To the Graduate Council:

I am submitting herewith a thesis written by Lyle E. Taylor entitled "Fifth-year Measurements of Loblolly Pine Across Tennessee Following Various Silvicultural Treatments." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Forestry.

J C Rennie

John C. Rennie, Major Professor

We have read this thesis
And recommend its acceptance:

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Accepted for the Council:

Vice Chancellor
Graduate Studies and Research

FIFTH-YEAR MEASUREMENTS OF LOBLOLLY PINE ACROSS TENNESSEE FOLLOWING VARIOUS SILVICULTURAL TREATMENTS

A Thesis

Presented for the

Masters of Science

Degree

The University of Tennessee, Knoxville

Lyle E. Taylor

December 2000

ACKNOWLEDGMENTS

I wish to express my sincere appreciation to Dr. John C. Rennie of the Department of Forestry, Wildlife & Fisheries at The University of Tennessee, for serving as major professor and for his guidance and technical assistance in preparing this thesis.

Appreciation is also extended to Dr. David Buckley and Dr. Vernon Reich for serving as members of my committee and for their advice, critical reviews and support while preparing this thesis.

Thanks to Dr. Arnold Saxton for his statistical expertise and advice with Statistical Analysis Systems (SAS) and to Brien Ostby for his never-ending willingness to help with data collection and entry. Also, thanks to Nathan Hartgrove of the Natural Resources Conservation Service, for his help identifying soils types and classification levels and Dr. John Ammons of the Department of Plant and Soil Sciences, for explaining how to read and interpret United States Soil Conservation Service Soil Surveys.

I would like to thank my parents, Mr. and Mrs. Edward E. Taylor for always supporting me and inspiring me to continue my education.

Finally, I wish to thank my wife Sarah for her support, patience and understanding throughout this project.

ABSTRACT

Loblolly pine (*Pinus taeda*) was planted at nine locations across Tennessee in 1993-94 and 1994-95 using a customized fractional factorial design. Two sites, good and poor, were chosen at each location to compare soil effects on height and survival. At each site three treatments were evaluated: spacing (8X8, 8X10, and 10X10 feet), herbicide (2.0 oz/ac Oust and 4.0 oz/ac Arsenal), fertilization at planting (three, 9 gm fertilizer tablets per tree (22-8-2)). After the fifth growing season, height measurements and survival counts were taken.

The least square estimate of mean overall height and survival at good and poor sites combined after five growing seasons was, 12 feet and 84 percent, respectively. Results after five growing seasons indicate that herbicide increased tree height by 8 percent on the good and poor sites combined. Survival increased 13 percent when herbicide was used at good and poor sites. There were significant differences found between experiment stations at ($P<0.05$). Mean height estimates for stations after five growing seasons ranged from 9.5 feet at the West Tennessee Experiment Station to 13.5 feet at Ames Plantation. Survival ranged from 59 percent at the Dairy Experiment Station to 99 percent at the Highland Rim Forestry Experiment Station. There were also significant differences ($P<0.05$) found between mean survival estimates for site by herbicide at good and poor sites combined.

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CHAPTER I

INTRODUCTION

In recent history a significant amount of the South's agricultural land has been converted to forestland. Intensive forest management in the southern United States has developed rapidly in recent years as a result of the increased demand of timber. Due to the intensive management needed to meet demands, a shift from management of natural stands to pine plantation management has developed. This shift to pine plantation management created a market for timber from Tennessee's non-industrial private landowners. Non-industrial private landowners own approximately 69.3 percent of the 13.3 million acres of commercial forestland in Tennessee (Tennessee Division of Forestry, 1999). These forests are usually found on the less productive sites. In the past, natural regeneration was used on these forests sites, but it has resulted in poorly stocked stands with low value species.

Planting genetically improved pine seedlings has proven to be the most efficient method for establishing forests on the less productive sites. Loblolly pine (*Pinus taeda*), which makes up more than half of the total southern yellow pine volume, is the most important softwood species in the South (Sheffield and Knight, 1983). In Tennessee, it is only native to the southern counties; however, it is the most hardy and versatile of all southern pines and has the ability to grow rapidly on diverse sites. Even north of its native range it exhibits its natural growth trend and out-grows native species. On less productive sites silvicultural techniques such as spacing, herbicides, thinning, and fertilization have been shown to increase the quality and volume of loblolly pine. Therefore, it may be profitable for Tennessee's non-industrial private landowners to convert old-fields and less productive sites to loblolly pine plantations. Conversion of old-fields and unproductive sites to forestland may be a more profitable way for landowners to maintain their land for the future.

Research on loblolly pine has been performed in many of the states surrounding Tennessee but little research has been done within the state. This research on loblolly pine in Tennessee will enable non-industrial private landowners to make better decisions when planting loblolly pine across the state. Also, landowners would be able to determine better planting sites and necessary silviculture applications.

CHAPTER II

OBJECTIVES OF THE STUDY

The general purpose of this study was to develop a set of silvicultural treatment combinations for loblolly pine that will best facilitate establishment of forest plantations on agricultural land. Non-industrial forest landowners were of particular interest.

More specifically, the study was designed to:

1. Evaluate the survival and growth rate of genetically improved loblolly pine planted on site/location combinations commonly found across Tennessee.

2. Determine the effects on survival and growth rate of loblolly pine of various combinations of silvicultural treatments.

CHAPTER III

LITERATURE REVIEW

This chapter is divided into sections corresponding to the variables that were incorporated when the study was established. The two variables included in the experimental design that were not tested are fertilization at stand closure and thinning as stand basal area reaches 120 ft^2/ac because these treatments had not been applied by the fifth year. Therefore, these were not included in the literature review. The information provided is based solely on literature from past studies on loblolly pine.

I. SPACING

When considering an appropriate planting density a forest manager should consider rotation length, economic returns and desired product. Initial spacing in a plantation strongly influences the size of trees removed, stem quality, and amount of wood available at thinning and final harvests (Campbell and Mann, 1974). Planting density affects survival, height, diameter, volume and basal area.

Balmer et al. (1975) reported that through age 7 there were no significant differences in average height across spacings ranging from 6 X 6 to 10 X 10 feet. Differences in height appeared as competition for resources became a limiting factor in the growth and development of the stand. At age 20, Harms and Lloyd (1981) reported that average stand height increased about 2 feet with each 2 X 2 foot increase in spacing from 6 X 6 to 12 X 12 feet. McClurkin (1976) and Gilmore and Gregory (1974) reported that the effect of increasing number of stems per acre on height was more pronounced as the stand aged. Crown length and the ratio of crown length to total tree height increased as spacing increased (Harms and Lloyd, 1981).

As with height growth, Pienaar and Shiver (1993) and Gilmore and Gregory (1974) showed that diameter decreased as the initial number of stems per acre increased. Average diameter on 12 X 12 foot plots was 3.6 inches greater (58 percent) than the diameter on the 6 X 6 foot plots (Harms and Lloyd, 1981). Soil moisture is a limiting factor when deciding on the appropriate spacing. Gilmore and Gregory (1974) concluded that soil moisture was not a limiting factor in a stand at wider spacing, resulting in a longer growing season and larger annual diameter increment.

Basal area increased as spacing decreased (Harms and Lloyd, 1981; Balmer et al. 1975). Pienaar et al. (1997) reported that basal area at age 14 ranged from 79.3 ft^2/ac for 100 trees/ac to 202 ft^2/ac for 1000 trees/ac. Basal area has an effect on the quality and grade of sawtimber. Plots planted at 6 X 6 feet and thinned to 100 ft^2/ac, at age 18 and then repeatedly thinned at 5 year intervals through age 38, produced 60 percent No. 2 and better lumber, while plots planted at a 12 X 12 foot spacing and thinned as described above yielded 42 percent No. 2 and better lumber (Clark et al., 1994).

Much like basal area, merchantable volume increased as spacing decreased (Pienaar and Shiver, 1993; Gilmore and Gregory, 1974). The greatest total and merchantable volume was produced at an 8 X 8 foot spacing. Overcrowding resulted in smaller diameters and shorter stems producing less merchantable volume in a planting with a 6 X 6 foot spacing (Harms and Lloyd, 1981; Balmer et al., 1975). An increase from 300 to 900 trees/ac at establishment increased yields at age 30 from 33 to 49 cunits/ac (Bailey, 1986). However, establishment density is highly dependent on the product distribution desired by the land manager.

II. FERTILIZATION AT PLANTING

In the South, forest fertilization has grown over the past 30 years from a few experimental trials to a widespread operational practice. By the end of 1998, more than 8 million acres had been fertilized; in 1998 alone 1.2 million acres were fertilized (Allen, 1999). Forest fertilization is being used to increase forest growth and value. Fertilization represented one of the most cost-efficient treatments that managers could apply to accelerate stand development and growth, thereby increasing financial returns (Wells and Allen, 1985; Ford, 1984).

Colbert et al. (1990) and Watterston (1972) reported nitrogen and phosphorus deficiencies were the dominant problem in loblolly pine site productivity. This deficiency for nutrients is greatest immediately following regeneration or site disturbance. The demand for nutrients was the greatest when leaf-area expansion was at a maximum, during the stand's rapid-growth phase, and before the annual volume increment culminated (Allen, 1987).

Although nitrogen and phosphorus are two of the nutrients that are deficient in many southeastern soils, there are factors that limit the effectiveness of fertilizers added to the soil. Phosphorus responsive sites have been identified based on soil and foliar tests and soil types (Fisher and Garbett, 1980; Pritchett and Gooding, 1975; Wells et al., 1973). Foliar concentrations of phosphorus were the best indicator of the need to fertilize. Allen (1987) reported that of all the diagnostic tools available for selecting responsive stands, foliar analysis had the most potential. Wells and Allen (1985) identified the guidelines for phosphorus fertilization based on foliar concentrations (Table 1).

Table 1- Guidelines for Phosphorus Fertilization Based on Foliar Concentrations (Wells Allen, 1985)

Percent Concentration	Interpretation
<0.10	Deficient, high probability of response
0.10 - 0.12	Critical range, generally responsive in combination with nitrogen
>0.12	Generally not responsive

Allen (1987) noted that established stands had large variations in response to fertilizers within each soil type. In the Southeast, adequate application rates are often determined on particular soil types based on past research and experience. Another commonly used practice in agriculture, soil testing, is used to identify fertilizer needs. Based on 3 to 5 year response data, soil tests from surface soil samples have proven useful in identifying sites responsive to phosphorus fertilization in the Southeast, where phosphorus was the overriding factor influencing growth (Allen, 1987).

Nitrogen deficient soils can be identified by a measure of stand density, foliar nitrogen concentrations, soil moisture, and site index (Wells and Allen, 1985; Allen and Ballard, 1982). As with phosphorus, nitrogen deficiencies are most reliably determined through foliar analysis. Wells (1968) and Fowells and Krauss (1959) reported that growth responses to nitrogen fertilization have been noted at nitrogen foliar concentration of 1.16 to 1.35 percent. Moderate stand density (basal area of 90-120ft^2/ac for loblolly pine) had the greatest net volume growth response to nitrogen (Allen, 1987). Over-stocked stands do not utilize fertilization to increase net volume growth. Over-stocked stands lower the growing space needed for development of crowns. These stands also shade the ground, which slows decomposition, and the release of nutrients back to the soil.

Fertilizers that are added to the soil often lose effectiveness only a few years after application. Tiarks and Haywood (1986) and Merrifield and Foil (1967) reported that both fertilization and herbicide increased pine height until age 2 and had little effect on height growth beyond 2 years.

Other important factors to examine when considering fertilizing a newly established stand are rates and time of application. As noted by Allen (1987) and Walker (1962), the typical amount of nitrogen and phosphorus to be applied, ranged from 150 to 200 lb/ac of nitrogen and 25 to 50 lb/ac of phosphorus in the Southeast. Applying 50 lb/ac of phosphorus increased loblolly pine site index (age 25) by 10 to 15 feet on typical very poorly, poorly, and somewhat poorly drained soils on the lower Coastal Plain (Wells and Allen, 1985). If the rate of application is excessive, fertilizers can be detrimental to production and even become toxic to the pine. The form of nitrogen and phosphorus can be a limiting factor. Ballard (1981) reported that there were no significant differences between sources over varying soils and site conditions. Mobilization and application costs pose the major problem when selecting the source of fertilizer. Fertilizers are most effective during the spring and fall, when leaching from summer rains is at a minimum (Allen, 1987).

Research has shown that fertilizers have an effect on the growth and yield of loblolly pine plantations. Fertilizers at planting have resulted in significant height and diameter growth (Haywood and Tiarks, 1990; Bolstad and Allen, 1987). These increases in height and diameter depend on the condition of the soil. McKee and Wilhite (1986) reported that application of phosphorus increased heights by 12 percent on a moderately well-drained site and 26 percent on a poorly drained site at age 2. By age 10, heights increased by 95 percent on poorly drained sites. Fertilization is also very attractive based on economic returns. The addition of phosphorus to deficient soils can increase the return on investment (ROI) from 9.0 to 15.6 percent (Wells and Allen, 1985).

III. HERBICIDES

Another factor that greatly affects the growth and survival of young pine plantations is herbaceous weed control. In newly established plantations, grasses were the most competitive herbaceous plants in southern hardwood and loblolly pine forest types (Wolters and Wilhite, 1974). Therefore, it is critical to control or remove competitive vegetation to achieve optimal growth and survival. Controlling herbaceous plants is often the key to added volume and shortened rotations. Use of herbicides allows rotation lengths to be shortened 2 to 3 years with a comparable yield (Busby, 1992; and Glover et al., 1989).

As with fertilization, there are factors that can influence the productivity of a stand. Herbaceous plants compete with pines for available nutrients and water. Limited nutrients and soil moisture often hinder proper establishment and optimum growth of a stand (McDonald, 1986; Zutter et al., 1986; and Nelson et al., 1981). Nelson et al. (1981) showed that an application of herbicide on a site with high weed biomass improved height relative to a site with low weed biomass. An increase in available moisture and nutrients increased the survival rate of loblolly where soil moisture and rainfall were low and competition was a problem (Haywood and Tiarks, 1990; Creighton et al., 1987).

Several herbicides have been demonstrated to reduce herbaceous cover in forest stands. These are often site specific and application rate must be adjusted accordingly. Oust ® (Sulfometuron methyl) is a herbicide that is commonly used in newly planted pine plantations. It has been shown that 2 years following a herbicide treatment, seedlings in plots treated with 0.25 lbs ai/ac (2 oz/acre) of Oust ® were ½ foot taller than those in untreated plots (Michael, 1985). Williams and Earl (1998) noted that regardless of seedling age or the method of site preparation, the most consistent finding is that 2 oz Oust ® and 4 oz Arsenal AC ® per acre showed the highest height and diameter growth.

Different methods of application - broadcast, spot, and banded - appear to have no significant effect on growth and yield of young plantations (Busby, 1992; and Creighton et al., 1987). Although there are no significant differences in growth response, each method has its advantage as a management tool. Forest managers must make decisions about cost, time constraints, and the area of application. The cost of spot and banded application on old-fields is approximately $15/ac as opposed to $20/ac for broadcast application (Busby, 1992). Time required for application varies with method: broadcast takes the least time, while spot application requires the most time.

Ultimately, pines respond with improved height growth following herbicide application. Miller et al. (1991) and Creighton et al. (1987) reported that herbaceous control significantly increased fifth-year height by an average of 3 feet with a range of 2 to 7 feet depending on the quality of the site. Glover, Creighton and Gjerstad (1989) showed that herbaceous weed control increased mean basal area by 42.2 ft^2/ac and total volume by 894 ft^3/ac. Miller et al. (1991) found that total volume was increased by 171% over 5 years when using a herbicide.

IV. OPTIMAL SOILS FOR LOBLOLLY PINE

The amount and quality of timber that is grown on a tract of land is dependent on various soil characteristics of a specific site. Production of timber is affected by factors such as soil physical properties, slope, acidity, and moisture. If these factors are considered when planting seedlings, production can be greatly improved.

The optimal soil for loblolly pine has an A horizon at least 6 inches deep and a very friable, well drained subsoil to promote rooting (Schultz, 1997). Loblolly pine is predominantly grown on soils within the Ultisols order (Baker and Langdon, 1990). Loblolly pines tend to attain greater heights on soils that are loamy than on soils that are predominantly coarse or fine textured (Debell et al., 1982; Shoulders and Walker, 1979; Ashe, 1915).

Organic matter concentration in the soil is the most important indicator of soil quality since organic matter affects the physical and chemical properties of soil (Schultz, 1997). Available nitrogen is bound by organic matter and is important for tree growth. Goggans and Schultz (1958) reported that when the A horizon was missing, tree growth was normally very poor. Initial spacing can have an effect on the amount of organic matter present in a stand. Stands having fewer than 445 trees/ac have been shown to produce lower levels of surface soil organic matter (Gilmore and Rolfe, 1980).

Slope affects the amount of soil moisture, temperature, light and decomposition available for tree growth. Steeper slopes tend to incur more runoff, thus reducing the amount of soil moisture that is available for tree growth (Zahner, 1958). The optimal slope for tree growth on azonal soils is 1 to 2 percent (Schultz, 1997). Shoulders and

Walker (1979) stated that loblolly pine grew taller on slightly sloping soils than on level ground, but growth slowed down at slopes of 4 percent or more.

Site index also plays an important role in volume production in pine plantations. Campbell and Mann (1974) showed that volumes on site index 105 (base age 50 years) were 2.4 to 3.0 times greater than on site index 70.

Soil pH is another factor that can influence the growth of loblolly pine. Schultz (1997) reported that loblolly pine grew best on soils with a pH between 4.5 and 6.0. When competing vegetation was controlled, loblolly grew in a pH as low as 4.0 and as high as 6.7 (Jain et al., 1989). As the stand ages, the soil pH under the crown declines as the amount of leachate from needles accumulates, usually by age 4 (Lane, 1964).

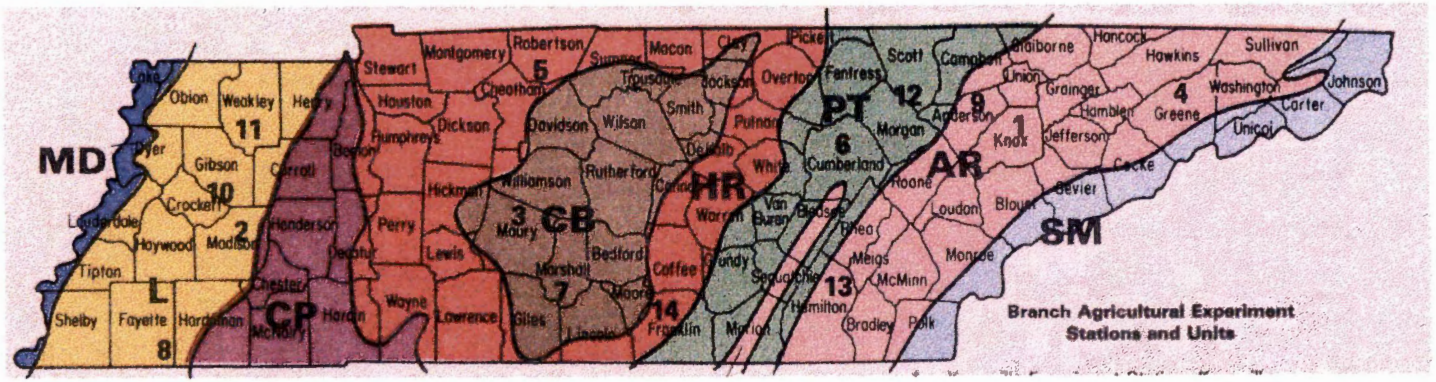
Soil moisture is probably the most important factor influencing survival of loblolly pine stands (Wahlenberg, 1960). Prolonged lack of moisture of more than three weeks resulted in 65 percent seedling mortality (Stransky and Wilson, 1967). Prolonged moisture stress (lack of available soil moisture) can slow or interrupt tree growth (Schultz, 1997). In years where trees were able to grow without moisture stress, merchantable volume growth was three times greater than years when moisture stress occurred (Bassett, 1964). The time of year has a major effect on the rate at which pines grow. Summer months, which are the primary growing season, in the northern and western portions of loblolly pine's range, are prone to droughts that decrease soil moisture, thus reducing tree growth (Shoulders and Tiarks, 1980). Soil texture also plays an important role in the survival and growth of loblolly pine. Loblolly pines should not be planted on excessively well-drained sandy soils because of moisture stress. (Burns, 1968).

CHAPTER IV

DESCRIPTION OF STUDY AREAS

This study was established in two phases, 1993-94 and 1994-95, at nine different locations across the state of Tennessee. All nine locations are located on University of Tennessee Agricultural Experiment Stations. The nine study locations were established at these locations to allow examination of the effects of differences in previous management of land, soil, topographic, and climatic conditions on loblolly performance. The nine locations occur in five of Tennessee's eight major physiographic regions: West Tennessee Slope, Highland Rim, Central Basin, Cumberland Plateau and Great Valley (Figure I) (May 1991). No locations were established in the Mississippi Bottoms, Western Valley, and Unaka-Smoky Mountains Regions due to a lack of Tennessee Agricultural Experiment Stations in these regions.

Three locations, Ames Plantation, Martin Experiment Station and West Tennessee Experiment Station, are in the West Tennessee Slope region. The western part of this region is characterized by a broad plain sloping to the west, with bluffs overlooking the Mississippi River Valley. The eastern part of this region is highly dissected by streams, creating numerous valleys and ridges. The Highland Rim Forestry Station is located in the eastern edge of the Highland Rim region. This region, subdivided into three sections, surrounds the Central Basin. The eastern section of the Highland Rim is a plain extending west from the Cumberland Plateau. The eastern edge has deep stream dissection forming steep, rounded hills. Two locations, the Dairy and Middle Tennessee Experiment Stations, are in the Central Basin. This region is a depression formed by the weathering of limestone rock. The topography of the land has a gentle rolling surface. The Plateau



2. W. Tenn. Exp. Station
3. Middle Tenn. Exp. Station
4. Tobacco Exp. Station
6. Plateau Exp. Station
7. Dairy Exp. Station
8. Ames Plantation
9. Oak Ridge Exp. Station
11. Martin Exp. Station
13. Highland Rim Forestry Station

L = West Tennessee Slope
HR = Highland Rim
CB = Central Basin
PT = Cumberland Plateau
AR = Great Valley

Figure I. Physiographic Regions and Experiment Stations in Tennessee used in Loblolly Pine Treatment Study. (Sternitzke, 1995)

Experiment Station is located in the Cumberland Plateau region. The Cumberland Plateau, bounded by the Highland Rim on the west and the Great Valley on the east, is a flat rolling tableland. This region rises 800 to 1000 feet above the surrounding land (Law, 1949). The last locations, the Tobacco Experiment Station and the Oak Ridge Forestry Station, are in the Great Valley region of Tennessee. The Great Valley is made up of long narrow ridges sloping to the southwest, bordered by valleys on either side.

I. AMES PLANTATION

Location and Physiography

Ames Plantation is located in Fayette County (Figure I). It is located in the western part of the West Tennessee slope. Nearly all the county is covered with loess underlain by marine sediments of the Coastal Plain (Flower, 1964). Drainages in this area are well established. The streams in Fayette County flow westward toward the Mississippi River. The Wolf River is the primary watershed for this study area. The elevation of Fayette County ranges between 270 and 600 feet and averages approximately 400 feet. The topography of the county is dissected and hilly to moderately dissected and rolling.

Climate

Fayette County generally has hot summers and mild winters (Flowers, 1964). Summer temperatures range between a minimum of 60 degrees Fahrenheit and a maximum of 90 degrees. Winter temperatures range between 32 degrees and 55 degrees. There are approximately 210 frost-free days. The soils in Fayette County seldom freeze to a depth more than 3 inches, and remain frozen no more than 5 to 6 days. The mean annual precipitation in Fayette County is 51.66 inches. Most of this precipitation occurs in the winter and early spring. During the summer and early fall the soil is dry because evapotranspiration exceeds precipitation. By October hot weather declines and precipitation becomes greater than evapotranspirtion, recharging the soil. Total snowfall each year averages 2.4 inches. Appendix A-1 gives a summary of climatological data collected by the National Water and Climate Center for Moscow, Tennessee.

II. DAIRY EXPERIMENT STATION

Location and Physiography

The Dairy Experiment Station is located in Marshall County (Figure I). The station is in the southern portion of the Central Basin. The topography is level to gentle rolling. Mississippian rock and weathered limestone underlie much of Marshall County (Fullerton, 1977). The soils in this area are well drained. The major drainage is the Duck River watershed. The average elevation is 600 feet above sea level.

Climate

The climate in Marshall County is humid to temperate with adequate precipitation in all seasons. Summers tend to be mild with little extended periods of extremely hot weather. Winters are much like the summers in that they are mild with short periods of extreme cold temperatures. The average annual temperature is 57.0 degrees Fahrenheit. The average maximum and minimum temperature is 69.1 and 45.0 degrees, respectively.

The mean annual precipitation in Marshall County is 54.70 inches. The greatest amount of precipitation occurs during the winter and spring months. Total snowfall averages 5.3 inches per year. Appendix A-1 gives a summary of climatological data collected by the National Water and Climate Center for the Dairy Experiment Station, near Lewisburg.

III. HIGHLAND RIM FORESTRY STATION

Location and Physiography

The Highland Rim Forestry Station is located in Franklin County (Figure I). The station is in the eastern portion of the Highland Rim. The topography here is gently rolling to sloping. This area is north of the Elk River in a portion of the Highland Rim known as "the Barrens." Drainage here is not well developed and little stream dissection occurs. Sedimentary rocks and limestone underlie much of the surface of the Highland Rim. The soils that occur most frequently in the Barrens are shallow and cherty; they tend to weather easily. The average elevation is 970 feet above sea level. The highest and lowest elevations are approximately 2000 and 800 feet, respectively.

Climate

The climate in Franklin County is typically temperate and humid. Summers are very hot and the winters have only short periods of cold weather. The average annual temperature in Franklin County is 59.3 degrees Fahrenheit. The average maximum and minimum temperature is 69.8 and 47.4, respectively. There is an average of 190 frost-free days

The mean annual precipitation in Franklin County is 57.31 inches. The greatest precipitation occurs in the spring and winter. Summer rains are usually short and heavy, causing high levels of erosion. Snow rarely exceeds 3 or 4 inches in depth and melts within a day or two. Total snowfall averages 7.2 inches per year. Appendix A-1 gives a summary of climatological data collected by the National Water and Climate Center for the Highland Rim Forest Station.

IV. MARTIN EXPERIMENT STATION

Location and Physiography

The Martin Experiment Station is located in the northern part of Weakley County (Figure I). The station is located in the physiographic region of the West Tennessee slope. Weakley County is part of the Southern Mississippi Valley Silty Upland (Moore, 1992). The uplands have level to sloping ridgetops, which are generally narrow from top to bottom. Bottomland is broad, and nearly level along streams. The soils on upland sites are made up of mainly loess deposits ranging from 5 to 20 feet in thickness (Moore, 1992). The county is drained by the North, Middle, and South Forks of the Obion River. Elevation ranges from 290 to 578 feet above sea level.

Climate

Weakley County has long, hot summers and cool winters. The average annual temperature is 58.3 degrees Fahrenheit. The summer and winter average temperatures are 78 and 39 degrees, respectively (Moore, 1992). The mean annual precipitation is 53.09 inches and snowfall total 6.6 inches. Approximately 50 percent of the annual precipitation falls from April to September. The growing season for most crops occurs during this period. During the summer, afternoon thunderstorms account for most of the rain. Appendix A-1 gives a summary of climatological data collected by the National Water and Climate Center for the Martin Experiment Station.

V. MIDDLE TENNESSEE EXPERIMENT STATION

Location and Physiography

The Middle Tennessee Experiment Station is located in the northeast portion of Maury County in the outer Central Basin (Figure I). Maury County is subdivided into nine soil associations. This area has moderate dissection, broad ridgetops and steep valleys. The underlying rocks are phosphatic sandy limestone and shale (Harmon, 1959). Elevation in Maury County ranges from about 550 to 1000 feet above sea level. The entire county lies within the Tennessee River watershed. The Duck River system drains the county except for a small portion in the extreme southwest.

Climate

The climate in Maury County is humid and temperate. Winters are moderate and the summers are warm; neither have extreme seasonal temperatures. The average annual temperature in Maury County is 58.0 degrees Fahrenheit. There are approximately 192 frost-free days.

The mean annual precipitation is 53.25 inches. Often in the summer and fall there are short periods of drought. Snow usually falls in small amounts and lasts a short period of time before melting. The total amount of snowfall averages 5.6 inches. Appendix A-1 gives a summary of climatological data collected by the National Water and Climate Center for Columbia, Tennessee.

VI. FORESTRY EXPERIMENT STATION

Location and Physiography

The Forestry Experiment Station is located near Oak Ridge in the southern portion of Anderson County (Figure I). The station is located in the Great Valley region. Narrow valleys separated by long parallel ridges, sloping to the southwest characterize this area. The soils of this region are underlain by dolomite, shale, sandstone, and limestone (Bivens, 1978). The study area is located in the Clinch River drainage system. Elevation in Anderson County ranges from 760 to 3534 feet above sea level.

Climate

The climate in Anderson County typically includes very warm summers and cool winters. The average maximum temperature is 68.2 degrees Fahrenheit and minimum temperature is 45.8 degrees. The annual average temperature is 57.0 degrees.

Rainfall is evenly distributed throughout the year and is usually very heavy. The summer rain is brought by frequent afternoon thunderstorms. Thunderstorms occur about 53 days each year. During the winter, rainfall is at its peak, and is found mostly in the form of rain with some snow in the upper elevation. There is 53.80 inches of annual precipitation in Anderson County. Of the total 53.80 inches, 45 percent or 25 inches falls in April through September (Bivens, 1978). Total snowfall averages 11.3 inches annually. Appendix A-1 gives a summary of climatological data collected by the National Water and Climate Center for Oak Ridge, Tennessee.

VII. PLATEAU EXPERIMENT STATION

Location and Physiography

The Plateau Experiment Station is located in the northwest portion of Cumberland County (Figure I). The station is located in the Cumberland Plateau physiographic region. The Cumberland Plateau is generally a plain, dissected by valleys with steep slopes. The floor of these valleys - Crab Orchard Gap and Grassy, Little, and Swagerty Coves - are 200 to 600 feet lower than the Plateau. Sandstone and shale are present over most of the Plateau with limestone found in the coves. Elevation in Cumberland County ranges from approximately 1000 to 3000 feet above sea level.

Climate

The climate of the Cumberland Plateau is mostly temperate; winters are moderate and the summers are mild. The average winter and summer temperatures are 38.7 and 72.1 degrees Fahrenheit, respectively (Hubbard, 1950). The average annual temperature is 58.6 degrees. It is rare to have summer temperature greater than 90 degrees. There is an average of 179 frost-free days. The mean annual precipitation is 59.15 inches. The rain is evenly distributed during the winter, spring and summer months. Total snowfall averages 17.4 inches annually.

Climatic conditions are fairly uniform, except on Crab Orchard Mountain, Grassy Cove and Sequatchie Valley. Crab Orchard Mountain is approximately 1000 feet higher than the surrounding plateau; therefore, the number of frost-free days is lower and precipitation is higher. The coves and the valleys are subject to higher temperatures, less rainfall, and more frost-free days. Appendix A-1 gives a summary of climatological data collected by the National Water and Climate Center for the Plateau Experiment Station.

VIII. TOBACCO EXPERIMENT STATION

Location and Physiography

The Tobacco Experiment Station is located in the southwest section of Greene County (Figure I). The station is in the physiographic region of the Great Valley. The region consists of parallel ridges and valleys sloping to the southwest. The land in Greene County that is in the Great Valley consists of three sections. The section that the experiment station is in is broad rolling to hilly ridgeland. It is underlain mostly by dolomitic limestone. The Nolichucky River is the main drainage in this region. Elevation in this county ranges from approximately 600 and 2500 feet above sea level.

Climate

The typical climate in Greene County is warm and long summers, and cool and moderately short winters. The average annual temperature is 56.2 degrees Fahrenheit. The summer has an average temperature of 75.4 degrees and the winters average temperature is 40.1 degrees (Edwards, 1958). There are approximately 185 frost-free days annually. Total snowfall averages 10.9 inches annually. The mean annual precipitation is 42.11 inches. The majority of the rain occurs during the winter. The driest months are June, July and August. Appendix A-1 gives a summary of climatological data collected by the National Water and Climate Center for the Tobacco Experiment Station.

IX. WEST TENNESSEE EXPERIMENT STATION

Location and Physiography

The West Tennessee Experiment Station is located in the northwestern part of Madison County (Figure I). The station is located in the physiographic region of the plateau slope of western Tennessee. This area is mainly gently rolling uplands that are dissected by the tributaries of the Forked Deer River. The slopes in the northwestern part of the county are mild. The soils are formed mainly of loess and have a high content of silt. All soils in Madison County have low organic matter content, are strongly acidic, and low in phosphorus and potassium (Brown, 1978). The Middle and South Fork of the Forked Deer River are the main source of drainage in Madison County. Elevation ranges from 310 feet to 634 feet above sea level.

Climate

Madison County is generally temperate, although, there are definite periods of seasonal change. These changes are caused by variations in weather patterns that move across the region. These changes occur mostly in the winter months. The average annual temperature is 58.9 degrees Fahrenheit. The mean annual precipitation is 52.51 inches. Almost 60 percent of the precipitation falls during the winter and spring (Brown, 1978). Thunderstorms provide most of the rainfall during the summer. Yearly there are about 55 thunderstorms to provide ample precipitation for crops during the growing season. Appendix A-1 gives a summary of climatological data collected by the National Water and Climate Center for the West Tennessee

CHAPTER V

MATERIALS AND METHODS

I. STUDY ESTABLISHMENT

The study was implemented at nine locations on University of Tennessee Experiment Stations (Table 2). It was installed in two phases: Phase 1: in 1993-94, two or three sites were installed at each of five locations. Phase 2.: in 1994-95, two sites were installed at each of the four locations. At each of the nine locations, sites were chosen and evaluated during the winter of each year. The location of each site at the experiment stations was based on availability of land and past land use. Designation of good and poor site was based on the input of the station superintendent. Soil moisture was the main factor used to distinguish a good site from a poor site. The sites at each location were either poor or intermediate for agricultural purposes and designated poor or good for loblolly pine. The sites selected were previously pasture, alfalfa, corn, soybeans or forest. In addition, a third site type was selected at the Dairy Station to test loblolly pine plantation establishment on wet sites. Also, a third type was selected at the Plateau Station to test techniques for converting stands from low-quality hardwoods to pine plantations.

Plot Description

The experimental units were 110 X 110 feet square where the site permitted based on the topography and available land (Appendix B, Figure II). Each experimental unit contained 81 measurement trees. There were one or two border rows, depending on spacing, to minimize border effect (Figure III). Other configurations were used where necessary, (e.g. 8 rows by 10 columns (80 measurement trees)) with one or two border

Table 2. Description of sites at nine locations established in two growing seasons for loblolly pine treatment study

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Phase I: establishment 1993-94

Dairy Experiment Station – Lewisburg, Tennessee

3 sites (poor-pasture, good-alfalfa, and wet-corn[1])

Middle Tennessee Experiment Station – Spring Hill, Tennessee

2 sites (poor-pasture, good-alfalfa)

Plateau Experiment Station – Crossville, Tennessee

3 sites (poor-pasture, good-pasture, and hardwood conversion-forested)

Tobacco Experiment Station – Greenville, Tennessee

2 sites (poor-pasture, good-pasture)

West Tennessee Experiment Station – Jackson, Tennessee

2 sites (poor-soybeans, good-corn)

Phase II: establishment 1994-95

Ames Plantation – Grand Junction, Tennessee

2 sites (poor-forested, good-soybeans)

Highland Rim Forestry Field Station – Tullahoma, Tennessee

2 sites (poor-pasture, good-pasture)

Martin Experiment Station – Martin, Tennessee

2 sites (poor-corn[2], good-pasture)

Oak Ridge Forestry Station – Oak Ridge, Tennessee

2 sites (poor-forested, good-forested)

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[1]The wet site at the Dairy Experiment Station was lost to natural hardwood regeneration between the third and fifth growing season

[2] The poor site at the Martin Experiment Station was lost to a sewage lagoon for a new service between the third and fifth growing season

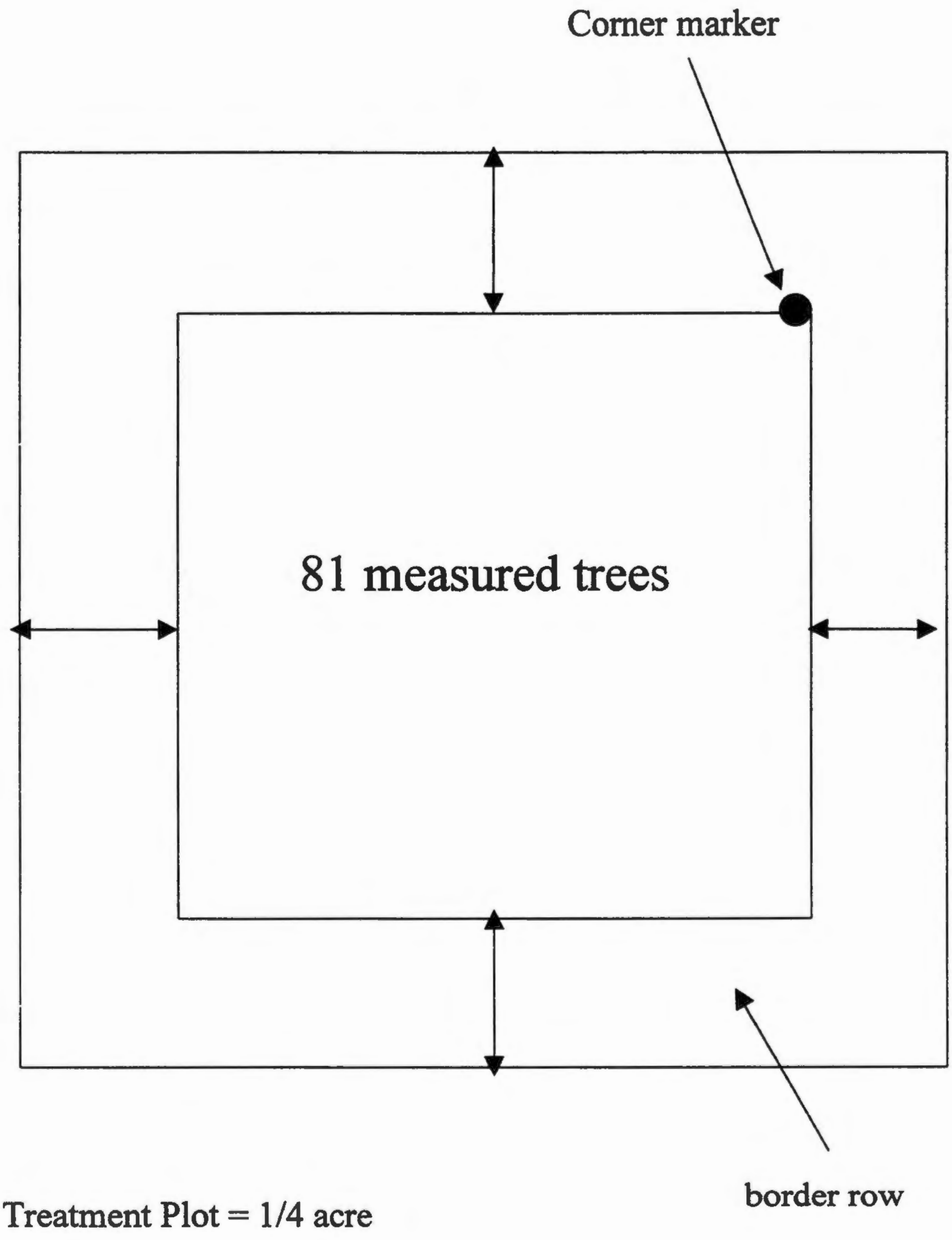


Figure III. Typical layout of treatment plot with surrounding border rows used in loblolly pine treatment study rows, to fit within the land available at a site. Each planting location was marked with a color-coded wire flag to represent the assigned treatment combination. During the fifth year measurements, experimental units were marked at the corners of measurement plots with a metal fence post.

Planting Procedure

Genetically improved seedlings obtained from the Tennessee Division of Forestry (TDF), East Tennessee Nursery were used in this study. All seedlings were grown in one bed using one seed lot, during respective years, to insure uniform genetic and cultural influences. Seedlings were lifted and packaged by TDF, then held in cold storage until planting. Bags of seedlings were selected randomly to be outplanted at each location. Crews supervised by TDF were instructed in proper handling and planting procedures to minimize damage to seedlings. Seedlings were inspected and graded. Seedlings that were damaged or were not of a uniform size were discarded. The seedlings were planted using a standard OST (Dibble) bar. Each seedling was planted with the root collar about 2 inches below the soil surface, taking extra precautions not to J-root the taproot.

Application of Treatments

Those seedlings receiving fertilizers at planting received three-9 gm forest starter tablets composed of (22-8-2) fertilizer. The first tablet was placed in the closing hole of the seedling, while the two remaining tablets were placed in holes about 1 inch deep, at the 10:00 and 2:00 position 4 to 6 inches from the seedling.

The herbicide treatment was applied between mid April and early May of the year of planting (after spring green-up). Two oz Oust ® and 4.0 oz Arsenal AC ® were mixed with 20 gallons of water for each acre. All treated experimental units received the mix in a 4 foot band around each tree. The herbicide was applied with a pack sprayer.

II. TREATMENTS

Variables that were evaluated (Table 3) in this study were: 1) site, 2) spacing, 3) competition control, and 4) fertilization at planting. Two other factors that will be tested once the stand has developed are; 5) fertilization at stand closure, and 6) thinning as stand basal area reaches 120 ft^2/ac.

III. EXPERIMENTAL DESIGN

A customized fractional factorial (Incomplete block) design developed by Dr. William Sanders, University of Tennessee Agricultural Experiment Station Statistician, was utilized for each of the 1994 plantings.

$$
\begin{aligned}
Y_{ijklmno} = \quad & \mu + L_i + P_j + L{*}J_{ij} + L{*}J{*}St_{ijn} \\
& + H_k + T_l + Sp_m + St_n \\
& + Sp{*}T_{ml} + Sp{*}H_{mk} + H{*}T_{kl} + H{*}T{*}Sp_{klm} + H{*}St_{kn} + T{*}S_{ln} \\
& + Sp{*}St_{mn} \\
& + e_{ijklmno}
\end{aligned}
$$

L_i= Location
P_j= Phase
H_k= Herbicide
T_l= Fertilizer Tablet
Sp_m= Spacing
St_n= Site
e= error

The design required at least nine experimental units at each of the Phase 1 locations. Based on the 1994 design, Dr. Arnold Saxton, University of Tennessee Agricultural Experiment Station Statistician, randomly assigned treatment combinations to the Phase 2

Table 3. Variables Applied and Measured to Evaluate Differences in Height and Survival of Loblolly Pine After Five Growing Seasons

Variables	Tested levels
Site	good and poor; wet-site and hardwood conversion
Spacing	8 X 8 feet (681 trees/ac), 8 X 10 feet (544 trees/ac), 10 X 10 feet (435 trees/ac)
Competition control	none and 4 foot band
Fertilization at planting	none and three-9gm 22-8-2 forest starter tablets
Fertilization at stand closure[1]	none, and 35 lbs/ac of phosphorus, and 100 lbs/ac of nitrogen when basal area reaches 70 ft^2/ac
Thinning[1]	none and thin when basal area reaches 120 ft^2/ac

[1]Plots had not reached basal areas for fertilization at stand closure or thinning at age 5

locations. A total of four replications of the treatment combinations were needed to complete the design; therefore, experimental units were added in Phase 2 planting. The Martin Experiment Station had 12 experimental units on the poor site. The Highland Rim Forestry Field Station and Ames Plantation had 11 experimental units on both poor and good sites, respectively. All other sites had 10 experimental units.

IV. MEASUREMENTS

Data Collection

To determine the growth responses and survival of loblolly pine, height measurements and survival observations were taken. All sample trees in both phases were measured in early June of the planting years. Following the initial measurements, Phase 1 was measured in the dormant seasons following the 1994, 1995, 1996, and 1998 growing seasons. Phase 2 was measured in the dormant seasons following the 1995, 1996, 1997, and 1999 growing seasons. No measurements were taken following the fourth growing season.

Height Measurements

Height measurements were to the nearest tenth of a foot on all sample trees. A telescoping measuring pole with a maximum height of 25 feet was used. Each sample tree was measured to the top of the terminal bud. Height of trees with broken tops or leaning due to ice or snow damage was measured from ground to the highest point on the tree.

Survival

Survival rate of each plot was measured through ocular observation. The total number of live trees was recorded after each growing season, (excluding year four), for five growing seasons. Extent of damage due to snow or ice was recorded where it occurred

Soil Identification and Classification

Soils at each location and site were identified using United States Soil Conservation Service (US SCS) soil surveys for each of the Tennessee counties where experiment stations are located (Table 4). The Natural Resources Conservation Service (NRCS) provided information related to site index, drainage, and capability classes (Table 4). These were determined using soil interpretation records and series identification charts. Site index, drainage, and capability class were determined to compare the growth and survival between locations, sites, and treatment combinations.

IV. STATISTICAL ANALYSIS

All statistical analyses were conducted using SAS Version 7.0 (SAS Institute 1999). An error level of $\alpha = 0.05$ was chosen to indicate significant differences in the analyses. Individual tree data from each plot were combined and PROC MEANS was used to calculate the mean total height and survival at each experimental plot.

A mixed model analysis (PROC MIXED) was used to detect treatment differences on total height and survival for an incomplete block factorial. Significant differences among the least square means of treatments were detected using F-tests, generated with the PDIFF option. Pairwise comparisons of means were made using least significant differences.

Table 4. Soil & Site Information for Each Site at Each Location in Loblolly Pine Study

STATION	SITE	SOIL TYPE*	SITE INDEX**	DRAINAGE**	CAPABILITY CLASS***
Ames	Good	Collins silt loam, 0 to 2 % slopes, local alluvium	90	Deep, mod. well drained	I
		Falaya fine sandy loam, 0 to 2 % slopes	90	Very deep, mod. poorly drained	IIIw
	Poor	Loring silt loam, 2 to 5 % slopes	95	Moderately well drained	IIe
Dairy	Good	Harpeth silt loam, 5 to 10 %, slopes, eroded	80	Very deep, well drained	IIIe
		Maury silt loam 5 to 12 % slopes, eroded****			
	Poor	Marsh-Stiversville complex 15 to 35 % slopes, severely eroded	69	Moderately deep, well drained	VIs
		Culleoka loam, 12 to 20 % slopes, eroded****			
High. Rim	Good	Dickson silt loam, 2 to 5 % slopes, undulating phase	80	Very deep, moderately well drained	IIe
	Poor	Dickson silt loam, 2 to 5 % slopes, eroded undulating phase	80	Very deep, moderately well drained	IIe
Middle Tenn.	Good	Maury silt loam, 2 to 5 % slopes, eroded gently sloping	80	Deep, well drained	IIe
	Poor	Donerail silt loam, 0 to 5 % slopes, gently sloping phase	80	Deep, moderately well drained	IIe
Martin	Good	Grenada silt loam, 5 to 8 % slopes, severely eroded	75	Very deep, moderately well drained	IVe
		Grenada silt loam, 2 to 5 % slopes, eroded	85	Very deep, moderately well drained	IIe
Oak Ridge	Good	Fullerton cherty silt loam, 5 to 12 % slopes	90	Very deep, well drained	IVe
	Poor	Armuchee shaly silty clay loam, 12 to 20 % slopes, sev. eroded	60	Moderately deep, well drained	VIIe
		Armuchee shaly silty clay loam, 20 to 45 % slopes, sev. eroded	60	Moderately deep, well drained	VIIe
		Armuchee silt loam 5 to 12 % slopes	60	Moderately deep, well drained	IVe
Plateau	Good	Hartsells fine sandy loam, 0 to 5 % slopes	70	Moderately deep, well drained	IIe
		Hartsells fine sandy loam, 5 to 9 % slopes, rolling phase	70	Moderately deep, well drained	IIIe
	Poor	Hartsells fine sandy loam, 0 to 5 % slopes	70	Moderately deep, well drained	IIe
Tobacco	Good	Dunmore cherty silty clay loam, 12 to 25 % slopes, eroded hilly	70	Very deep, well drained	IVe
		Dunmore cherty silty clay loam, 5 to 12 % slopes, eroded rolling	70	Very deep, well drained	IIIe
	Poor	Dunmore silty clay loam, 5 to 12 % slopes, eroded rolling	70	Very deep, well drained	IVe
		Nolichucky loam, 5 to 12 % slopes, eroded rolling phase	70	Deep, well drained	IIIe
West Tenn	Good	Freeland silt loam eroded sloping phase	84	Very deep, moderately well drained	IVe
	Poor	Collins silt loam, 0 to 2 % slopes	95	Deep, moderately well drained	I
		Falaya fine sandy loam, 0 to 2 % slopes	90	Very deep, mod. poorly drained	I

* Information provided by the United States Soil Conservation Service Soil Survey
** Provided by the Natural Resources Conservation Service
*** Provided by United States Soil Conservation Service and local Natural Resources Conservation Service (Table A-2)
**** Updated soils by the Natural Resources Conservation Service

CHAPTER VI

RESULTS

The results in Section I are based on all the data, including the damaged tree measurements. Section II presents the results using only data from undamaged trees. Damaged trees were those that had tops out, were bent over or uprooted. This damage was attributed to ice, snow, or both.

I. SECTION I – ALL TREES

Survival After Five Growing Seasons Across All Sites

The data being analyzed were normally distributed using the PROC UNIVARIATE. The W value (0.9509) supported the hypothesis of normality. The stem and leaf plot showed a symmetric bell shaped curve, also indicating normality. The ANOVA table for fixed effects is located in Table A-4.

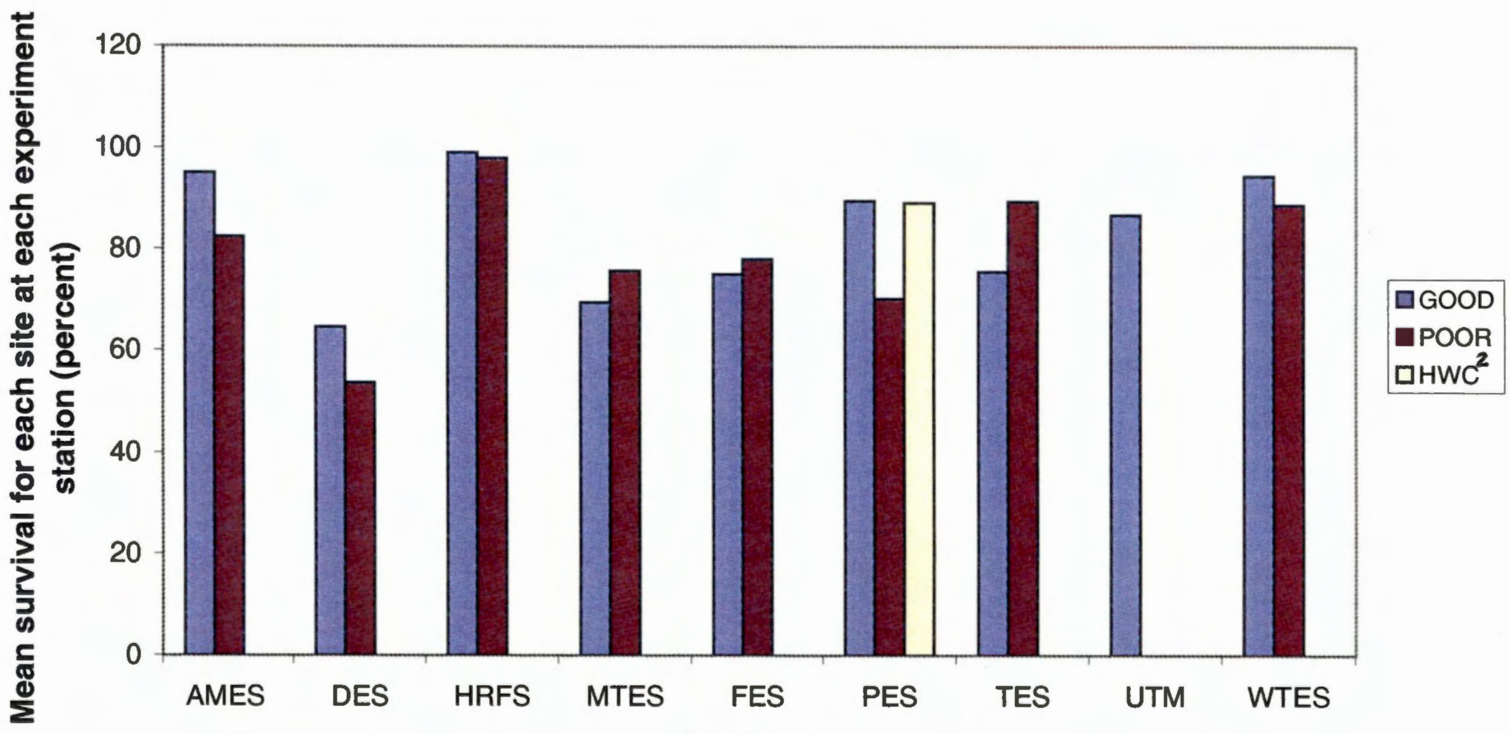
After the fifth growing season, the least square estimate of the mean survival (no. of plots=173) for all trees across all locations and sites was 82.5 percent. Mean survival at each station across all sites after the fifth growing season is found in Table 5. The mean survival for each site at each station after five growing seasons is found in Figure IV. No statistically significant differences were found among sites at locations.

The analysis of variance for random effects across all sites after five growing seasons showed significant differences among mean survival estimates. The covariance parameter estimate for year (0.001994), location (0.009537) and year by location (0.000142) showed significant differences among mean survival estimates. Location was temporarily set as a fixed effect, in the mixed model, to compare mean survival estimates. Estimates of years were not compared since location confounds each year;

Table 5: Least square estimates of mean survival at each location after five growing seasons – all trees

Locations[1]	Mean survival at all sites[2]		Mean survival at only good and poor sites[2]	
AMES	91.5	B[3]	87.7	B
DES	62.3	E	59.1	E
HRFS	100.0	A	99.1	A
MTES	75.9	D	72.4	D
FES	82.7	CD	76.2	CD
PES	82.7	CD	79.1	CD
TES	86.6	BC	83.4	BC
UTM	88.3	BC	-----[4]	
WTES	95.0	AB	91.4	AB

[1]Locations were temporarily set as fixed effects to show differences between mean survival estimates; see Table A-3 for location corresponding to each abbreviation
[2]Mean survival calculated to the nearest tenth percent
[3]Means with the same letters are not significantly different (P<0.05)
[4]Data for UTM were only taken at good site and mean survival was not included in analysis for good and poor sites



[1]No differences were found between sites at each location when tested at (P<0.05)

[2]HWC - Hardwood Conversion Site

Figure IV: Least square estimates of mean survival for each site at all locations[1] - all trees

therefore, location and years could not be used in the model at the same time. Location was found to be significantly different. Highland Rim Forestry Station had the greatest mean survival, while the Dairy Experiment Station had the least, 100.00 and 62.28 percent, respectively (Table 5).

Survival without herbicide (81.0 %) was significantly lower than survival with herbicide (89.0 %). No significant differences were found for mean survival among treatment combinations.

Survival After Five Growing Seasons at Good and Poor Sites

The least square estimate of the mean survival (no. of plots=164) for all trees at good and poor sites after the fifth growing season was 83 percent. Mean survival at each location for good and poor sites after the fifth growing season are found in Table 5. The ANOVA table for fixed effects is located in Table A-5.

Analysis of variance showed significant differences among mean survival estimates for location, and location by site after five growing seasons. Location was temporarily set as a fixed effect, in the mixed model, to compare mean survival estimates. The Martin Experiment Station was not included in the analysis since no data were taken at the poor site, and the statistical model could not calculate estimates for this location. The Highland Rim Forestry Station had the greatest mean survival, while the Dairy Experiment Station had the least, 99.1 and 59.1 percent respectively (Table 5). Significant differences were also found between location and site. The good site at Ames Plantation had significantly higher survival than the poor site, and the good site at the Plateau Station had significantly higher survival than the poor site (Table 6).

Table 6: Least square estimate of mean survival for locations and sites at only good and poor sites after five growing seasons[1] – all trees

Treatment Combinations	Mean[2]	Standard Deviation	Letter Group
AMES-Good	93.7	0.040	AB[3]
AMES-Poor	81.8	0.040	CDEF
DES-Good	64.4	0.045	HI
DES-Poor	53.7	0.044	I
HRFS-Good	99.4	0.041	A
HRFS-Poor	98.4	0.041	AB
MTES-Good	68.0	0.045	GH
MTES-Poor	76.7	0.044	EFGH
FES-Good	74.5	0.042	FGH
FES-Poor	77.8	0.042	CDEFG
PES-Good	89.8	0.045	ABC
PES-Poor	68.4	0.045	GH
TOB-Good	77.1	0.045	DEFG
TOB-Poor	89.8	0.045	ABCD
WTES-Good	95.8	0.046	AB
WTES-Poor	86.9	0.046	BCDE

[1]Significant differences were found when tested at ($P<0.05$)
[2]Mean survival estimates calculated to the nearest tenth percent
[3]Means with same letter are not significantly different ($P<0.05$)

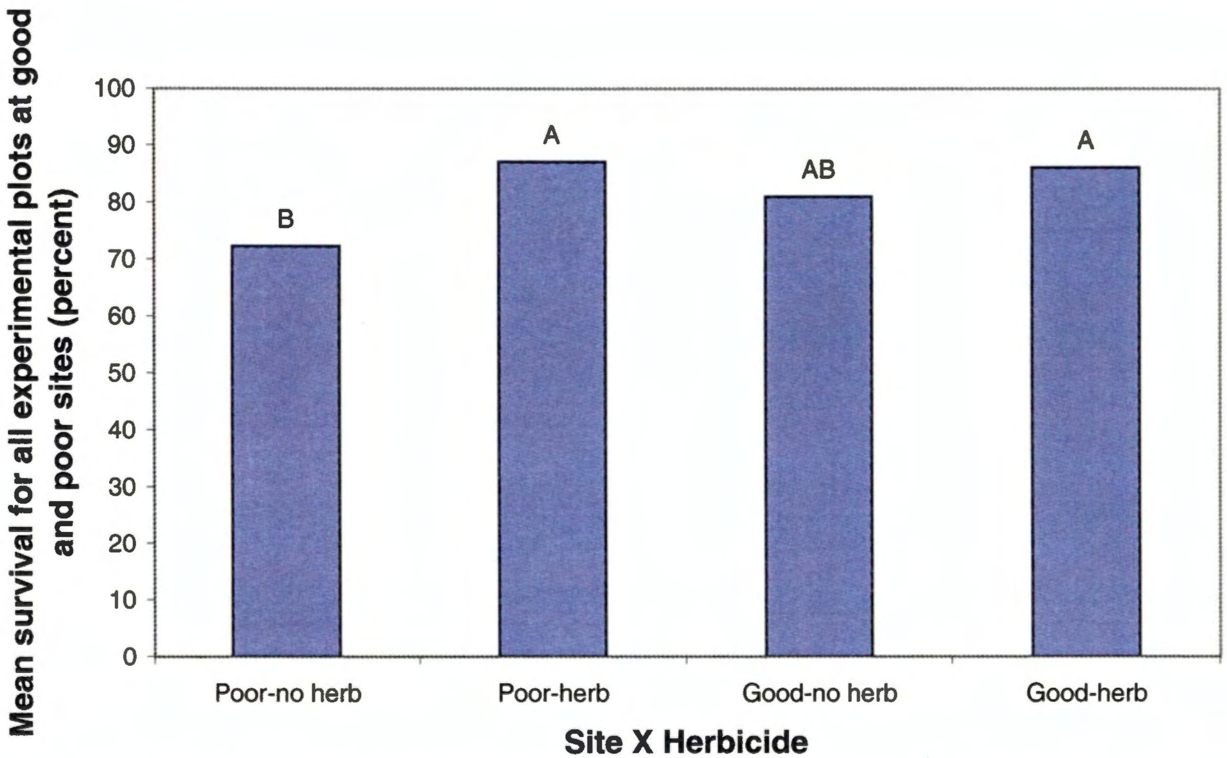
Analysis of variance indicated significant differences in mean survival for herbicide and site by herbicide. Survival without herbicide (76.7 %) was significantly lower than survival with herbicide (86.6 %). Significant differences were found for interactions involving herbicide application. The interaction between site and herbicide was significant because the increase in survival due to herbicide on poor sites was more than herbicide on good sites (Figure V).

Heights After Five Growing Seasons Across All Sites

Using PROC UNIVARIATE the data were tested for normality. The W value (0.9907) supported the hypothesis of normality. The stem and leaf plot showed a symmetric bell- shaped curve also indicating normality.

The least square estimate of mean height (number of plots=173) for all trees across all locations and sites after five growing seasons was 11.9 feet. Mean heights at each location across all sites after the fifth growing season are found in Table 7. Mean heights for each site after five growing seasons are found in Figure VI. No differences were found among sites at locations. The ANOVA table for fixed effects is located in Table A-6.

Locations were temporarily set as fixed effects in the mixed model to compare least square estimates of the mean height. The analysis of variance for locations after the fifth growing season showed significant differences (Table 7). Ames Plantation had the tallest mean height while the West Tennessee Experiment Station had the shortest mean height, 12.9 and 8.8 feet, respectively.



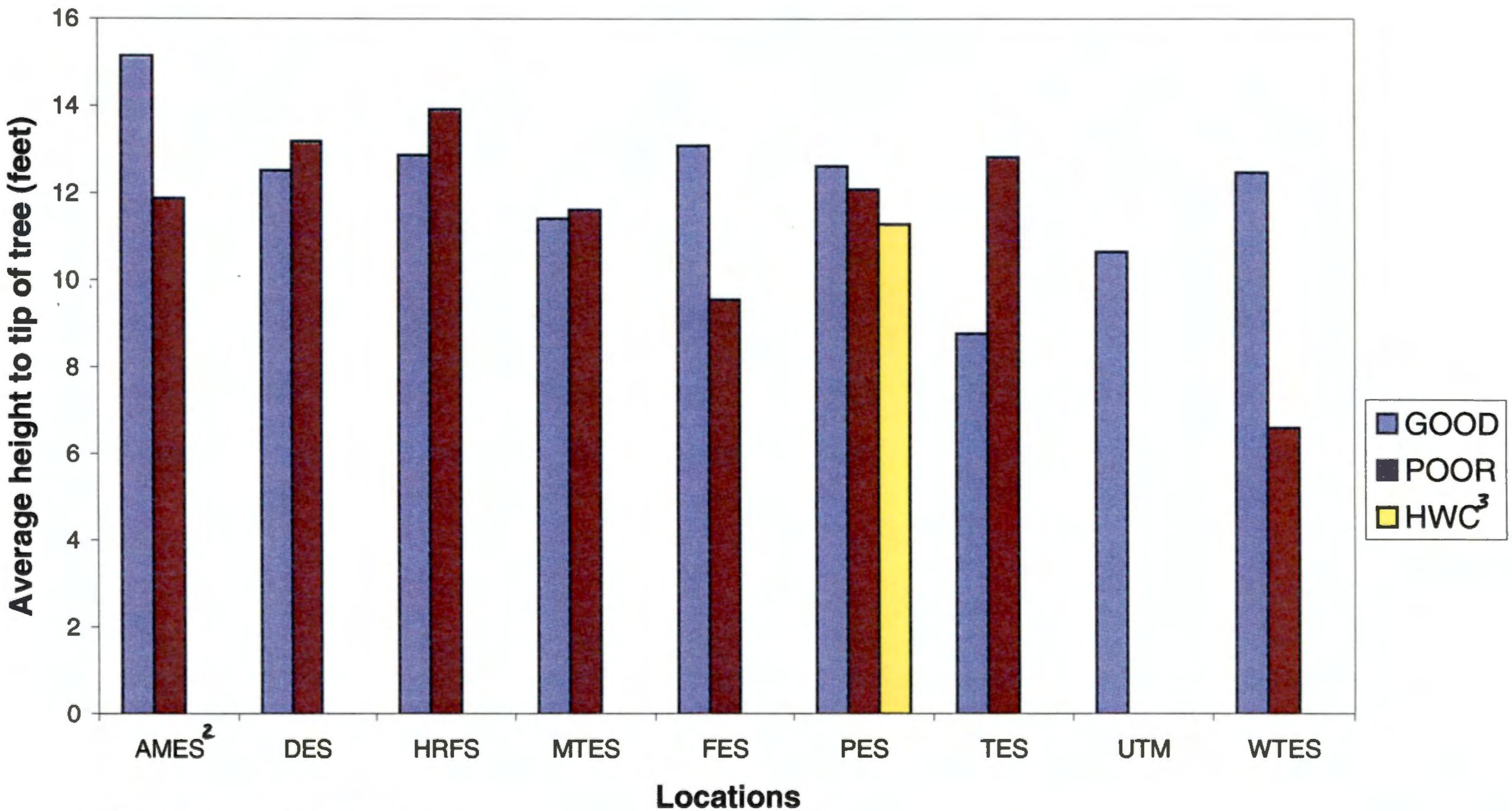
[1]Means with same letter are not significantly different from each other ($P<0.05$)

Figure V: Least square estimate of mean survival for site and herbicide at good and poor sites[1] - all trees

Table 7: Least square estimates of mean height at each location after five growing seasons – all trees

Locations[1]	Mean height at all sites[2]		Mean height at only good and poor sites[2]	
AMES[3]	12.9	A[4]	13.5	A
DES	12.2	AB	12.8	A
HRFS	12.9	A	13.5	A
MTES	11.0	BC	11.6	B
FES	10.7	C	11.3	B
PES	12.4	A	13.1	A
TES	10.2	C	10.9	B
UTM	9.4	CD	-----[5]	
WTES	8.9	D	9.5	C

1Locations temporarily set as fixed effects to show differences between mean height estimates
[2]Mean heights calculated to the nearest tenth of a foot
[3]Explanation for abbreviations are found in Table A-3
[4]Means with same letter are not significantly different ($P<0.05$)
[5]Data for UTM were only taken at good site; therefore, UTM was not included in analysis for good and poor sites



[1]No differences between sites

[2]Explanations for abbreviations are found in Appendix A

[3]HWC - Hardwood Conversion Site

Figure VI: Least square estimate of mean heights for each site at all locations[1] - all trees

The analysis of variance across all sites after five growing seasons showed significant differences between heights for herbicide only (11.4 ft vs 12.0 ft). No interactions were significant.

Heights After Five Growing Seasons at Good and Poor Sites

After five growing seasons, the least square estimate of mean height (no. of plots=164) at good and poor sites was 11.9 feet. The mean heights at each location for the good and poor sites are found in Table 7. When locations were set as fixed effects in the mixed model, significant differences were found. The Martin Experiment Station was not included in these analyses since no data were taken at the poor site. Ames Plantation had the tallest mean height (13.5 feet) while the West Tennessee Experiment Station had the shortest mean height (9.5 feet) (Table 7). The ANOVA table for fixed effects is located in Table A-7.

After five growing seasons a significant differences was found between herbicide treatments for height at only good and poor sites. The mean height on plots receiving herbicide (12.4 feet) was 8 percent greater than plots without herbicide (11.4 feet). No other main effects and no interactions were significant.

SECTION II – UNDAMAGED TREES

Survival After Five Growing Seasons Across All Sites

Using PROC UNIVARIATE, the data were tested for normality. The W value (0.9618) supported the hypothesis of normality. The stem leaf plot showed a symmetric bell shaped curve also indicating normality.

Least square estimate of the mean survival (no. of plots=173) for all trees across all sites after the fifth growing season was 79 percent. Mean survival at each location across all sites is found in Table 8. The mean survival for each site at each location after the fifth growing season is found in Figure VII. No differences were found between sites at location. The ANOVA table for fixed effects is located in Table A-8.

Location was temporarily set as a fixed effect in the mixed model to compare mean survival. Significant differences were found among stations after the fifth growing season (Table 8). The Highland Rim Forest Station had the highest mean survival (100 percent) and the Plateau Experiment Station had the smallest mean survival (62 percent).

The only main effect that was significant was herbicide; mean survival without herbicide was 80 percent while with herbicide it was 86 percent. No interactions were significant.

<u>Survival After Five Growing Seasons at Good and Poor Site</u>

After five growing seasons the least square estimate of the mean height (no. of plots=164) at good and poor sites was 79 percent. The mean height at each location for good and poor sites is found in Table 8. The ANOVA table for fixed effects is located in Table A-9.

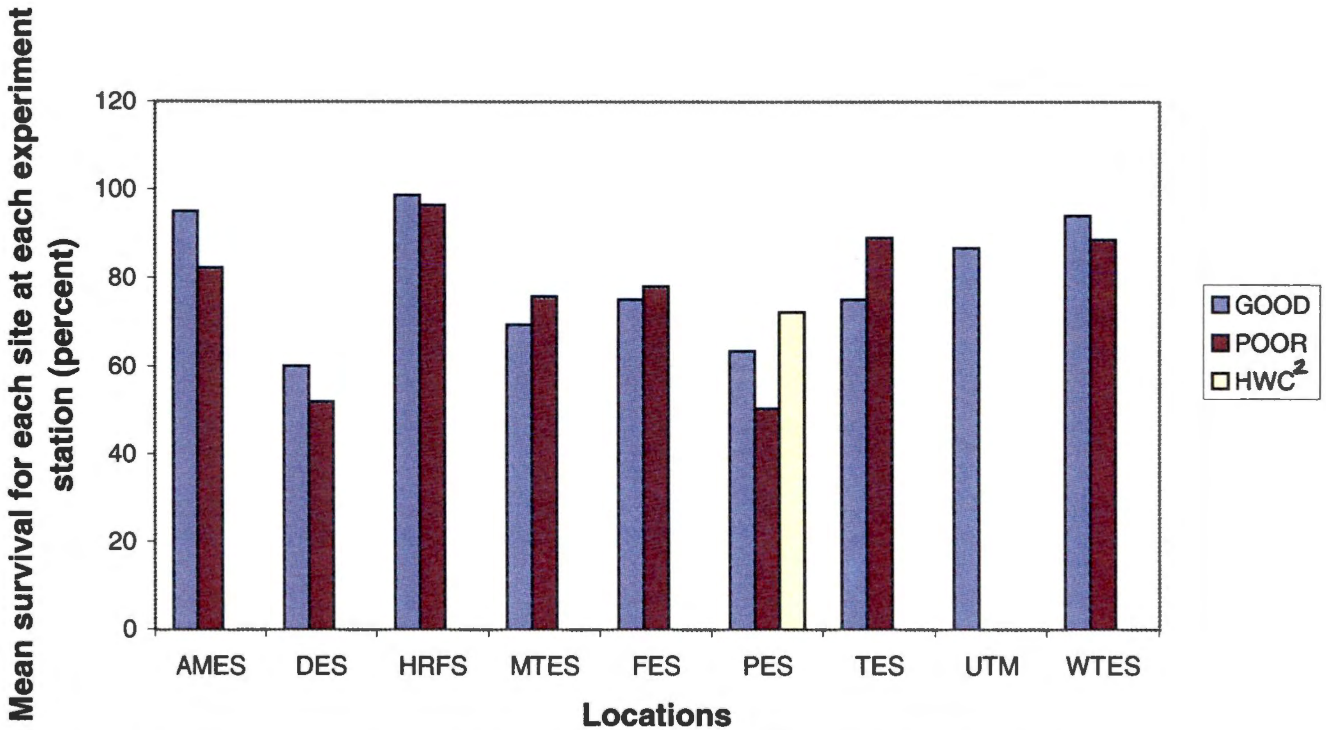
Locations were temporarily set as a fixed effect in the mixed model to compare mean survival estimates. Significant differences were found between locations after the fifth growing seasons Table 8. The Martin Experiment Station was not included in the analysis since no data were taken at the poor site. The Highland Rim Forest Station had the highest mean survival while the Plateau Experiment Station had the lowest, 98 and 56 percent, respectively.

Mean survival without herbicide (75.6%) was significantly lower than survival height with herbicide (83.4%). No interactions were significant.

Table 8: Least square estimate of mean survival at each location after five growing seasons – undamaged trees

Locations[1]	Mean survival at all sites[2]		Mean survival at only good and poor sites[2]	
AMES	93.0	BC[3]	87.4	BC
DES	61.1	F	56.1	F
HRFS	100.0	A	97.7	A
MTES	77.7	E	77.2	E
FES	81.5	DE	76.2	DE
PES	61.7	F	56.2	F
TES	87.9	CD	82.8	CD
UTM	90.7	BCD	-----[4]	
WTES	96.7	AB	91.3	AB

[1]Locations were temporarily set as fixed effects to show differences between survival estimates
[2]Mean survival calculated to the nearest tenth percent
[3]Means with same letter are not significantly different ($P<0.05$)
[4]Data for UTM were only taken at good site and mean survival was not included in analysis for good and poor sites



[1]No differences were found between sites at each location when tested at (P<0.05)

[2]HWC - Hardwood Conversion Site

Figure VII: Least square estimate of mean survival for each site at all locations[1] - undamaged trees

Heights After Five Growing Seasons Across All Sites

Using PROC UNIVARIATE the data were tested for normality. The W value (0.9894) supported the hypothesis of normality. The stem leaf plot showed a symmetric bell shaped curve also indicating normality.

The least square estimates of the mean height (no. of plot=173) for all undamaged trees across all locations and sites after five growing seasons was 12.1 feet. Mean height all locations across all sites are found in Table 9. Mean heights for each site at each location after five growing seasons are found in Figure VIII. No differences in sites were found. The ANOVA table for fixed effects is located in Table A-10.

Locations were temporarily set as a fixed effect in the mixed model to compare mean heights. Significant differences were found between locations after the fifth growing seasons (Table 9). The Plateau Experiment Station had the highest mean height while the West Tennessee Experiment Station had the lowest mean height, 13.1 and 8.7 feet, respectively.

The analysis of variance for herbicide across all sites after five growing seasons showed significant differences between mean heights. On the plots receiving herbicide (12.2 feet) the mean heights were 5.5 percent taller than plots without herbicide (11.5 feet). No interactions were significant.

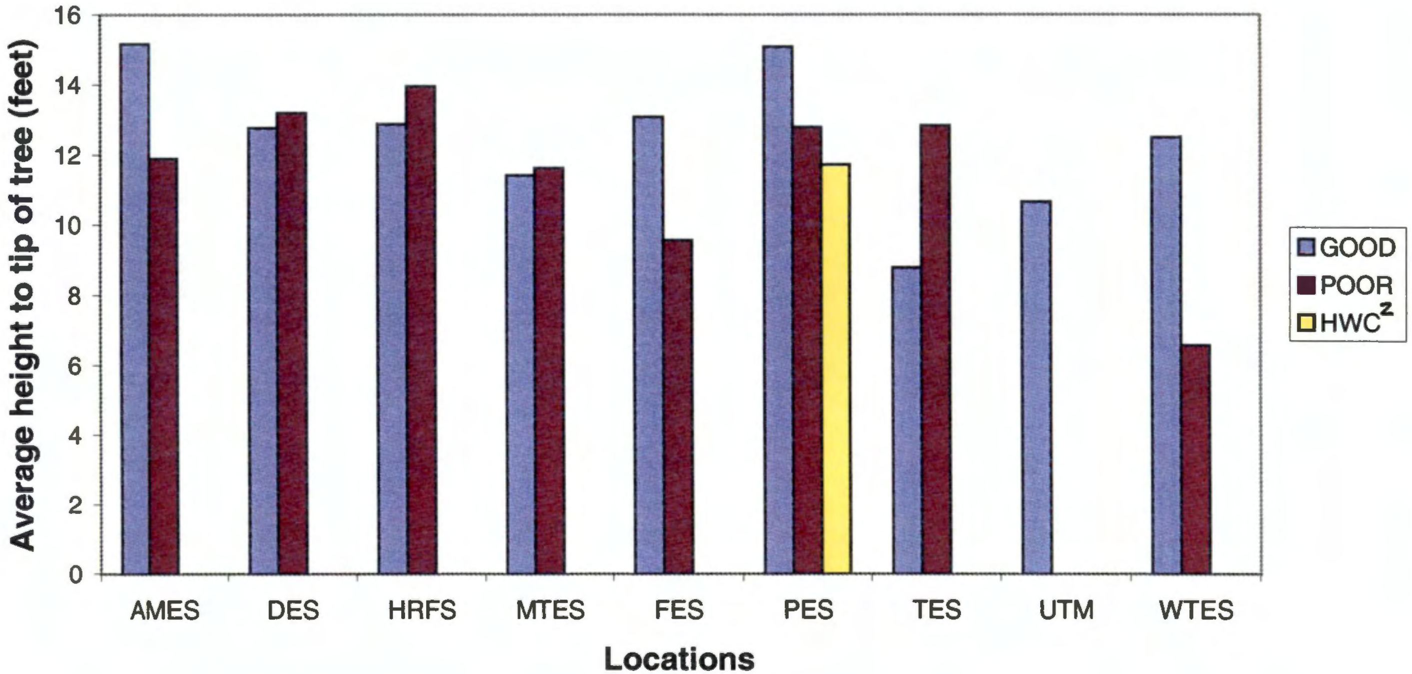
Height After Five Growing Seasons at Good and Poor Sites

After five growing seasons, the least square estimate of the mean height (no. of plots=164) at good and poor sites was 12.1 feet. The mean height at each location for the good and poor sites is found in Table 9. When location was set as a fixed effect in the mixed model, significant differences were found. The Martin Experiment Station was not

Table 9: Least square estimates of mean height at each location after five growing seasons – undamaged trees

Locations[1]	Mean height at all sites[2]		Mean height at only good and poor sites[2]	
AMES	12.8	A[3]	13.5	AB
DES	12.2	A	13.0	B
HRFS	12.8	A	13.5	AB
MTES	10.9	B	11.6	C
FES	10.5	B	11.3	C
PES	13.1	A	13.9	A
TES	10.1	B	10.9	C
UTM	9.3	BC	-----[4]	
WTES	8.7	C	9.5	D

[1]Locations were temporarily set as fixed effects to show difference between survival estimates
[2]Mean heights calculated to the nearest tenth of a foot
[3]Means with same letter are not significantly different ($P<0.05$)
[4]Data for UTM were only taken at good site and mean height was not included in analysis for good and poor sites



[1]No differences between sites

[2]HWC - Hardwood Conversion Site

Figure VIII: Least square estimates for mean height for each site at all locations[1] - undamaged trees

included in these analyses since no data were taken at poor site. The Plateau Experiment Station had the tallest mean height (13.9 feet), while the West Tennessee Experiment Station had the shortest mean height (9.5 feet) (Table 9). The ANOVA table for fixed effects is located in Table A-11.

Mean height without herbicide (11.5 feet) was significantly lower than height with herbicide (12.5 feet). No interactions were significant.

CHAPTER VII

DISCUSSION

In section I the discussion is based on the data including both the undamaged and damaged trees. Section I will discuss only the results at good and poor sites. When the hardwood conversion site was included in the analysis there was a one percent difference between mean survival for all sites, and good and poor sites. Mean height showed one-tenth of a foot difference between all site, and good and poor sites. The hardwood conversion site showed no significant differences when tested as a main effect and in interaction with other treatments. Section II presents the discussion using only data from undamaged tree measurements. Section II discusses only the results at good and poor sites. As with the results for all trees, there were no differences between all sites, and good and poor sites for mean survival and height. The hardwood conversion site showed no significant differences when tested as a main effect and in interaction with other treatments.

I. SECTION I

Significant differences were found between mean height growth and survival rates among locations (experiment stations). The Highland Rim Forestry Station and Ames Plantation had the highest height growth and survival rates. This may be due to these being located within loblolly's natural range. Also, these stations had the highest overall height and survival rate for both good and poor sites; and ranked among the highest in site index in the study. This indicates that growing loblolly pine on good sites such as those at Highland Rim Forestry Station and Ames Plantation would be most practical and beneficial to landowners.

The sites at each station showed no significant differences for evaluated variables. Soil surveys were not conducted for this study. To accommodate for a lack of information, soil maps were used to determine these variables. The good and poor sites at Ames Plantation and Highland Rim Forestry Station had the highest mean heights and survival rates (Figure IV and VI) and were some of the best as far as site index. These sites also have soils classified as being very deep to deep, well drained, loamy soils. Schultz (1997) and Debell et al. (1982) suggest that deep soils provide optimal conditions for growing loblolly pines.

After five growing seasons, herbicide was the most effective silvicultural treatment in improving height and survival at all experiment stations, and sites. Mean height with herbicide was 8 percent greater than without herbicide. Mean survival with herbicide was 10 percent greater than survival without herbicide. On poor sites, herbicide increased survival by 19 percent, while it increased survival by only 6 percent on good sites. Since a majority of the land that is converted to pine plantations is old field or less productive sites, herbicide could be beneficial in maximizing growth, survival and economic value of a stand. By minimizing the amount of competing herbaceous vegetation at an early stage in the development of the seedling, more moisture may have been available to the pines and thus resulted in increased survival and height.

The fertilizer tablets used as a main effect in this experiment did not prove significant in increasing height and survival after five growing seasons. Since fertilizer tablets are not a common practice in the management of pine plantations a minimal amount of research has been done using this method. Thus, there is no past evidence of positive growth or survival due to fertilizer starter tablets. As Tiarks and Haywood (1986) report much of the significant growth may have ceased after 2 years, therefore not showing significant increases in height growth and survival. Significant results that fertilization may have on tree growth and survival may be observed after the fertilization at stand closure. Other factors such as source and amount of fertilizer could have had an effect on lack of significance. When fertilization was used in combination with herbicide, fertilization had no significance on the increase of height and survival.

When spacing was considered as a main effect no significant differences were found. Although the spacing by herbicide interaction was not significant, survival without herbicide was significantly less than survival with herbicide at 8 X 8, but not at 8 X 10 and 10 X 10 feet.

II. SECTION II

When the analysis was done without damaged trees, herbicide application also seemed to have the greatest positive effect on height growth and survival rate. Mean survival without herbicide was 7 percent less than with herbicide. Mean height without herbicide was 8 percent less than with herbicide. There were no significant interactions between herbicide and fertilizer tablets or fertilizer used as a main effect.

Overall, when damaged trees were removed from analysis, mean survival was 79 percent and mean height was 12.1 feet. These results were similar to the estimates in Section I. Survival may be the only measured variable that is of practical significance. This information can be used as an indication of what survival may be like when conditions (environmental, human disturbances) are normal. Therefore, if survival is greater, a landowner would be able to grow more volume and have higher economic return.

When damaged trees were removed from the analysis, there was a significantly large difference in survival at Dairy Experiment Station and Plateau Experiment Station. The Dairy Experiment Station had a 5 percent decrease and the Plateau Experiment Station had a 41 percent decrease in survival when damaged trees were removed. This may be due to the fact that these experiment stations are found in a geographical position that typically get more exposure to ice and snow. These stands were subjected to large amounts of ice, causing severe damage to loblolly stems which decreased survival rate. Due to these environmental conditions, landowners should give consideration before planting loblolly pines in these geographical locations.

CHAPTER VIII

CONCLUSIONS

On the basis of this study of the growth and survival of loblolly pine following various silvicultural treatments, the following conclusions may be drawn:

1. When damaged trees were included in analysis, mean survival was 83 percent and mean height was 12 feet. Little difference was seen when damaged trees were removed from the analysis. Mean survival was 79 percent and mean height was 12 feet.

2. Herbicide was the only main effect that showed significance.

3. Survival without herbicide (76.7 percent) was significantly lower than survival with herbicide (86.6 percent). Height without herbicide (11.4 feet) was significantly lower than height with herbicide (12.4 feet).

4. Mean survival on poor sites increased 19 percent while it only increased 6 percent on good sites when herbicide was applied.

5. The Highland Rim Forestry Station and Ames Plantation had the highest height and survival rates. Both locations are within loblolly's natural range.

Based on the results, herbicide should be applied to increase survival and height. Loblolly pine would be most successful if planted within the natural range. These sites had the highest site index and deep, well-drained soils which are most optimal conditions for loblolly. The ice and snow damage in the Cumberland Plateau and Central Basin regions is a serious climatic condition that a landowner should consider before planting loblolly pine.

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APPENDICES

APPENDIX A

CLIMATIC DATA

A-1. Mean 1961-1990 monthly temperatures, precipitation, and snowfall for nine experiment stations

Station	Statistic	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Monthly Average	Yearly Total
Ames															
	Temp.	37.7	42.4	52.6	61.2	68.4	75.7	78.9	77.5	71.3	60.3	51.2	42.1	59.9	
	Max.	48.2	53.5	64.4	73.5	79.8	86.8	89.7	89.1	83.4	74.2	63.1	52.7	71.5	
	Min.	27.1	31.2	40.8	48.9	57.1	64.5	68.1	65.8	59.3	46.4	39.3	31.5	48.3	
	Precip.	3.6	4.2	4.9	5.5	5.1	3.5	4.2	3.1	3.9	3.0	5.0	5.4		51.7
	Snowfall	1.0	0.3	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.6		2.4
Dairy															
	Temp.	34.7	38.5	47.7	57.1	65.2	73.3	76.9	76.0	69.7	58.0	48.4	39.1	57.0	
	Max.	45.6	50.1	59.9	69.9	77.8	85.2	88.3	88.0	82.0	71.8	60.4	50.0	69.1	
	Min.	23.9	26.8	35.6	44.2	52.7	61.4	65.5	63.9	57.3	44.2	36.4	28.2	45.0	
	Precip.	4.5	4.1	6.0	4.7	5.7	3.9	5.2	3.3	3.8	3.8	4.9	5.0		54.7
	Snowfall	3.2	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.9		5.3
Highland Rim															
	Temp.	37.2	41.1	50.5	59.4	66.6	73.7	77.0	76.3	70.6	59.6	50.1	41.3	58.6	
	Max.	47.0	51.8	62.1	71.8	78.4	85.1	87.7	87.3	81.8	72.2	61.0	51.2	69.8	
	Min.	27.3	30.4	38.9	46.9	54.7	62.3	66.3	65.3	59.4	47.0	39.1	31.4	47.4	
	Precip.	5.0	4.8	6.3	4.9	5.3	3.9	5.0	3.5	3.9	2.7	5.0	3.6		57.3
	Snowfall	3.1	2.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	1.1		7.2
Middle Tenn.															
	Temp.	35.8	40.2	48.8	58.5	66.2	73.8	77.6	76.6	70.2	58.6	49.2	40.2	58.0	
	Max.	46.7	51.8	61.3	71.8	78.7	86.2	89.3	88.5	82.5	72.5	61.5	51.2	70.2	
	Min.	24.9	28.6	36.4	45.2	53.6	61.4	65.9	64.8	58.0	44.7	36.9	29.2	45.8	
	Precip.	4.2	4.3	5.8	4.9	5.6	3.7	4.8	3.7	3.5	3.4	4.5	5.0		53.3
	Snowfall	3.1	1.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.9		5.6
Martin															
	Temp.	33.4	37.9	48.5	58.7	67.2	75.1	78.4	76.7	70.8	59.3	48.9	38.4	57.8	
	Max.	43.4	48.4	59.6	70.5	78.9	86.8	89.8	88.5	83.1	72.7	60.1	48.4	69.2	
	Min.	23.3	27.3	37.4	47.0	55.5	63.5	66.9	64.8	58.6	46.0	37.7	28.4	46.4	
	Precip.	4.0	4.2	5.3	5.0	5.0	4.1	5.1	3.9	3.8	3.2	4.8	5.3		53.1
	Snowfall	3.8	2.6	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	1.0		8.7

A-1. (Continued)

Station	Statistic	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Monthly Average	Yearly Total
Oak Ridge															
	Temp.	35.3	39.1	48.4	57.3	65.3	72.8	76.2	75.6	69.5	57.8	47.8	38.8	57.0	
	Max.	44.8	49.8	60.3	70.1	77.6	84.5	87.0	86.3	80.4	70.2	58.8	48.3	45.8	
	Min.	25.8	28.3	36.5	44.4	53.1	61.2	65.5	64.9	58.6	45.4	36.8	29.4	68.2	
	Precip.	4.6	4.4	5.7	4.1	4.7	4.3	5.5	3.7	3.9	3.2	4.6	5.3		53.8
	Snowfall	4.1	3.7	0.9	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.1	2.3		11.3
Plateau															
	Temp.	31.3	35.0	44.7	53.9	61.8	68.9	72.3	71.5	65.7	54.7	45.7	35.8	53.4	
	Max.	41.5	45.8	55.5	65.2	73.2	80.0	83.0	82.5	76.8	67.0	56.3	46.0	64.4	
	Min.	21.2	24.2	33.9	42.7	50.4	57.8	61.5	60.4	54.5	42.4	35.1	25.7	42.5	
	Precip.	5.2	4.8	6.2	5.0	5.6	4.4	5.5	3.9	4.2	3.7	5.1	5.6		59.2
	Snowfall	6.1	5.5	2.1	0.3	0.0	0.0	0.0	0.0	0.0	0.0	1.0	2.4		17.4
Tobacco															
	Temp.	34.9	38.4	47.6	55.7	64.3	71.9	75.3	74.4	68.6	56.9	47.6	38.8	56.2	
	Max.	46.0	50.4	60.7	69.6	77.5	84.2	86.9	86.2	80.9	70.6	60.3	50.3	68.6	
	Min.	23.8	26.3	34.6	41.9	51.0	59.6	63.8	62.7	56.3	43.2	34.9	27.2	43.8	
	Precip.	3.3	3.4	4.0	3.4	4.0	3.8	4.9	3.5	3.3	2.7	3.1	3.0		42.1
	Snowfall	4.2	3.1	0.7	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.3	1.8		10.9
West Tenn.															
	Temp.	35.6	39.8	49.7	59.6	67.9	75.5	79.0	77.7	71.5	60.1	50.0	40.1	58.9	
	Max.	44.9	49.8	60.1	70.7	78.4	86.0	89.1	88.4	82.5	72.6	60.6	49.6	69.4	
	Min.	26.2	29.8	39.3	48.5	57.3	65.0	68.9	67.0	60.5	47.5	39.3	30.6	48.3	
	Precip.	3.9	4.4	5.0	5.1	5.5	4.1	4.2	2.9	3.9	3.3	4.8	5.4		52.5
	Snowfall	2.0	1.7	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.5		5.0

SOURCE: "Climatological Data, Tennessee," U. S. Department of Agriculture, National Water and Climate Center, Climate Analysis for Wetlands (by individual county).

Table A-2. Capability Classes and Subclasses

Best soils for agriculture	Class I. – Soils that are easy to farm and have no more than slight limitations in use. They may be used for intensive cultivation without any special measures to control excess water or erosion. They may be expected to produce high yields under normal good management. There are no subclasses under class I.
	Class II. – Soils that can be used for tilled crops and that have only moderate conservation problems or limitations. IIe. – Gently sloping soils subject to moderate erosion. IIw. – Imperfectly drained alluvial and colluvial soils.
	Class III. – Soils that have one or more serious conservation problems when used for tilled crops. IIIe. – Deep well-drained soils of the rolling uplands and terraces. IIIs. – Shallow soils that have poor moisture-supplying capacities. IIIw. - Poorly drained bottom land soils and somewhat poorly drained terrace soils.
	Class IV. – Soils that have very serious conservation problems when cultivated and therefore require very careful treatment and management. IVe. – Deep well-drained soils of the hilly upland and terraces. IVs. – Shallow soils that have unfavorable subsoils and poor moisture supplying capacities. IVw. – Poorly drained soils of the terrace lands.
	Class VI. – Soils requiring permanent vegetation, usually long-producing pasture and forage, and having only moderate conservation problems under such use. VIe. – Deep soils of the hilly and steep uplands. VIs. – Stony and cobbly soils of the rolling to hilly uplands.
Soils poorest for agriculture and thus usually used for trees	Class VII. – Soils generally best suited to trees. The more favorable sites are suited to limited grazing. VIIe. – Deep well-drained soils of the steep uplands; and gullied land. VIIs. – Shallow droughty soils of the steep uplands; and stony land.

From: Edwards, Max J., et al. 1958. Soil Survey, Greene County Tennessee. United States Department of Agriculture, Series 1947, No. 7, p 72

Table A-3. Abbreviations for Locations

AMES – Ames Plantation

DES – Dairy Experiment Station

HRFS – Highland Rim Forestry Station

MTES – Middle Tennessee Experiment Station

FES – Forestry Experiment Station

PES – Plateau Experiment Station

TES – Tobacco Experiment Station

UTM – University of Tennessee Martin

WTES – West Tennessee Experiment Station

Table A-4. ANOVA Table for Survival After Five Growing Seasons Across All Sites – all trees

Fixed Effect	DF[1]	F Value	Pr > F
Spacing	2	0.05	0.9536
Fertilizer	1	0.85	0.3581
Spacing*Fertilizer	2	1.58	0.2100
Herbicide	1	4.74	0.0312*
Spacing*Herbicide	2	0.57	0.5685
Fertilizer*Herbicide	1	0.39	0.5352
Spacing*Fertilizer*Herbicide	2	1.16	0.3155
Site	2	0.97	0.4233
Site*Herbicide	2	2.83	0.0624
Site*Fertilizer	2	0.16	0.8483
Site*Spacing	4	0.24	0.9177

[1]Degrees of Freedom
*Significant differences were found between main effects across all sites

Table A-5. ANOVA Table for Survival After Five Growing Seasons at Good and Poor Sites – all trees

Fixed Effect	DF[1]	F Value	Pr > F
Spacing	2	0.87	0.4201
Fertilizer	1	1.64	0.2028
Spacing*Fertilizer	2	1.73	0.1811
Herbicide	1	23.31	<0.0001*
Spacing*Herbicide	2	0.64	0.5311
Fertilizer*Herbicide	1	0.49	0.4837
Spacing*Fertilizer*Herbicide	2	1.20	0.3047
Site	1	0.85	0.3864
Site*Herbicide	1	4.71	0.0318*
Site*Fertilizer	1	0.29	0.5927
Site*Spacing	2	0.21	0.8130

[1]Degrees of Freedom
*Significant differences were found between main effects across all sites

Table A-6. ANOVA Table for Height After Five Growing Seasons Across All Sites – all trees

Fixed Effect	DF[1]	F Value	Pr > F
Spacing	2	0.54	0.5837
Fertilizer	1	0.27	0.6069
Spacing*Fertilizer	2	0.59	0.5542
Herbicide	1	3.71	0.0560*
Spacing*Herbicide	2	0.62	0.5406
Fertilizer*Herbicide	1	0.49	0.4838
Spacing*Fertilizer*Herbicide	2	0.64	0.5305
Site	2	0.36	0.7119
Site*Herbicide	2	1.50	0.2267
Site*Fertilizer	2	1.06	0.3499
Site*Spacing	4	0.24	0.9177

[1]Degrees of Freedom
*Significant differences were found between main effects across all sites

Table A-7. ANOVA Table for Height After Five Growing at Good and Poor Sites – all trees

Fixed Effect	DF[1]	F Value	Pr > F
Spacing	2	0.56	0.5753
Fertilizer	1	1.62	0.2055
Spacing*Fertilizer	2	0.68	0.5065
Herbicide	1	20.86	<0.0001*
Spacing*Herbicide	2	0.64	0.5290
Fertilizer*Herbicide	1	0.60	0.4418
Spacing*Fertilizer*Herbicide	2	0.43	0.6491
Site	1	0.64	0.4492
Site*Herbicide	1	1.87	0.1743
Site*Fertilizer	1	0.04	0.8453
Site*Spacing	2	0.17	0.8423

[1]Degrees of Freedom
*Significant differences were found between main effects across all sites

Table A-8. ANOVA Table for Survival After Five Growing Across All Sites–undamaged trees

Fixed Effect	DF[1]	F Value	Pr > F
Spacing	2	0.42	0.6568
Fertilizer	1	0.42	0.5174
Spacing*Fertilizer	2	2.52	0.0844
Herbicide	1	3.86	0.0514*
Spacing*Herbicide	2	0.64	0.5297
Fertilizer*Herbicide	1	0.64	0.4267
Spacing*Fertilizer*Herbicide	2	0.96	0.3852
Site	2	1.56	0.2757
Site*Herbicide	2	2.18	0.1175
Site*Fertilizer	2	0.05	0.9500
Site*Spacing	4	0.25	0.9110

[1]Degrees of Freedom
*Significant differences were found between main effects across all sites

Table A-9. ANOVA Table for Survival After Five Growing at Good and Poor Sites–undamaged trees

Fixed Effect	DF[1]	F Value	Pr > F
Spacing	2	2.01	0.1386
Fertilizer	1	1.53	0.2183
Spacing*Fertilizer	2	2.68	0.0726
Herbicide	1	16.37	<0.0001*
Spacing*Herbicide	2	0.54	0.5861
Fertilizer*Herbicide	1	0.71	0.4012
Spacing*Fertilizer*Herbicide	1	1.15	0.3184
Site	1	0.61	0.4608
Site*Herbicide	1	3.89	0.0506
Site*Fertilizer	1	0.08	0.7845
Site*Spacing	2	0.06	0.9381

[1]Degrees of Freedom
*Significant differences were found between main effects across all sites

Table A-10. ANOVA Table for Height After Five Growing Across All Sites– undamaged trees

Fixed Effect	DF[1]	F Value	Pr > F
Spacing	2	0.66	0.5185
Fertilizer	1	0.17	0.6790
Spacing*Fertilizer	2	0.59	0.5575
Herbicide	1	4.13	0.0441*
Spacing*Herbicide	2	0.66	0.5169
Fertilizer*Herbicide	1	0.44	0.5084
Spacing*Fertilizer*Herbicide	2	0.62	0.5414
Site	2	0.33	0.7319
Site*Herbicide	2	1.60	0.2061
Site*Fertilizer	2	0.88	0.4162
Site*Spacing	4	0.29	0.8873

[1]Degrees of Freedom
*Significant differences were found between main effects across all sites

Table A-11. ANOVA Table for Height After Five Growing at Good and Poor Sites– undamaged trees

Fixed Effect	DF[1]	F Value	Pr > F
Spacing	2	0.71	0.4912
Fertilizer	1	1.59	0.2099
Spacing*Fertilizer	2	0.70	0.4960
Herbicide	1	24.09	<0.0001*
Spacing*Herbicide	2	0.74	0.4781
Fertilizer*Herbicide	1	0.4451	0.4769
Spacing*Fertilizer*Herbicide	2	0.45	0.6392
Site	1	0.65	0.4474
Site*Herbicide	1	1.88	0.1731
Site*Fertilizer	1	0.02	0.8907
Site*Spacing	2	0.25	0.7801

[1]Degrees of Freedom
*Significant differences were found between main effects across all sites

APPENDIX B

PLOT LAYOUTS

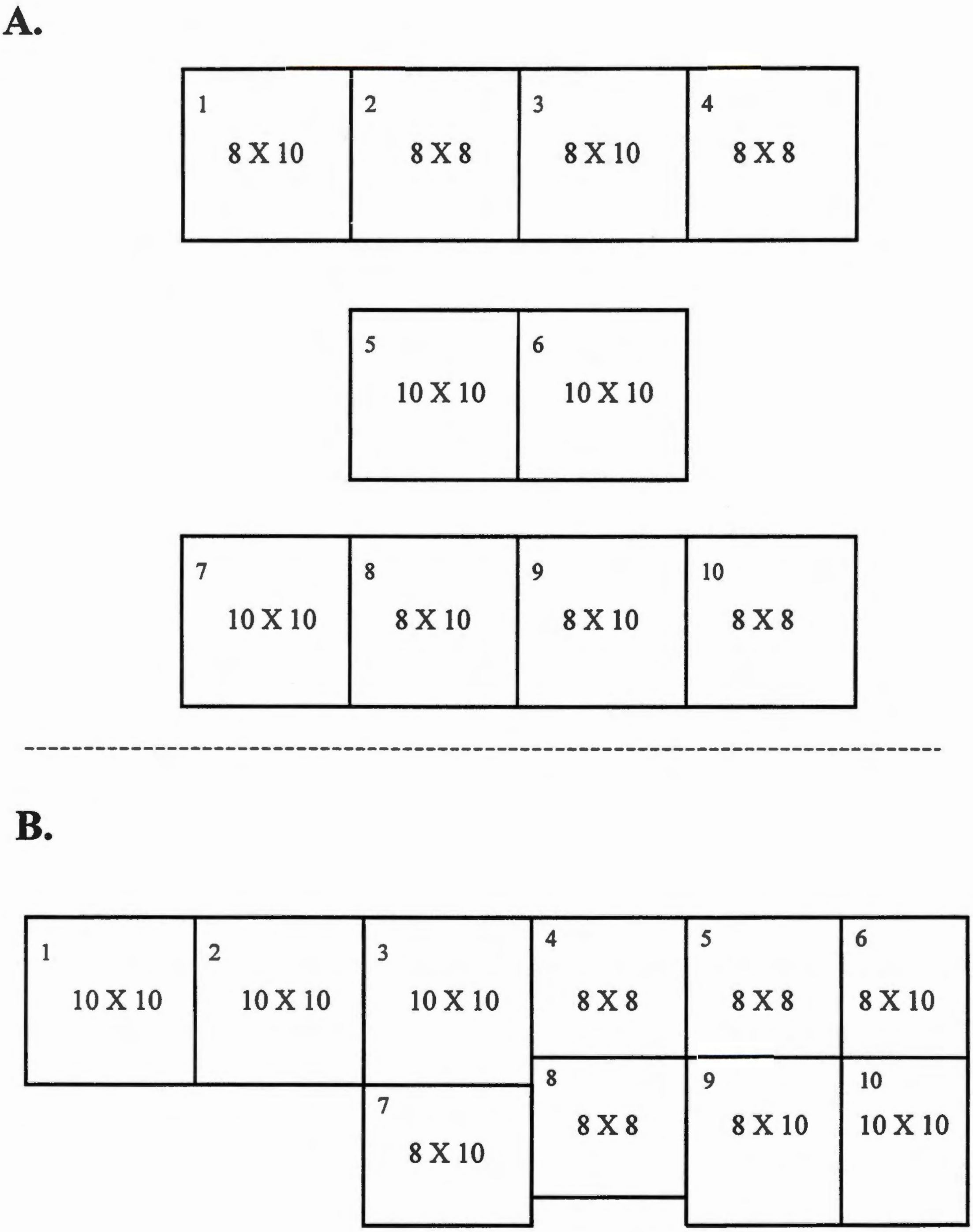


FIGURE II-a. Oak Ridge plot layout - A. (poor site) and B. (good site)

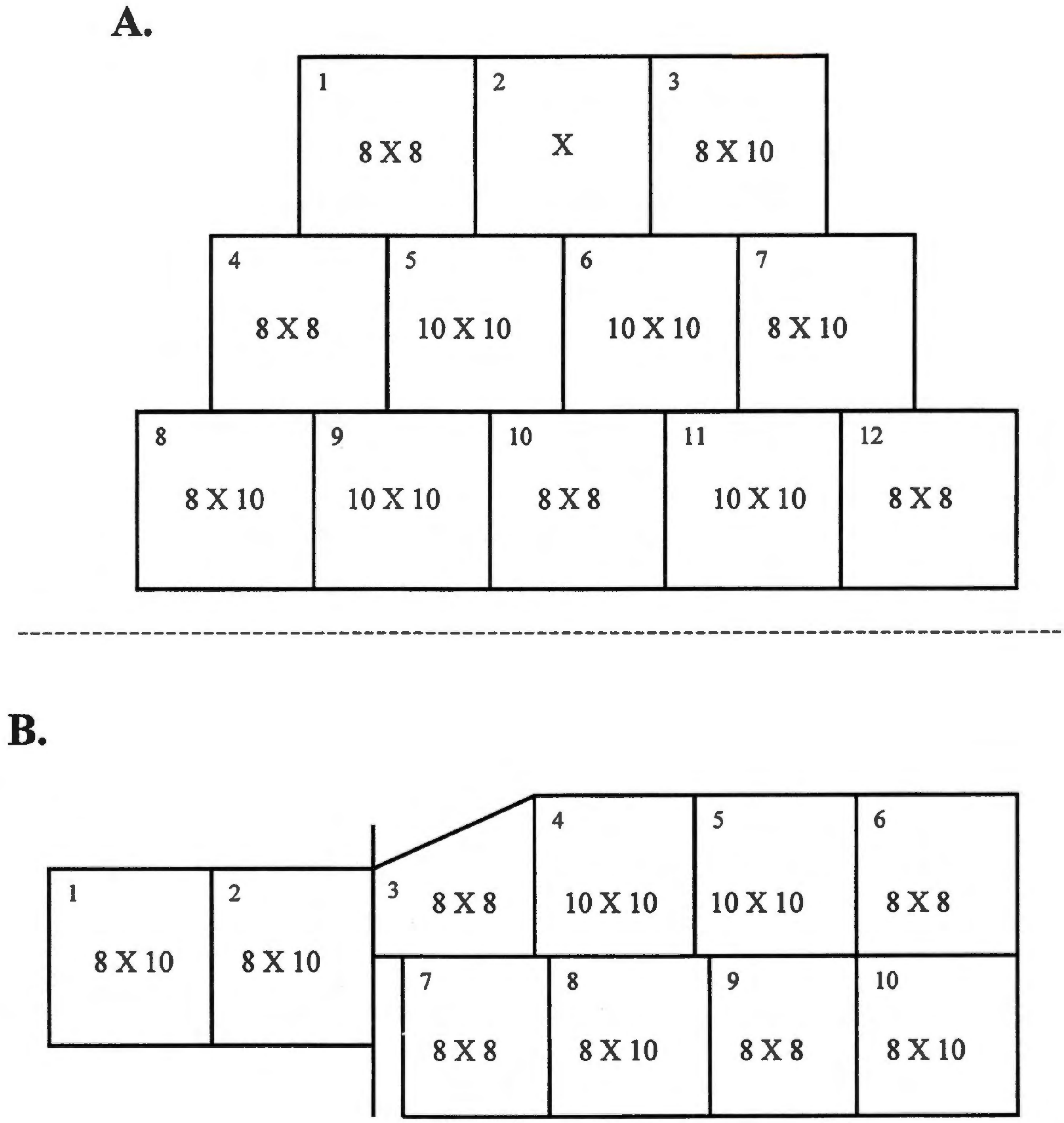


FIGURE II-b. Martin Experiment Station plot layout - A. (poor site) and B. (good site)

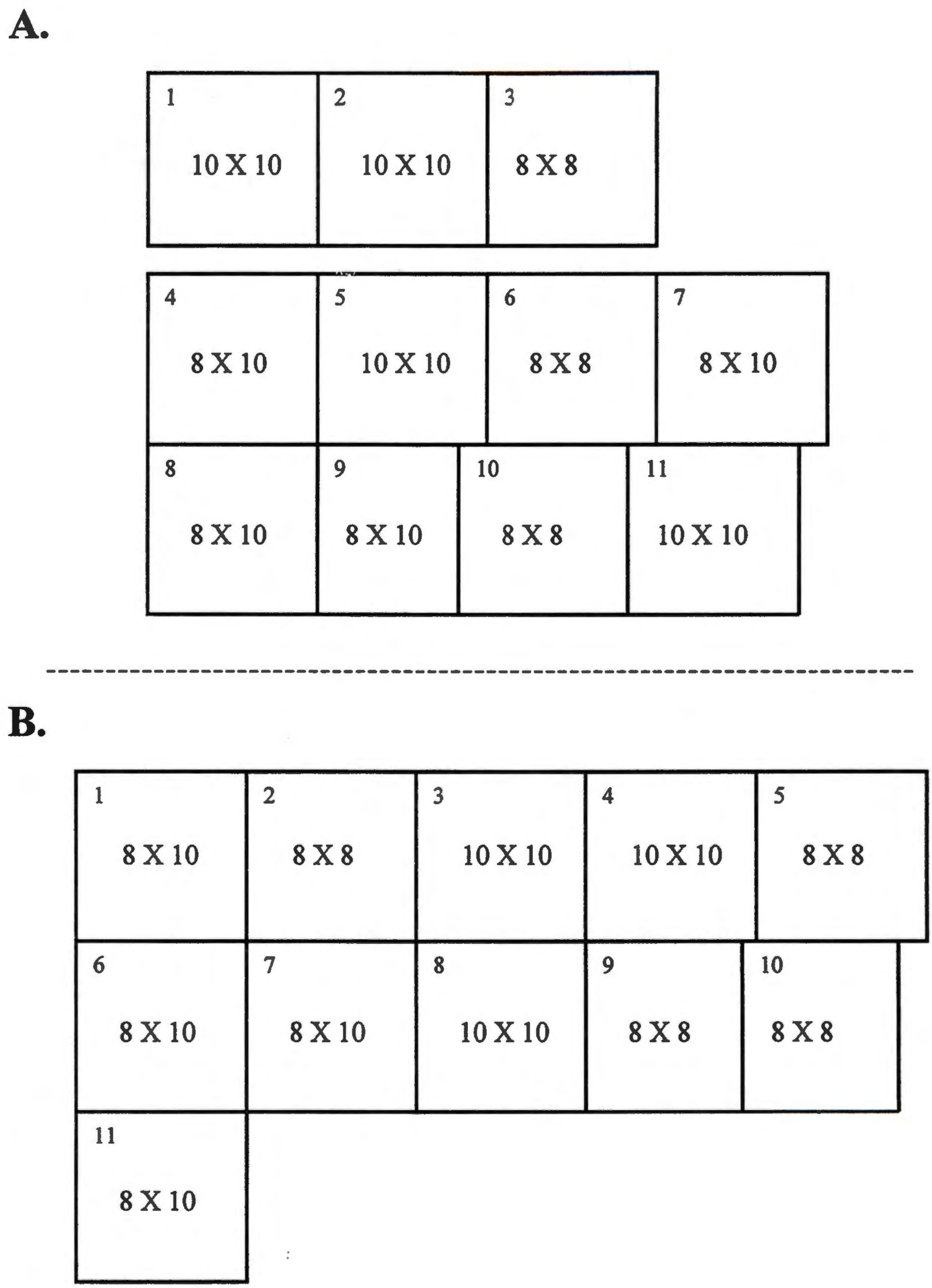


FIGURE II-c. Highland Rim Experiment Station plot layout - A. (poor) and B. (good)

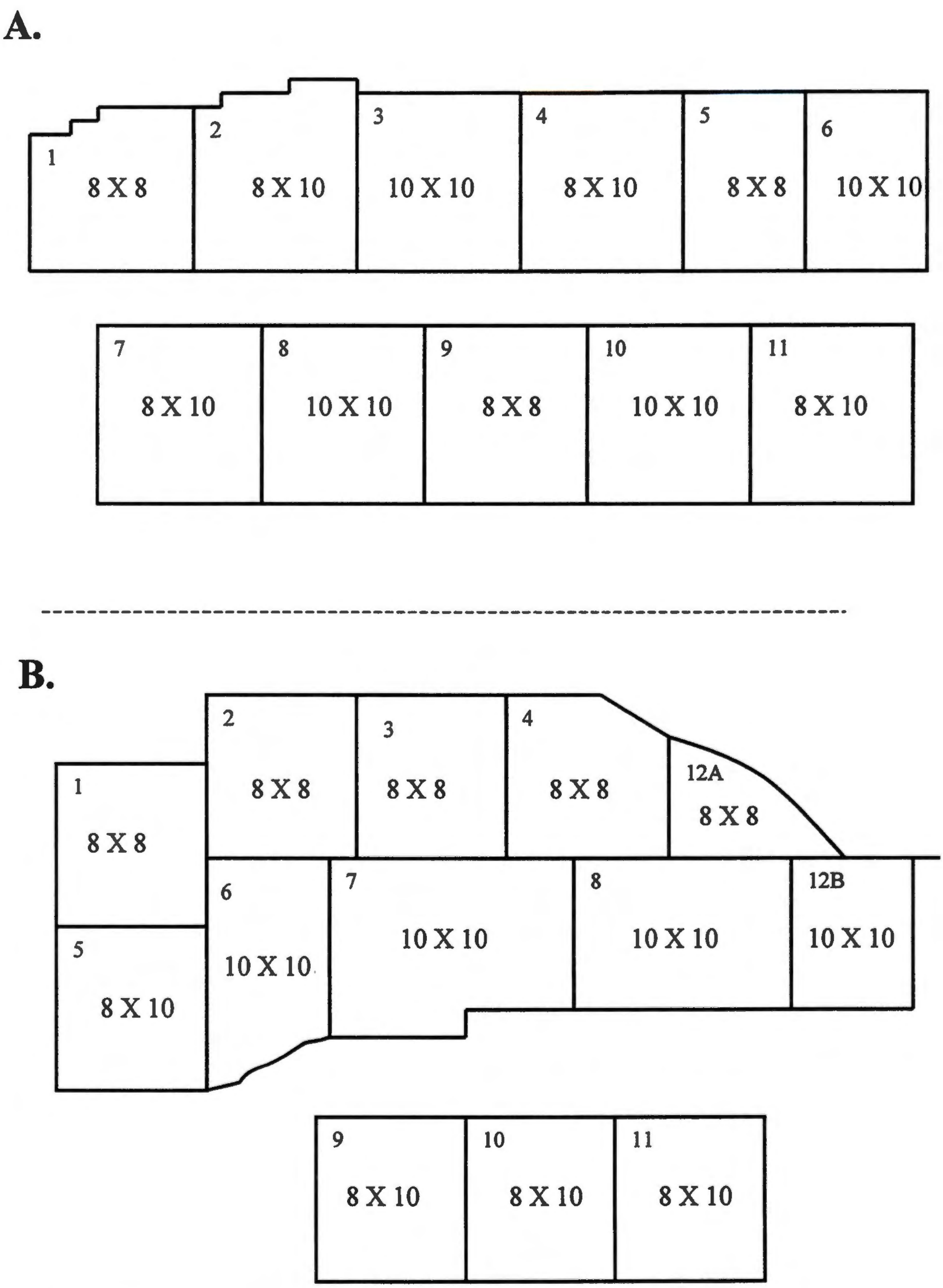


FIGURE II-d. Ames Plantation plot layout - A. (poor) and B. (good)

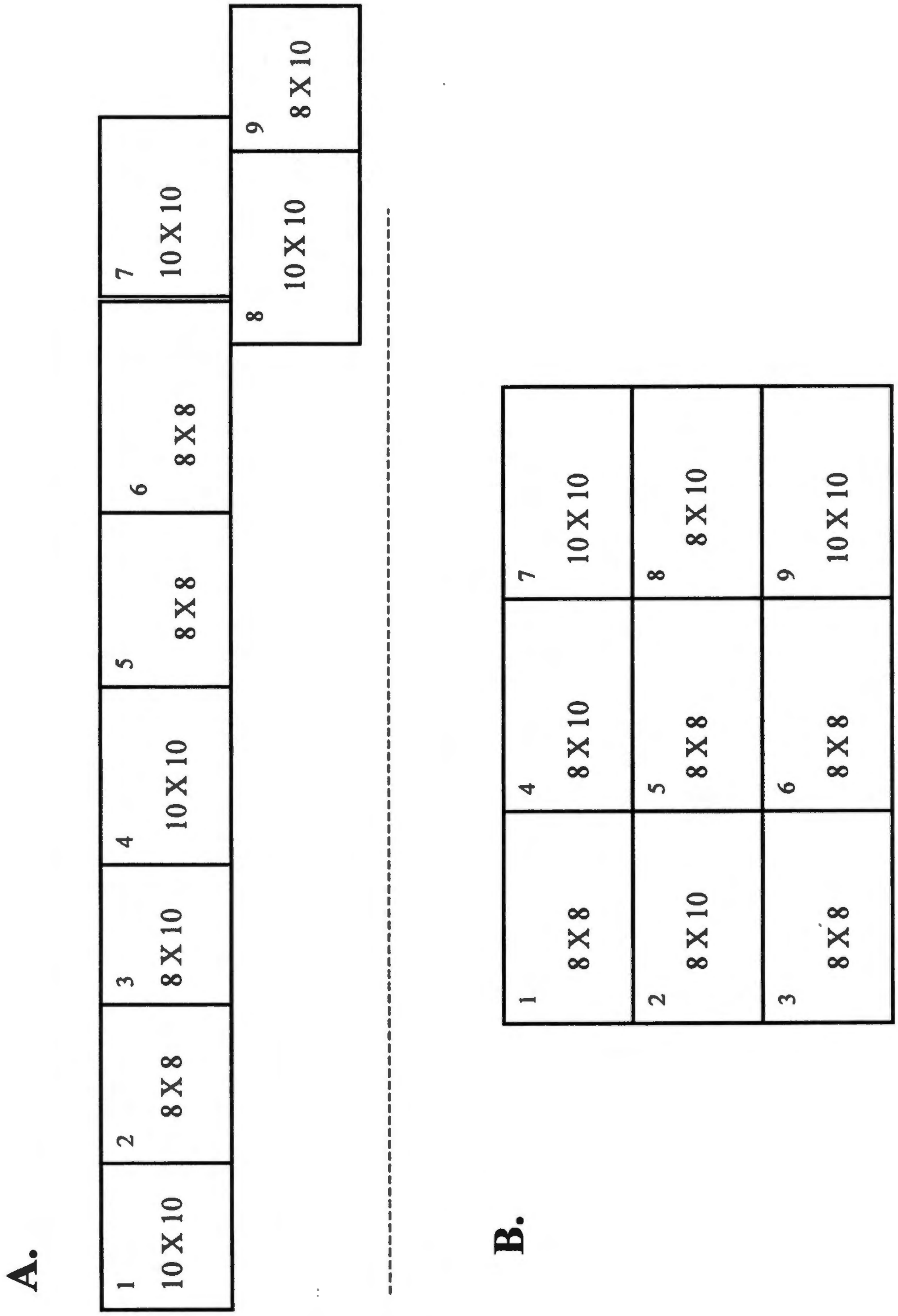


FIGURE II-e. West Tennessee Experiment Station plot layout - A. (poor) and B. (good)

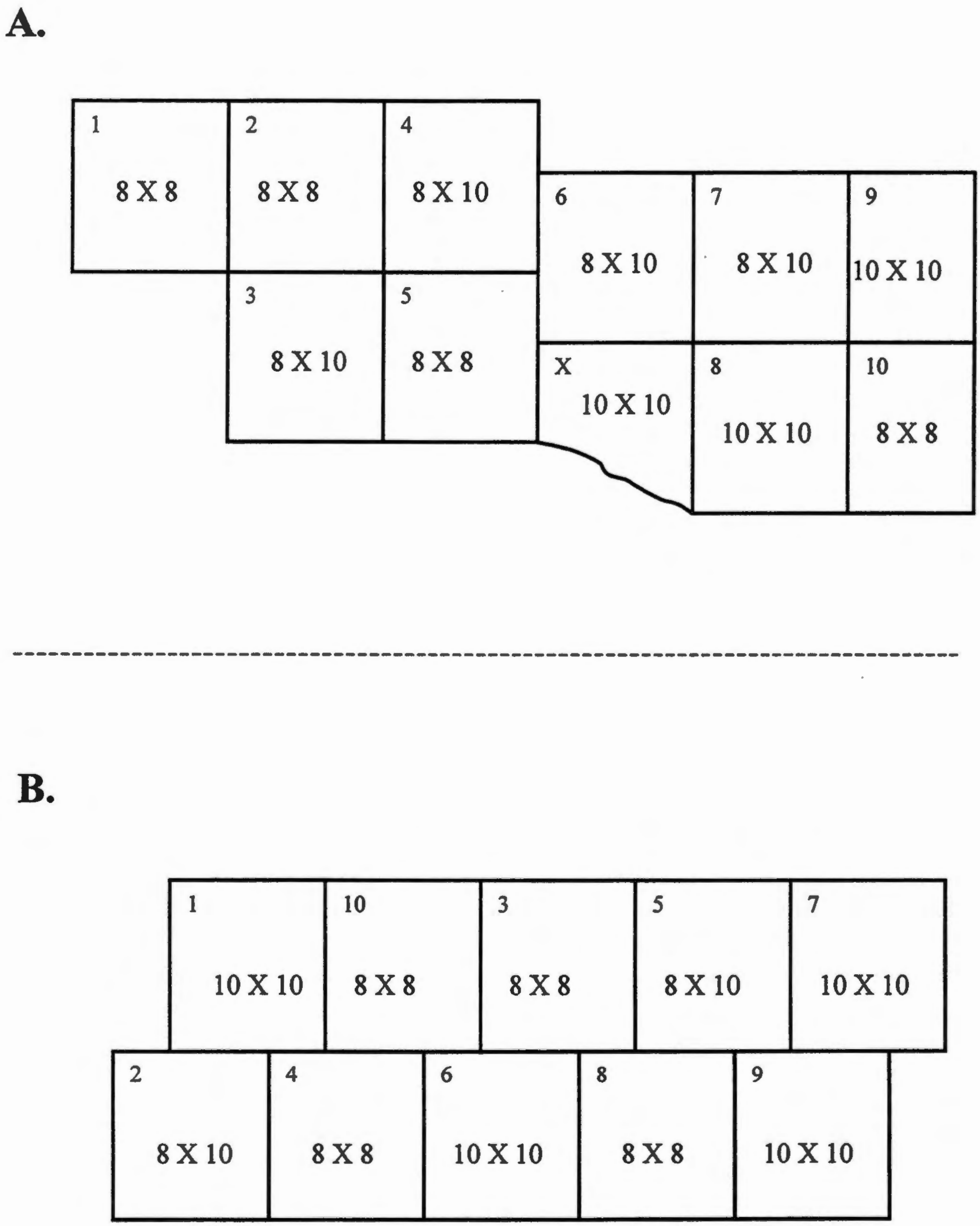


FIGURE II-f. Tobacco Experiment Station plot layout - A. (poor) and B. (good)

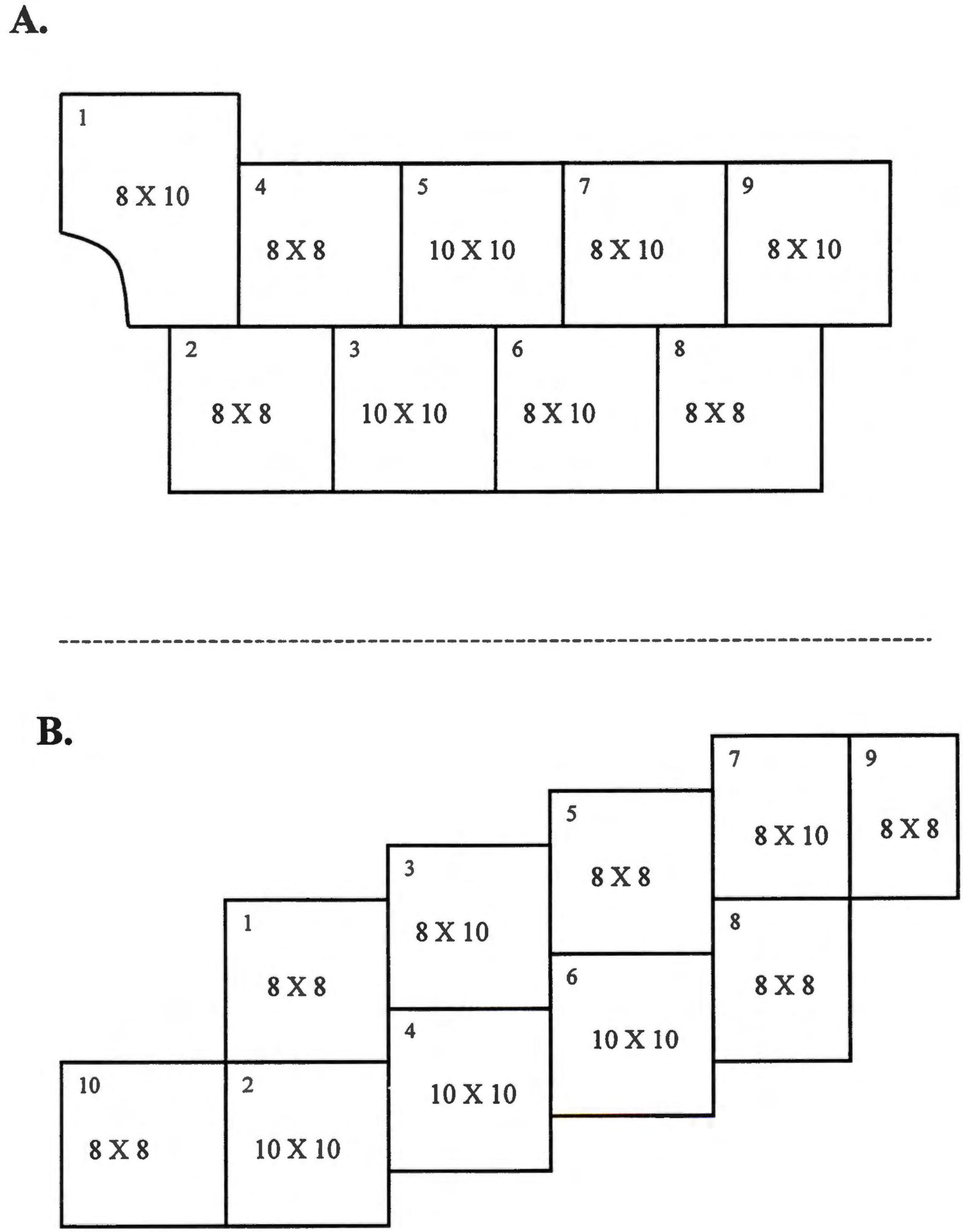


FIGURE II-g_1. Plateau Experiment Station plot layout - A. (poor) and B. (good)

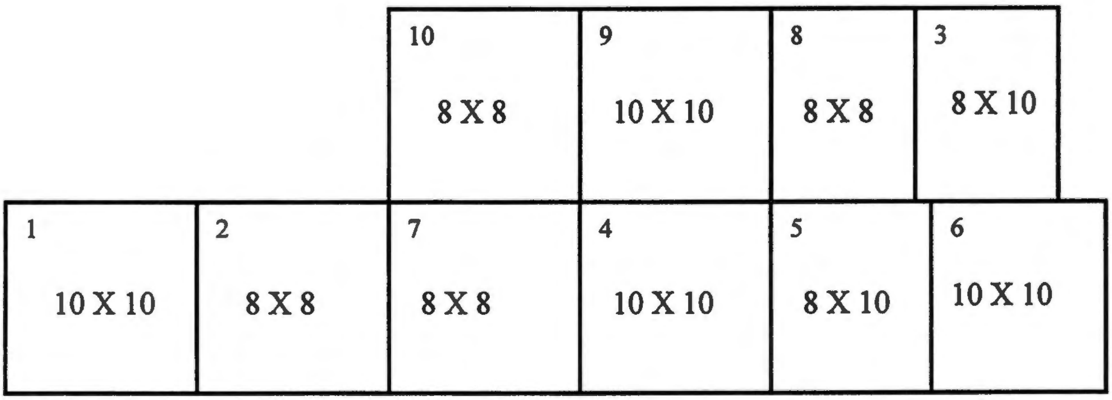
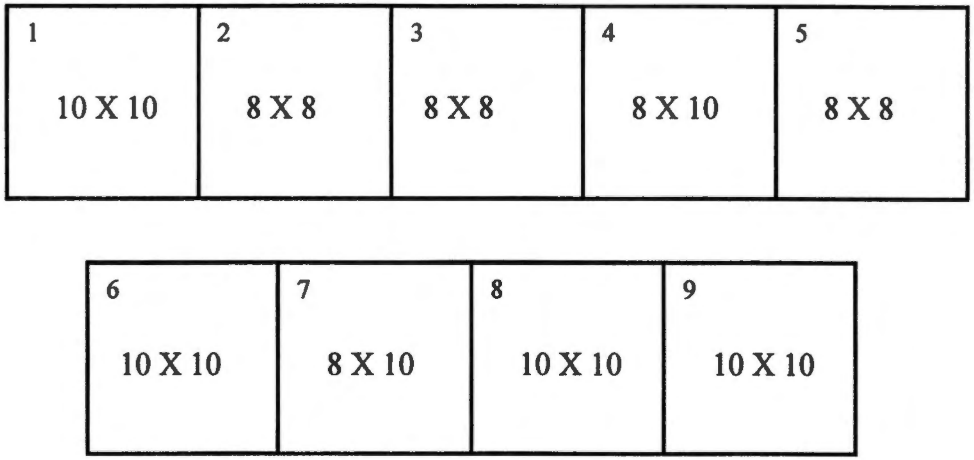


FIGURE II-g_2. Plateau Experiment Station Hardwood Conversion Site

A.



B.

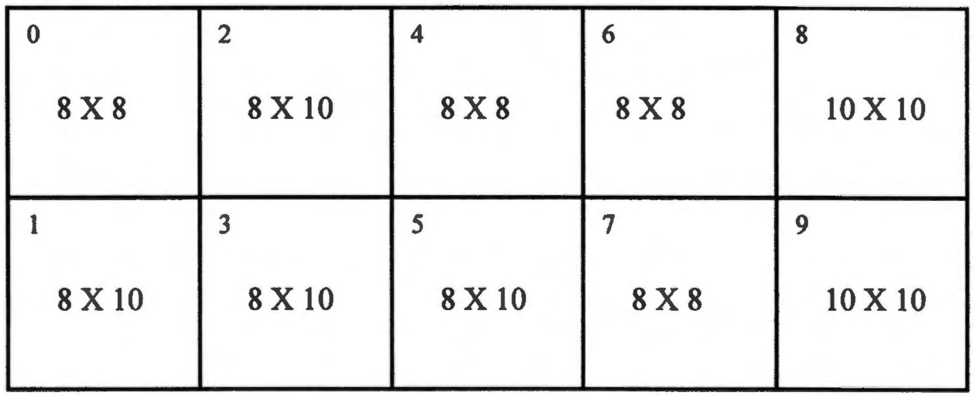


FIGURE II-h. Middle Tennessee Experiment Station Plot Layout - A. (poor) and B. (good)

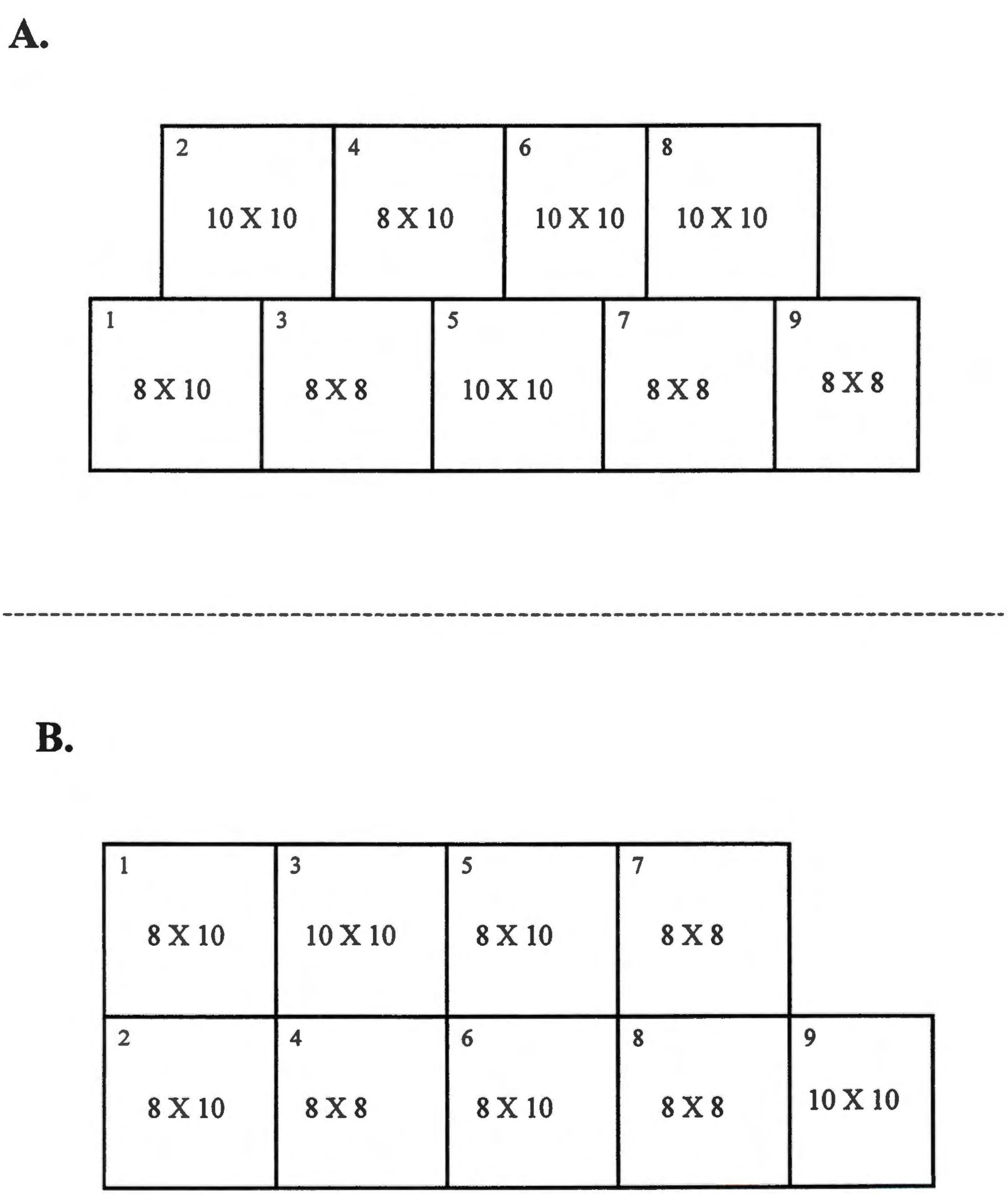


FIGURE II-i. Dairy Experiment Station Plot Layout - A. (poor) and B. (good)

VITA

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