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# Spacing effects on planted pines of four species

Olufemi Omiyale

To the Graduate Council:

I am submitting herewith a thesis written by Olufemi Omiyale entitled "Spacing effects on planted pines of four species." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Forestry.

Eyvind Thor, Major Professor

We have read this thesis and recommend its acceptance:

John C. Rennie, J. W. Barrett

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

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

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F. C. Rennie

Accepted for the Council:

Hilton A. Smith

Vice Chancellor for
Graduate Studies and Research

# SPACING EFFECTS ON PLANTED PINES OF FOUR SPECIES

A Thesis

Presented for the

Master of Science

Degree

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Olufemi Omiyale

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# ABSTRACT

Pine seedlings of four species were planted in two acre split plots at the Highland Rim Forest Experiment Station in 1965 using four spacings. At the end of the first growing season, all the dead trees were replanted.

After five growing seasons survival count and height of living trees were taken. At the end of ten growing seasons, survival, height, diameter and pruning height of the living trees were recorded.

Chi-Square contingency table tests indicated that survival, species, except for white pine, and spacings were dependent at the 5 percent level of probability. The same test at the same level indicated that self pruning is dependent on the species and the spacings used.

The analysis of variance indicated that there were differences due to species for height to live crown, total height, diameter, basal area and volume. Spacing has a significant effect on the branch mortality, diameter, basal area and volume. The interactions between species and spacing was also significant for height to live crown and for volume.

The result of this study could offer immediate guidance to the private, state and corporate land owners in choosing a spacing for planting any of the four species to meet their specific production needs.

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# CHAPTER I

# INTRODUCTION

Mann et al. (1972) observed that the real necessity for plantations in forestry practice is evident when we consider the rapidity with which the productive forest areas in the United States is decreasing and the condition in which a large part of the cut over land is left after logging. On many of these cut-over areas a second forest crop may be assured only by artificial regeneration.

Many factors combine in the life of trees to affect such attributes as tree height, diameter at breast height, pruning quality and volume. Among these factors are tree spacings, rainfall, soil moisture, nutrition and cultural operations. There are also variations due to genetic characteristics.

One of the vital decisions a forester has to make is the financially best spacing of species to be planted. The spacings will be determined by the forest management goal, sawtimber, firewood, pulpwood production or erosion control, and by the rotation length.

As a reflection of the large scale expansion of pulping processes for which pine is favored, demand for total soft wood timber has increased in the southern part of the United States. This demand raises the question: Which species should be used for maximum timber production in Tennessee?

The objective of this study is to compare the development of four different species of pine under four different spacings. The pines are loblolly pine (*Pinus taeda* L.), shortleaf pine (*Pinus echinata* Mill.), Virginia pine (*Pinus virginiana* Mill.), and eastern white pine (*Pinus strobus* L.).

The spacings used are 6 x 6, 9 x 9, 12 x 12 and 15 x 15 foot spacing. The characteristics measured to evaluate the stated objective are height, diameter, basal area growth, volume growth and pruning ability.

# CHAPTER II

# LITERATURE REVIEW

## Plantations Versus Natural Regeneration

Among the various advantages of plantations are that a new crop is started immediately after the removal of the old stand. The planted trees may be of genetically improved varieties. The establishment of plantations is independent of local occurence of seed years, since seed may be brought in from outside the region or stored from excess crops of previous years. Stand density can be controlled to obtain the growth and quality desired, and precommercial thinnings will not be needed.

Also, artificial regeneration enables the forest manager to develop a simpler and more definite plan for the management of the forest in his charge.

One of the disadvantages of plantation establishment, however, particularly on open land, is that it exposes the young plants to greater danger from frost, fire, weeds and insects. Toumey (1930) observed that clear cutting of large areas prior to planting exposes the soil to adverse climatic conditions which may seriously affect its fertility. In planting, there is a smaller number of plants per acre than with natural regeneration. As a result, the trees are likely to be more branchy, except where the planting is close enough to reduce branching.

In natural regeneration it is seldom that a single year will suffice to obtain full stocking. Thus, there is variation in age within a stand arising from natural regeneration. The main advantage of natural regeneration is that establishment cost tends to be much lower.

## History of Forest Plantations

Perhaps the world's most heroic example of reclaiming important areas by forest planting is found in France, where the past 170 years have seen the establishment of almost two million acres of maritime pine forest on the sand dunes of Gascony and the drained swampy areas of the Landes (Allen et al., 1960). Other European examples are plantations on lands once covered with forests including planting on lands once covered with forests including planting on lands devastated during the two world wars or areas failing to respond to natural seeding. However, the largest tree planting program in the world is in the southeastern United States of America with one million acres per year.

The objectives for the establishment of plantations vary among land owners (Thor et al., 1962). Bower (1973) concluded that the principal motives for planting are: to restore idle land, to produce timber, pulpwood, poles or firewood; to control erosion; to establish windbreaks; for improvement of recreation and wildlife habitat. Other objectives may be to reforest stripmined land or establish Christmas tree plantations.

## Factors Determining Management Decisions about Spacing

Factors determining management decisions about spacing are: (1) expected mortality, (2) cost of establishment, (3) desirability of thinnings, (4) harvesting equipment, (5) rotation length and (6) size of products.

Expected mortality. In an experiment with loblolly pine planted at 4 x 4, 6 x 6, 6 x 8, 8 x 8 and 10 x 10 foot spacings at the North Louisiana Hill Farm Experiment Station, it was discovered that between the ages 5 and 12, mortality in 4 x 4 foot spacing was 20 percent, 32 percent in 6 x 6 foot spacing, 29 percent in 6 x 8 foot spacing, 25 percent in 8 x 8 foot spacing and 13 percent in the 10 x 10 foot spacing. Between the ages of 12 and 18 the mortality was as follows: in 4 x 4 foot spacing 11 percent, 6 x 6 foot spacing 3 percent, 6 x 8 foot spacing 2 percent, 8 x 8 foot spacing 1 percent and no mortality in the 10 x 10 foot spacing (Hansbrough, 1968).

In another experiment at Calhoun Experimental Forest near Union, South Carolina survival of slash pine (*Pinus elliottii* Engelm) ranged from 85 percent in a six foot spacing to 96 percent in a ten foot spacing (Dell et al., 1975). Campbell and Mann (1974) found out that survival of loblolly pine was not influenced by the planting spacing. In a growth and yield of planted slash pine on cutover sites in the West Gulf, Feduccia (1974) concluded that survival at age 14 was inversely related to the number of trees planted per acre.

Cost of establishment. Funk (1961), Limstrom (1963), and Daniel (1972) noted that establishment costs decrease with wide spacings because fewer trees are planted, thus reducing time and labor required for planting operations.

_Thinnings_. Funk (1961) and Dell et al. (1968) observed that wider spacings not only require less labor and planting stock but also postpone the need for thinnings. In a spacing experiment with slash pine, future yields of slash pine were increased by an initial commercial thinning of severely cankered and crowded trees to a residual density of 100 square feet of basal area per acre. Bower (1965), in his conclusions from 15-year-old stands of loblolly pine in the Quachita Mountains of Arkansas, said, "Heavy precommercial thinnings tripled diameter growth. Average annual diameter growth for three years after thinning was 0.11 inch on check plots (3 x 3 foot spacing) and 0.17 inch on 5 x 5 foot plots." Daniel et al. (1972) found that one of the advantages of lower initial stocking was that precommercial thinnings are not required.

_Harvesting equipment_. The present-day forest manager has to include in his plan the type of equipment to use during the harvesting operations. Spacing of the trees therefore becomes crucial. Mann (1971) and Daniel et al (1972) both recommended wide spacings. They discovered that a spacing that permits easy passage of large equipment for mechanized harvesting and allows trees to reach large diameter at early age is highly desirable.

_Rotation length_. According to Daniel et al. (1972) on their work on density growth relationships in a nine-year-old red pine (_Pinus resinosa_ Ait.) plantation, concluded that "one of the advantages of lower initial stocking was that a shorter rotation is possible." Consequently, interest rate on the investment will be lowered.

Size of desirable products. In all the preceding paragraphs, the objective of plantation establishment has been stated to be to determine the size of the desirable products. If maximum production of cubic volume is the goal, then a close spacing would be used. If rapid growth is desired to obtain saw logs as quickly as possible then wider spacings seem to be best (Applequist et al., 1965 and Balmer et al., 1975). Brender (1973) in his silviculture of loblolly pine in the Georgia Piedmont, concluded as follows: "Eighty to 100 square feet basal area per acre was desirable. Self-pruning of lower limbs two inches in diameter and larger will begin and wood of plywood and lumber quality will be produced on a knotty core of 10 to 16 inches in diameter. Early artificial pruning in open grown stands could improve tree quality. Such a practice will make it possible to produce a full 16 foot log and will increase merchantable height by reducing the rate of taper."

## Characteristics Affected by Spacing

Height growth. Throughout the literature review, different conclusions were found regarding the effects of spacing on height growth of pine trees. Bramble et al. (1949), Hansbrough (1968) and Balmer et al. (1975) all concluded that pine plantations established at spacings (10 x 10, 8 x 8, and 12 x 12 foot) produced trees of greater height than those plantations at spacings of 4 x 4 or 6 x 6 feet. Bennett (1960), Bower (1965), Daniel et al. (1972), Limstrom (1963), Ware and Stahelin (1948) and Williams (1959) all concluded that spacing has no significant effect on height growth of the pine plantations used in their various experiments.

Diameter growth. The merchantability of any pine plantation is largely a function of the diameter of the trees. The effects of spacing on the diameter growth of trees is therefore very important. Ware and Stahelin (1948), Nelson (1952), Williams (1959), Bennett (1960), Nelson et al. (1961), Funk (1961), Box et al. (1964), Harns and Collins (1969), Brender (1973), Feduccia (1974), Campbell and Mann (1974), and Baker et al. (1975) all concluded in their experiments that wide spacings promote better diameter growth. Hansbrough (1968) found that in a plantation where the trees are growing at a 10 x 10 foot spacing, their diameter is almost twice as large as those planted at a 4 x 4 foot spacing and 20 percent larger than those at an 8 x 8 foot spacing. Bower (1965) concluded that average annual diameter growth for three years after thinning was 0.11 inch on a 3 x 3 foot spacing, 0.17 inch on a 5 x 5 foot spacing and 0.34 inch on a 8 x 8 foot spacing. Harns and Collins (1965) concluded that comparison at age 12 of eight spacings of old field planted slash pine shows average tree diameter is positively correlated with spacings.

Form class. Avery (1975) said that for a given species, form quotients are lowest for open grown trees with long live crowns and highest for forest grown trees with relatively short crowns. Little et al. (1965), Dell et al. (1968), Hamilton and Matthews (1965), all found that there is a positive relationship between crown ratio and spacing. The wider spacings had the greatest effects in increasing live crown ratio. Brender (1973) found that open grown, widely spaced loblolly pine grows fast in diameter, retains branch stubs all the way to the ground, and tapers excessively.

Pruning. The quality of a tree is enhanced by pruning. Hopkins (1958) said "under the best of conditions, loblolly pine does not prune itself as rapidly as is desirable and even though the lower limbs may die when still relatively small, they frequently persist for years after death. Since this is true, it would be desirable to employ more intensive management practices and prune 70 to 100 crop trees per acre artificially. The objectives should be to produce a clear stem 16 to 32 feet long which has a knotty core with a diameter of five inches or less. When the pruning job is left to nature, this objective is attained very infrequently and then only by trees which are long suppressed." Tryon et al. (1960) concluded that trees which grow together in a forest develop trunks which tend to be straight and also develop small and relatively few limbs as a result of natural pruning. Trees spaced far apart develop large limbs resulting in lumber of lower quality. Also, where wide spacing exists, the trees are not utilizing the site for maximum lumber production because much of the wood develops into limbs instead of diameter growth. Funk (1961), Applequist et al. (1964), and Brender (1973) arrived at the same findings as Tryon. Bennett (1969) discovered from his experiment on spacing and quality timber production in slash pine that close spacing induce early self pruning. Bower (1965), Nelson (1952) and Brender (1973) concluded that closer spacings provided for better pruning.

Wood density. This is another important wood property, especially in the pulp industry. Spacings have an important effect on wood density. Hamilton and Matthews (1965) found that the specific gravity of a tree was influenced by stand density to a significant degree. They reported that for loblolly pine and shortleaf pine, trees with highest specific gravity occurred in the five foot spacing. Closer and more distant spacings contained trees with lower average specific gravities. Hansbrough (1968) also concluded that individual tree growth, volume production, merchantability and wood density are all affected by the number of trees growing on the site. Baker (1969) reported that widely spaced red pines contain 74 percent more wood by volume than the closely spaced ones but they average somewhat lower in specific gravity. Echols (1959), on the other hand, reported that there was not any significant difference in specific gravity of the wood as a result of initial spacings.

Erosion control. Limstrom (1960) recommended that conifers may be planted at slightly wider spacings than hardwoods to meet the objective of establishing a plantation for cover purposes. His experiment indicated that a spacing of 7 x 7 foot now in use is perhaps the best for most plantings on strip mined lands. On good sites, however, conifers could probably be planted safely at 8 foot spacing. Thor et al. (1964) concluded "considering, however, the more uniform stand obtained by planting, this method was recommended on steep spoil banks in preference to seeding. Close spacing (5 x 5 or 6 x 6 feet) was recommended for the rapid establishment of cover capable of controlling erosion."

## CHAPTER III

## METHODS

### Study Area

The experimental plantation is located at the Highland Rim Forestry Field Station in Coffee County, four miles southwest of Tullahoma, Tennessee, on the northern section of the Eastern Highland Rim.

Coffee County is characterized by a warm humid climate. Summers are hot (July mean temperature 77.1°F.) and humid (precipitation averages 12.45 inches). Autumns are cooler (mean monthly temperatures decrease from 71° to 48°F.) and precipitation varies from 3.85 to 2.56 inches. Winter mean monthly temperatures range from 41.5° to 43°F. and precipitation increases, ranging to 6.19 inches in January. Spring temperatures increase rapidly and precipitation ranges from 6.06 to 3.62 inches. A 196-day average frost free season occurs (Dickson, 1960).

Three broad physiographic divisions are located within Coffee County: the Cumberland Plateau section of the Appalachian Plateau province, the Highland Rim and the Central Basin. The Highland Rim is underlain by the St. Louis and Warsaw limestone groups. Fort Payne chart forms the Rim's escarpment and underlies the area referred to as the barrens. A silty loess mantle is still evident. Chattanooga shale forms the dividing line between the Highland Rim and the adjoining Central Basin (Bassler, 1932).

The Highland Rim and its escarpment occupy about two-thirds of Coffee County. On the west, it is bounded by the escarpment that descends to the adjoining Central Basin about 300 feet below. On the east, the Rim is bounded by an escarpment which ascends approximately 1,000 feet to the Cumberland Plateau (Fox et al., 1958). The Rim is characterized by some rolling hills and wide valleys, but in the barrens, it is a flat plain, furrowed by numerous ravines and traversed by frequent streams (Safford, 1869). The Rim has an average elevation of about 970 feet above sea level. The experimental site has an elevation of approximately 1,000 feet about the sea level.

Experimental Site

The soils occupying the experimental site have developed from residual materials weathered from the underlying cherty limestone or loess. The Dickson soil series on which the experimental plots are situated occurs on a major portion of this upland area chiefly as a silt loam. Found in close association with the Dickson soils are Lawrence and Guthrie soils. All three soils are strongly to very strongly acid, as well as low in organic matter and plant nutrients. The upper part of the profile is permeable to air, roots, and water, but a silt pan, occurring between 18 to 30 inches below the soil's surface is only slightly permeable. For all three soil types, runoff is slow and internal drainage medium to low (Fox et al., 1958).

The 32 acre experimental area was mist blown with 2, 4, 5-T, and overstory trees were injected with 2, 4-D. Site preparation was completed by burning.

Planting

Seedlings of four species were planted in two-acre plots (295' x 295'). The Hiwasee Land Company, Calhoun, Tennessee, supplied the loblolly and Virginia pines from the Rose Island Nursery. Division of Forestry, Fisheries and Wildlife Development of the Tennessee Valley Authority (TVA), Norris, Tennessee, supplied the eastern white pine and shortleaf pine seedlings from the Clinton nursery. Characteristics of planting stock is listed in Table I.

Table I

Characteristics of Planting Stock Used in Spacing Study

| Species | Stock | Seed Source |
|---|---|---|
| Loblolly pine | 1 - 0 | North Georgia or North Alabama |
| Shortleaf pine | 1 - 0 | East Tennessee |
| Virginia pine | 1 - 0 | East Tennessee |
| Eastern white pine | 2 - 0 | East Tennessee or West North Carolina |

Each two-acre plot was divided into four half-acre split plots (147.5' x 147.5'); the split plot treatments consisted of four different spacings. Seedlings were planted by the bar method between February and March 1966; after the end of the first growing season all dead plants were replaced. See Table II.

Table II

Description of Sampled Trees in the Plots

| Spacing | Row Measured | Starting Point | Number of Trees Planted/Acre | Total Number of Trees Measured | Sampling Intensity |
|---|---|---|---|---|---|
| 6' x 6' | Every sixth row | Fourth tree in the fifth row from SW corner | 1210 | 51 | 4.2% |
| 9' x 9' | Every third row | Third tree in the third row from the SW corner | 538 | 48 | 8.9% |
| 12' x 12' | Every other row | Second tree in the second row from the SW corner | 303 | 50 | 16.5% |
| 15' x 15' | All trees except the outer-most rows | Second tree from the edge of the second row nearest the SW corner | 194 | 56 | 28.9% |

## Inventory

Due to the large number of trees in each plot only a sample of the trees were actually measured (Table II). At the end of five growing seasons, height measurement and survival count were carried out.

At the end of ten growing seasons, all sampled trees were measured for total height, diameter and height of tree to live crown.

## Definitions

The following definitions applied to the ten year assessment.

Total height. Height of the tree to the nearest foot from the base to the tallest leading shoot.

Diameter (D.B.H.). Measurement to the nearest one-tenth of an inch across the tree at 4.5 feet from the base of the tree.

Self pruning. A tree whose lower limbs are dead at a height of at least six inches from the base is considered to have initiated self pruning.

Pruning height. Distance from the base of the tree to the first live limb in the crown.

Basal area. Determined by the formula $BA = 0.005454 \times (DBH)^2$.

Stem volume. Derived from volume equations in Table III.

## Experimental Design and Statistical Methods

The experiment was laid out in split plot design with four replications. The four main treatment plots (species) were split into four subplots (spacing).

Difference in survival and branch mortality among species and among spacings within species were tested with chi-square contingency tables.

Table III

Determination of Stem Volume by Formula for Each of the Four Species of Pine

| Species | Volume |
| --- | --- |
| Loblolly[a] | $0.3371 + 0.0196128 \times (DBH)^2 \times$ height |
| Shortleaf[a] | $-0.00489 + 0.0206058 \times (DBH)^2 \times$ height |
| Virginia[a] | $0.02056 + 0.0218664 \times (DBH)^2 \times$ height |
| Eastern white pine[b] | $0.00258896 - 0.184542 \times (DBH)^2 \times$ height |

[a]Source: Goebel and Warner (1966).

[b]Source: Vimmerstedt (1961).

Analysis of variance was used to test for significance among species, spacings and their interactions (Table IV). Using the statistical analysis system the Duncan's New Multiple Range Test was used for the separation of treatment means for measured and computed variables. Both species and spacings were considered fixed.

Table IV

Analysis of Variance of Split Plot Spacing Experiment on Planted Pines of Four Species

| n | Source | Degrees of Freedom | Expected Mean Square |
|---|---|---|---|
| a | Species | a-1 = 3 | $\delta_E^2 + b\delta_m^2 + rb\delta_A^2$ |
| r | Blocks | r-1 = 3 | $\delta_E^2 + b\delta_m^2 + ab\delta_R^2$ |
| | Error A | (a-1)(r-1) = 9 | $\delta_E^2 + b\delta_m^2$ |
| b | Spacing | b-1 = 3 | $\delta_E^2 + ra\delta_B^2$ |
| | Spacing x Species | (b-1)(a-1) = 9 | $\delta_E^2 + r\delta_{A \times B}^2$ |
| | Error B | (b-1)(r-1) a = 36 | $\delta_E^2$ |

Where a = species
r = blocks
b = spacing
$\delta_m^2$ = variation due to species x replications

$\delta_E^2$ = variation due to spacing x replications plus species x replications

$\delta_{AB}^2$ = variation due to species x spacing

$\delta_A^2$ = variation due to species

$\delta_R^2$ = variation due to blocks

$\delta_B^2$ = variation due to spacing

# CHAPTER IV

# RESULTS

## Survival

A summary of survival by species and spacing was given in Table V. At the end of five growing seasons the survival of the pooled four species of pine and the pooled four spacings were dependent based on chi-square contingency table test. The test also indicated that for species within spacings, only loblolly and shortleaf pines had survival dependent on the spacings after the end of ten growing seasons. At ten years survival was found to be dependent on the pooled four species of pine. The same test for individual species indicated that the survival of loblolly, shortleaf and Virginia pines were dependent on the spacings used (see Table VI), while there was no apparent effect of spacing on survival of eastern white pine.

## Self Pruning

The pruning ability is dependent on the pooled four species under study as well as on the pooled four spacings used. At the 5 percent level of probability, chi-square contingency table indicated that each species pruning ability is dependent on the spacings used (see Table VII).

## Height to Live Crown

After ten growing seasons the analysis of variance of height to live crown indicated that there are significant effects due to the

Table V

Summary of Survival by Species and Spacing after Five and Ten Growing Seasons

| Species | Spacing (Foot) | Five Growing Seasons | | | Ten Growing Seasons | | |
|---|---|---|---|---|---|---|---|
| | | Number of Trees Alive | Number of Trees Dead | Percent Alive | Number of Trees Alive | Number of Trees Dead | Percent Alive |
| Loblolly pine | 6 x 6 | 168 | 36 | 82 | 150 | 54 | 73.5 |
| | 9 x 9 | 166 | 26 | 86 | 156 | 36 | 81.3 |
| | 12 x 12 | 180 | 20 | 90 | 171 | 29 | 85.5 |
| | 15 x 15 | 188 | 36 | 84 | 183 | 41 | 81.7 |
| Mean | | | | 84 | | | 80.0 |
| Shortleaf pine | 6 x 6 | 162 | 42 | 79 | 144 | 60 | 70.6 |
| | 9 x 9 | 169 | 23 | 88 | 157 | 35 | 81.8 |
| | 12 x 12 | 143 | 57 | 72 | 117 | 83 | 58.5 |
| | 15 x 15 | 146 | 78 | 65 | 134 | 90 | 59.8 |
| Mean | | | | 65 | | | 67.0 |
| Virginia pine | 6 x 6 | 174 | 30 | 83 | 172 | 32 | 84.3 |
| | 9 x 9 | 177 | 15 | 92 | 139 | 53 | 72.4 |
| | 12 x 12 | 178 | 22 | 89 | 147 | 53 | 73.5 |
| | 15 x 15 | 197 | 27 | 88 | 162 | 62 | 72.3 |
| Mean | | | | 88 | | | 76.0 |
| Eastern white pine | 6 x 6 | 187 | 17 | 92 | 174 | 30 | 85.3 |
| | 9 x 9 | 175 | 17 | 91 | 169 | 23 | 88.0 |
| | 12 x 12 | 185 | 15 | 93 | 174 | 26 | 87.0 |
| | 15 x 15 | 208 | 16 | 93 | 205 | 19 | 91.5 |
| Mean | | | | 93 | | | 88.0 |

Table VI

Summary of Chi-Square Values for the Effect of Species by Spacing on Survival at the End of Five and Ten Growing Seasons

| Source | Chi-Square Values | |
|---|---|---|
| | Five Years | Ten Years |
| Species pooled over spacing | 99.99* | 107.97* |
| Spacing pooled over species | 16.73* | $6.76^{ns}$ |
| Spacing within loblolly pine | $5.48^{ns}$ | 9.76* |
| Spacing within shortleaf pine | 32.74* | 32.06* |
| Spacing within Virginia pine | $4.76^{ns}$ | 11.29* |
| Spacing within eastern white pine | $0.49^{ns}$ | $4.24^{ns}$ |

*Significant at 5 percent level of probability.

$^{ns}$Not significant.

Table VII

Summary of Percent of Trees Self Pruned and Chi-Square Values for Tests

| Source | Percent Trees Pruned | Chi-Square Values |
|---|---|---|
| Species pooled over spacing | 52 | 974.44* |
| Spacing pooled over species | 52 | 146.98* |
| Spacing within loblolly pine | 85 | 101.48* |
| Spacing within shortleaf pine | 69 | 33.00* |
| Spacing within Virginia pine | 42 | 136.8* |
| Spacing within eastern white pine | 13 | 9.7* |

*Significant at the 5 percent level of probability.

species, spacing and their interaction (Table VIII). In all the four species, 6 x 6 foot spacing promotes larger height to live crown than of the other spacings used (Figure 1). The significant interaction of species and spacing indicates that the four species respond differently to the spacings for heights to live crown.

The Duncan's New Multiple Range Test showed that at the 5 percent level of probability, the means of the height to live crown of all the four species in the study are significantly different (Table IX). The same test on the effect of spacings on height to live corwn indicated that the mean height to live crown of 12 x 12 and 15 x 15 foot spacing are not significantly different at the 5 percent level of probability, but both are significantly different from the mean height to live crown of 9 x 9 and 6 x 6 foot spacing. Six by 6 and 9 x 9 foot spacing are also significantly different from each other at the 5 percent level of probability (Table X).

## Height after Five Growing Seasons

After five growing seasons, the mean height ranged from 5.59 foot in eastern white pine to 9.18 foot in loblolly pine.

The analysis of variance of height after five growing seasons indicated that differences in height for the species were significant at the 5 percent level of probability. No other treatment or interaction showed statistical significance (Table VIII).

The new Duncan's Multiple Range Test showed that at 5 percent level of probability, all the four species, loblolly, shortleaf,

Table VIII

Means Square Values from Analyses of Variance

| Source | df | Height to Live Crown | Height | | DBH | Basal Area | | Volume | |
|---|---|---|---|---|---|---|---|---|---|
| | | | after 5 Years | after 10 Years | | Per Tree | Per Acre | Per Tree | Per Acre |
| Species | 3 | 132.30* | 55.07* | 147.52* | 10.27* | .0214* | 2912.47* | 2.95* | 486736.66* |
| Block | 3 | $1.33^{ns}$ | $1.73^{ns}$ | $4.33^{ns}$ | $0.22^{ns}$ | $.0019^{ns}$ | 355.49* | $0.11^{ns}$ | $15699.77^{ns}$ |
| Error A | 9 | 0.55 | 1.25 | 3.67 | 0.57 | .009 | 69.45 | 0.12 | 10124.73 |
| Spacing | 3 | 22.84* | $0.36^{ns}$ | $4.38^{ns}$ | 1.73* | .0045* | 6634.49* | 0.18* | 570775.96* |
| Spacing X Species | 9 | 2.41* | $0.27^{ns}$ | $1.54^{ns}$ | $0.13^{ns}$ | $.0003^{ns}$ | $227.28^{ns}$ | $0.03^{ns}$ | 57805.2* |
| Error B | 36 | 0.44 | 0.48 | 2.45 | 0.22 | .002 | 123.96 | 0.03 | 12698.09 |
| Total | 63 | | | | | | | | |

*Significant at the 5 percent level of probability.

$^{ns}$Not significant.

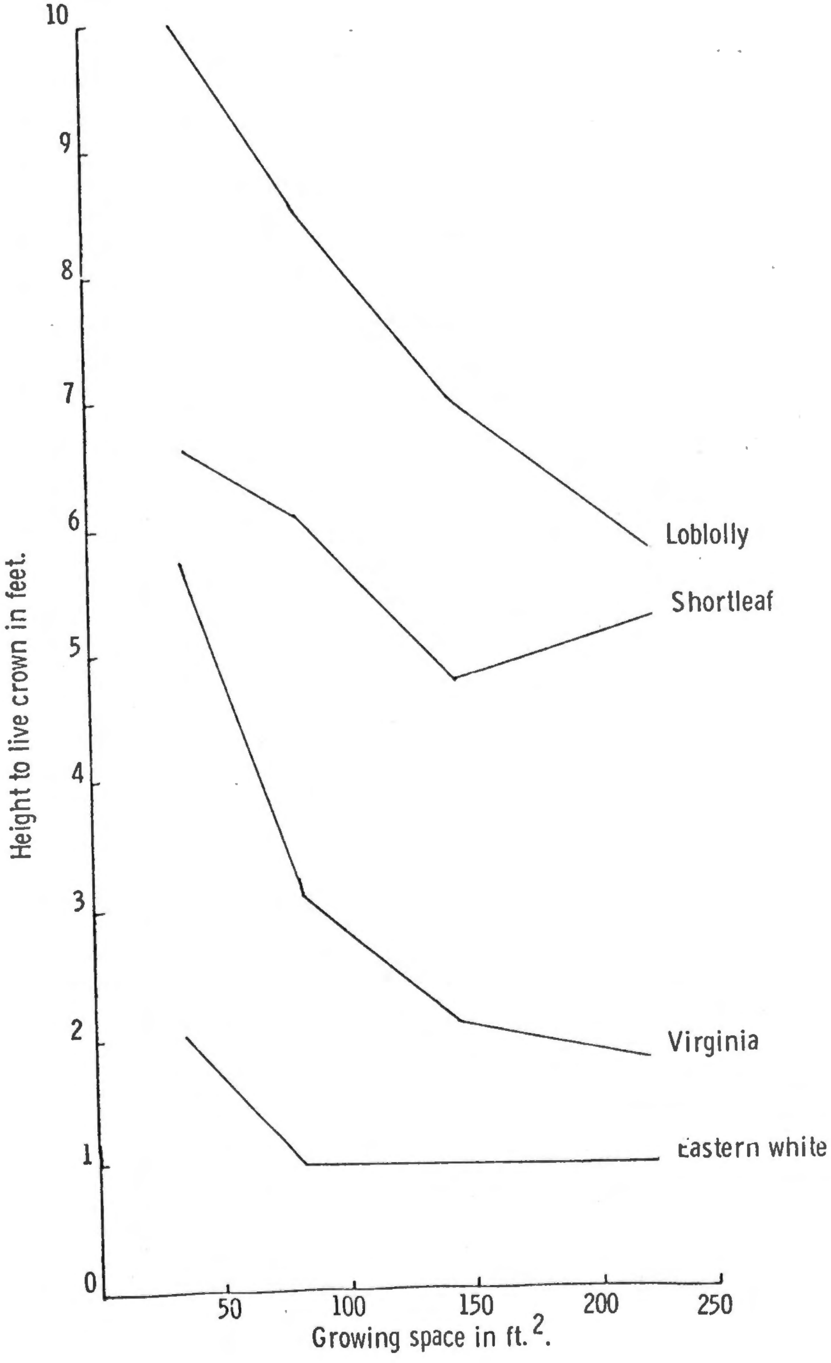


Figure 1. Effect of spacing on height to live crown.

Table IX

Duncan's New Multiple Range Tests on Height to Live Crown, Height, Diameter, Basal Area and Cubic Foot Volume

| Species | Height to Live Crown | Height | | DBH | Basal Area | | Volume | |
|---|---|---|---|---|---|---|---|---|
| | | After 5 Years | After 10 Years | | Per Tree | Per Acre | Per Tree | Per Acre |
| Loblolly Pine | 7.85[a] | 9.18[a] | 24.71[a] | 4.78[a] | 0.14 | 53.1[a] | 1.37 | 552.0[a] |
| Virginia Pine | 3.20 | 5.86 | 19.45 | 4.13 | 0.10 | 33.1 | 0.82 | 286.1 |
| Shortleaf Pine | 5.75 | 8.64 | 20.00 | 3.02 | 0.06 | 23.0 | 0.46 | 171.1 |
| Eastern White Pine | 1.28 | 5.59 | 17.56 | 3.19 | 0.06 | 28.7 | 0.46 | 195.1 |

[a]Significantly different at 5 percent level of probability.

Two means joined by a line are not significantly different.

Table X

Duncan's New Multiple Range Test on Means of Variables with Significant Spacing

| | Height to Live Crown (Feet) | DBH (Inches) | Basal Area | | Volume | |
|---|---|---|---|---|---|---|
| | | | Per Tree | Per Acre | Per Tree | Per Acre |
| 6 x 6 | 6.13[a] | 3.35[a] | 0.07[a] | 62.1[a] | 0.65 | 559.3[a] |
| 9 x 9 | 4.69 | 3.74 | 0.09 | 37.6 | 0.75 | 317.9 |
| 12 x 12 | 3.71 | 4.02 | 0.10 | 23.1 | 0.84 | 197.3 |
| 15 x 15 | 3.34 | 4.18 | 0.10 | 16.1 | 0.89 | 130.1 |

[a]Significant at the 5 percent level of probability.

Two means joined by a line are not significantly different.

Virginia and eastern white pine are significantly different in height (Table IX, p. 26).

## Height after Ten Growing Seasons

At the end of ten growing seasons, the mean height ranged from 17.6 feet in shortleaf pine to 24.7 feet in loblolly pine.

The analysis of variance of height after ten growing seasons indicated differences in height for species to be significant at the 5 percent level of probability. No other treatments or interaction showed statistical differences (Table VIII, p. 24).

The Duncan's New Multiple Range Test showed that at the 5 percent level of probability the means of all four species of pine in this study are significantly different from each other (Table IX, p. 26).

## Diameter after Ten Growing Seasons

Loblolly pine had the highest overall diameter mean of 4.78 inches. Virginia pine had a mean of 4.13 inches DBH, white pine had a mean of 3.19 and shortleaf pine a mean of 3.02 inches. Fifteen by 15 foot spacing had the largest diamter with 4.18 inches, 12 x 12 foot spacing was 4.02 inches, 9 x 9 and 6 x 6 foot spacing were 3.74 inches and 3.35 inches, respectively.

In loblolly pine, 15 x 15 foot spacing had a mean of 5.3 inches, 12 x 12 foot spacing had a mean of 5.01 inches, 9 x 9 foot spacing had a mean of 4.49 while 6 x 6 foot spacing had a mean of 4.31 inches.

In shortleaf pine the mean diameter ranges from 3.26 inches for 15 x 15 foot spacing to 2.58 inches for 6 x 6 foot spacing. Virginia pine has the largest diameter of 4.47 inches in 15 x 15 foot spacing with the least of 3.46 inches in 6 x 6 foot spacing. In eastern white pine the diameter has the same pattern as the other three species; the highest overall mean of 3.42 inches is found in 15 x 15 foot spacing and the least mean diameter of 2.84 inches is in 6 x 6 foot spacing.

Average diameters were strongly affected by spacing (Figure 2). In all the species 15 x 15 foot spacing gives the largest diameter while 6 x 6 foot spacing gives the smallest diameter.

The analysis of variance of diameter indicated that differences among species and spacings are significant at the 5 percent level of probability. No other treatment or interaction showed statistical difference. (Table VIII, p. 24.)

The Duncan's New Multiple Range Test showed that at 5 percent level of probability, the overall diameter for Virginia pine and loblolly pine are statistically different; the mean diameter for shortleaf and eastern white pine are not statistically different, but both are different statistically from Virginia pine and loblolly pine (Table IX, p. 26).

## Basal Area after Ten Growing Seasons

Basal area per tree. After the end of ten growing seasons the mean basal area per tree is found to be largest in loblolly pine with a mean of 0.14 $ft^2$, Virginia pine ranked second with a mean basal area of 0.10 $ft^2$. Shortleaf pine and eastern white pine each has a mean basal area per tree of 0.06 $ft^2$. Duncan's New Multiple Range Test did not indicate any significant difference between the mean basal area of

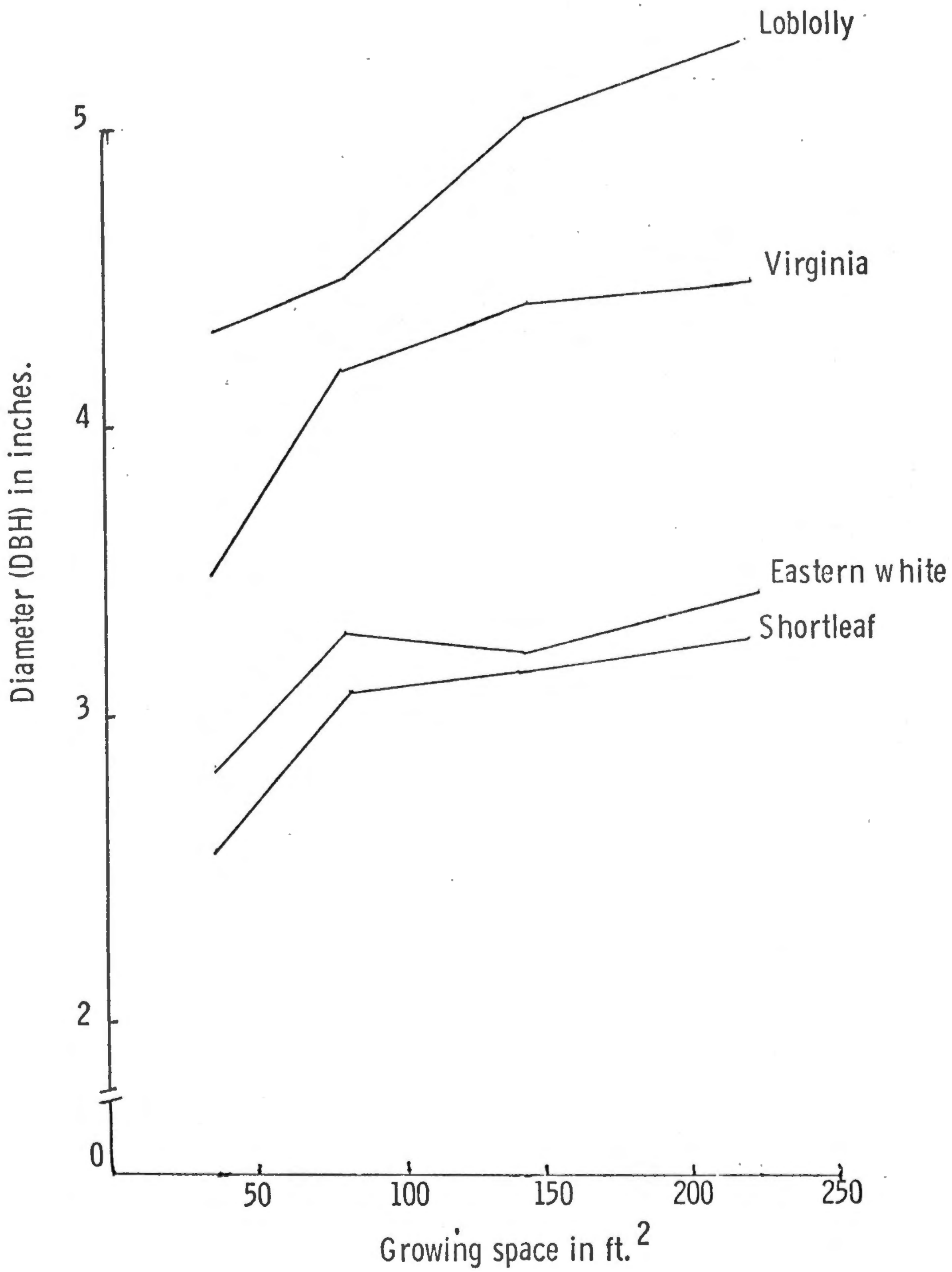


Figure 2. Effect of spacing on diameter (DBH).

shortleaf pine and eastern white pine. The same test indicated no difference between the mean basal area between Virginia and loblolly pine. (Table IX, p. 26)

For the spacings, the mean basal area per tree was found to range from 0.07 $ft^2$ in 6 x 6 foot spacing to 0.10 $ft^2$ in 15 x 15 foot spacing. The Duncan's New Multiple Range Test indicates that the mean basal area per tree is not significantly different between 6 x 6 and 9 x 9 foot spacing and the same test did not show any significant difference between the mean basal area between the 12 x 12 and 15 x 15 foot spacing (Table X, p. 27).

Basal area by spacing has been plotted for each species. Figure 3 indicates that the wider spacings for loblolly and Virginia pine result in greater basal area growth per tree. The slower growing white and shortleaf pines apparently do not yet compete with each other at the wider spacings and little or no increase in basal area per tree was observed for spacings greater than 9 x 9 foot.

<u>Basal area per acre</u>. At the end of ten growing seasons the mean basal area per acre of 53.2 $ft^2$ in loblolly pine is the largest. Virginia pine ranked next with 33.1 $ft^2$. White pine and shortleaf pine have a mean basal area of 28.7 $ft^2$, and 23.9 $ft^2$ per acre, respectively.

The analysis of variance of basal area per acre indicated that the differences in basal area for species, blocks and spacings are significant at the 5 percent level of probability. However, the species x spacings interaction was not statistically significant (Table VIII, p. 24).

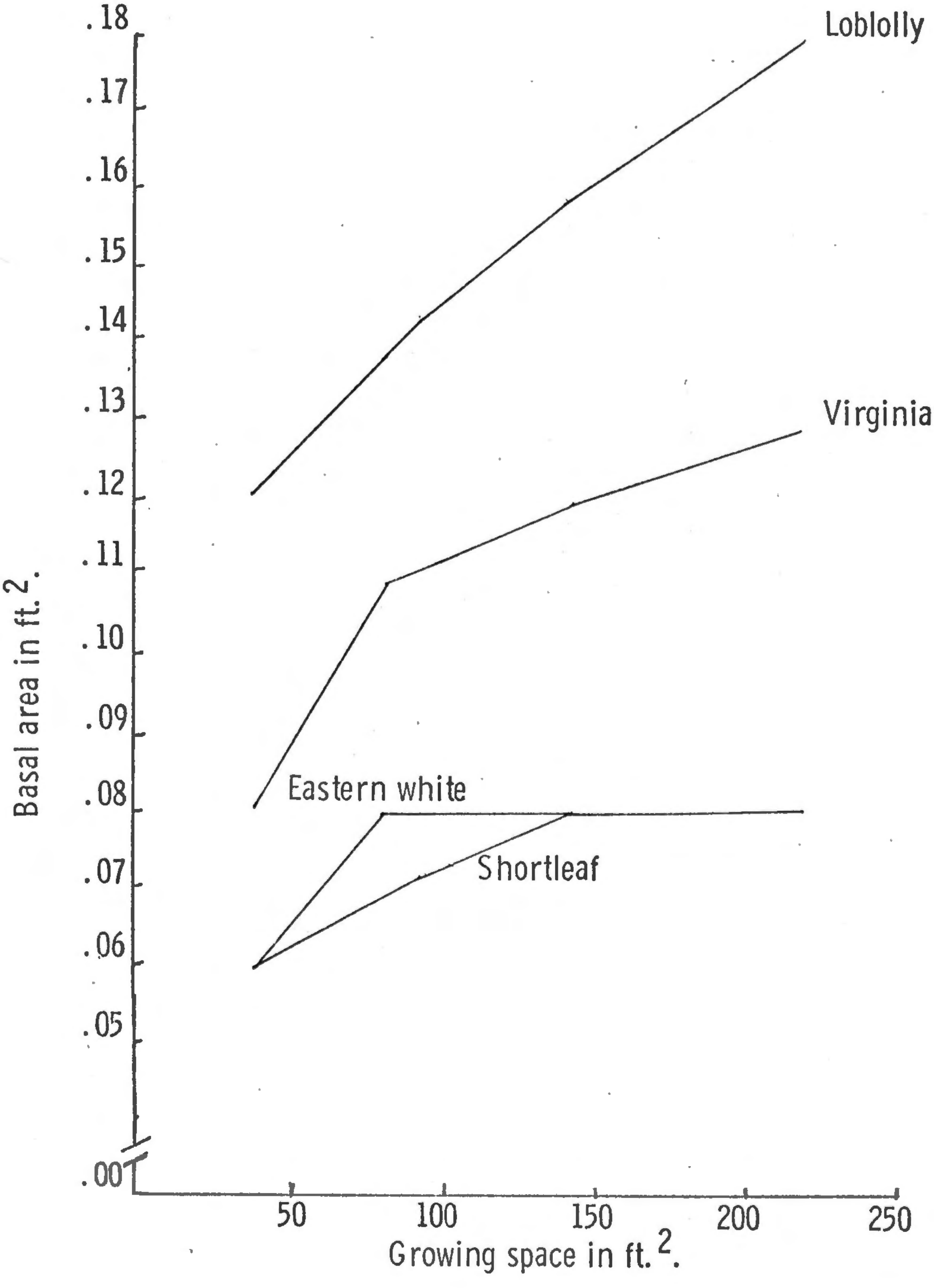


Figure 3. Effect of spacing on basal area per tree.

The Duncan's New Multiple Range Test indicated that at the 5 percent level of probability the mean basal area per acre for all four species are statistically significant (Table IX, p. 26). The same test also showed that the mean basal area per acre for all the four spacings are significantly different from one another at the 5 percent level of probability (Table X, p. 27).

The reduction in basal area per acre is particularly large going from 6 x 6 to 9 x 9 foot spacing indicating the relatively low levels of competition among trees during the first ten years of plantation growth. Figure 4 indicates that the 6 x 6 foot spacing promotes higher basal area in all the species than any of the other three spacings.

<u>Volume after Ten Growing Seasons</u>

<u>Volume per tree</u>. At the end of the ten growing seasons the mean volume per tree was largest in loblolly pine, having a mean volume of 1.37 $ft^3$. Virginia pine ranked next with a mean of 0.82 $ft^3$, while shortleaf and eastern white pine each had a volume of 0.46 $ft^3$ per tree. The analysis of variance for volume per tree indicated that there were differences due to both species and spacing (Table VIII, p. 24). The Duncan's New Multiple Range Test indicated that at the 5 percent level of probability, the difference in volume per tree between shortleaf and white pine is not significant (Table IX, p. 26). However, these two species have a significantly lower mean volume per tree than Virginia and loblolly pines. Loblolly pine had a larger volume than all the other species. The test for mean volume per tree indicates that, on

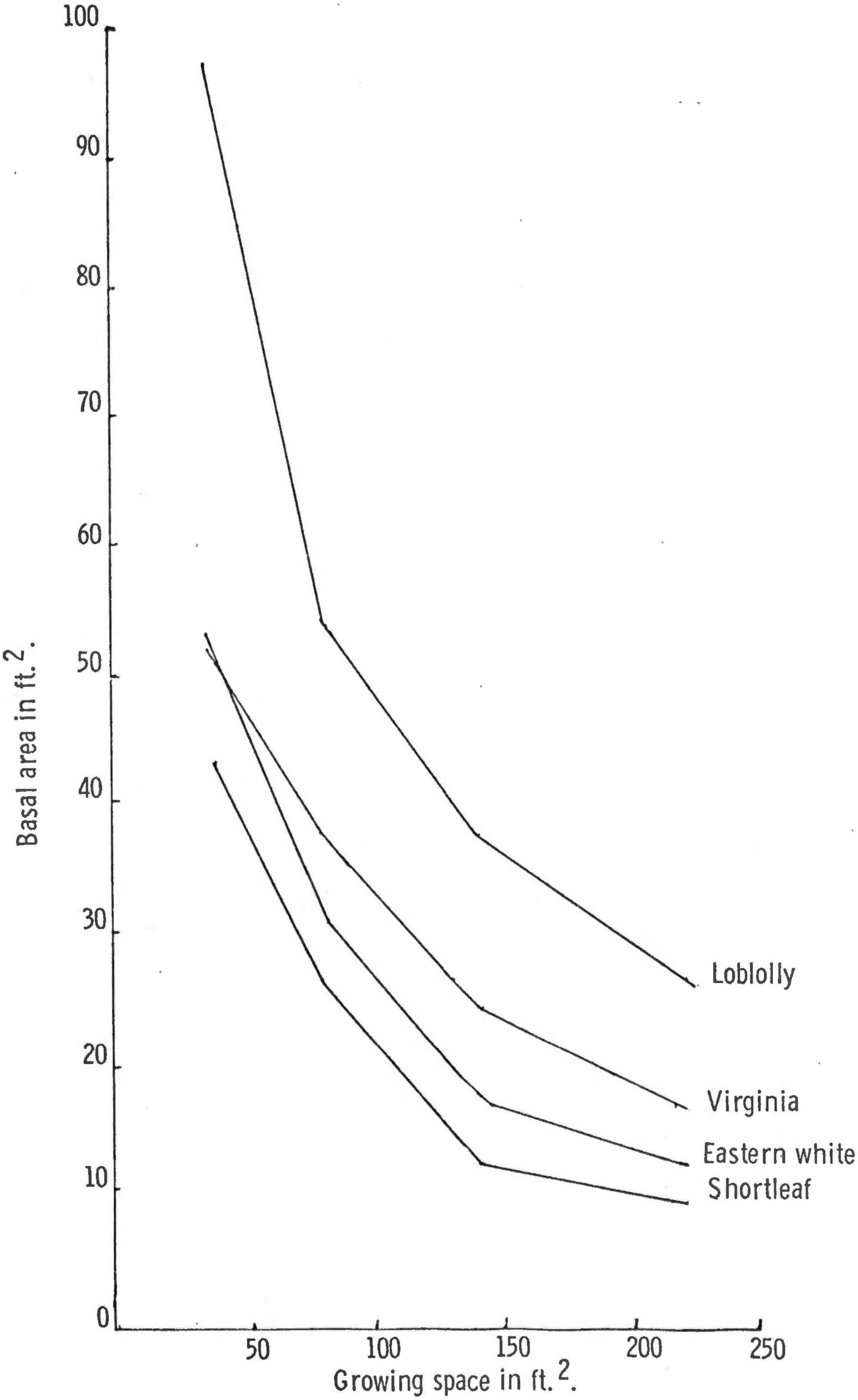


Figure 4. Effect of spacing on basal area per acre.

the average for all four species there is no significant differences between 6 x 6 and 9 x 9 foot spacing or 12 x 12 and 15 x 15 foot spacing, but the 6 x 6 spacing has trees with smaller volumes than those with 12 x 12 and 15 x 15 foot spacing (Table X, p. 27). In all the species, the 15 x 15 foot spacing has the largest volume per tree and the 6 x 6 foot spacing the smallest (Figure 5).

Volume per acre. Cubic foot volume per acre after ten growing seasons indicated that among the species, loblolly pine ranked first with a mean volume per acre of 552 $ft^3$, Virginia pine was second with a mean volume per acre of 286.1 $ft^3$. Eastern white pines and shortleaf ranked third and fourth with means of 195.3 $ft^3$ and 171.1 $ft^3$, respectively (Table X, p. 26).

The effect of spacing on the volume per acre indicates that 6 x 6 foot spacing ranked first with a mean volume of 559.3 $ft^3$, 9 x 9 foot spacing has a mean of 317.9 $ft^3$, 12 x 12 foot spacing 197.3 $ft^3$ and 15 x 15 foot 130.1 $ft^3$ (Table X, p. 27). In loblolly pine, the mean volume per acre ranged from 246.7 $ft^3$ in 15 x 15 foot spacing to 1070 $ft^3$ in 6 x 6 foot spacing (Figure 6).

The analysis of variance on volume per acre indicated that there were differences in volume per acre for species, spacings and their interactions at the 5 percent level of probability. The interaction of the species and spacing was an indication that the species behaved differently at the four spacings.

Volume per acre has been plotted for each species in Figure 6 and indicated that the 6 x 6 foot spacing resulted in larger cubic foot

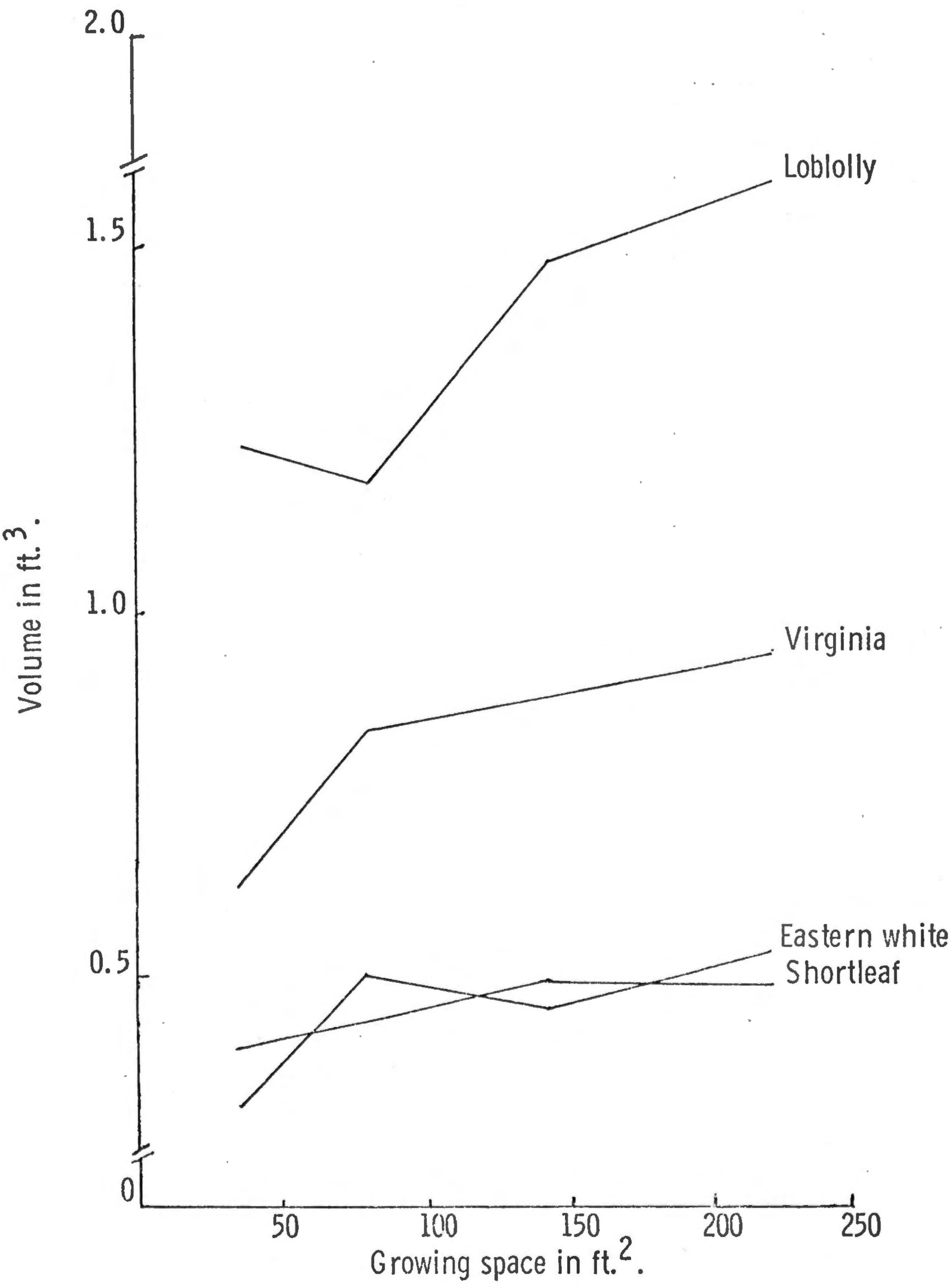


Figure 5. Effect of spacing on cubic foot volume per tree.

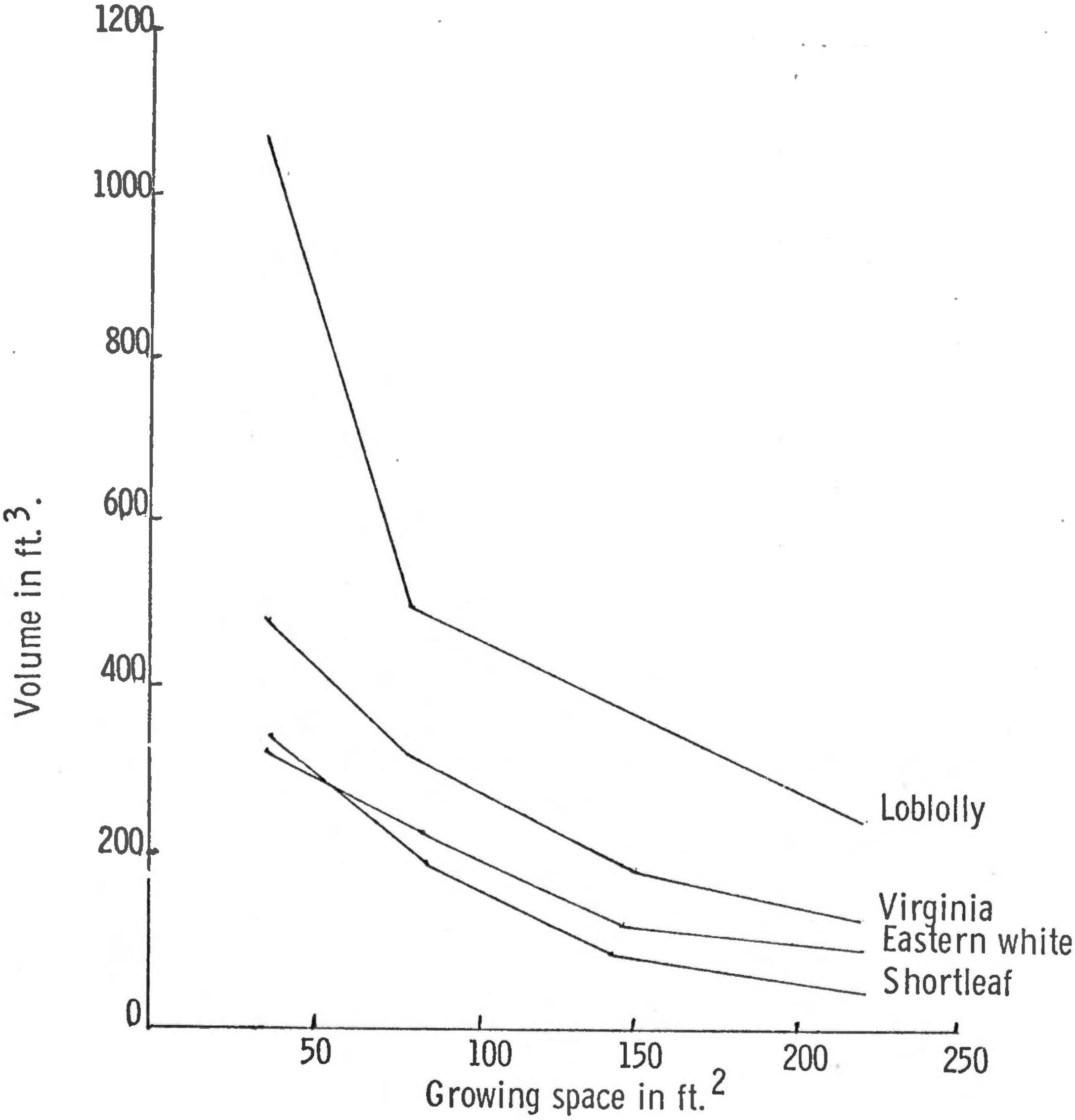


Figure 6. Effect of spacing on cubic foot volume per acre.

volume per acre. The Duncan's New Multiple Range Test at the 5 percent level of probability indicated that the mean volume per acre for all the species and spacing were different (Table IX, p. 26, and Table X, p. 27).

# CHAPTER V

# DISCUSSION

At the Highland Rim Forest Experiment Station, the spacings used in planting the four species of pine had significant effects on the characteristics of the trees.

After the end of five growing seasons, eastern white pine and Virginia pine had better than 90 percent survival. Loblolly pine had a survival of 86 percent while shortleaf pine had 76 percent living trees. The survival appeared lowest in 6 x 6 foot spacing in loblolly pine and Virginia pine. The 12 x 12 foot spacing had the lowest survival in shortleaf pine and survival in eastern white pine appeared the same in all spacings. The lower survival of loblolly pine, Virginia pine, and shortleaf pine at close spacing was in agreement with the results of Hansbrough (1968), Dell et al. (1968) and Balmer et al. (1975) that mortality was higher in narrow spacings than in the wider spacings but in contrast to the finding of Feduccia (1974) that mortality was higher in wider spacing. The survival of eastern white pine was in agreement with the findings of Campbell and Mann (1974) who found that survival was not influenced by spacing. No biological explanation could be given for the low survival at the close spacings.

After the end of five and ten growing seasons, analyses of variance for total height indicated significant differences among the species. Differences due to spacings were not found to be significant.

The result obtained in the study was in agreement with the findings of Bennett (1965), Bower (1965), Daniel et al. (1972), Limstrom (1963), Ware and Stahelin (1948) and Williams (1959) that spacing had no significant effect on height growth of pine plantations. This was, however, in contrast to the conclusions of Bramble et al (1949), Hansbrough (1968) and Balmer (1975) that wider spacings produced trees of greater height than trees planted at narrow spacings.

At the end of ten growing seasons, loblolly pine has the largest number of self pruned trees. Shortleaf, Virginia and eastern white pine followed in that order in degree of self pruning. The 6 x 6 foot spacing recorded the largest number of self pruned trees as well as the largest pruned tree height in all the species. The analysis of variance indicated differences of pruning height due to species, spacings as well as the interaction of species and spacing indicating that the four species responded differently to the spacings. This result was in agreement with the findings of Tryon (1960), Bower (1965), Nelson (1952) and Brender (1973) that close spacings induced self pruning in trees. Since there were more trees per acre at close spacing there was greater competition for light to be used in the photosynthetic processes. As the lower branches were shaded, the photosynthetic processes may be very low or perhaps absent; death would normally occur when the respiration rate became greater than the rate of photosynthesis. The wider spacings, however, promote the growth of many branches since the competition among the trees is low and much light reaches the foliage on the lower limbs. Trees planted at wide spacing have low or no competition for light, water or mineral nutrients. All the needles of the trees are exposed to the full rays of the sun, therefore photosynthetic processes go on at near maximum rates for the species involved providing photosynthesis for the diameter growth of the stem.

Loblolly pine has the largest basal area. Virginia, shortleaf, and white pine mean basal area are in that order of large to small. The largest basal area was in the 15 x 15 foot spacing for individual trees in all the four species of pine. The mean basal area per acre was the largest in the narrow spacing. It was evident, therefore, that the basal area per tree increases as the spacing increases and vice versa for the basal area per acre in all the four species of pine. The analysis of variance indicated that there were significant differences due to species and spacings at the 5 percent of probability. This result was in agreement with the findings of Bower (1965) and Balmer et al. (1975) that narrow spacings gave higher basal area per acre than wide spacings.

After ten growing seasons the volume per tree was the highest in the wider spacing (15 x 15 foot) in all the species. The volume per acre, however, was found to be largest in the narrow spacing (6 x 6 foot). Balmer et al. (1975) also found that the narrow spacings promote higher volume per acre than wide spacings. The analysis of variance indicated that the differences due to species, spacings and the interaction of species and spacings were significant.

The analyses of variance indicate significant interactions at the 5 percent level of probability for species by spacing for height to live crown and volume per acre. This interaction is an indication that the four species respond differently to the four spacings for volume per acre and height to live crown.

The effect of spacing on pruning height is plotted in Figure 1, p. 25. From this figure, a general drop from the 6 x 6 to 15 x 15 foot spacing is observed for loblolly pine. In shortleaf and white pines the drop from one spacing to another for height to live crown does not appear to be as great as in loblolly and Virginia pines. Figure 1, p. 25, suggests that shortleaf pine prunes relatively well at all spacings while eastern white pine does not prune well at any spacing; pruning height of loblolly and Virginia pines, on the other hand, appears to be strongly influenced by stand density.

The interaction effect of spacing by species for volume per acre is shown in Figure 6, p. 37. Loblolly pine has a much greater reduction in volume from 6 x 6 to 9 x 9 foot spacing than the other three species. For Virginia, shortleaf and eastern white pines there was not much difference in reduction from one spacing to the other that could account for the significant interaction. It is therefore assumed that the reduction in volume of loblolly pine from 6 x 6 to 9 x 9 feet accounted for the significant interaction observed for volume per acre.

## CHAPTER VI

## CONCLUSIONS AND RECOMMENDATIONS

Narrow spacings (6 x 6 and 9 x 9) promote early death of lower branches, larger basal area per acre and larger cubic foot volume per acre in the four species of pine under study while wide spacing (12 x 12 and 15 x 15) promote larger basal area per tree as well as larger cubic foot volume per tree.

Based on the findings of this study, loblolly pine could be recommended for planting on a large scale in an area of the same or similar soil and climate as the Highland Rim Forest Experiment Station. For production of cubic foot volume as pulpwood, close spacing (6 x 6) would be recommended. Loblolly pine planted at close spacing would be satisfactory for sawtimber production provided a market would be available for early thinning, because the close spacing (6 x 6) would provide self pruned trees although at a decreased diameter. Wide spacing (12 x 12 and 15 x 15) if used in planting loblolly pine for sawtimber would require artificial pruning to produce lumber of good quality.

Virginia pine would be the second choice for planting on a commercial basis for pulpwood production; planting should be at 6 x 6 or 9 x 9 foot spacing. Shortleaf pine does not appear to be desirable on any site similar to the experimental site; poor survival and growth obtained during the first ten years of this study does not justify the planting of shortleaf pine either as sawtimber or for the production or pulpwood.

Eastern white pine generally is not suitable for pulping. If white pine is planted on a similar area as the study area, wide spacing would be used and artificial pruning would be required to produce lumber of good quality.

For maximum production of cubic foot volume of pulpwood, close spacing of loblolly pine is recommended since such plantations can be mechanically harvested at the end of a short rotation. At 6 x 6 foot spacing loblolly pine produced 12 cords per acre (assuming 90 cu ft/cord) in ten years. It is anticipated (Smalley and Bailey, 1974) that at the end of a 20-year pulpwood rotation a total of 36 cords per acre may be harvested.

Higher quality sawtimber and veneer could be harvested from narrow spacings provided an early thinning would be economically feasible. If wide spacing is used to provide larger diameter, artificial pruning would be necessary to meet such objectives.

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APPENDIX

Table XI

Survival of Four Species at Four Spacings after Five Growing Seasons

| Species | Spacings (Foot) | Block | | | | Percent Alive |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | |
| Loblolly pine | 6 x 6 | 42[a] | 37 | 41 | 48 | 82 |
| | 9 x 9 | 37 | 42 | 45 | 42 | 86 |
| | 12 x 12 | 41 | 43 | 47 | 49 | 90 |
| | 15 x 15 | 47 | 39 | 42 | 50 | 84 |
| Shortleaf pine | 6 x 6 | 42 | 28 | 44 | 48 | 79 |
| | 9 x 9 | 42 | 37 | 43 | 47 | 88 |
| | 12 x 12 | 29 | 28 | 37 | 49 | 72 |
| | 15 x 15 | 29 | 14 | 52 | 51 | 65 |
| Virginia pine | 6 x 6 | 46 | 32 | 49 | 47 | 85 |
| | 9 x 9 | 44 | 43 | 44 | 46 | 92 |
| | 12 x 12 | 43 | 45 | 47 | 43 | 89 |
| | 15 x 15 | 45 | 47 | 52 | 53 | 88 |
| Eastern white pine | 6 x 6 | 47 | 44 | 49 | 47 | 92 |
| | 9 x 9 | 43 | 45 | 45 | 42 | 91 |
| | 12 x 12 | 48 | 42 | 47 | 48 | 93 |
| | 15 x 15 | 51 | 48 | 56 | 53 | 93 |

a = number of trees alive.

Table XII

Survival of Four Species at Four Spacings after Ten Growing Seasons

| Species | Spacing (Foot) | Block | | | | Percent Alive |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | |
| Loblolly pine | 6 x 6 | 39[a] | 33 | 32 | 46 | 73.5 |
| | 9 x 9 | 34 | 40 | 42 | 40 | 81.3 |
| | 12 x 12 | 38 | 43 | 43 | 47 | 85.5 |
| | 15 x 15 | 43 | 38 | 50 | 52 | 81.7 |
| Shortleaf pine | 6 x 6 | 40 | 21 | 39 | 44 | 70.6 |
| | 9 x 9 | 35 | 34 | 43 | 45 | 81.8 |
| | 12 x 12 | 17 | 22 | 30 | 48 | 58.5 |
| | 15 x 15 | 14 | 21 | 50 | 49 | 59.8 |
| Virginia pine | 6 x 6 | 43 | 35 | 45 | 49 | 84.3 |
| | 9 x 9 | 29 | 34 | 39 | 37 | 72.4 |
| | 12 x 12 | 33 | 39 | 35 | 40 | 73.5 |
| | 15 x 15 | 36 | 35 | 44 | 47 | 72.3 |
| Eastern white pine | 6 x 6 | 46 | 34 | 48 | 46 | 85.3 |
| | 9 x 9 | 40 | 45 | 45 | 39 | 88.0 |
| | 12 x 12 | 43 | 39 | 47 | 45 | 87.0 |
| | 15 x 15 | 51 | 47 | 53 | 54 | 91.5 |

a = number of trees alive.

Table XIII

Mean Pruning Height (Foot) by Species and Spacing after Ten Growing Seasons

| Species | Spacing | Block | | | | Mean |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | |
| Loblolly pine | 6 x 6 | 9.18 | 8.82 | 10.75 | 11.33 | 10.02 |
| | 9 x 9 | 8.26 | 8.63 | 8.09 | 9.08 | 8.52 |
| | 12 x 12 | 7.79 | 6.49 | 6.21 | 7.72 | 7.05 |
| | 15 x 15 | 6.28 | 4.92 | 5.42 | 6.63 | 5.81 |
| Shortleaf pine | 6 x 6 | 7.23 | 5.00 | 7.38 | 7.14 | 6.69 |
| | 9 x 9 | 6.43 | 5.09 | 5.93 | 7.04 | 6.12 |
| | 12 x 12 | 5.12 | 4.50 | 4.70 | 5.02 | 4.84 |
| | 15 x 15 | 5.29 | 5.43 | 5.34 | 5.29 | 5.34 |
| Virginia pine | 6 x 6 | 7.77 | 4.53 | 5.58 | 5.21 | 5.77 |
| | 9 x 9 | 2.45 | 3.20 | 2.74 | 4.03 | 3.11 |
| | 12 x 12 | 2.06 | 2.82 | 1.85 | 1.73 | 2.12 |
| | 15 x 15 | 2.11 | 2.34 | 1.57 | 1.21 | 1.81 |
| Eastern white pine | 6 x 6 | 1.76 | 2.18 | 1.62 | 2.76 | 2.08 |
| | 9 x 9 | 1.00 | 1.00 | 1.02 | 1.00 | 1.00 |
| | 12 x 12 | 1.00 | 1.03 | 1.00 | 1.04 | 1.02 |
| | 15 x 15 | 1.09 | 1.00 | 1.00 | 1.04 | 1.03 |

Table XIV

Mean Height Growth of Species by Spacings after Five Growing Seasons (Feet)

| Species | Spacing | Block 1 | 2 | 3 | 4 | Mean |
|---|---|---|---|---|---|---|
| Loblolly pine | 6 x 6 | 9.03 | 8.05 | 9.56 | 9.92 | 9.14 |
| | 9 x 9 | 9.50 | 9.29 | 9.54 | 8.52 | 9.21 |
| | 12 x 12 | 11.21 | 7.96 | 8.90 | 8.47 | 9.14 |
| | 15 x 15 | 10.47 | 8.04 | 10.14 | 8.21 | 9.22 |
| Shortleaf pine | 6 x 6 | 5.86 | 5.13 | 6.90 | 6.27 | 6.04 |
| | 9 x 9 | 5.60 | 6.77 | 6.80 | 6.40 | 6.39 |
| | 12 x 12 | 3.99 | 6.31 | 5.28 | 6.12 | 5.43 |
| | 15 x 15 | 4.37 | 4.59 | 6.61 | 6.74 | 5.58 |
| Virginia pine | 6 x 6 | 10.21 | 7.77 | 9.38 | 8.83 | 9.05 |
| | 9 x 9 | 9.44 | 8.24 | 8.58 | 8.29 | 8.64 |
| | 12 x 12 | 7.71 | 7.86 | 9.25 | 8.79 | 8.40 |
| | 15 x 15 | 8.82 | 8.20 | 8.19 | 8.62 | 8.46 |
| Eastern white pine | 6 x 6 | 5.20 | 5.40 | 5.06 | 6.81 | 5.62 |
| | 9 x 9 | 5.66 | 4.66 | 5.46 | 5.98 | 5.44 |
| | 12 x 12 | 5.71 | 5.58 | 5.33 | 6.06 | 5.67 |
| | 15 x 15 | 5.68 | 5.43 | 5.91 | 5.41 | 5.61 |

Table XV

Mean Height (Feet) Growth by Species and Spacing after Ten Growing Seasons

| Species | Spacing | Block 1 | 2 | 3 | 4 | Mean |
|---|---|---|---|---|---|---|
| Loblolly pine | 6 x 6 | 24.44 | 24.52 | 27.06 | 26.61 | 25.66 |
| | 9 x 9 | 25.15 | 25.52 | 23.86 | 22.35 | 24.22 |
| | 12 x 12 | 27.05 | 22.44 | 25.72 | 23.66 | 24.72 |
| | 15 x 15 | 25.72 | 24.13 | 25.70 | 21.33 | 24.22 |
| Shortleaf pine | 6 x 6 | 18.28 | 15.67 | 20.72 | 17.11 | 17.95 |
| | 9 x 9 | 15.17 | 19.67 | 19.58 | 18.31 | 18.18 |
| | 12 x 12 | 12.94 | 19.27 | 16.90 | 18.36 | 16.87 |
| | 15 x 15 | 16.50 | 14.85 | 18.96 | 18.59 | 17.23 |
| Virginia pine | 6 x 6 | 23.23 | 19.00 | 21.96 | 21.68 | 21.47 |
| | 9 x 9 | 20.28 | 18.93 | 20.87 | 20.92 | 20.25 |
| | 12 x 12 | 18.52 | 19.41 | 18.94 | 19.85 | 19.18 |
| | 15 x 15 | 19.56 | 18.77 | 18.64 | 19.45 | 19.01 |
| Eastern white pine | 6 x 6 | 18.54 | 19.91 | 18.94 | 19.26 | 19.16 |
| | 9 x 9 | 20.75 | 18.27 | 19.80 | 21.05 | 19.97 |
| | 12 x 12 | 20.30 | 17.95 | 18.62 | 19.27 | 19.02 |
| | 15 x 15 | 19.37 | 18.45 | 20.81 | 19.96 | 19.65 |

Table XVI

Mean DBH (Inches) by Species and Spacing after Ten Growing Seasons

| Species | Spacing | Block | | | | Mean |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | |
| Loblolly pine | 6 x 6 | 3.97 | 4.31 | 4.61 | 4.36 | 4.31 |
| | 9 x 9 | 4.82 | 4.99 | 4.61 | 3.56 | 4.49 |
| | 12 x 12 | 5.84 | 4.29 | 5.73 | 4.19 | 5.01 |
| | 15 x 15 | 6.04 | 5.59 | 5.88 | 3.67 | 5.30 |
| Shortleaf pine | 6 x 6 | 2.80 | 2.79 | 2.34 | 2.38 | 2.58 |
| | 9 x 9 | 2.23 | 3.85 | 3.57 | 2.69 | 3.09 |
| | 12 x 12 | 1.86 | 3.99 | 3.27 | 3.59 | 3.18 |
| | 15 x 15 | 2.95 | 2.72 | 3.74 | 3.62 | 3.26 |
| Virginia pine | 6 x 6 | 3.66 | 2.95 | 3.69 | 3.55 | 3.46 |
| | 9 x 9 | 4.26 | 4.13 | 4.32 | 4.04 | 4.19 |
| | 12 x 12 | 4.09 | 4.44 | 4.55 | 4.53 | 4.40 |
| | 15 x 15 | 4.43 | 4.11 | 4.72 | 4.63 | 4.47 |
| Eastern white pine | 6 x 6 | 2.72 | 3.15 | 2.84 | 2.64 | 2.84 |
| | 9 x 9 | 3.39 | 3.03 | 3.20 | 3.58 | 3.30 |
| | 12 x 12 | 3.73 | 2.96 | 3.11 | 3.04 | 3.21 |
| | 15 x 15 | 3.22 | 3.38 | 3.56 | 3.53 | 3.42 |

Table XVII

Mean Basal Area ($ft^2$) by Species and Spacing per Tree for Ten Growing Seasons

| Species | Spacing | Block | | | | Mean |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | |
| Loblolly pine | 6 x 6 | .10 | .11 | .12 | .11 | 0.11 |
| | 9 x 9 | .14 | .14 | .13 | .09 | 0.13 |
| | 12 x 12 | .19 | .11 | .19 | .10 | 0.15 |
| | 15 x 15 | .21 | .18 | .20 | .09 | 0.17 |
| Shortleaf pine | 6 x 6 | .05 | .05 | .07 | .04 | 0.05 |
| | 9 x 9 | .03 | .09 | .07 | .05 | 0.06 |
| | 12 x 12 | .03 | .09 | .07 | .08 | 0.07 |
| | 15 x 15 | .06 | .05 | .08 | .08 | 0.07 |
| Virginia pine | 6 x 6 | .07 | .05 | .08 | .07 | 0.07 |
| | 9 x 9 | .10 | .10 | .11 | .09 | 0.10 |
| | 12 x 12 | .10 | .11 | .12 | .12 | 0.11 |
| | 15 x 15 | .11 | .12 | .13 | .12 | 0.12 |
| Eastern white pine | 6 x 6 | .05 | .06 | .05 | .05 | 0.05 |
| | 9 x 9 | .07 | .06 | .06 | .08 | 0.07 |
| | 12 x 12 | .08 | .06 | .06 | .06 | 0.07 |
| | 15 x 15 | .06 | .07 | .08 | .07 | 0.07 |

Table XVIII

Mean Basal Area ($ft^2$) per Acre by Species and Spacing after Ten Growing Seasons

| Species | Spacing | Block 1 | Block 2 | Block 3 | Block 4 | Mean |
|---|---|---|---|---|---|---|
| Loblolly pine | 6 x 6 | 92.55 | 86.14 | 91.12 | 120.07 | 97.5 |
| | 9 x 9 | 53.36 | 62.78 | 61.21 | 40.36 | 54.4 |
| | 12 x 12 | 43.75 | 28.66 | 49.51 | 28.48 | 37.6 |
| | 15 x 15 | 31.24 | 23.67 | 34.6 | 16.19 | 26.14 |
| Shortleaf pine | 6 x 6 | 47.46 | 24.92 | 64.78 | 41.76 | 44.7 |
| | 9 x 9 | 11.77 | 34.3 | 33.74 | 25.22 | 26.3 |
| | 12 x 12 | 3.09 | 12.0 | 12.73 | 22.79 | 12.7 |
| | 15 x 15 | 2.91 | 3.63 | 13.84 | 13.46 | 8.5 |
| Virginia pine | 6 x 6 | 71.43 | 22.54 | 85.43 | 31.56 | 52.7 |
| | 9 x 9 | 32.51 | 33.63 | 48.09 | 37.33 | 37.9 |
| | 12 x 12 | 20.00 | 26.00 | 24.72 | 29.09 | 24.9 |
| | 15 x 15 | 13.7 | 14.53 | 19.79 | 19.51 | 16.9 |
| Eastern white pine | 6 x 6 | 54.58 | 48.41 | 56.95 | 54.58 | 53.6 |
| | 9 x 9 | 31.39 | 30.27 | 30.27 | 34.98 | 31.7 |
| | 12 x 12 | 20.85 | 14.18 | 17.09 | 16.36 | 17.1 |
| | 15 x 15 | 10.59 | 11.38 | 14.67 | 13.08 | 12.4 |

Table XIX

Mean Cubic Foot Volume per Tree by Spacing after Ten Growing Seasons

| Species | Spacing | Block 1 | Block 2 | Block 3 | Block 4 | Mean |
|---|---|---|---|---|---|---|
| Loblolly pine | 6 x 6 | .92 | 1.62 | 1.25 | 1.11 | 1.23 |
| | 9 x 9 | 1.29 | 1.34 | 1.22 | .85 | 1.18 |
| | 12 x 12 | 1.95 | 1.27 | 1.80 | .94 | 1.49 |
| | 15 x 15 | 1.97 | 1.67 | 1.96 | .75 | 1.59 |
| Shortleaf pine | 6 x 6 | .36 | .41 | .59 | .27 | .41 |
| | 9 x 9 | .23 | .67 | .58 | .37 | .46 |
| | 12 x 12 | .18 | .69 | .49 | .62 | .50 |
| | 15 x 15 | .42 | .36 | .61 | .56 | .49 |
| Virginia pine | 6 x 6 | .73 | .46 | .71 | .63 | .63 |
| | 9 x 9 | .86 | .77 | .92 | .79 | .84 |
| | 12 x 12 | .82 | .88 | .91 | .92 | .88 |
| | 15 x 15 | .89 | .93 | .99 | .97 | .95 |
| Eastern white pine | 6 x 6 | .24 | .47 | .30 | .29 | .33 |
| | 9 x 9 | .58 | .39 | .44 | .64 | .51 |
| | 12 x 12 | .66 | .39 | .37 | .41 | .46 |
| | 15 x 15 | .47 | .48 | .65 | .57 | .54 |

Table XX

Cubic Foot Volume per Acre by Species and Spacing after Ten Growing Seasons

| Species | Spacing | Block 1 | Block 2 | Block 3 | Block 4 | Mean |
|---|---|---|---|---|---|---|
| Loblolly pine | 6 x 6 | 851.43 | 1268.61 | 949.2 | 1211.65 | 1070.2 |
| | 9 x 9 | 491.67 | 600.86 | 574.4 | 381.14 | 512.0 |
| | 12 x 12 | 449.05 | 330.94 | 469.04 | 267.73 | 379.2 |
| | 15 x 15 | 293.09 | 219.57 | 339.08 | 134.94 | 246.7 |
| Shortleaf pine | 6 x 6 | 341.71 | 204.32 | 546.03 | 281.91 | 343.5 |
| | 9 x 9 | 90.24 | 255.36 | 279.58 | 186.65 | 202.9 |
| | 12 x 12 | 18.54 | 91.99 | 89.08 | 176.59 | 94.1 |
| | 15 x15 | 20.34 | 26.16 | 33.96 | 94.94 | 43.9 |
| Virginia pine | 6 x 6 | 744.88 | 207.4 | 758.17 | 284.05 | 498.6 |
| | 9 x 9 | 279.58 | 258.95 | 402.21 | 327.67 | 317.1 |
| | 12 x 12 | 163.98 | 207.98 | 187.5 | 223.01 | 195.6 |
| | 15 x 15 | 110.86 | 112.62 | 150.72 | 157.74 | 132.9 |
| Eastern white pine | 6 x 6 | 261.98 | 379.21 | 341.71 | 316.56 | 324.9 |
| | 9 x 9 | 260.07 | 196.74 | 221.96 | 279.8 | 239.6 |
| | 12 x 12 | 171.98 | 92.17 | 105.38 | 111.81 | 120.3 |
| | 15 x 12 | 82.94 | 78.06 | 119.20 | 106.5 | 96.7 |

# VITA

The author was born on February 3, 1949, in Imesi-ile, Ijesha Division of former Western Nigeria now Oyo State, Nigeria. He graduated in Nigeria with a high school diploma. He was trained as a Forest Technician in Nigeria and in the United Kingdom. He entered Abraham Baldwin Agricultural College, Tifton, Georgia in 1972, and graduated with an associate of science degree in 1974. He entered the University of Tennessee the same year and received his Bachelor of Science in 1975 with a major in Forestry.