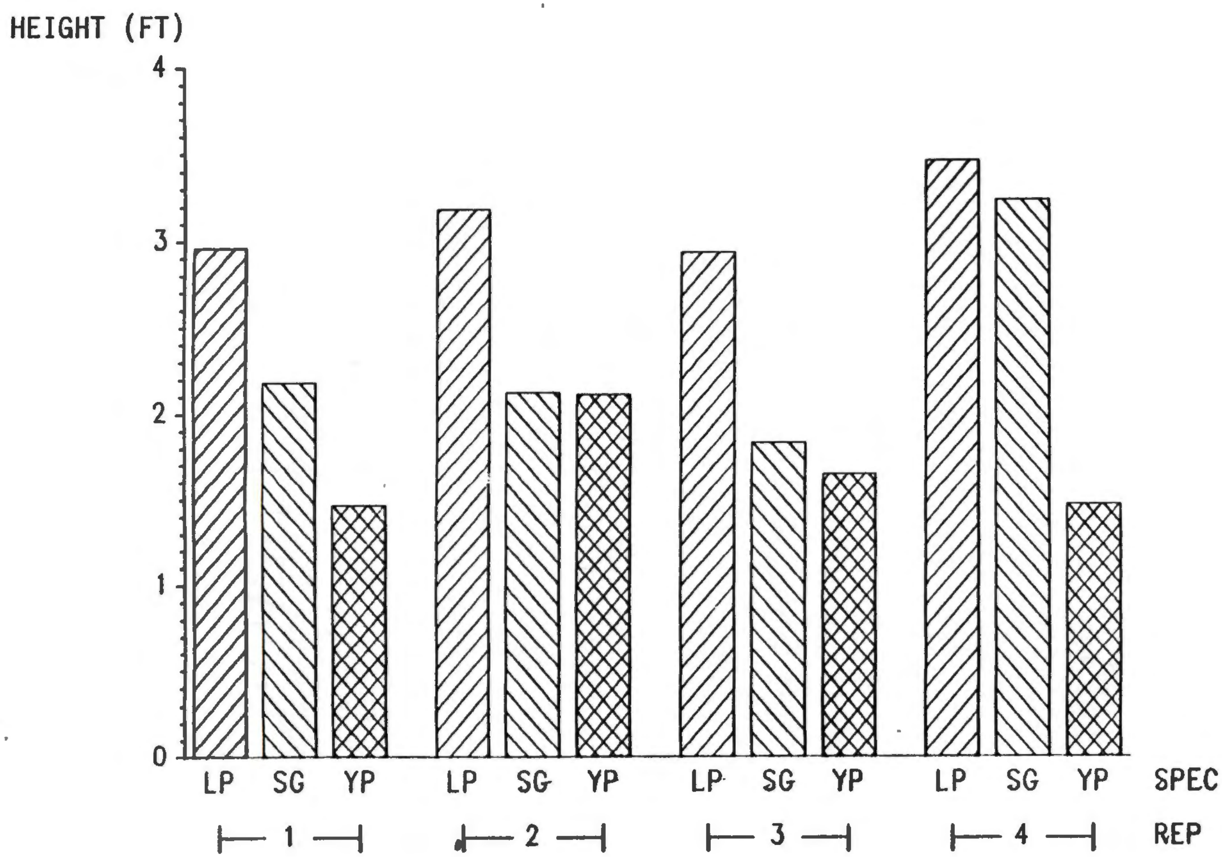

Figure 15. Annual height growth (ft) of loblolly pine, sweetgum, and yellow-poplar during the first growth period on lower slope control plots. (SP=species, LP=loblolly pine, SG=sweetgum, YP=yellow-poplar, REP=replication)

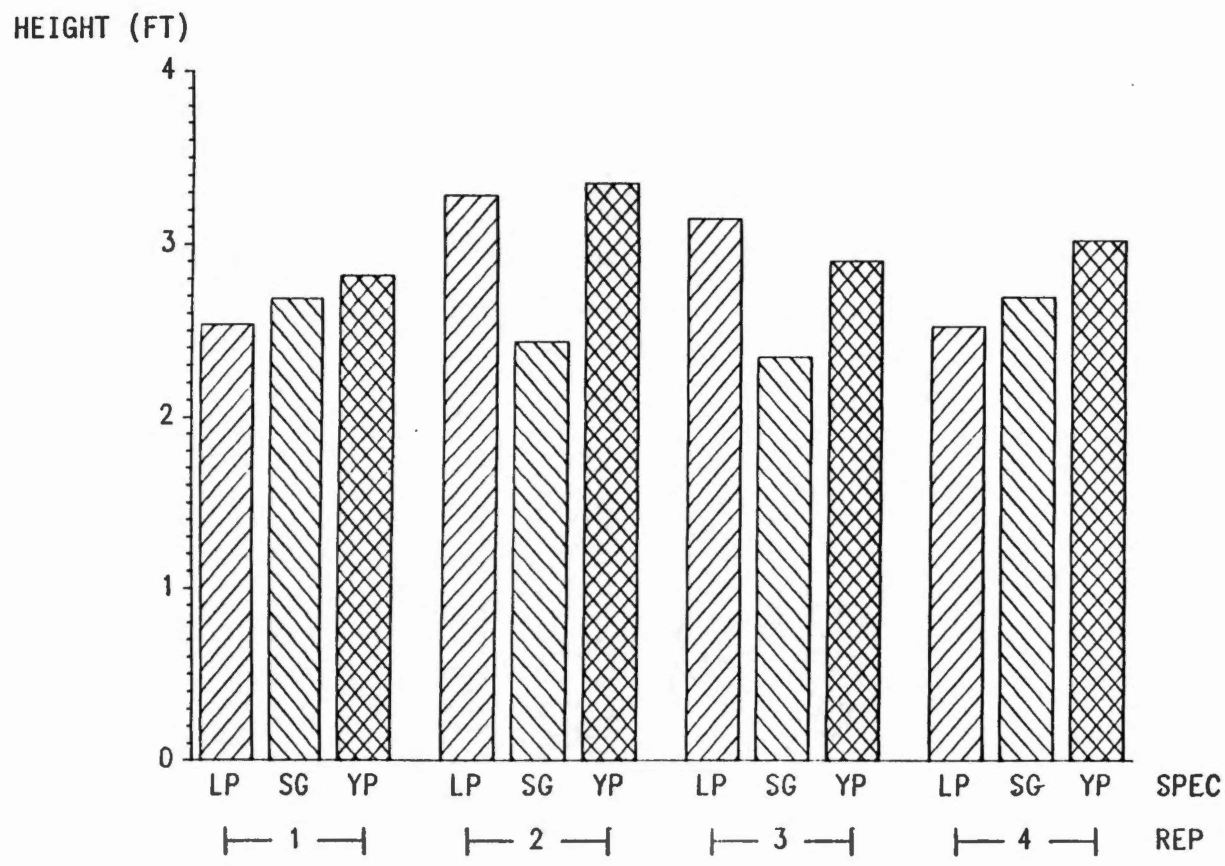

Figure 16. Annual height growth (ft) of loblolly pine, sweetgum, and yellow-poplar during the second growth period on lower slope control plots. (SPEC=species, LP=loblolly pine, SG=sweetgum, YP=yellow-poplar, REP=replication)

reflected in the deeper soil. The landform shape and position made this a potentially adequate site for yellow-poplar.

Mean annual growth of yellow-poplar and sweetgum for the first seven growing seasons was 2.1 feet per year, as compared to 3.2 feet per year for loblolly pine (Figure 15). These growth rates suggested that this site was adequate for yellow-poplar but the pine was still able to outgrow the other two species.

During the second growth period yellow-poplar, sweetgum, and loblolly pine averaged 3.3, 2.4, and 3.3 feet per year, respectively (Figure 16). The increased growth of yellow-poplar relative to the other two species suggests the site was rapidly recovering from the old field condition. Yellow-poplar was taller on this site than it was on the other untreated plots on the lower slope in both 1971 and 1986. The good growth of yellow-poplar during both growth periods indicates this was a good site for this species despite the old field condition. Loblolly pine also grew best on this site during both growth periods.

The control plot for replication 3 lies along the footslope. Topography was quite steep and the landform shape was convex-linear parallel and perpendicular to the contour. These landform shapes shed water and normal geologic erosion is accelerated on these surfaces resulting in a moderately deep soil with a large percentage of chert fragments and a thin A horizon. Such sites have been reported to be poor for yellow-poplar growth (Russell, 1977).

For the first growth interval, mean annual height growth of yellow-poplar, sweetgum, and loblolly pine was 1.6, 1.8, and 2.9 feet per year, respectively (Figure 15). This plot was one of the poorer sites in terms of yellow-poplar growth at this time. Sweetgum performance here was poorest of the lower slope sites, and it was intermediate in quality for loblolly pine.

In the second growth interval, yellow-poplar, sweetgum, and loblolly pine grew at an average annual rate of 2.9, 2.3, and 3.1 feet per year, respectively (Figure 16). The performance of each species relative to 1971 height indicates this was not a high quality site for any of the species tested.

The control plot in replication 4 was moderately steep in the back section of the plot where the yellow-poplar was situated and nearly level in the front portion where the sweetgum and loblolly pine were located. The back section was of linear-concave shape, parallel and perpendicular to the contour. Relief on this replication was not as great as in other areas on the lower slope site. Soil was moderately deep with a thin A horizon with large concentration of coarse fragments throughout the soil profile.

Mean annual height growth of yellow-poplar was the poorest at age 7 on this plot and the control plot of replication 1 (1.5 ft per year). However, sweetgum and loblolly pine achieved their best growth here with average annual growth rates of 3.2 and 3.5 feet per year, respectively (Figure 15). The portion of the plot occupied by these two species closely resembled a flatwoods bottomland site and was very close to a small intermittent stream.

Mean annual height growth for the second growth period was 3.0, 2.7, and 2.5 feet per year for yellow-poplar, sweetgum, and loblolly pine, respectively (Figure 16). Yellow-poplar outgrew the other two species during this period, possibly a result of an improving soil condition. The topographic position and landform shape indicate this would be an adequate site for yellow-poplar. Growth of sweetgum was best on this site in the second growth interval and at age 22 sweetgum was taller here than on the other lower slope control plots.

During the first growth period loblolly pine grew the fastest of the three species on lower slope control plots, while yellow-poplar had the slowest rate of growth. By the end of the second growth period yellow-poplar had the fastest rate of growth in all but one replication. The increase in growth rate demonstrated by yellow-poplar was indicative of the improving site conditions on the lower slope.

The poorest site for yellow-poplar on the lower slope was characterized by very steep slopes with concave linear plot surface shape (parallel and perpendicular to the contour). The soils on this area had a very thin A horizon overlying a clayey B horizon with a high coarse fragment content.

The best site for yellow-poplar on the lower slope had only moderately steep slopes with a linear-concave surface shape parallel and perpendicular to the contour. The soil had a thick A horizon overlying a permeable B horizon. The soil was evidently derived from colluvium and was situated in an inherently moist topographic position at the base of the slope.

Control Plots on Upper Slope, Forest Soil

The soils on the upper slope site were well-developed forest soils and in a relatively undisturbed condition.

Topography was more uniform than on the lower slope (Figure 14, page 86).

The control plot of replication 1 on the upper slope site was located on a landform that was linear along the contour and concave up and down slope. Soil was quite deep and well-drained with very few coarse fragments. The A horizon was a very dark, thick (almost 10 inches) silt loam. Topography was moderately steep.

The three test species were taller in this plot than on any of the other untreated plots on the upper slope site age 7. Yellow-poplar, sweetgum, and loblolly pine had mean annual height growth rates of 2.6, 3.4, and 3.1 feet per year, respectively (Figure 17). The performance of all three species here indicated this was a relatively good site.

In the second growth period, mean annual height growth of yellow-poplar and loblolly pine was 2.7 feet per year and 2.3 feet per year for sweetgum (Figure 18).

The control plot for replication 2 was on a nearly level site. The landform shape was linear-convex both parallel and perpendicular to the landform. The convex portion is a very gentle slope. The soil here was different than that on replication 1. The A horizon was very dark and thick with a silt loam texture. The A overlay a permeable yellow subsoil horizon which was overlying a red somewhat clayey horizon. The yellow color suggested the soil was well to moderately well-drained and could store significant amounts of moisture. Very few coarse fragments were present in the soil.

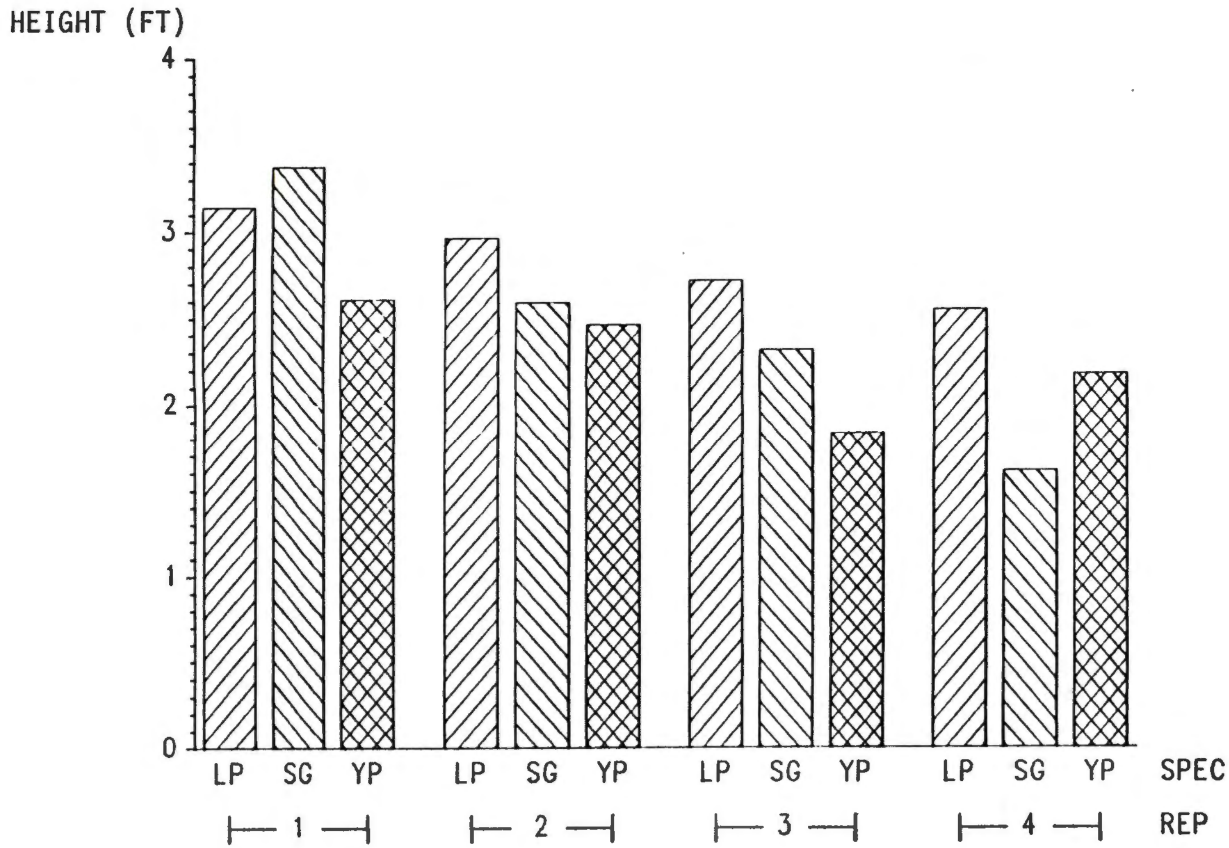

Figure 17. Annual height growth (ft) of loblolly pine, sweetgum, and yellow-poplar during the first growth period on upper slope control plots. (SPEC=species, LP=loblolly pine, SG=sweetgum, YP=yellow-poplar, REP=replication)

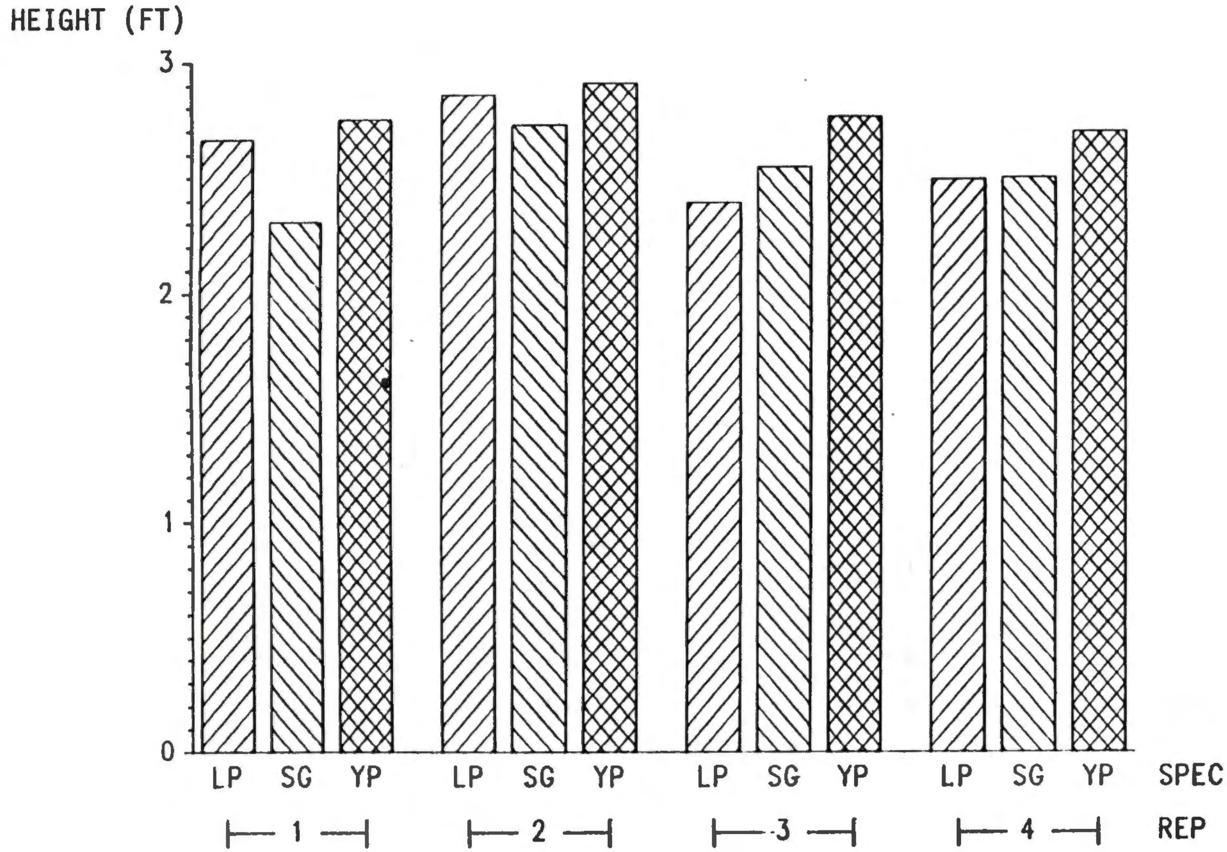

Figure 18. Annual height growth (ft) of loblolly pine, sweetgum, and yellow-poplar during the second growth period on the upper slope control plots. (SPEC=species, LP=loblolly pine, SG=sweetgum, YP-yellow-poplar, REP=replication)

Annual height growth of all three species was good in 1971. Yellow-poplar, sweetgum, and loblolly pine averaged 2.5, 2.6, and 3.0 feet per year, respectively (Figure 17). The relatively good performance of these species and the combination of soil and topographic variables indicate this was a good site.

During the second growth interval yellow-poplar grew an average of 2.9 feet annually, sweetgum 2.7 feet annually, and loblolly pine 2.8 feet annually (Figure 18). Average annual height growth on this plot was the best for all species on upper slope control plots during the second period. The better performance of yellow-poplar relative to the other species indicated this was a good site.

The control plot for replication 3 was located further down the slope. Topography was steeper and the landform shape was linear-linear, parallel and perpendicular to the contour. The A horizon of this soil was dark and had a silt loam texture. The A horizon was thinner than that of replications 1 or 2. This was probably because this plot was on a portion of the landscape more subject to geologic erosion. The B horizon was well-drained and somewhat clayey.

Mean annual growth for the first seven growing seasons of all three species was less here than on replications 1 and 2. Yellow-poplar grew an average of 1.8 feet per year, its poorest performance on the upper slope control plots. Sweetgum and loblolly pine grew an average of 2.3 and 2.7 feet per year, respectively (Figure 17). In the second growth interval mean annual height growth ranged from

2.8 for yellow-poplar to 2.4 feet per year for loblolly pine (Figure 18). Growth was much better for yellow-poplar during this period but topographic and soil variables were not indicative of a high quality site.

The topography of the control plot on replication 4 was very steep. It was located right at the point on the ridge where the linear portion of the slope began. Landform shape was linear-convex parallel and perpendicular to the contour. A different soil was present here. This soil has a thin A horizon over a thick clayey subsoil. The soil contained a very large percentage of chert fragments. The soil was relatively undisturbed but the site was located on a part of the landscape subject to more intense geologic erosion. The landform shape and soil characteristics would make this somewhat droughty.

During the first growth period mean annual height of yellow-poplar was 2.2 feet per year on this plot. Sweetgum and loblolly pine grew an average of 1.6 and 2.5 feet per year, respectively (Figure 17). Despite the site characteristics, yellow-poplar outgrew the sweetgum but yellow-poplar grew less than loblolly pine.

During the second growth period yellow-poplar grew an average of 2.7 feet annually and outgrew the other two species by 0.2 feet annually (Figure 18). Growth of yellow-poplar on this plot was lowest for this species in the upper slope control plots; however, growth differences among control plots were quite small for this species on the upper slope.

On the upper slope the poorest site for yellow-poplar also had steep slopes and a linear-linear or linear-convex surface shape parallel and perpendicular to the contour. Soils had a thin A horizon over a clayey, well-drained horizon with a high coarse fragment content.

On the upper slope the best growth of yellow-poplar was on sites with moderately steep slopes with linear-concave shapes parallel and perpendicular to the contour and linear-convex shapes where the convex slopes were very gentle and the linear portion were nearly level. Soils here had deep A horizons overlying a permeable B horizon with few coarse fragments.

Loblolly pine had the fastest growth rate in the first growth period and yellow-poplar had the slowest growth rate in upper slope control plots. In the second growth period yellow-poplar was the fastest growing species.

In the first growth period the rate of growth of yellow-poplar was slower on control plots on the lower slope than on the upper slope. However, the rate of growth of yellow-poplar on the lower slope control plots during the second growth period was faster than on the upper slope. This was indicative that the lower slope site was recovering from the old field condition and was becoming a better site for yellow-poplar than the upper slope site.

Species Comparison

Insight into comparative species/site relationships was provided by a comparison of the growth of loblolly pine, sweetgum, and yellow-poplar. Although no statistical analysis was performed on the pine data, an examination of treatment means for this species revealed some useful information especially in relation to the performance of yellow-poplar and sweetgum.

Wide differences in performance of the three species were noted at age 7. Yellow-poplar exhibited the greatest sensitivity to modification of site conditions by fertilization on both the lower and upper slopes, and irrigation on the upper slope (Figures 19 and 20). Sweetgum was somewhat responsive to these treatments while loblolly pine showed only slight differences in height among treatments.

Yellow-poplar was responsive to fertilization and irrigation and growth was significantly greater on the undisturbed forest soil on the upper slope site (Figure 20). Irrigation treatments increased height and volume more on the upper slope while response to fertilization was greater on the lower slope site (Figure 19). The tallest yellow-poplar trees were on the upper slope site where fertilization and irrigation treatments were combined.

Sweetgum's response was similar to that of yellow-poplar although the magnitude of the response was less (Figures 19 and 20). Sweetgum grew taller than yellow-poplar under conditions where yellow-poplar growth was poor, but sweetgum was not as tall as yellow-poplar under site conditions that favored yellow-poplar.

Loblolly pine outgrew both species under all site and treatment conditions with the exception of the fertilized and irrigated plots

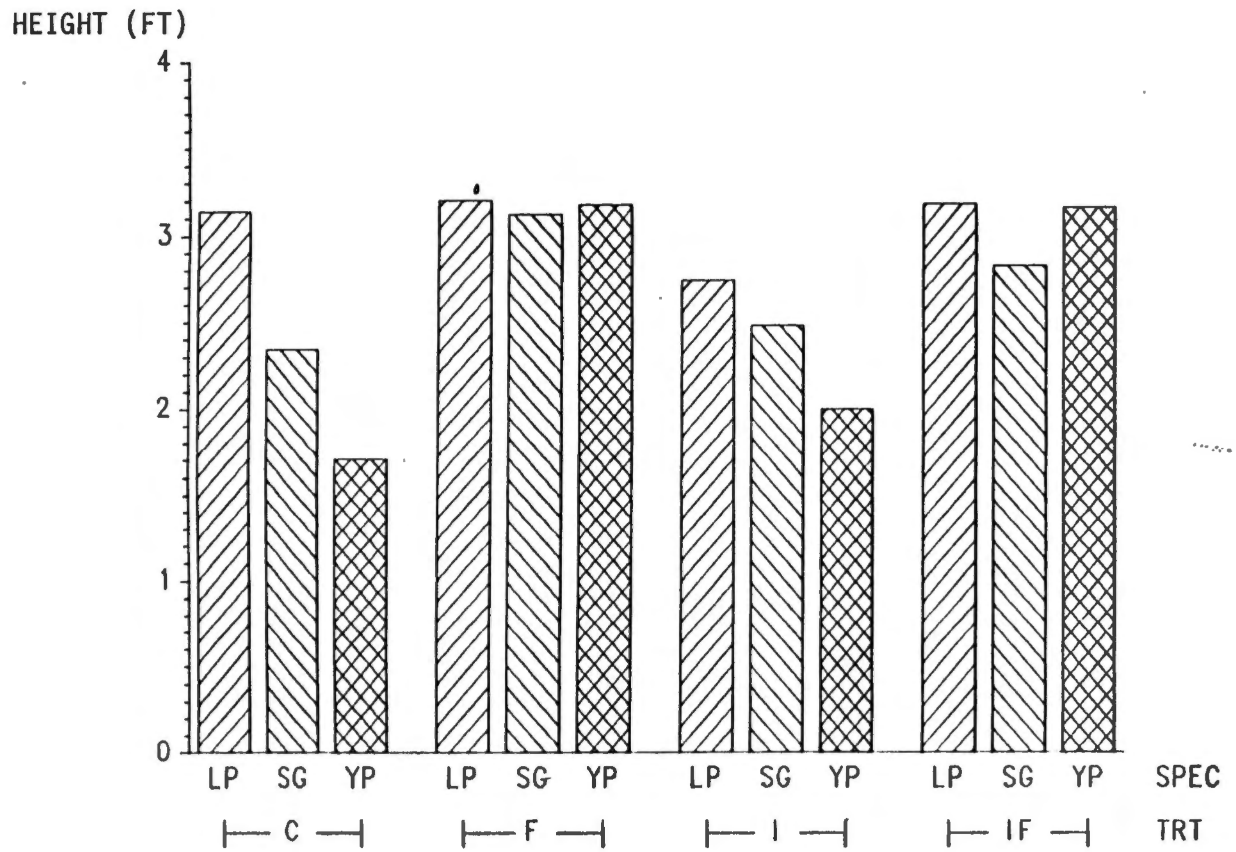

Figure 19. Annual height growth (ft) of loblolly pine, sweetgum, and yellow-poplar by treatment during the first growth period on the lower slopes. (SPEC=species, LP=loblolly pine, SG=sweetgum, YP=yellow-poplar, TRT=treatment, C=control, F=fertilized, I=irrigated, IF=irrigated & fertilized)

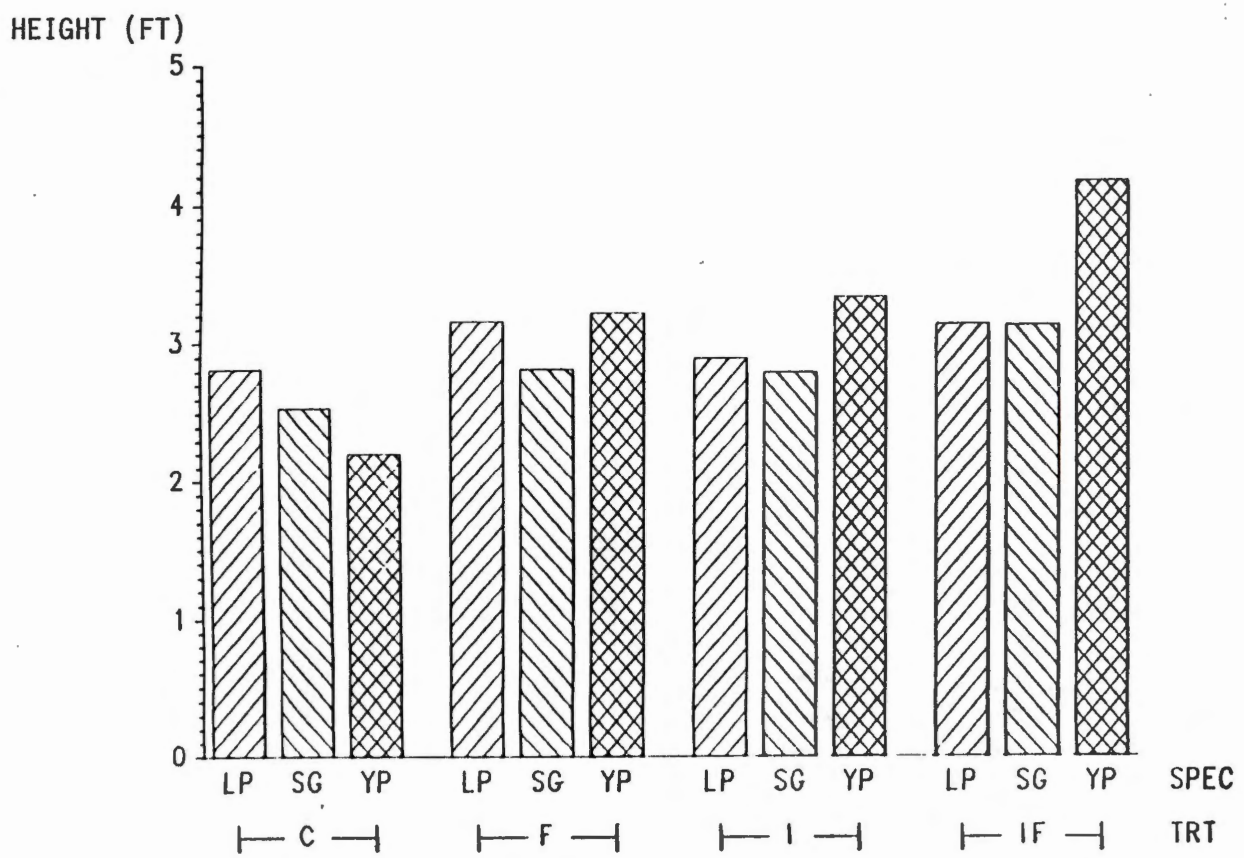

Figure 20. Annual height growth (ft) of loblolly pine, sweetgum, and yellow-poplar by treatment during the first growth period on the upper slope. (SPEC=species, LP=loblolly pine, SG=sweetgum, YP=yellow-poplar, TRT=treatment, C=control, F=fertilized, I=irrigated, IF=irrigated & fertilized)

on the upper slope (Figures 19 and 20), where yellow-poplar was the tallest.

By age 22 the pattern of tree heights for treatment/site combinations was similar to that at age 7 (Figures 21 and 22). The magnitude of the response between treatments had decreased for each species and any increases in tree height in relation to treatments had ceased during the second growth period.

Yellow-poplar exhibited the same pattern of response to treatments at age 22 that was evident at age 7 (Figures 21 and 22). Height was greater on fertilized and irrigated plots and the tallest trees were on areas where the two treatments had been applied together on the upper slope site (Figure 22). Fertilized trees were tallest on the lower slope site but a marked decrease in relative height was noted on irrigated plots on this site (Figure 21). These trends illustrate the site sensitive nature of this species.

The height of sweetgum after 22 years demonstrated little growth response to fertilization and irrigation treatments on the upper slope site (Figure 22). However, an apparent response to fertilizer treatments was still evident on the lower slope site (Figure 21). The height pattern of sweetgum among treatments on the lower slope site was similar to that of yellow-poplar but total height was less than that of yellow-poplar.

There was little height variation among treatments means for loblolly pine (Figures 21 and 22). The tallest trees at age 22 were on the lower slope site where the pine consistently outgrew yellow-poplar and sweetgum. The height of yellow-poplar where fertilization

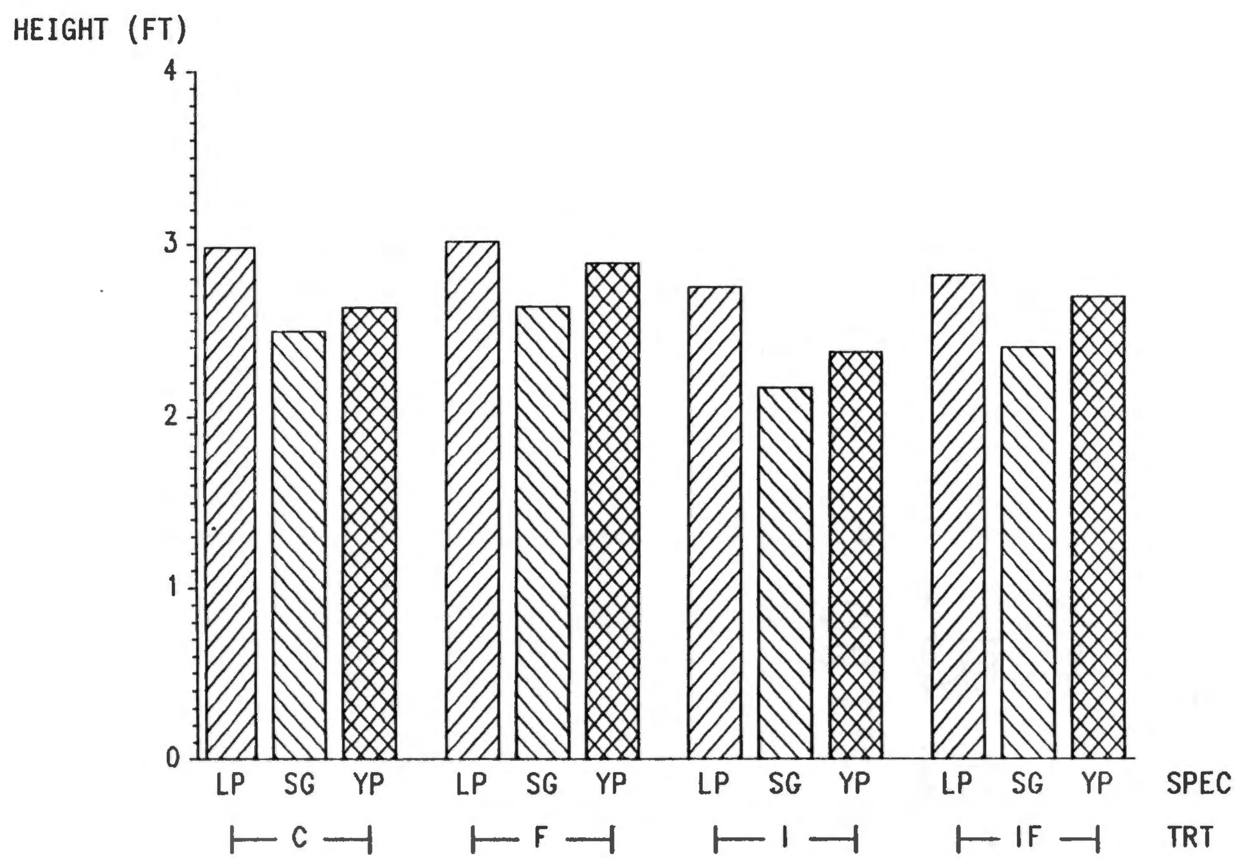

Figure 21. Annual height growth (ft) of loblolly pine, sweetgum, and yellow-poplar by treatment during the first and second growth periods on the lower slope. (SPEC=species, LP=loblolly pine, SG=sweetgum, YP=yellow-poplar, TRT=treatment, C=control, F=fertilized, I=irrigated, IF=irrigated & fertilized)

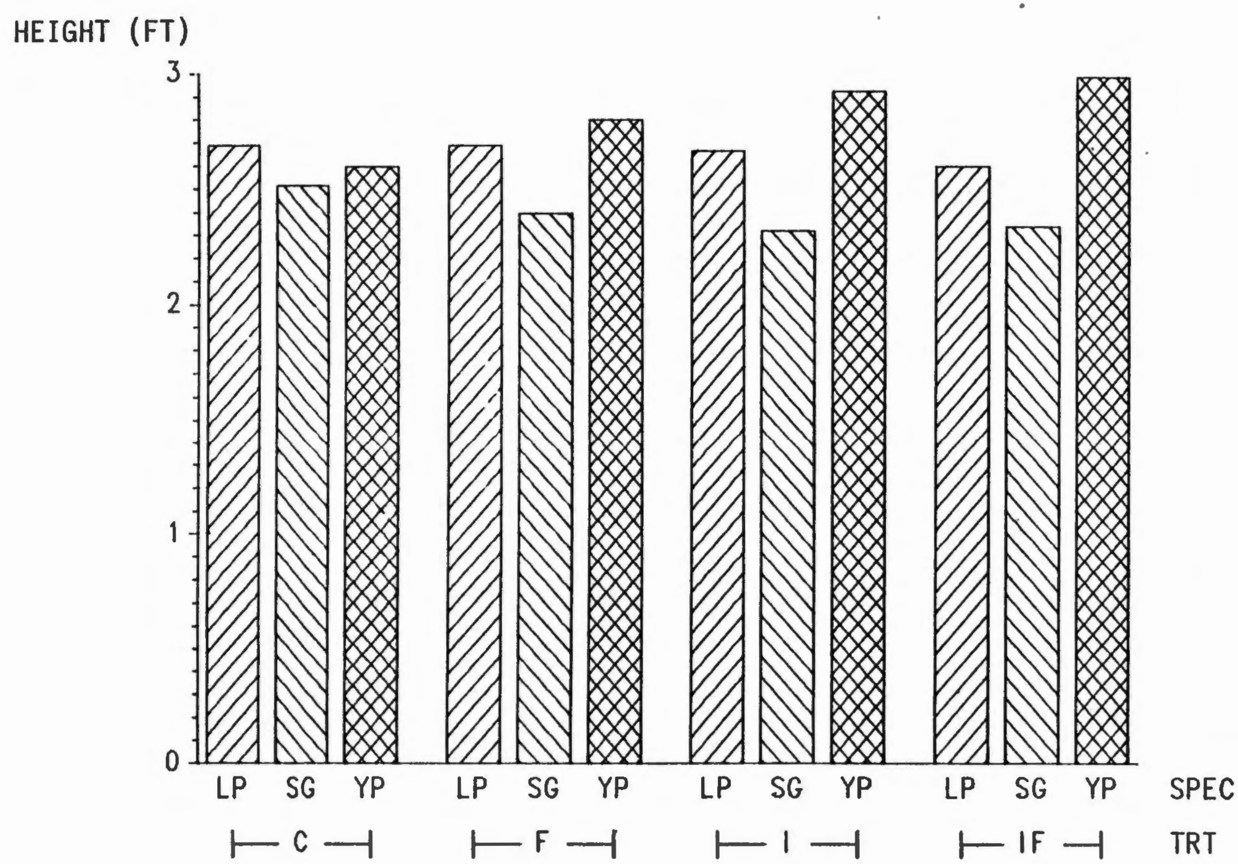

Figure 22. Annual height growth (ft) of loblolly pine, sweetgum, and yellow-poplar by treatment during the first and second growth periods on the upper slope. (SPEC=species, LP=loblolly pine, SG=sweetgum, YP-yellow-poplar, TRT=treatment, C=control, F=fertilized, I-irrigated, IF=irrigated & fertilized)

and irrigation treatments were combined on the upper slope site was still greater than that for loblolly pine under any site or treatment combination after 22 years.

A comparison of height growth in the second growth period on treatment plots for the three test species reveals a very different pattern from that noted for mean height at ages 7 or 22 (Figures 23 and 24). During this time period, growth of yellow-poplar and sweetgum have shifted radically; growth of loblolly pine essentially was unchanged.

The height growth of yellow-poplar indicated that during the second growth interval all treatment effects had apparently worn off. The best growth on both upper and lower slope sites had shifted to control plots (Figures 23 and 24). The general trend of height growth on both sites was controls > fertilized > irrigated > fertilized and irrigated. On the upper slope site this was essentially the reverse of the growth pattern found during the first growth period. While it was not surprising that the effects of the small fertilizer application and short-term irrigation treatment did not persist over 22 years, the reverse pattern is difficult to explain.

The best growth during the second growth interval was on the lower slope site. This suggested the site quality of the old field was changing over time. Carmean, _et al_. (1976) reported similar results for growth of hardwood species planted on an old field site in Indiana. He found that the best growth of test species was on areas of the old field that had been occupied by forest tree species prior to planting the hardwoods.

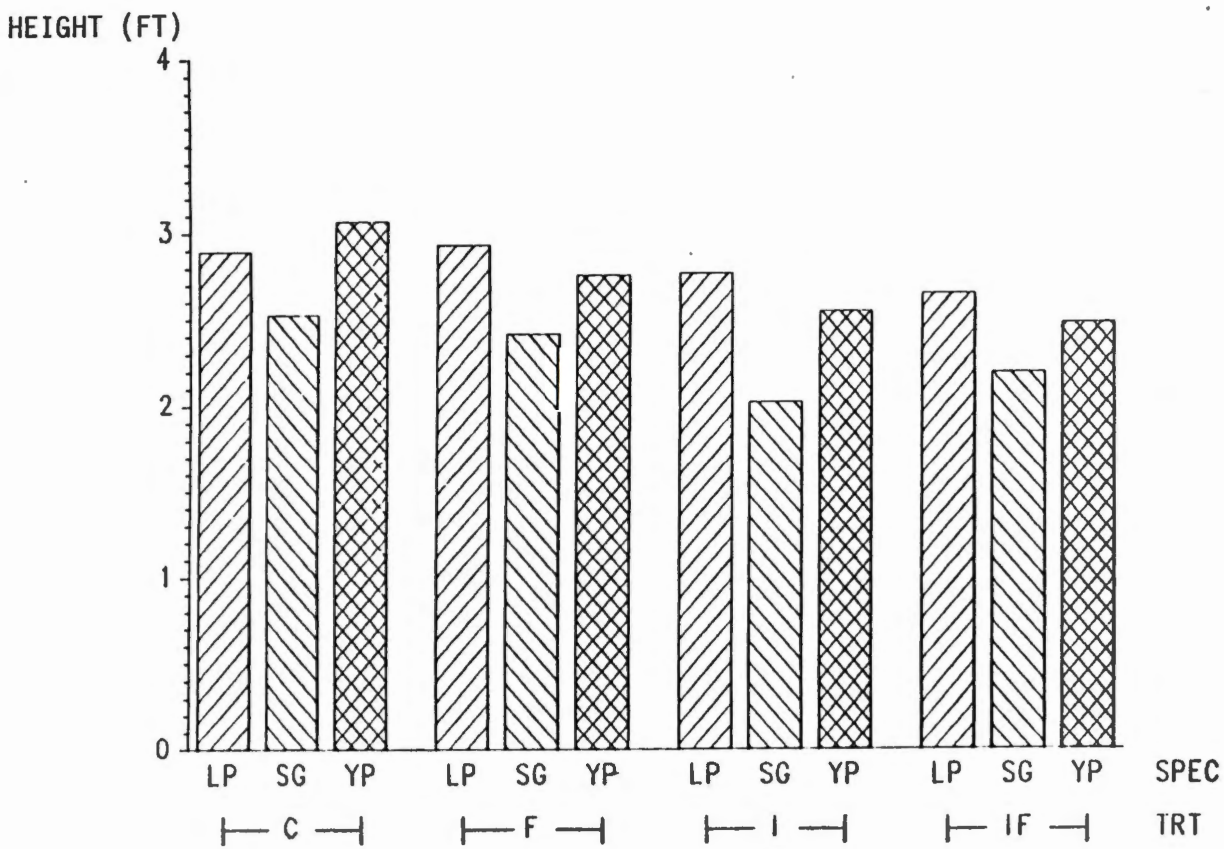

Figure 23. Annual height growth (ft) of loblolly pine, sweetgum, and yellow-poplar by treatment during the second growth period on the lower slope. (SPEC=species, LP=loblolly pine, SG=sweetgum, YP-yellow-poplar, TRT=treatment, C=control, F=fertilized, I=irrigated, IF=irrigated & fertilized)

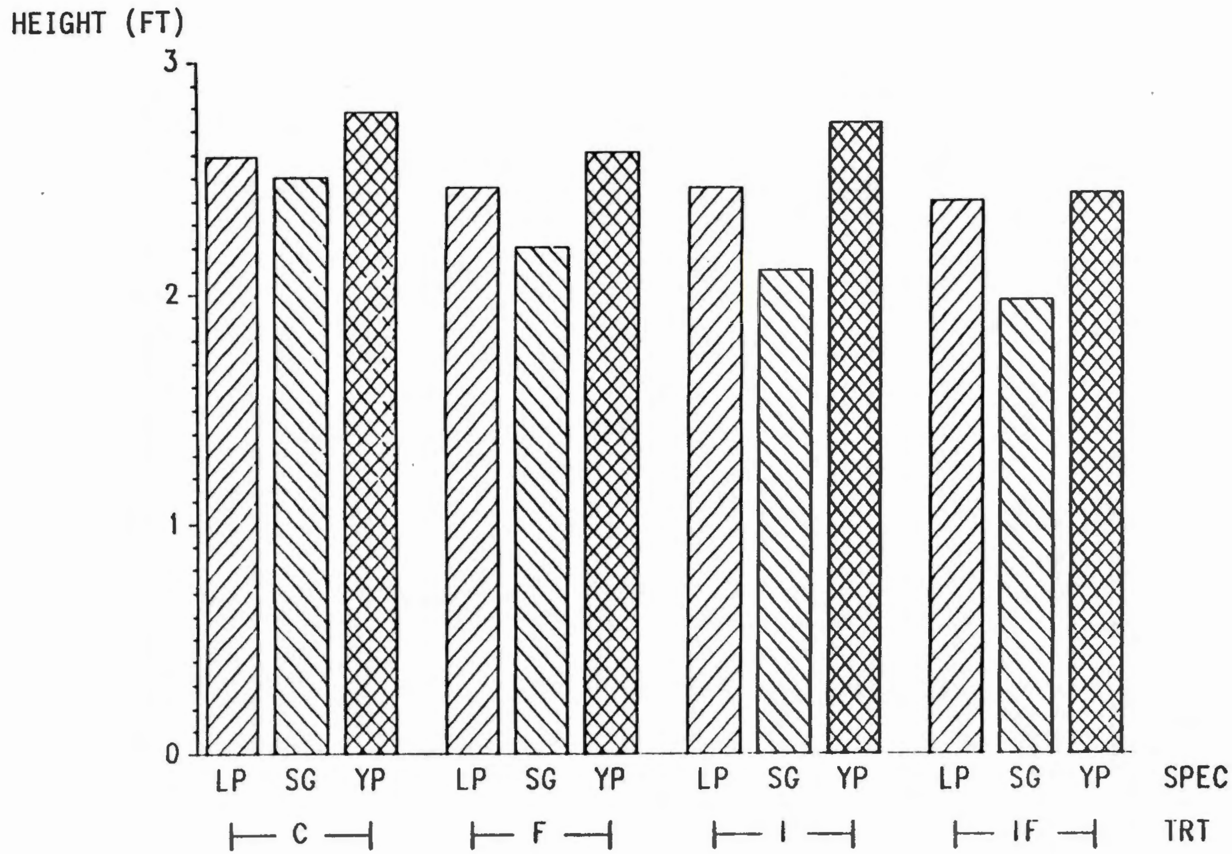

Figure 24. Annual height growth (ft) of loblolly pine, sweetgum, and yellow-poplar by treatment during the second growth period on the upper slope. (SPEC=species, LP=loblolly pine, SG=sweetgum, YP-yellow-poplar, TRT=treatment, C=control, F=fertilized, I=irrigated, IF=irrigated & fertilized)

Prior to this study (up to 1964) the lower slope site supported a dense stand of 22-year-old Virginia and shortleaf pines. Apparently this forest cover had begun the rejuvenation of this site prior to the establishment of this study. Conditions at that time were still severe enough to be detected by growth of a site-sensitive species like yellow-poplar between ages 7 and 22. However, 15 years later this effect on height growth, though apparent in total height of this species at age 22, was not detectable when growth in the second growth period was analyzed separately.

The pattern of height growth for sweetgum was very similar to that of yellow-poplar (Figures 23 and 24). Trees on control plots were outgrowing trees on the previously treated plots and best growth was concentrated on the lower slope site.

The growth pattern for loblolly pine between ages 7 and 22 was similar to that of the first 7 years (Figures 23 and 24). The best growth was on the lower slope site and little variation in height growth was noticeable among treated plots.

The dramatic reduction in growth of both yellow-poplar and sweetgum on treated plots during the second growth period is confusing. It is apparent this decrease in growth is more than just of treatment effects diminishing over time. There are several plausible explanations to explain this situation.

During the first growth period, environmental conditions were changed in treated plots. This probably affected populations of soil flora and fauna. Increased fertility on fertilized areas and changes in moisture regimes on irrigated areas would create vastly different sets of conditions on these sites. During the first growth period the trees planted in fertilized and/or irrigated areas became "conditioned" to these environments. When treatments ceased the soil environment changed radically and, as a result, the populations of soil fauna and flora probably changed as conditions were altered. Tree growth could have been adversely affected by changes in soil biology during the second growth period. Yellow-poplar and sweetgum both have mycorrhizal relationships that could have been adversely affected by the changes in soil organisms. Mycorrhizal development is weak or virtually non-existent on high fertility sites (Pritchett and Fisher, 1987).

It is also possible that fertilizer and irrigation treatments caused trees to grow more rapidly at an early age relative to untreated (control) trees. During this period of rapid growth tree crowns were expanding in treated trees at faster rates than controls due to better growing conditions. As fertilizer effects diminished over time and irrigation treatments ceased, the growing conditions became insufficient to support the larger live crown ratios of treated trees and a phase of crown reduction began. Meanwhile, trees on untreated plots reached a phase of faster growth as they matured and their crowns were expanding while the crowns of treated trees were diminishing. The larger crowns of controls relative to those of treated trees would allow them to produce more photosynthate and grow at a faster rate than the previously treated trees.

Another explanation for the reduction in tree growth during the second growth period on treated plots may be the mineralization of soil organic matter reserves under different soil conditions due to treatments. Organic matter content in soils on the upper slope was probably higher compared to lower slope soils since organic matter content is generally higher in forest soils than old-field soils. When tree cover was removed prior to planting in 1965 soil temperatures on both sites would have increased. The increase in soil temperature accompanied by changes in site quality associated with treatments could have caused organic matter reserves to decompose at faster rates, particularly on the upper slope. The release of nutrients bound in organic matter may have significantly enhanced the available nutrient pool on plots receiving fertilization and irrigation. On plots which received both treatments the mineralization rate of organic matter may have been higher than when either treatment was applied separately. This enhanced fertility may help explain the faster growth on the upper slope dueing the first growth interval.

As trees grew larger and their crown canopies expanded and a new litter layer developed, tree crowns closed and the shaded soils became cooler. Decomposition rates would decrease as a result of the cooler soil temperatures and the organic matter content of the soils would stabilize. The reduction in the rate of decomposition would slow the release of nutrients from organic matter. As site conditions changed when irrigation treatments were discontinued and the fertilizer application was utilized, the decrease in mineralization rates became more pronounced.

This was possibly a factor in the reduction in tree growth on treated plots relative to controls evident during the second growth interval. Carmean, et al. (1976) reported a similar decrease in growth of planted yellow-poplar and sweetgum on an old field in Indiana. Early growth was better on sites that had supported tree cover following abandonment but diminished at an earlier time than tree growth on a treeless area. They attributed part of this decline in growth to faster mineralization of organic matter reserves and a reduction in the rate of nutrient release as soils cooled when trees reoccupied the site.

There is evidence that root to shoot ratios are less under ideal growth conditions than in an adverse soil environment (Barber, 1984). Trees do not need to exploit a large volume of soil if all the nutrients and water they need are immediately available. This condition may apply in this situation. When treatments ceased and nutrients and water were no longer readily available, the root system of the trees was not exploiting as wide a volume of soil as it might otherwise do under less desirable conditions. If this was the case, the trees on treated plots were not able to exploit enough water or nutrient reserves to maintain their previous growth rate. The reduction in growth during the second growth period could be explained in this fashion.

The data available are not sufficient to determine which (if any) of these factors account for the results obtained in this study. It is possible that any one or a combination of these conditions were involved.

CHAPTER V

SUMMARY AND CONCLUSIONS

Fertilization and irrigation treatments, singly and in combination, were applied to planted seedlings of yellow-poplar, sweetgum, northern red oak and loblolly pine on upper and lower slope sites. Fertilizer was applied as trees were planted and trees were irrigated for the first 7 growing seasons. No treatments were applied after that time. Growth was measured annually up to age 7 and again in 1986 after 22 growing seasons.

On the basis of this study the following conclusions seem to be valid:

1. The sensitivity of yellow-poplar to enhanced growing conditions related to fertilization and irrigation treatments was apparent during the first 7 years and was still observed on undisturbed forest soils on the upper slope site at age 22. On this site, the pattern of tree height and treatments was identical to the response pattern evident at age 7. However, the pattern of growth in relation to treatments was completely reversed during the second growth period. Although total height reflected the original gains due to treatments, trees which grew the fastest during the first growth interval grew more slowly during the second growth interval.

2. On the lower slope, old field, soils the pattern of height growth of yellow-poplar in relation to treatments was similar to

the pattern evident at age 7. As was true on the upper slope, trees which grew the fastest during the first growth period now appeared to be growing more slowly during the second growth interval.

3. Differences in site conditions between the upper and lower slope sites strongly influenced height growth during the first 7 years and are still apparent in total height and volume of yellow-poplar at age 22. However, analysis of growth during the second growth interval indicated that best growth was now on the lower slope site. This suggests that this site was recovering from the old field condition as tree species continued to occupy this site.

4. Changes in growing conditions following cessation of irrigation treatments and utilization of the small fertilizer application seemed to have had adverse effects on tree growth during the second growth interval. Best growth of both sweetgum and yellow-poplar during the second growth period was on untreated plots. The trend was that the more intensive the treatment applied during the first growth interval, the worse growth was during the second growth interval.

5. Although mortality of loblolly pine was great during the second growth interval, this species outgrew sweetgum under all conditions. While it outgrew yellow-poplar under most conditions during the first growth period, its growth seemed to have stagnated and yellow-poplar grew better than the pine during the second growth interval. Although loblolly pine was the least sensitive of the species used in this study to soil-site conditions, it generally

grew the best. The poor survival evident at age 22 may have been due to climatic factors resulting in high mortality after the seventh growing season.

6. The general insensitivity of sweetgum to soil-site factors was still apparent during the second growth interval. Yellow-poplar outgrew sweetgum under all site conditions tested during the second growth period.

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APPENDIX

Table 20. Survival (%) of yellow-poplar trees at age 7 by replication and treatment.

Site	Control	Fertilized	Irrigated	Irrigated & Fertilized
Lower Slope Replication				
1	78	89	67	100
2	67	78	78	78
3	78	78	67	89
4	89	89	78	78
Upper Slope Replication				
1	100	56	100	78
2	100	56	89	67
3	89	56	89	89
4	89	100	89	100

Table 21. Survival (%) of yellow-poplar trees at age 22 by replication and treatment.

Site	Control	Fertilized	Irrigated	Irrigated & Fertilized
Lower Slope Replication				
1	56	89	56	100
2	56	67	78	78
3	78	78	67	78
4	89	89	78	78
Upper Slope Replication				
1	100	56	89	67
2	100	56	89	67
3	89	56	89	89
4	89	100	78	100

Table 22. Survival (%) of sweetgum trees at age 7 by replication and treatment.

Site	Control	Fertilized	Irrigated	Irrigated & Fertilized
Lower Slope Replication				
1	89	44	89	78
2	100	100	100	89
3	89	89	78	89
4	89	100	78	56
Upper Slope Replication				
1	100	100	100	78
2	89	56	100	67
3	89	78	89	78
4	78	100	89	67

Table 23. Survival (%) of sweetgum trees at age 22 by replication and treatment.

Site	Control	Fertilized	Irrigated	Irrigated & Fertilized
Lower Slope Replication				
1	56	33	78	67
2	67	78	89	89
3	44	78	67	89
4	89	89	78	56
Upper Slope Replication				
1	78	89	89	67
2	78	56	89	67
3	89	78	89	67
4	44	89	78	67

Table 24. Survival (%) of loblolly pine trees at age 7 by replication and treatment.

Site	Control	Fertilized	Irrigated	Irrigated & Fertilized
Lower Slope Replication				
1	78	44	78	44
2	89	56	100	78
3	56	33	78	33
4	67	56	67	100
Upper Slope Replication				
1	56	78	33	67
2	100	33	89	67
3	56	44	67	56
4	89	67	44	67

Table 25. Survival (%) of loblolly pine trees at age 22 by replication and treatment.

Site	Control	Fertilized	Irrigated	Irrigated & Fertilized
Lower Slope Replication				
1	22	33	33	44
2	56	56	67	67
3	56	22	33	22
4	67	33	56	100
Upper Slope Replication				
1	33	56	11	22
2	44	33	44	22
3	44	33	33	11
4	56	22	33	67

Table 26. Mean height (ft) of dominant and codominant yellow-poplar trees at age 7 by replication and treatment.

Site	Control	Fertilized	Irrigated	Irrigated & Fertilized
Lower Slope Replication				
1	10.2	24.4	11.7	26.2
2	14.7	17.0	17.7	25.1
3	11.5	24.2	10.7	19.4
4	10.2	23.8	17.7	19.1
Upper Slope Replication				
1	18.2	22.7	23.7	35.0
2	17.2	23.5	22.5	31.7
3	12.8	21.0	23.0	26.1
4	15.2	23.0	23.8	27.7

Table 27. Mean height (ft) of dominant and codominant yellow-poplar trees at age 22 by replication and treatment.

Site	Control	Fertilized	Irrigated	Irrigated & Fertilized
Lower Slope Replication				
1	52.5	68.2	45.0	64.0
2	65.0	55.6	49.0	59.7
3	55.0	66.2	52.7	60.0
4	55.5	64.6	63.7	56.0
Upper Slope Replication				
1	59.5	61.5	61.7	71.7
2	60.8	64.5	62.3	71.7
3	54.2	65.7	67.5	64.3
4	55.6	57.2	65.0	59.8

Table 28. Mean height (ft) of dominant and codominant yellow-poplar trees from ages 7 to 22 by replication and treatment.

Site	Control	Fertilized	Irrigated	Irrigated & Fertilized
Lower Slope Replication				
1	42.2	43.9	33.2	37.7
2	50.2	38.6	31.3	34.6
3	43.5	42.0	42.0	40.6
4	45.2	40.8	46.0	36.9
Upper Slope Replication				
1	41.2	38.7	38.0	36.7
2	43.6	41.0	39.8	40.0
3	41.4	44.7	44.5	38.2
4	40.4	34.2	41.2	32.1

Table 29. Relative plot volume (ft^3/ac) of yellow-poplar trees at age 22 by replication and treatment.

Site	Control	Fertilized	Irrigated	Irrigated & Fertilized
Lower Slope Replication				
1	768	4,496	798	1,591
2	2,187	1,643	962	2,705
3	1,522	2,959	1,007	1,979
4	1,491	3,423	2,151	1,849
Upper Slope Replication				
1	1,451	1,555	3,018	4,457
2	2,991	2,368	2,382	3,962
3	1,541	3,192	3,630	3,835
4	1,792	2,731	3,220	3,265

Table 30. Mean height (ft) of dominant and codominant sweetgum trees at age 7 by replication and treatment.

Site	Control	Fertilized	Irrigated	Irrigated & Fertilized
Lower Slope Replication				
1	15.2	20.7	12.9	20.2
2	14.8	20.7	20.9	24.1
3	12.8	24.5	23.7	16.0
4	22.6	21.2	13.7	19.6
Upper Slope Replication				
1	23.6	22.3	23.7	24.0
2	18.1	19.0	20.6	23.1
3	16.2	18.9	14.2	16.6
4	11.2	18.3	20.7	22.5

Table 31. Mean height (ft) of dominant and codominant sweetgum trees at age 22 by replication and treatment.

Site	Control	Fertilized	Irrigated	Irrigated & Fertilized
Lower Slope Replication				
1	55.5	61.0	38.2	48.0
2	51.3	55.3	47.7	58.0
3	49.0	64.8	53.7	51.2
4	63.0	54.0	52.3	54.7
Upper Slope Replication				
1	58.2	56.2	54.8	53.0
2	59.0	51.7	52.6	55.0
3	54.3	33.5	44.3	47.5
4	48.7	48.8	53.8	49.2

Table 32. Mean height (ft) of dominant and codominant sweetgum trees from ages 7 to 22 by replication and treatment.

Site	Control	Fertilized	Irrigated	Irrigated & Fertilized
Lower Slope Replication				
1	40.2	40.2	25.3	27.8
2	36.5	34.7	26.8	33.9
3	35.1	40.3	30.0	35.2
4	40.4	32.7	38.6	35.1
Upper Slope Replication				
1	34.6	33.9	31.1	29.0
2	40.9	32.7	32.0	31.9
3	38.2	34.6	30.2	30.9
4	37.5	30.5	33.1	26.7

Table 33. Relative plot volume (ft^3/ac) of sweetgum trees at age 22 by replication and treatment.

Site	Control	Fertilized	Irrigated	Irrigated & Fertilized
Lower Slope Replication				
1	1,621	1,863	839	1,482
2	1,268	2,489	1,822	3,057
3	1,036	3,704	1,483	1,496
4	2,771	2,147	2,159	1,718
Upper Slope Replication				
1	2,826	3,232	2,615	2,198
2	2,786	1,749	2,729	2,211
3	1,662	2,210	1,492	1,550
4	1,222	1,645	2,068	1,425

VITA

James P. Groton, Jr. was born in Atlanta, Georgia on February 18, 1955. He attended elementary schools in that city. He was graduated from the South Kent School in South Kent, Connecticut in May 1973. The following September he entered The University of The South in Sewanee, Tennessee and in May 1979 he was graduated with departmental honors with a Bachelor of Science degree in Natural Resources. In the spring of 1982 he was admitted to The University of Tennessee, Knoxville where he began study toward a Master's degree in Forestry. This degree was awarded in August 1988.

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