# PMRC COASTAL PLAIN CULTURE / DENSITY STUDY:

# AGE 12 ANALYSIS

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## SUMMARY

The Coastal Plain Intensive Culture / Density study was established in 1995/96 to examine the effects of intensive silviculture and current operational practices on the growth and yield of slash and loblolly pine across a wide range of densities. The study was installed across a range of CRIFF soil types so soil type interactions could be tested. Seventeen installations were established in the Coastal Plain of Georgia and Florida. All of the installations contained loblolly pine and 9 installations also included slash pine at three densities. By age 12, 13 loblolly and 7 slash installations remain.

Site preparation and subsequent silvicultural treatment regimes were designed to represent two levels of management intensity; operational and intensive culture. The operational treatment consisted of bedding in the spring followed by a fall herbicide treatment applied in 5-foot bands over the rows. At planting, 500 lbs. of 10-10-10 fertilizer was applied. In the spring of the eighth and twelfth growing seasons, operation treatment plots were fertilized with the equivalent of 200 lbs. N and 25 lbs. P per acre.

The intensive cultural treatment consisted of bedding in the spring followed by a broadcast herbicide application in the fall. The intensive cultural treatment plots received additional herbicide treatments to keep them as completely free of competing vegetation as possible throughout their rotation. Insecticides (usually Pounce) designed to control tip moths were applied as often as necessary to maintain tip moth control through the first two growing seasons. At planting, 500 lbs. of 10-10-10 fertilizer was applied. In the spring of the third growing season, the plots received 600 lbs/ac 10-10-10 plus micronutrients and 117 lbs/ac $NH_4NO_3$. An additional 117 lbs/ac $NH4NO_3$ was applied in the spring of the fourth growing season, 300 lbs/ac $NH_4NO_3$ was added in the spring of the sixth growing season, and 200 lbs of elemental N and 25 lbs of elemental P were applied in the spring of the eighth, tenth and twelfth growing seasons.

Within both the intensive and operational treatments, six loblolly pine subplots with densities of 300, 600, 900, 1200, 1500 and 1800 trees per acre (TPA) were randomly located and established. Slash pine subplots were established at densities of 300, 900 and 1500 TPA. The arrangement of soil groups, cultural treatments and planting densities results in a split-split plot design. The main plots are soil groups, subplots are cultural treatments and densities are the sub-subplots. The installations are considered as a random sample of all possible locations so the installation (replication) factor is considered random. Since the other factors are fixed, this results in a "mixed model" and was analyzed as such. The analysis was carried out for average DBH, average height, dominant height, percent survival, percent cronartium infection, per-acre

basal area, per-acre outside bark total volume, per-acre total outside bark green weight, per-acre chip-n-saw yield, stand density index, relative spacing, crown ratio and crown length for each species.

For loblolly pine, the management intensity, density and soil factors had significant effects on average DBH. There were also significant density x management and soil x management interactions for average DBH. Though the trend was the same across densities for the two management intensities, the accelerated stand development in the more intensively managed treatment plots resulted in greater differences in average DBH across densities. This effect was more pronounced on the B2 and D soil groups.

Management intensity and planting density had significant effects on both loblolly pine average height and dominant height. Average heights were taller on more intensively managed treatments and the higher densities, particularly 1500 and 1800 trees per acre, had shorter average heights and average dominant heights than lower densities. The soil x management interaction also significantly affected average dominant height. The height growth responses to more intensive management were 8.4' and 13' greater on the B2 and D soil groups, respectively, as compared to 3.8' for the other soil groups.

Management intensity and density significantly impacted loblolly pine survival through age 12. Operational treatment plots survived better than more intensively managed plots by about 9%. Cronartium infection levels increased with decreasing density and with increased management intensity. In general, infection rates were greater on the A and B2 soil groups.

The trends for per-acre basal area, per-acre green weight and per-acre total stem volume were similar. The management intensity and initial density factors had significant effects on these per-acre values. In general as the management intensity increased the basal area per acre, total volume per acre, and green weight per acre increased. Likewise, as the density increased the values of all the variables increased as well. For each of these stand characteristics, the soil x management interaction was also significant. As with other analysis variables, the response to more intensive management was greater on the B2 and D soil groups.

Merchantable, per-acre green tons for potential chip-n-saw trees was calculated. Management and density significantly affected chip-n-saw yield. There were also significant interactions between CRIFF soil group and management intensity and between management intensity and density. More intensive management resulted in greater increases in chip-n-saw yield on lower density plots.

For the limiting density variables, stand density index (SDI) and relative spacing (RS), the significant factors were density and management intensity with a soil group x management interaction. More intensive management and higher densities resulted in significantly higher SDI and lower RS values. The management effects were more pronounced on the B2 and D soil groups.

Crown ratio and crown length are recognized factors indicating tree vigor and affecting tree form. Management intensity and initial density significantly affected crown ratio while only density affected crown length. Operational treatment plots had consistently greater crown ratios but nearly equal crown lengths compared to more intensively-managed plots. The lower density plots (300 TPA) had 50% greater crown lengths than higher initial densities.

For slash pine, management intensity, density and their interaction significantly impacted average DBH. The interaction resulted from a larger gain in average DBH from intensive management at the lowest density as compared to the 900 or 1500 TPA densities.

Management intensity and density were significant factors for average slash pine height. Intensively managed treatments were taller by about 2.4’ compared to operational treatments. There was about a 3’ difference in average height from 300 to 1500 trees per acre. The same factors significantly affected average dominant height and the difference was about 2.1’ in favor of the intensive management treatment.

Density significantly affected slash pine survival through age 12. Compared to the lower density plots, the 1500 trees per acre initial density plots survived 5.3% and 17.4% less for intensive and operational plots, respectively. The density factor significantly affected the cronartium infection rate. Percent infection decreased with increasing density; ranging from 23.7% on 300 TPA plots to 15% on 1500 TPA plots. The spodosol installations (CRIFF C) had lower infection levels than the nonspodosols. On the nonspodosols, the plots on the B2 soil type had about 10% higher infection rates than other nonspodosol soils.

For per-acre basal area, per-acre green weight and total stem volume, initial planting density had the only significant effect. The higher densities resulted in higher values of all three stand characteristics. The results may have been confounded to some extent by plots that suffered increased mortality due to wildfire.

As with loblolly pine, merchantable per-acre green tons for potential chip-n-saw trees was calculated. Management, initial density and their interaction significantly affected chip-n-saw yield. More intensive management resulted in greater increases in chip-n-saw yield on lower density plots. The intensively-managed, 300 trees per acre plots had almost 80% more yield in chip-n-saw sized trees than the average of all other plots.

For stand density index (SDI) and relative spacing the only significant factor was initial density. Higher densities resulted in significantly higher SDI's and lower relative spacing values. As with other density-related factors, these results may have been affected by plots that experienced catastrophic mortality.

Only initial density significantly affected crown ratio and crown length for slash pine. Both crown metrics tended to increase with decreasing initial density. For each density level, crown ratio and crown length were nearly equal for both management intensity levels.

The average DBH, average height, survival, cronartium infection level, basal area, total green weight, total volume, stand density index, relative spacing, crown ratio and crown length of loblolly and slash pine were compared graphically. Comparisons were carried out for selected treatments and by treatment and soil class.

There were minimal differences in the DBH values for the two species when paired by management intensity and initial density. Loblolly had a 0.8" greater DBH at the 300 density with intensive management. For all other treatment/species pairs, the largest difference was about 0.4"

Loblolly averaged 7.1' taller than slash pine on the intensive treatments and 4.1' taller on the operational plots. In fact, the operational loblolly was taller than intensively-managed slash by an average of 1.7' across densities.

Both species had good survival at the lowest initial density. Higher density, intensively-managed plots for both species have begun to exhibit higher mortality rates that may be attributable to intra-species competition but are also skewed by catastrophic mortality on some slash pine plots.

The intensively managed slash pine plots had the highest level of cronartium infection across densities. Both species had the highest infection rates on the B2 soil type.

On the average for operationally-managed plots, loblolly pine had consistently more per-acre basal areas than slash pine by 18-42 $ft^2$/ac. On the intensively-managed plots, loblolly had 22-49 $ft^2$/ac more basal area than slash pine. The same trends apply when analyzed by soil group with loblolly having more per-acre basal area across all soil groups. The differences are slightly less on the B2 soil group.

The trends for per-acre, outside bark volume were the same as those seen for per-acre basal area, but the differences were accentuated because of the loblolly height advantage. Loblolly pine had more volume than slash by 493 to 1280 $ft^3$/ac for the operational treatments and 1050 to 1770 $ft^3$/ac on the intensive treatments. The trends for total green weight were similar to the trends for total volume. The advantage for loblolly pine in terms of green weight was 27-47 tons/ac for intensively managed stands and was 13-32 tons/ac for operational stands depending on the initial density.

In terms of crown ratio, the only apparent trends were with initial density. For each density level, crown ratios were nearly equal for each species and management intensity level. For crown length, there was a consistent trend within each initial density. Intensively-managed loblolly pine had the greatest crown length followed by operational loblolly, intensive slash and operational slash pine.

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# 1 INTRODUCTION

Commercial forest landowners in the southeastern U.S. have experienced increasing pressure to maximize per-acre volume production from loblolly and slash pine plantations. As the demand for forest products continues to increase, the amount of land on which pine plantation management is feasible or practical continues to decrease. These pressures have created significant interest in genetic improvement, control of competing vegetation and forest nutrition. Many studies carried out by the PMRC and other research organizations have reported significant gains in yield due to tree improvement and more intensive management practices. When contemplating the regeneration of a loblolly or slash pine plantation, forest managers still have unanswered questions regarding the relationships between management practices and establishment densities across a range of soil types. For example, there is some indication that convergence to a common asymptote of volume from different densities may occur much earlier on sites with high growth rates resulting from intensive management (Pienaar and Shiver, 1993). To address these issues, the PMRC established the Intensive Culture/Density Study in 1995/96. The objectives of this study are to:

- Quantify and contrast the effects of intensive silviculture and current operational practices on the growth and yield of loblolly and slash pine plantations across a wide range of densities,
- Investigate potential interactions between cultural intensity and stand density across broad soil categories, particularly in the areas of survival, fusiform rust infection, volume and weight production, product class distributions, and carrying capacity as measured by limiting density measures such as stand density index and relative spacing.

This report contains the findings of the study through age 12 for loblolly and slash pine.

# 2 METHODS

Seventeen installations were established in the Lower Coastal Plain of Georgia and Florida. All of the installations contained loblolly pine and nine installations included a slash pine component. At least three loblolly pine installations were established on each of five CRIFF soil groups A, B1, B2, C and D. Slash pine was established on all but the A soil group. Table 1 shows a description of the CRIFF soil groups. At the time of the age 12 measurement, 13 loblolly installations and 7 slash installations remained.

**Table 1**. CRIFF soil groups used in the Culture / Density Study.

| CRIFF Soil Group | Drainage Class | Diagnostic Horizons |
|---|---|---|
| A | Very poor – somewhat poor | No spodic, argillic < 20” |
| B1 | Very poor – somewhat poor | No spodic, argillic 20 – 40” |
| B2 | Very poor – somewhat poor | No spodic, argillic > 40” or absent |
| C | Very poor – somewhat poor | Spodic with argillic |
| D | Poor – moderately well | Spodic without argillic |

Site preparation and subsequent silvicultural treatments represent two levels of management intensity; operational and intensive culture. The operational treatment consisted of bedding in the spring followed by a fall herbicide treatment. The herbicide treatment consisted of 12 oz. Arsenal plus 1 qt. Garlon 4 per acre if competition was waxy-leafed species such as galberry ) (*Ilex glabra*) or palmetto (*Serenoa repens*), or 12 oz. Arsenal plus 1 qt. Accord per acre if the competition consisted mainly of grass or upland hardwood species. Herbicide was applied in 5-foot bands over the rows. At planting, 500 lbs. of 10-10-10 fertilizer was applied. In the spring of the eighth and twelfth growing seasons, operation treatment plots were fertilized with the equivalent of 200 lbs. N and 25 lbs. P per acre.

The intensive cultural treatment consisted of bedding in the spring followed by a fall herbicide application. The herbicide treatment was a broadcast application of 16 oz. Arsenal, 2 quarts Garlon-4 and 2 quarts Accord per acre. At planting, 500 lbs. of 10-10-10 fertilizer was applied on all plots. The intensive cultural treatment plots received additional herbicide treatments to keep them as completely free of competing vegetation as possible throughout their rotation. Beginning in the spring of the first growing season (1996), the plots were sprayed with 4 oz. Oust per acre along with directed sprays of Accord. Insecticides (usually Pounce) designed to control tip moths were applied as often as necessary to maintain tip moth control through the first two growing seasons. In the spring of the third growing season, the plots received 600 lbs/ac 10-10-10 plus micronutrients and 117 lbs/ac $NH_4NO_3$. An additional 117 lbs/ac $NH4NO_3$ was applied in the spring of the fourth growing season, 300 lbs/ac $NH_4NO_3$ was added in the spring of the sixth growing season, and 200 lbs of elemental N and 25 lbs of elemental P were applied in the spring of the eighth, tenth and twelfth growing seasons.

Within each site preparation treatment, six loblolly pine subplots with densities of 300, 600, 900, 1200, 1500 and 1800 trees per acre (TPA) were planted. Slash pine subplots were established at densities of 300, 900 and 1500 TPA. Bed widths were 6 feet for the 1200-1800 TPA plots, 8 feet for the 600 and 900 TPA plots and 12 feet for the 300 TPA plot. Table 2 shows the spacings and plot sizes for the density subplots. All Coastal Plain installations were planted with 7-56 stock.

To ensure the targeted initial density, each planting spot was double-planted and reduced to a single surviving seedling after the first growing season. At each installation (site) there was a random allocation of management intensity to one side of the site. Within a management intensity treatment the density subplots were randomly assigned. On plots with slash pine, the slash pine was randomly assigned to plots on both the intensive and operational areas.

**Table 2**. Spacing and plot sizes for the density subplots.

| Density (TPA) | Spacing (ft. x ft.) | Trees per meas. plot | Meas. plot size (ac) | Gross plot size (ac) |
|---|---|---|---|---|
| 1800 | 6 x 4 | 184 | 0.10 | 0.31 |
| 1500 | 6 x 4.8 | 160 | 0.11 | 0.32 |
| 1200 | 6 x 6 | 120 | 0.10 | 0.30 |
| 900 | 8 x 6 | 96 | 0.11 | 0.31 |
| 600 | 8 x 9 | 80 | 0.13 | 0.37 |
| 300 | 12 x 12 | 80 | 0.26 | 0.56 |

The arrangement of soil groups, management intensity treatments and planting densities results in a split-split plot design. The main plots are soil groups, subplots are management intensity treatments and densities are sub-subplots. Since the replications, or installations in this case, can be considered as a random sample of all possible locations, the replication factor must be considered as random. This results in a mixed model. In order to make proper inferences across all sites represented by the five soil groups, the presence of the random factor must be considered (Parrish and Ware, 1989; Littell et.al., 1991). The mixed model, split-split plot design with 13 installations results in the analysis of variance setup shown in Table 3.

**Table 3**. Analysis of variance table for the mixed model, split-split plot experiment for loblolly pine at age 12.

| Factor | | df |
|---|---|---|
| SOIL | | 4 |
| INST(SOIL) | [error (soil)] | 8 |
| MANAGEMENT | | 1 |
| MANAGEMENT*SOIL | | 4 |
| MANAGEMENT*INST(SOIL) | [error (a)] | 8 |
| DENSITY | | 5 |
| DENSITY*SOIL | | 20 |
| DENSITY*CULTURE | | 5 |
| DENSITY*CULTURE*SOIL | | 20 |
| DENSITY*INST(SOIL) | } [error (b)] | 40 |
| DENSITY*CULTURE*INST(SOIL) | | 40 |
| | Corrected total | 155 |

All factors containing installation are considered random and were listed in the RANDOM statement in SAS PROC MIXED (Littell et.al., 1996).

After the 12th growing season, diameters of all trees and heights on every other tree were measured. Height to the base of the live crown was measured on all trees that were measured for total height. A tree was considered a dominant tree if it was in the upper 50% of diameters on the plot. Each tree stem was also inspected for cronartium infection.

Individual tree, outside bark cubic foot volumes and green weights were calculated using the following equations from Pienaar, et al. (1987):

$$VOB = 0.00145519\,DBH^{1.826051}\,HT^{1.221965} \quad (1)$$

$$MVOB = VOB - 0.00253872\left[\frac{D_m^{3.741575}}{DBH^{1.741575}}\right](HT - 4.5) \quad (2)$$

$$GWOB = 0.0740959\,DBH^{1.829983}\,HT^{1.247669} \quad (3)$$

$$MGWOB = GWOB - 0.123329\left[\frac{D_m^{3.523107}}{DBH^{1.449947}}\right](HT - 4.5) \quad (4)$$

On each of the slash plots, individual tree outside bark cubic foot volumes and green weights were calculated using the following equations from Pienaar, et al. (1996):

$$VOB = 0.00456\,DBH^{2.0726}\,HT^{0.8114} \quad (5)$$

$$MVOB = VOB - 0.00265\left[\frac{D_m^{3.8846}}{DBH^{1.8846}}\right](HT - 4.5) \quad (6)$$

$$GWOB = 0.1763\,DBH^{1.9604}\,HT^{0.9761} \quad (7)$$

$$MGWOB = GWOB - 0.1167\left[\frac{D_m^{3.6422}}{DBH^{1.5441}}\right](HT - 4.5) \quad (8)$$

where *VOB* = total stem volume (cubic feet outside bark)

*MVOB* = merchantable stem volume (cubic feet outside bark)

*GWOB* = total stem green weight (pounds with bark)

*MGWOB* = merchantable stem green weight (pounds with bark)

*DBH* = diameter at breast height (in)

$D_m$ = outside bark upper-stem diameter (in)

$HT$ = total tree height (ft)

Equations (4) and (8) were used to calculate potential chip-n-saw yield for each plot. Green weight to a 6-inch top was calculated for all trees with DBH greater than or equal to 8 inches.

Stand density index was calculated for each plot using the following equation:

$$SDI = TPA*(10/Dq)^{-1.6}$$

where SDI = stand density index,
TPA = trees per acre surviving at the SDI age, and
Dq = quadratic mean DBH.

Relative spacing is the average distance between trees expressed as a proportion of the dominant height. It is calculated using the following equation:

$$RS = \frac{\sqrt{43560/TPA}}{HD}$$

where RS = relative spacing index,
TPA = trees per acre surviving at RS age,
HD = average height of dominant trees.

Analysis of variance as described above was carried out for average DBH, average height, average dominant height, percent survival, percent cronartium infection, per-acre basal area, total per-acre total volume, total per acre green weight, chip-n-saw green weight, stand density index, relative spacing, crown ratio and crown length.

## 3 LOBLOLLY PINE RESULTS

Table 4 shows the loblolly pine means by soil type, management intensity and initial density for all analysis variables at age 12. The number of installations included in the mean calculations for each soil group is indicated.

**Table 4**. Loblolly pine means by CRIFF soil group, management intensity and initial density at age 12.

**CRIFF Soil Type A (3 Installations)**

| | Intensive | | | | | | Operational | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 300 | 600 | 900 | 1200 | 1500 | 1800 | 300 | 600 | 900 | 1200 | 1500 | 1800 |
| Avg. DBH (in) | 10.3 | 8.1 | 7.1 | 6.3 | 6.2 | 5.5 | 8.9 | 7.4 | 6.5 | 6.0 | 5.5 | 5.4 |
| Avg. Height (ft) | 54.2 | 56.2 | 54.3 | 53.2 | 52.7 | 50.8 | 50.1 | 49.5 | 49.8 | 48.8 | 46.2 | 45.9 |
| Dom Height (ft) | 55.9 | 58.2 | 56.7 | 56.4 | 56.2 | 54.0 | 52.4 | 52.0 | 52.7 | 51.7 | 48.9 | 49.3 |
| % Survival | 76.7 | 82.1 | 76.4 | 76.9 | 53.5 | 69.7 | 90.8 | 82.5 | 85.8 | 77.5 | 72.5 | 64.5 |
| % Cron. | 32.2 | 35.8 | 28.5 | 23.2 | 23.2 | 16.9 | 22.7 | 22.8 | 24.0 | 16.9 | 18.7 | 11.6 |
| Basal Area ($ft^2$/ac) | 136 | 180 | 191 | 207 | 174 | 206 | 120 | 152 | 182 | 190 | 182 | 189 |
| Tot. Vol. ($ft^3$/ac) | 3233 | 4636 | 4840 | 5226 | 4469 | 5065 | 2683 | 3483 | 4252 | 4410 | 4035 | 4163 |
| Tot. Grn Wt (ton/ac) | 92 | 132 | 138 | 149 | 127 | 144 | 76 | 99 | 121 | 125 | 114 | 118 |
| CNS Wt (ton/ac) | 77.8 | 65.2 | 31.0 | 14.2 | 19.6 | 1.7 | 53.6 | 31.2 | 17.8 | 9.5 | 7.2 | 3.3 |
| Crown Ratio | 0.51 | 0.39 | 0.36 | 0.33 | 0.33 | 0.32 | 0.55 | 0.42 | 0.37 | 0.37 | 0.35 | 0.37 |
| Crown Length (ft) | 27.8 | 21.9 | 19.7 | 18.0 | 17.5 | 16.2 | 27.7 | 20.6 | 18.5 | 18.6 | 16.2 | 17.5 |

**CRIFF Soil Type B1 (2 Installations)**

| | Intensive | | | | | | Operational | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 300 | 600 | 900 | 1200 | 1500 | 1800 | 300 | 600 | 900 | 1200 | 1500 | 1800 |
| Avg. DBH (in) | 9.5 | 7.4 | 6.3 | 6.0 | 5.6 | 5.3 | 8.7 | 7.1 | 6.2 | 5.6 | 5.3 | 5.0 |
| Avg. Height (ft) | 58.0 | 55.0 | 54.1 | 53.6 | 5138 | 49.8 | 55.2 | 53.0 | 51.4 | 49.6 | 49.5 | 48.0 |
| Dom Height (ft) | 60.1 | 56.7 | 57.7 | 56.1 | 54.8 | 54.3 | 57.0 | 56.7 | 54.8 | 52.8 | 52.4 | 51.9 |
| % Survival | 87.5 | 75.6 | 79.2 | 66.7 | 63.8 | 60.6 | 95.0 | 86.9 | 78.1 | 74.2 | 76.9 | 71.5 |
| % Cron. | 24.1 | 13.0 | 14.2 | 5.6 | 6.1 | 4.9 | 11.8 | 10.1 | 8.0 | 8.6 | 5.3 | 6.0 |
| Basal Area ($ft^2$/ac) | 130 | 138 | 158 | 161 | 163 | 168 | 120 | 144 | 153 | 157 | 179 | 177 |
| Tot. Vol. ($ft^3$/ac) | 3381 | 3516 | 4090 | 4135 | 4093 | 4113 | 2972 | 3603 | 3781 | 3785 | 4317 | 4202 |
| Tot. Grn Wt (ton/ac) | 96 | 100 | 116 | 118 | 116 | 117 | 85 | 102 | 107 | 107 | 122 | 119 |
| CNS Wt (ton/ac) | 75.3 | 33.9 | 10.3 | 7.2 | 2.8 | 3.4 | 54.2 | 25.4 | 16.3 | 5.3 | 0.0 | 2.0 |
| Crown Ratio | 0.50 | 0.37 | 0.34 | 0.32 | 0.33 | 0.32 | 0.50 | 0.42 | 0.43 | 0.37 | 0.36 | 0.36 |
| Crown Length (ft) | 29.4 | 20.9 | 18.8 | 17.0 | 16.7 | 16.2 | 27.9 | 22.5 | 22.0 | 18.4 | 17.8 | 17.4 |

**CRIFF Soil Type B2 (2 Installations)**

| | Intensive | | | | | | Operational | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 300 | 600 | 900 | 1200 | 1500 | 1800 | 300 | 600 | 900 | 1200 | 1500 | 1800 |
| Avg. DBH (in) | 9.2 | 7.2 | 6.5 | 6.0 | 5.7 | 5.0 | 7.6 | 6.2 | 5.5 | 4.8 | 4.5 | 4.2 |
| Avg. Height (ft) | 55.9 | 53.8 | 54.9 | 53.8 | 53.3 | 50.4 | 46.7 | 47.7 | 48.3 | 42.8 | 43.6 | 42.7 |
| Dom Height (ft) | 57.4 | 55.9 | 57.2 | 56.5 | 56.3 | 53.5 | 49.3 | 49.9 | 51.1 | 46.0 | 46.6 | 46.2 |
| % Survival | 86.3 | 65.8 | 71.9 | 77.8 | 64.8 | 70.3 | 90.0 | 93.3 | 92.0 | 84.4 | 89.4 | 89.1 |
| % Cron. | 34.9 | 24.0 | 24.3 | 15.2 | 13.8 | 10.6 | 23.8 | 17.6 | 14.4 | 12.2 | 10.0 | 10.2 |
| Basal Area ($ft^2$/ac) | 122 | 114 | 153 | 188 | 177 | 181 | 88 | 121 | 143 | 132 | 152 | 159 |
| Tot. Vol. ($ft^3$/ac) | 3048 | 2820 | 4049 | 4888 | 4618 | 4501 | 1847 | 2703 | 3308 | 2763 | 3251 | 3385 |
| Tot. Grn Wt (ton/ac) | 87 | 80 | 115 | 139 | 131 | 128 | 52 | 77 | 94 | 78 | 92 | 96 |
| CNS Wt (ton/ac) | 64.5 | 20.4 | 11.8 | 5.5 | 4.7 | 0.0 | 22.8 | 3.1 | 0.0 | 0.5 | 0.0 | 0.0 |
| Crown Ratio | 0.52 | 0.38 | 0.40 | 0.37 | 0.35 | 0.35 | 0.58 | 0.48 | 0.38 | 0.40 | 0.37 | 0.37 |
| Crown Length (ft) | 29.2 | 21.0 | 22.1 | 20.2 | 19.0 | 17.9 | 27.2 | 23.1 | 18.6 | 17.2 | 16.2 | 16.2 |

**CRIFF Soil Type C (5 Installations)**

| | Intensive | | | | | | Operational | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 300 | 600 | 900 | 1200 | 1500 | 1800 | 300 | 600 | 900 | 1200 | 1500 | 1800 |
| Avg. DBH (in) | 9.2 | 7.3 | 6.3 | 5.8 | 5.4 | 5.2 | 8.0 | 6.9 | 5.8 | 5.1 | 4.8 | 4.6 |
| Avg. Height (ft) | 57.6 | 57.5 | 55.2 | 52.7 | 51.7 | 51.4 | 53.3 | 55.2 | 51.5 | 48.2 | 48.3 | 47.4 |
| Dom Height (ft) | 59.5 | 50.5 | 58.5 | 56.1 | 55.6 | 55.2 | 55.3 | 57.4 | 54.6 | 51.9 | 52.4 | 51.4 |
| % Survival | 88.8 | 82.5 | 82.5 | 77.2 | 71.9 | 61.2 | 92.5 | 79.8 | 77.9 | 90.5 | 86.5 | 77.6 |
| % Cron. | 18.2 | 11.7 | 7.8 | 6.0 | 6.5 | 6.0 | 15.5 | 14.0 | 10.1 | 6.5 | 6.4 | 6.2 |
| Basal Area ($ft^2$/ac) | 124 | 150 | 165 | 173 | 176 | 165 | 100 | 128 | 138 | 161 | 168 | 167 |
| Tot. Vol. ($ft^3$/ac) | 3222 | 4118 | 4392 | 4467 | 4485 | 4182 | 2432 | 3358 | 3487 | 3849 | 4069 | 4002 |
| Tot. Grn Wt (ton/ac) | 92 | 117 | 125 | 127 | 127 | 119 | 69 | 96 | 99 | 109 | 115 | 113 |
| CNS Wt (ton/ac) | 67.3 | 43.4 | 10.0 | 6.0 | 2.6 | 2.0 | 37.7 | 19.0 | 4.4 | 1.4 | 0.4 | 0.3 |
| Crown Ratio | 0.48 | 0.37 | 0.34 | 0.33 | 0.33 | 0.32 | 0.49 | 0.40 | 0.38 | 0.36 | 0.37 | 0.35 |
| Crown Length (ft) | 27.7 | 21.2 | 18.9 | 17.6 | 17.2 | 17.0 | 26.3 | 21.9 | 19.9 | 17.4 | 18.2 | 16.8 |

**CRIFF Soil Type D (1 Installation)**

| | Intensive | | | | | | Operational | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 300 | 600 | 900 | 1200 | 1500 | 1800 | 300 | 600 | 900 | 1200 | 1500 | 1800 |
| Avg. DBH (in) | 9.4 | 7.7 | 6.4 | 5.6 | 5.0 | 4.8 | 7.7 | 5.4 | 5.0 | 4.4 | 3.9 | 3.8 |
| Avg. Height (ft) | 54.0 | 57.2 | 54.9 | 50.4 | 45.5 | 47.2 | 45.7 | 37.6 | 37.7 | 37.7 | 37.7 | 34.8 |
| Dom Height (ft) | 55.9 | 59.4 | 57.6 | 53.3 | 47.6 | 51.4 | 47.1 | 40.0 | 40.1 | 41.4 | 42.1 | 39.4 |
| % Survival | 81.3 | 73.8 | 84.4 | 82.5 | 78.8 | 81.0 | 81.3 | 85.0 | 75.0 | 81.7 | 95.0 | 72.8 |
| % Cron. | 6.2 | 1.7 | 3.7 | 2.0 | 4.0 | 4.0 | 1.5 | 1.5 | 2.8 | 4.1 | 0.7 | 1.5 |
| Basal Area ($ft^2$/ac) | 118 | 149 | 176 | 174 | 167 | 187 | 80 | 86 | 94 | 112 | 130 | 111 |
| Tot. Vol. ($ft^3$/ac) | 2812 | 3982 | 4602 | 4239 | 3636 | 4375 | 1606 | 1486 | 1654 | 2061 | 2461 | 1988 |
| Tot. Grn Wt (ton/ac) | 80 | 113 | 131 | 120 | 103 | 124 | 45 | 42 | 47 | 58 | 69 | 56 |
| CNS Wt (ton/ac) | 62.0 | 51.3 | 13.7 | 1.7 | 0.0 | 0.0 | 16.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Crown Ratio | 0.57 | 0.42 | 0.33 | 0.34 | 0.34 | 0.32 | 0.60 | 0.50 | 0.46 | 0.37 | 0.35 | 0.42 |
| Crown Length (ft) | 30.9 | 24.0 | 17.8 | 17.3 | 15.6 | 15.6 | 27.3 | 18.6 | 17.4 | 14.2 | 13.5 | 15.2 |

### 3.1 Average DBH

Table 5 shows the results of the analysis of variance for average DBH for loblolly pine. The CRIFF soil group and management intensity factors were significant at the α = 0.05 level and there was a significant soil type x management intensity interaction. The density factor, as well as the management intensity x density interaction had significant affects on average DBH. Figure 1 shows the loblolly pine average DBH's by management intensity, initial density and CRIFF soil group.

**Table 5**. Analysis of variance results for loblolly pine average DBH at age 12.

| Source | Type III F | Pr > F |
|---|---|---|
| Soil | 4.00 | 0.0392* |
| Management | 85.05 | <0.0001* |
| Soil x Management | 3.66 | 0.0492* |
| Density | 938.24 | <0.0001* |
| Soil x Density | 1.32 | 0.1819 |
| Management x Density | 10.78 | <0.0001* |

*Significant at α = 0.05.

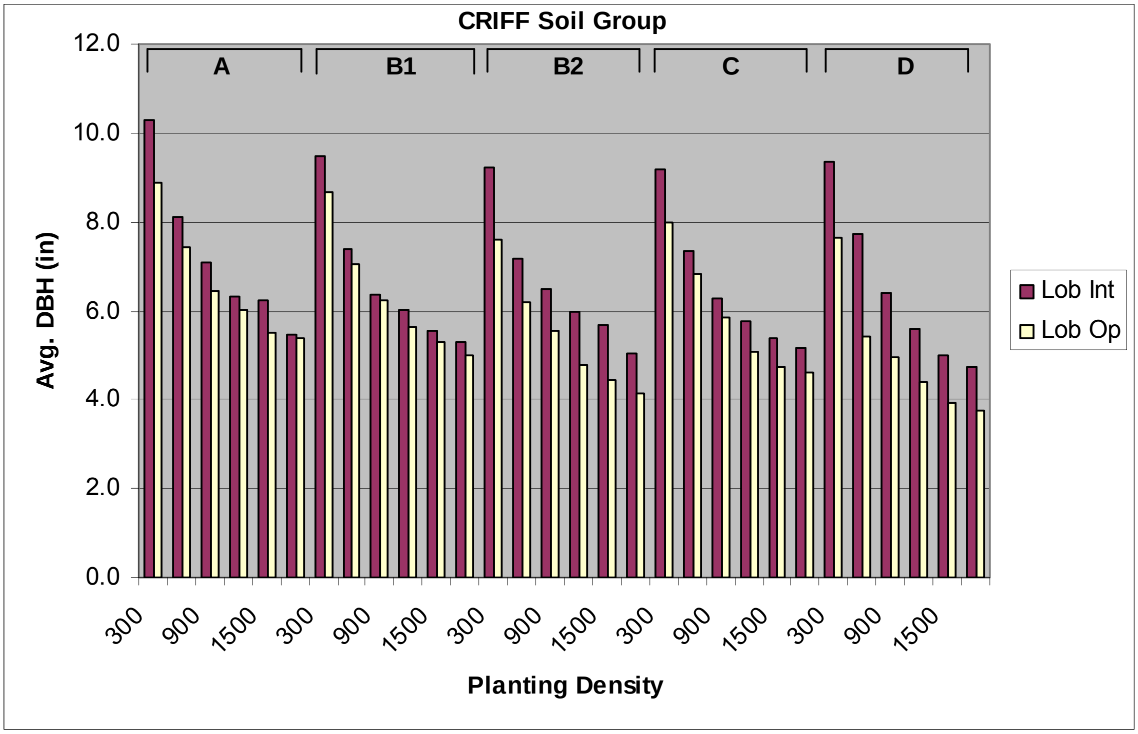


**Figure 1**. Average DBH by CRIFF soil group, planting density and management intensity for loblolly pine at age 12.

As in previous analyses, the increase in DBH due to management intensity at age 12 was more pronounced on the B2 and D soil groups. Recall that these soil groups have either a very deep or no argillic horizon.

It is clear that, though there is a management intensity x planting density interaction, the average DBH is increased by increasing management intensity regardless of density (Figure 2). Across all soil types, average DBH increases due to more intensive management were 1.3” for the 300 TPA initial density, 0.7” for densities of 600-1500 TPA and 0.5” for the 1800 TPA treatment.

The management intensity x density interaction is probably caused by the increased level of stand development on all of the intensive culture plots, regardless of initial density. As a result, there is a marked effect on DBH as density increases. On the intensive culture plots there is no effect on DBH from vegetation other than pines because it is all removed. While the same general trends are present on the operational plots, the differences between different densities are less obvious, especially at the higher densities. The difference between average DBH on operational 1500 and 1800 trees per acre is often minimal whereas the difference on the intensive culture plots for those densities is noticeable. The level of development indicates that the operational plots shade themselves at an early age at high densities, thus reducing the effect

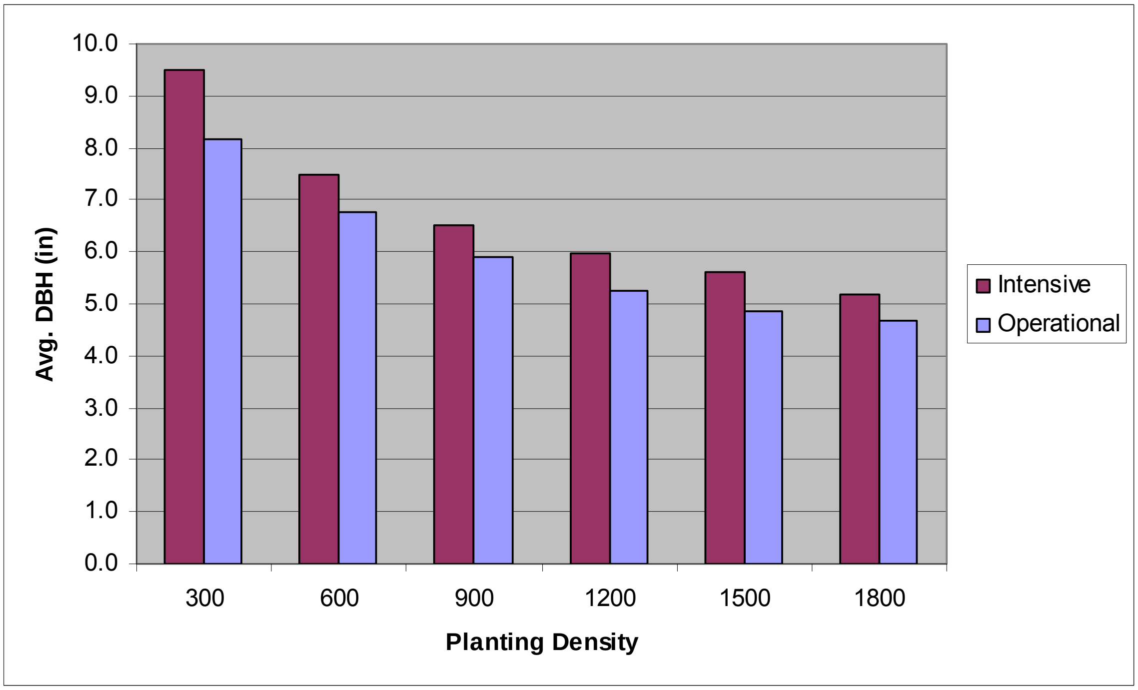


**Figure 2**. Average DBH by planting density and management intensity for loblolly pine at age 12.

of inter-specific competition. As a result there is less difference between the intensive culture and operational plots at high densities than at lower densities. This effect is less prevalent on soil types B2 and D, the two soil types that are almost completely sand. On these soils that tend to be infertile, the added nutrients from the intensive culture result in large differences in average DBH for the two management intensities even at the higher densities.

Figure 3 shows DBH development over time for selected treatments. The trends in average DBH due to initial density and management intensity remain consistent over time. There appears to be some convergence in average DBH between management intensity treatments within density classes. The growth rate of the more intensive treatment appears to have slowed by age 12.

### 3.2 Average Height and Dominant Height

Table 6 shows the results of the analysis of variance for loblolly pine average height. The management intensity factor was significant at the $\alpha = 0.05$ level with the intensive culture treatment heights averaging five to six feet taller across the different densities. The density factor also significantly affected average height (Figure 4). The lower densities (300 to 900 trees per

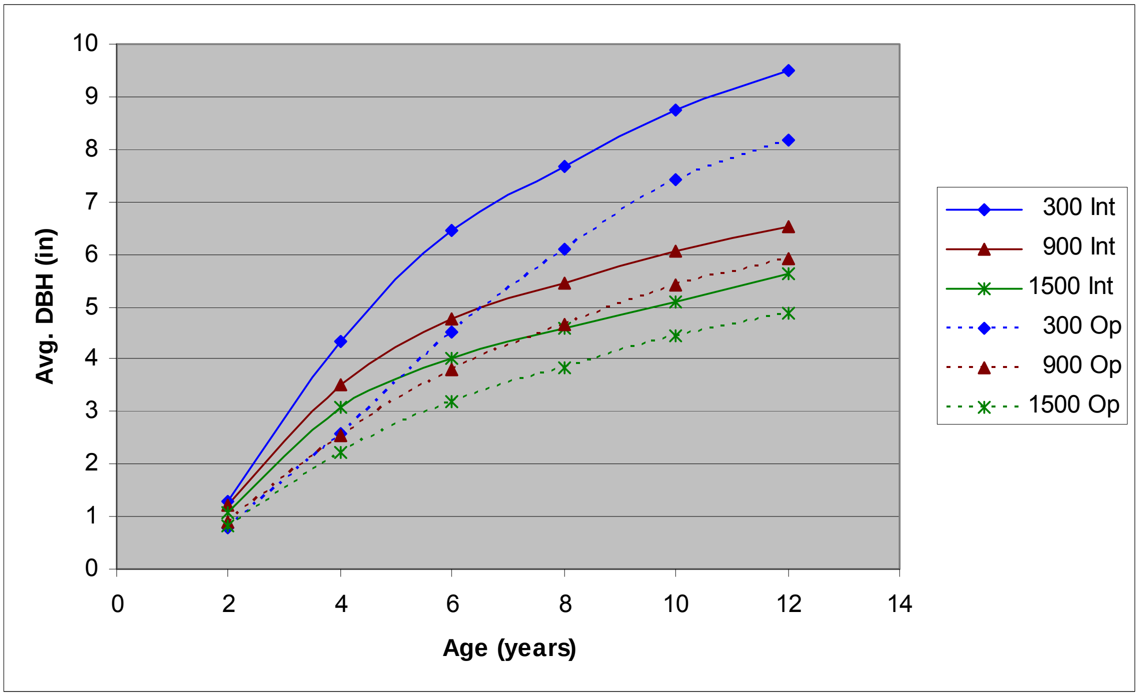


**Figure 3**. Average DBH growth by planting density and management intensity for selected loblolly pine treatments.

acre) had the highest average heights for both management treatment groups. In the range of densities that we normally manage loblolly pine, density does not significantly affect average height growth (Smith, 1962). Studies that included densities outside of the normal range, however, have identified density effects on average height for loblolly pine (Pienaar and Rheney, 1994; Sharma, *et.al*., 2002). This study also extends the density range on both the low end (300 trees per acre) and on the high end (1500-1800 per acre). Least squares mean difference tests show that there were no significant differences in adjacent density classes. There was a trend toward lower average height as initial density increased. It is possible that a higher proportion of small trees in the higher density plots could impact whether density was significant on average height. A subset of trees with DBH greater than the average DBH, called dominants, was made and their average heights were calculated. The result was the same as for average height when the analysis of variance was conducted. Management and initial density were significant at the 5% level of significance. Average dominant heights by planting density and management intensity are shown in Figure 5. The trend across densities is the same regardless of the management intensity. Differences between intensive and operational are slightly less, by about a ½ foot, for average dominant height as compared to average height.

**Table 6**. Analysis of variance results for loblolly pine average height at age 12.

| Source | Type III F | Pr > F |
|---|---|---|
| Soil | 2.41 | 0.1257 |
| Management | 143.81 | <0.0001* |
| Soil x Management | 8.99 | 0.0033* |
| Density | 29.42 | <0.0001* |
| Soil x Density | 1.29 | 0.2020 |
| Management x Density | 0.29 | 0.9162 |

*Significant at α = 0.05.

Figure 6 shows the average heights by management intensity, initial density and CRIFF soil group. As with average DBH, the significant soil group x management intensity interaction seems to be due to the B2 and D soil groups. The average increase in height due to more intensive management was 3.8 feet for the A, B1 and C soil groups. The increase in height due to more intensive management was 8.4 feet and 13 feet for the B2 and D soil groups, respectively.

Figure 7 shows average dominant height growth for selected treatments. The difference in height due to higher density is more pronounced at age 12 compared to previous years. The differences due to management intensity have remained consistent from ages 6 through 12.

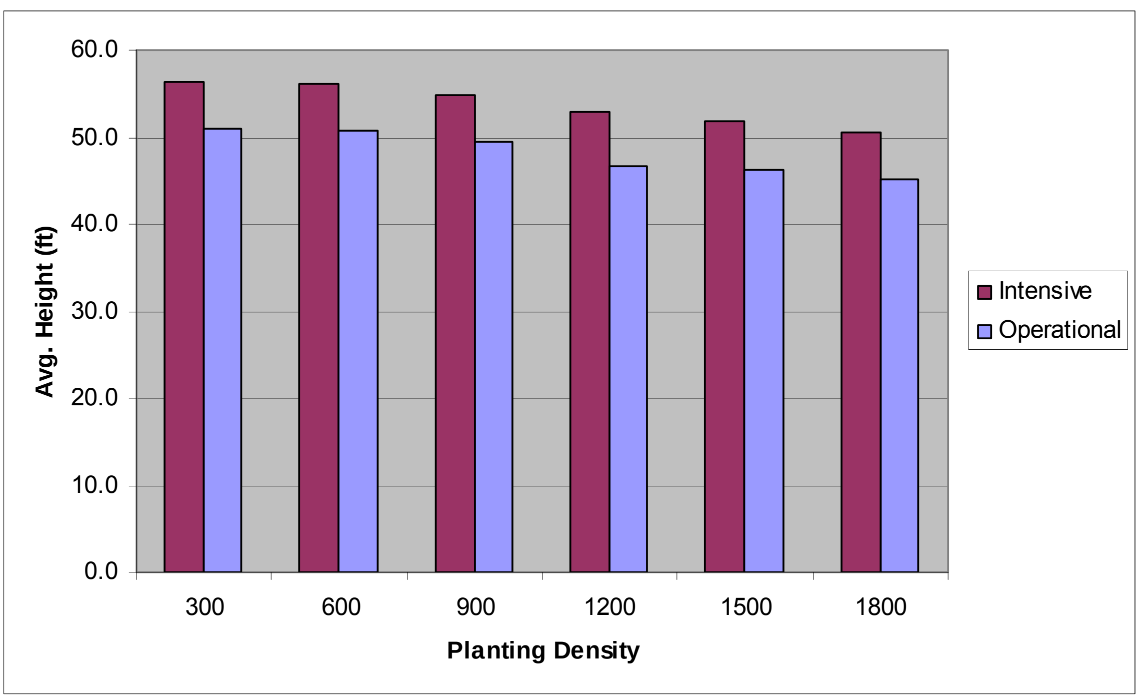


**Figure 4**. Average height by planting density and management intensity for loblolly pine at age 12.

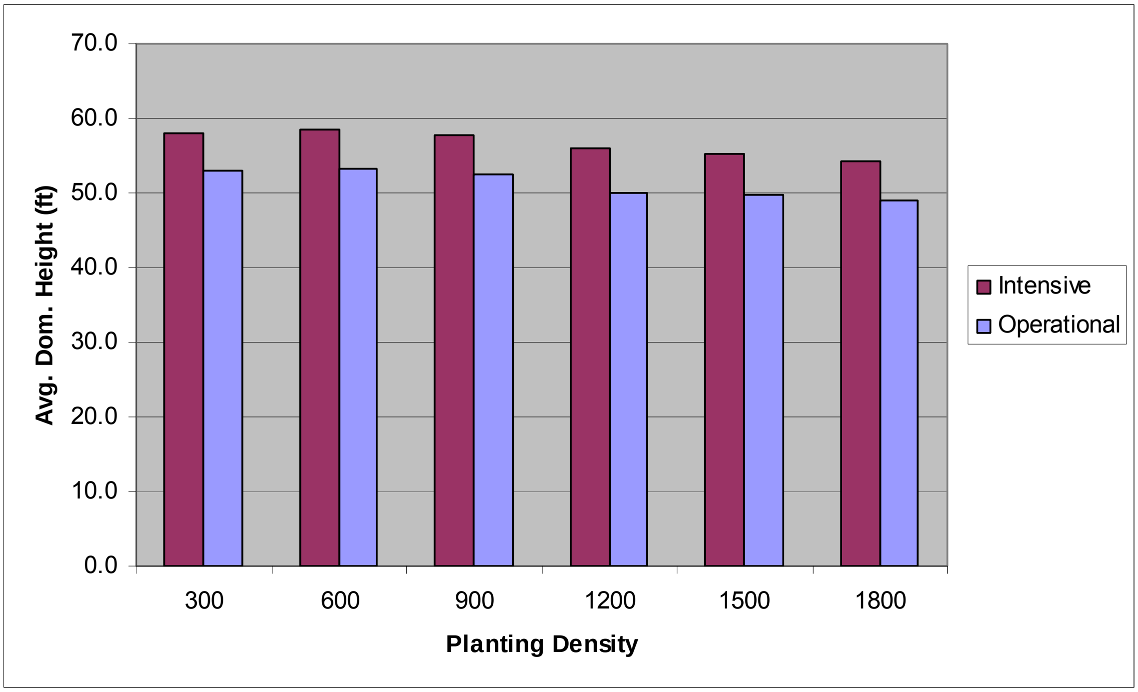


**Figure 5**. Average dominant height by planting density and management intensity for loblolly pine at age 12.

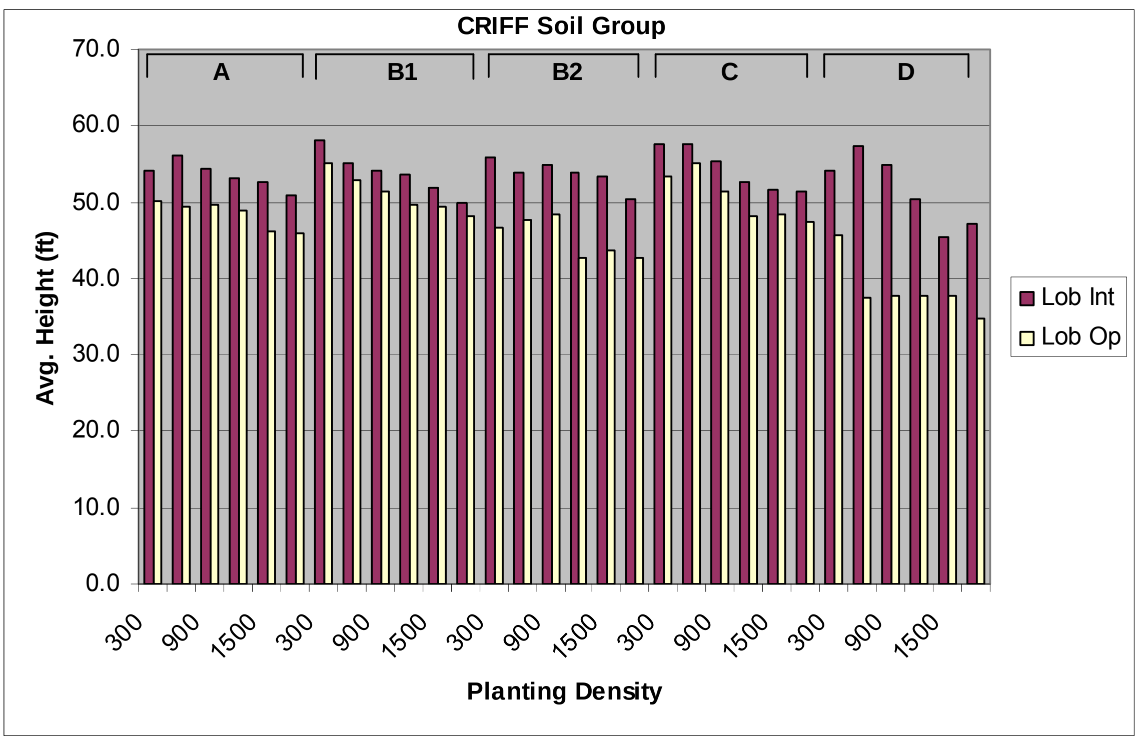


**Figure 6**. Average height by CRIFF soil group, planting density and management intensity for loblolly pine at age 12.

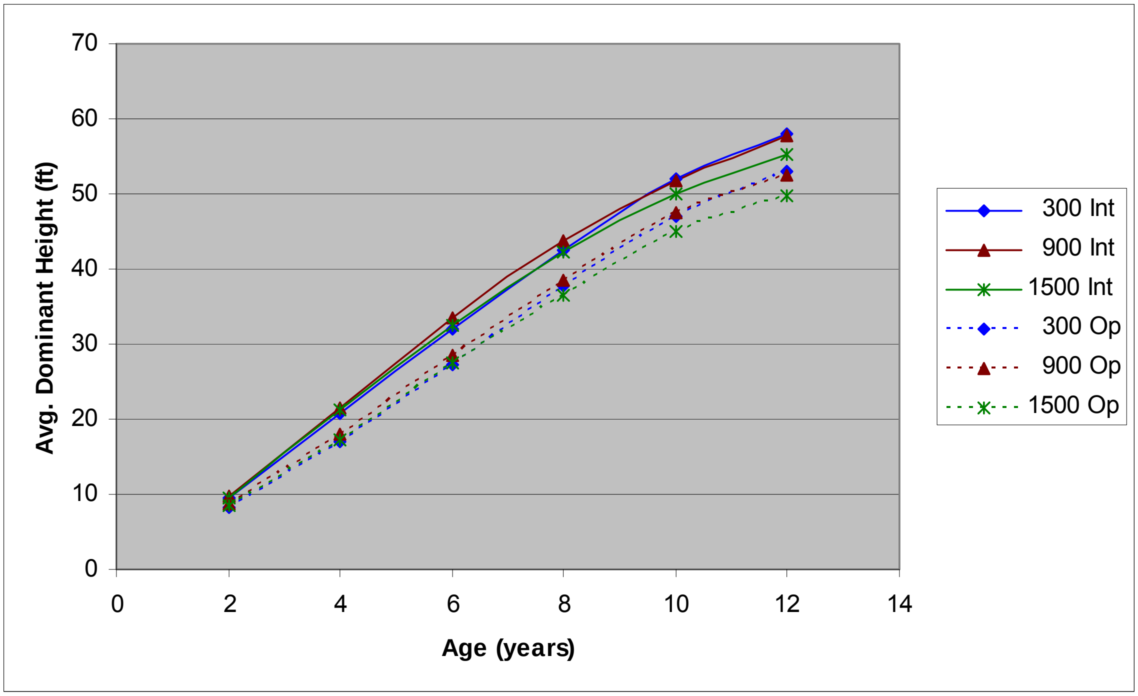


**Figure 7**. Average dominant height growth by planting density and management intensity for selected loblolly pine treatments.

### 3.3 Percent Survival

Table 7 shows the results of the analysis of variance for average percent survival. Average survival by management and density treatments ranged from 76-91% for loblolly pine. This was primarily the survival from age one to age 12 since trees were double-planted and one tree was randomly removed after the first growing season when both survived. Management intensity significantly impacted the survival rate. Figure 8 shows the average survival percentages by initial density and management intensity. The operational treatment survived better by about 9%. The differences due to management for the 1500 and 1800 TPA treatments were skewed, somewhat, by individual plots that had experienced excessive mortality (35%) by age 12.

No significant CRIFF soil group effects or interaction were observed at age 12 (Table 7). Figure 9 shows that there may be some emerging interaction between soil group and management intensity. Operational treatment plots survived 17% better than intensively-managed plots on B2 soils while the difference was only 5.7% on other soil groups.

**Table 7**. Analysis of variance results for loblolly pine average percent survival at age 12.

| Source | Type III F | Pr > F |
|---|---|---|
| Soil | 0.32 | 0.8566 |
| Management | 13.48 | 0.0051* |
| Soil x Management | 1.45 | 0.2937 |
| Density | 6.26 | <0.0001* |
| Soil x Density | 1.19 | 0.2765 |
| Management x Density | 1.75 | 0.1285 |

*Significant at $\alpha = 0.05$.

Figure 10 shows survival curves (ages 2-12 years) for selected loblolly pine treatments. The curves illustrate the relationships between average survival by initial density and management intensity. All density and management treatments are now exhibiting apparent density-related, intra-specific competition. The highest density (1500-1800 trees per acre), intensively-managed plots had approximately 66% survival by age 12.

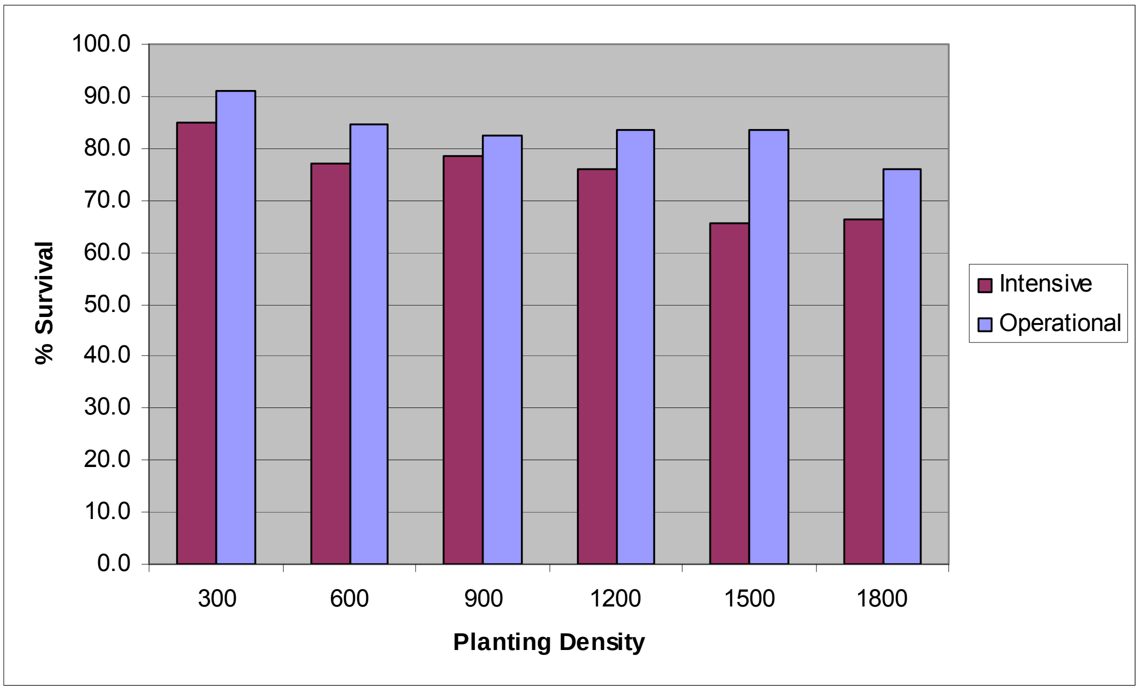


**Figure 8.** Percent survival by planting density and management intensity for loblolly pine at age 12.

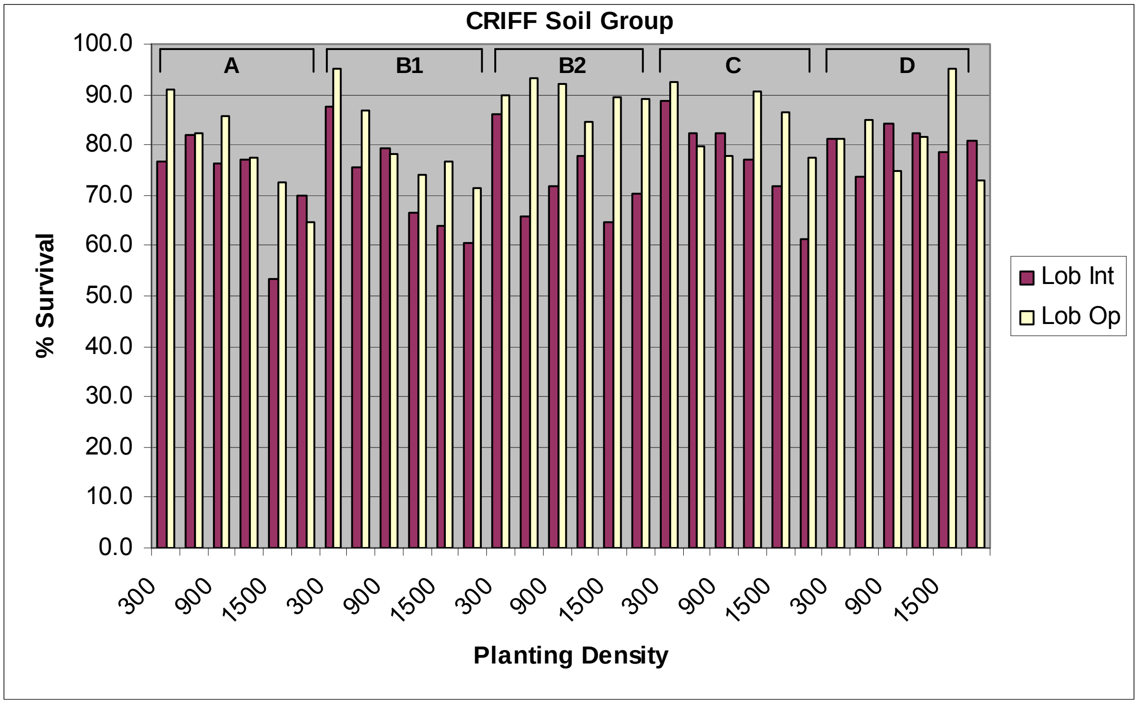


**Figure 9.** Percent survival by CRIFF soil group, planting density and management intensity for loblolly pine at age 12.

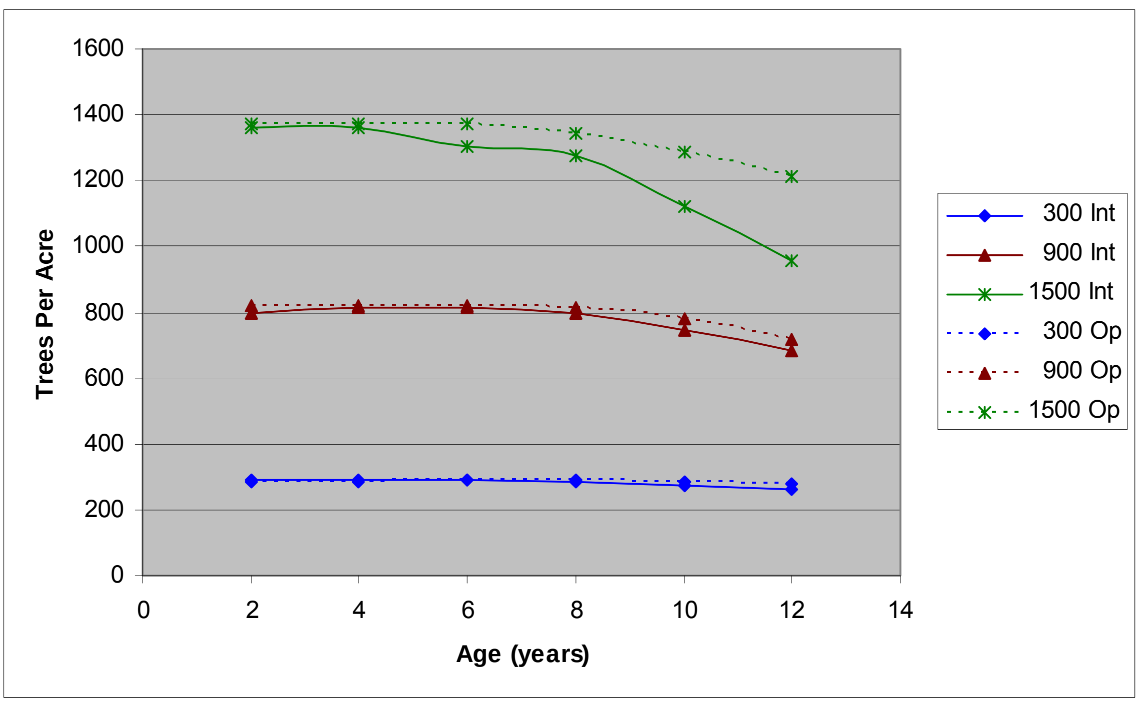


**Figure 10.** Trees per acre development by planting density and management intensity for selected loblolly pine treatments.

### 3.4 Percent Cronartium Infection

Table 8 shows the results of the analysis of variance for average percent cronartium infection. Average infection rates were moderate, ranging from approximately 8 to 25% for all densities and management regimes. Management intensity and initial density significantly affected the cronartium infection rate. As shown in Figure 11, there is a clear trend with both intensive management and operational management for percent infection to decrease as initial trees per acre increases from 300 trees per acre to 900 trees per acre. There is much less of a trend from 1200 through 1800 trees per acre. Figure 12 shows the average infection rates by CRIFF soil group and planting density and management intensity for those managers interested in the infection levels across soil types. The highest average infection rates were observed on soil group A where the intensively-managed plots had higher infection levels across all initial densities. The B2 soils also had higher infection levels for intensively-managed plots across all initial densities. For the B1 soil group and for the two spodosol soils, CRIFF C and D, the 300 trees per acre initial density is markedly higher in infection level for intensively-managed versus operationally-managed plots. Regardless of soil group, there is a trend toward lower infection levels as initial density increases.

**Table 8**. Analysis of variance results for loblolly pine average percent cronartium infection at age 12.

| Source | Type III F | Pr > F |
|---|---|---|
| Soil | 2.46 | 0.1206 |
| Management | 6.73 | 0.0290* |
| Soil x Management | 1.82 | 0.2085 |
| Density | 15.83 | <0.0001* |
| Soil x Density | 1.44 | 0.1180 |
| Management x Density | 1.59 | 0.1687 |

*Significant at α = 0.05.

### 3.5 Per-Acre Basal Area

Table 9 shows the results of the analysis of variance for per-acre basal area. Management intensity and density were significant factors for per-acre basal area. There was also a significant interaction between CRIFF soil group and management intensity. Basal area increased with increasing density, especially up to an initial density of 1200 trees per acre.

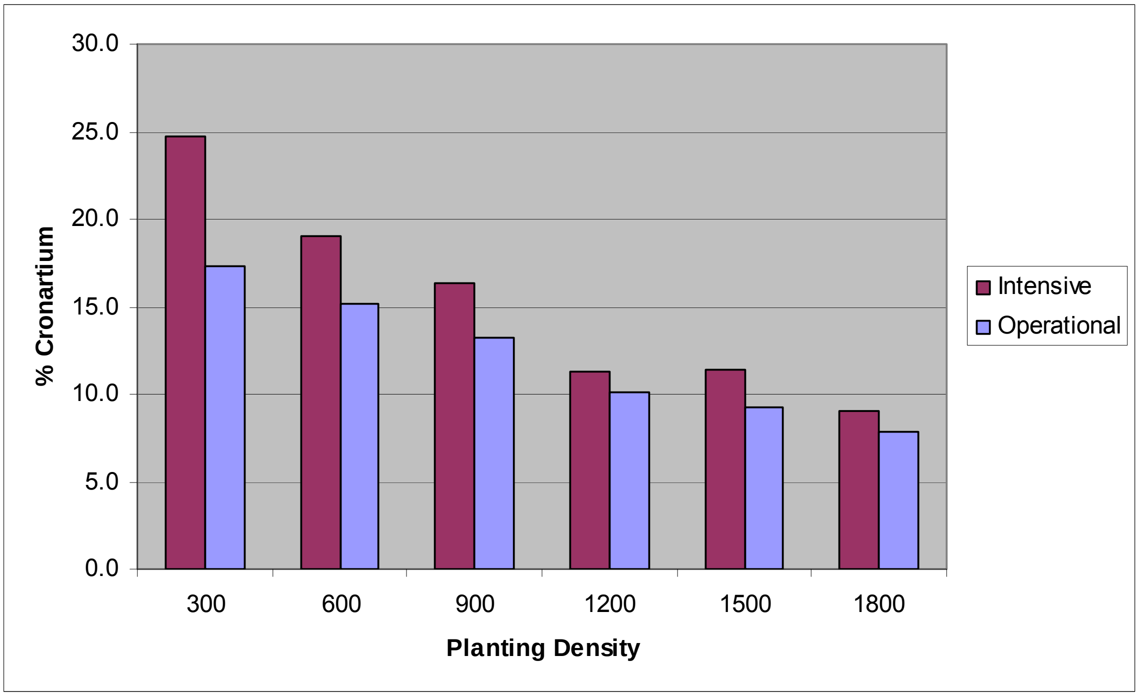


**Figure 11.** Average percent cronartium infection by planting density and management intensity for loblolly pine at age 12.

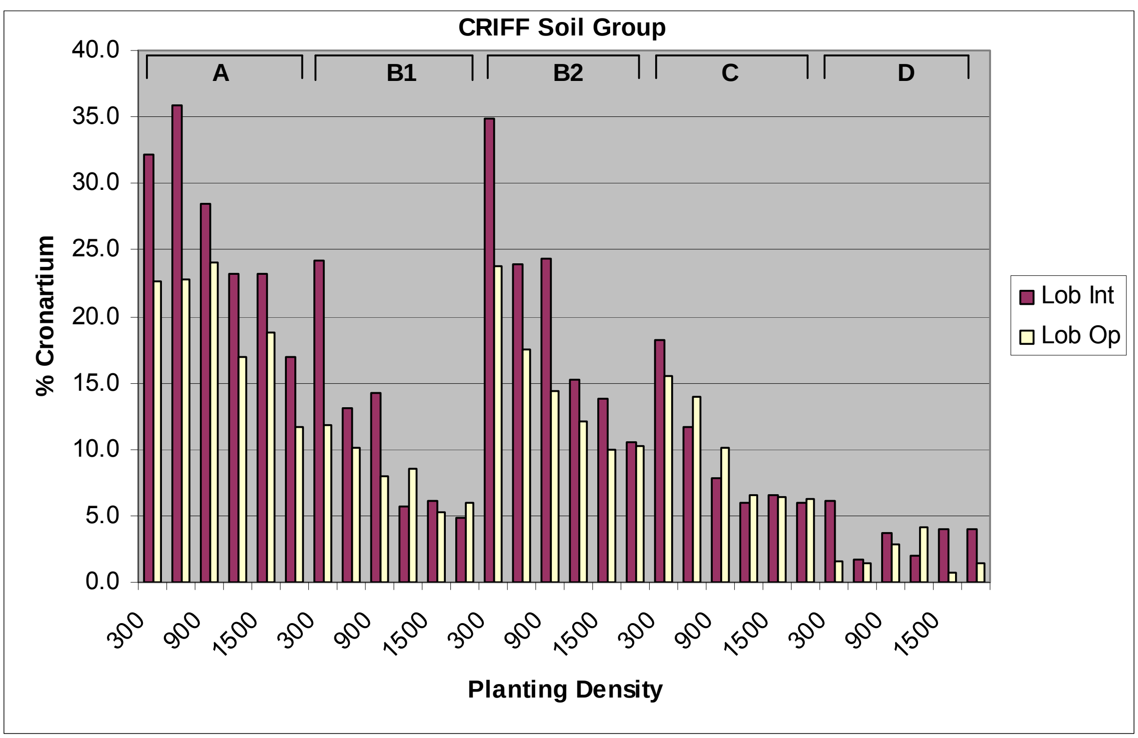


**Figure 12**. Average percent cronartium infection by CRIFF soil group, planting density and management intensity for loblolly pine at age 12.

**Table 9**. Analysis of variance results for loblolly pine average per-acre basal area at age 12.

| Source | Type III F | Pr > F |
|---|---|---|
| Soil | 2.79 | 0.0925 |
| Management | 48.73 | <0.0001* |
| Soil x Management | 6.59 | 0.0092* |
| Density | 36.74 | <0.0001* |
| Soil x Density | 0.90 | 0.5848 |
| Management x Density | 1.24 | 0.2947 |

*Significant at α = 0.05.

There is very little difference in per acre basal area for intensively-managed plots at age 12 for densities of 1200 and greater (Figure 13). There are still differences in per acre basal area in operational plantations at high densities with the trend being the same as for the intensively managed plots. Higher densities have higher per acre basal areas.

Intensively-managed plots averaged 7-25 $ft^2$/ac (4-23%) more per-acre basal area than the operationally-managed plots across all density levels. The level of basal area per acre exhibited by these plots at age 12 is extremely high for the intensively managed plots. The 1200 and greater initial density plots averaged 178 $ft^2$/ac across all soil types.

Figure 14 shows per-acre basal area at age 12 by management intensity, initial density and CRIFF soil group. As observed for other tree and stand characteristics, more intensive management resulted in greater gains in basal area on B2 and D soil groups. Observed differences were 23.4 and 59.6 $ft^2$/ac on B2 and D soils, respectively and only 8.7 $ft^2$/ac on other soil groups.

Figure 15 shows per-acre basal area development for selected loblolly pine treatments. The graph illustrates the effects of management intensity and initial density that have remained consistent over time. The curves also reveal decreasing basal area growth rates for high-density, high management intensity treatments. Basal area growth rates for low-density, low intensity treatments are still increasing at age 12.

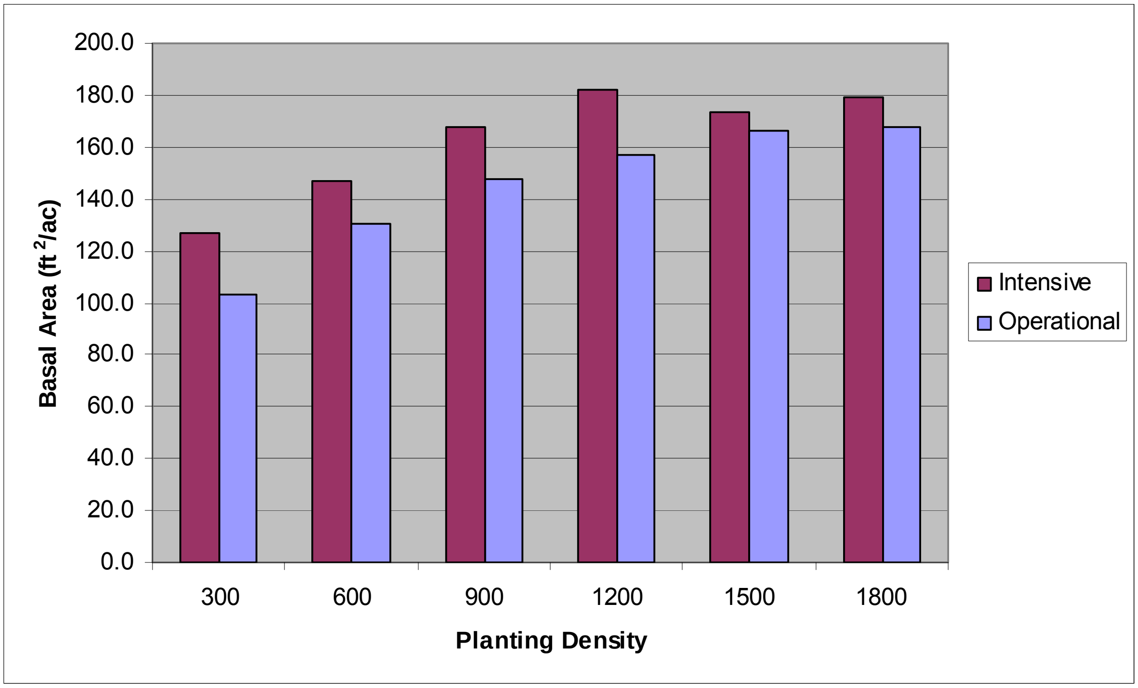


**Figure 13.** Average per-acre basal area (ft$^2$/ac) by planting density and management intensity for loblolly pine at age 12.

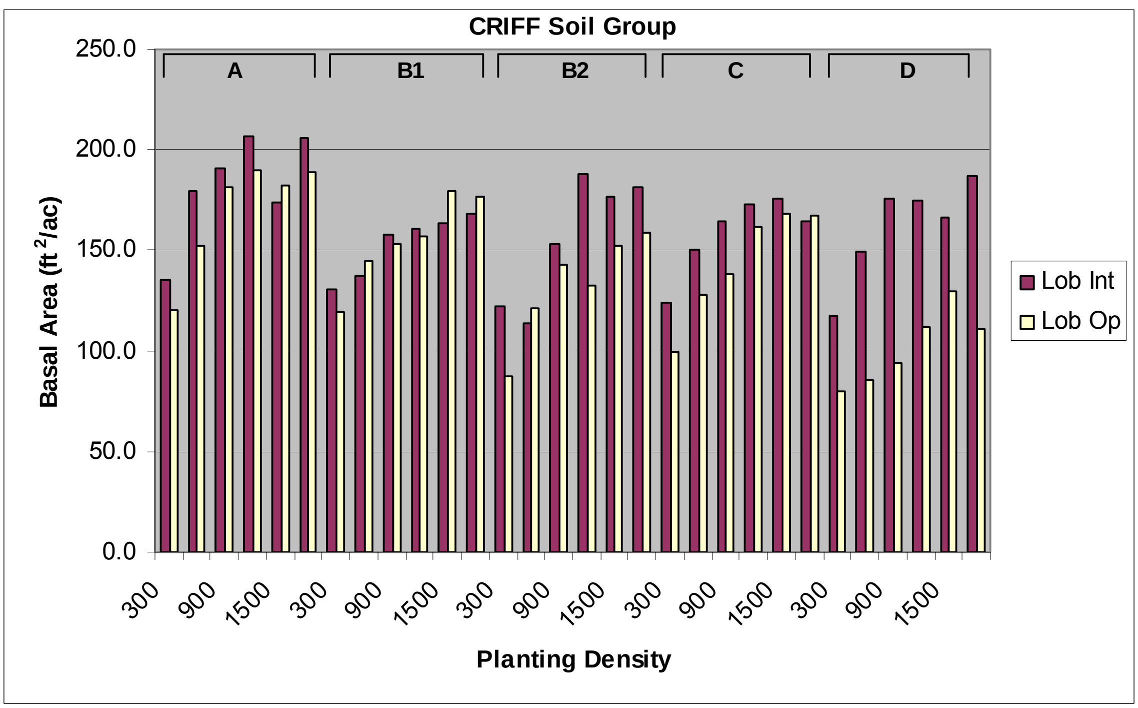


**Figure 14.** Average per-acre basal area (ft$^2$/ac) by CRIFF soil group, planting density and management intensity for loblolly pine at age 12.

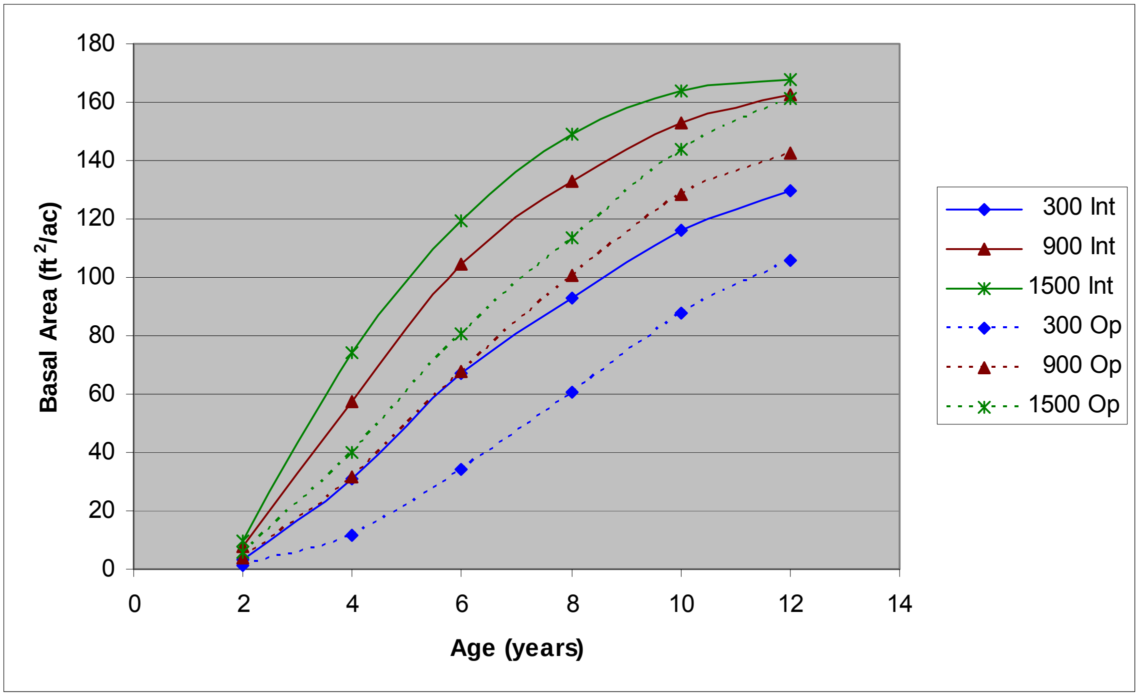


**Figure 15.** Average per-acre basal area growth ($ft^2$/ac) by planting density and management intensity for selected loblolly pine treatments.

### 3.6 Per-Acre O.B. Volume

Table 10 shows the results of the analysis of variance for per-acre total stem volume. Management intensity and initial density significantly affected per-acre volume (Figure 16). The increases in per-acre volume due to more intensive management were fairly consistent with respect to initial density treatment at age 12. The average increase in volume over all densities was 778 $ft^3$/ac. A significant interaction between CRIFF soil group and management intensity was also observed. Response to additional fertilizer and weed control averaged 1588 $ft^3$/ac on B2 and D soils while the difference on other soil groups averaged 488 $ft^3$/ac. Figure 17 shows per-acre volume growth over time for selected treatments.

**Table 10.** Analysis of variance results for loblolly pine average per-acre, total volume at age 12.

| Source | Type III F | Pr > F |
|---|---|---|
| Soil | 1.70 | 0.2328 |
| Management | 80.68 | <0.0001* |
| Soil x Management | 6.70 | 0.0087* |
| Density | 22.44 | <0.0001* |
| Soil x Density | 0.91 | 0.5746 |
| Management x Density | 0.82 | 0.5410 |

*Significant at α = 0.05.

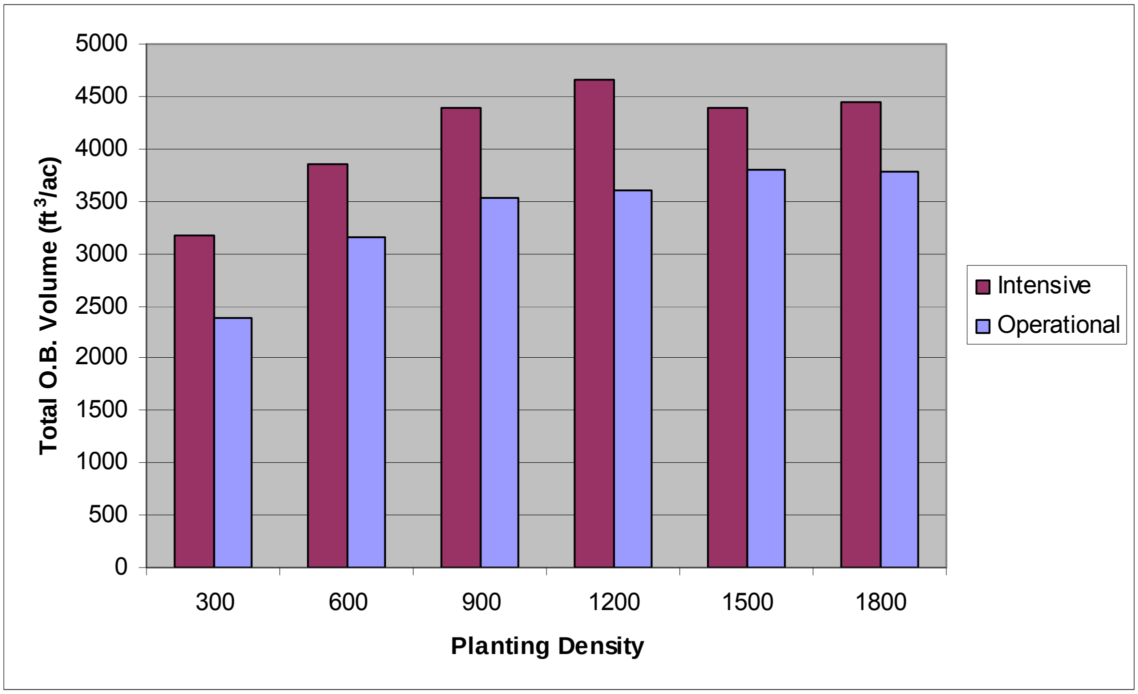


**Figure 16.** Average total per-acre outside bark volume ($ft^3/ac$) by planting density and management intensity for loblolly pine at age 12.

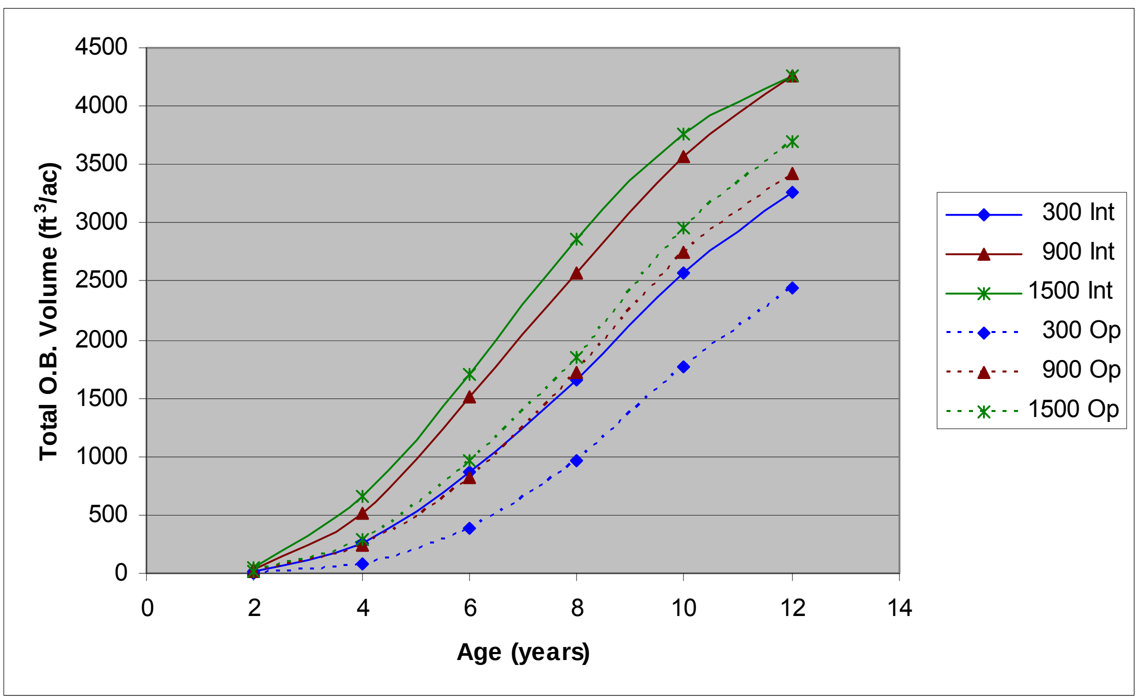


**Figure 17.** Total per-acre outside bark volume growth ($ft^3/ac$) by planting density and management intensity for selected loblolly pine treatments.

### 3.7 Per-Acre O.B. Green Weight

Table 11 shows the results of the analysis of variance for per-acre total green weight. The results show nearly identical trends as seen for per-acre volume. Management and density significantly affected per-acre green weight (Figure 18). Response due to more intensive management was, on the average, 25 tons/acre across initial density treatments. A significant interaction between CRIFF soil group and management intensity was also observed. Response to additional fertilizer and weed control averaged 46 tons/ac on B2 and D soils while the difference on other soil groups averaged 14 tons/ac.

Figure 19 shows green weight growth for selected treatments. More intensive management resulted in mean annual growth of about 10 tons/ac/yr which equals the Mean Annual Increment (MAI) value observed at age eight for the same plots. The corresponding value for the operational plots was about 8 tons/ac/yr. The 25% increase in MAI due to more intensive culture at age 12 compares to a 33% MAI increase noted at age 8 (Shiver and Harrison, 2004).

**Table 11**. Analysis of variance results for loblolly pine average per-acre, total green weight at age 12.

| Source | Type III F | Pr > F |
|---|---|---|
| Soil | 1.70 | 0.2339 |
| Management | 80.98 | <0.0001* |
| Soil x Management | 6.66 | 0.0089* |
| Density | 21.76 | <0.0001* |
| Soil x Density | 0.91 | 0.5743 |
| Management x Density | 0.81 | 0.5450 |

*Significant at α = 0.05.

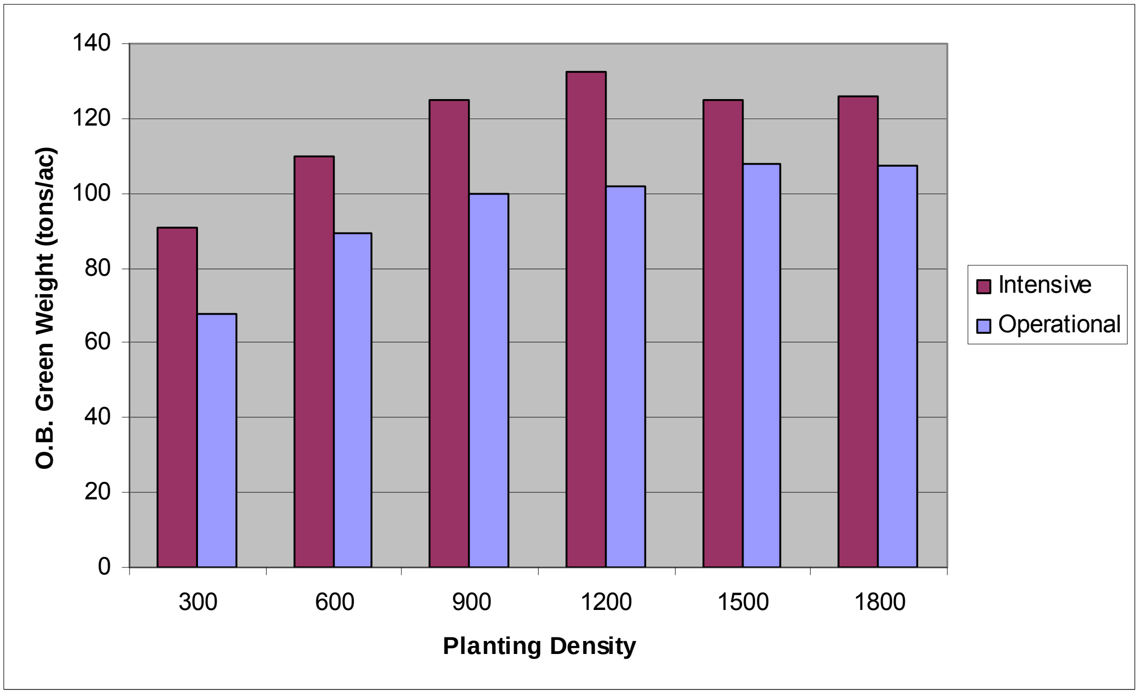


**Figure 18.** Average total per-acre outside bark green weight (tons/ac) by planting density and management intensity for loblolly pine at age 12.

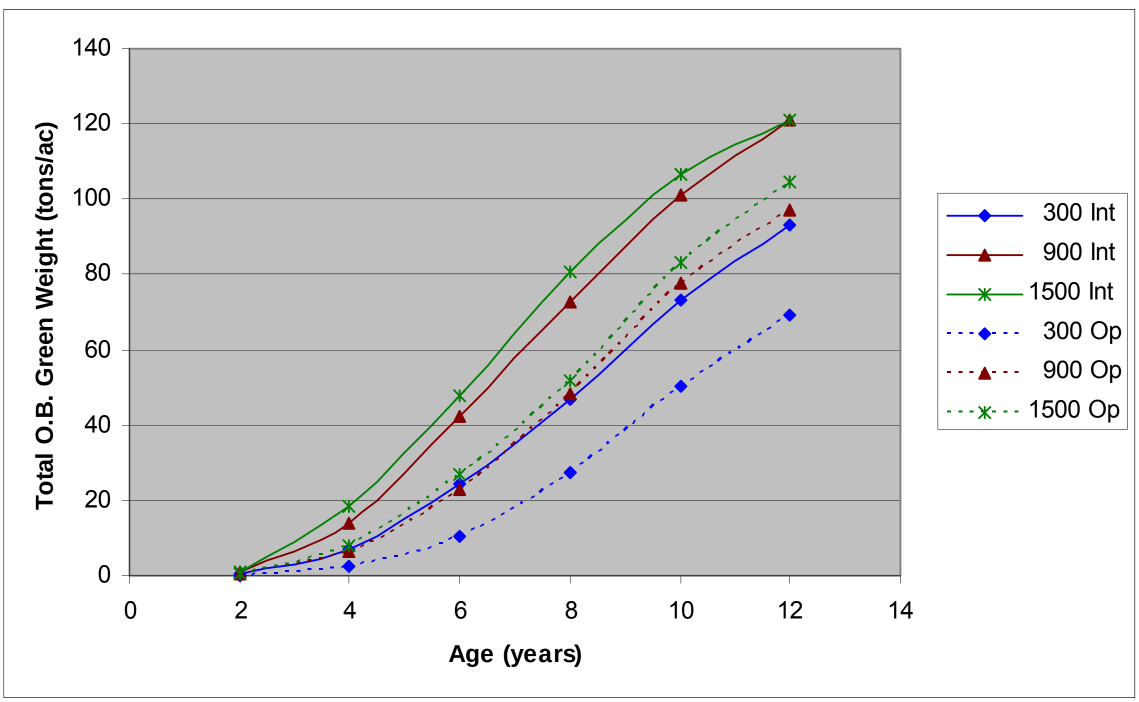


**Figure 19.** Total per-acre outside bark green weight (tons/ac) by planting density and management intensity for selected loblolly pine treatments.

### 3.8 Per-Acre Chip-N-Saw Yield

Table 12 shows the results of the analysis of variance for per-acre merchantable green weight to a 6” top (o.b.) for trees greater than or equal to 8” DBH. Even though 12-year-old trees would most likely not be suitable for solid wood products, this quantity is intended to represent potential chip-n-saw yield. Management and density significantly affected per-acre chip-n-saw green weight (Figure 20). Since height growth was not greatly affected by density, chip-n-saw yield was essentially a function of DBH. Therefore the lower densities had a much greater proportion of chip-n-saw sized trees. Note that there was no consideration of stem quality included in the calculation of potential chip-n-saw yield. Increased branch size and numbers of live branches at low densities (300 TPA planted) would most likely negatively impact the actual yield of solid wood products (Volfovicz and Borders, 2006).

Significant interactions between CRIFF soil group and management intensity and between management intensity and density were observed. As shown in Figure 20, more intensive management resulted in greater increases in chip-n-saw yield on lower density plots (300-1200 TPA).

Figure 21 shows average chip-n-saw yields by CRIFF soil group, management intensity and density. As was observed for other factors, complete vegetation control and the higher fertilization levels had greater effect on the B2 and D soil groups.

**Table 12**. Analysis of variance results for loblolly pine average per-acre, total green weight of chip-n-saw sized trees at age 12.

| Source | Type III F | Pr > F |
|---|---|---|
| Soil | 3.22 | 0.0669 |
| Management | 36.92 | 0.0002* |
| Soil x Management | 0.94 | 0.4857 |
| Density | 103.04 | <0.0001* |
| Soil x Density | 1.87 | 0.0212* |
| Management x Density | 13.04 | <0.0001* |

*Significant at $\alpha = 0.05$.

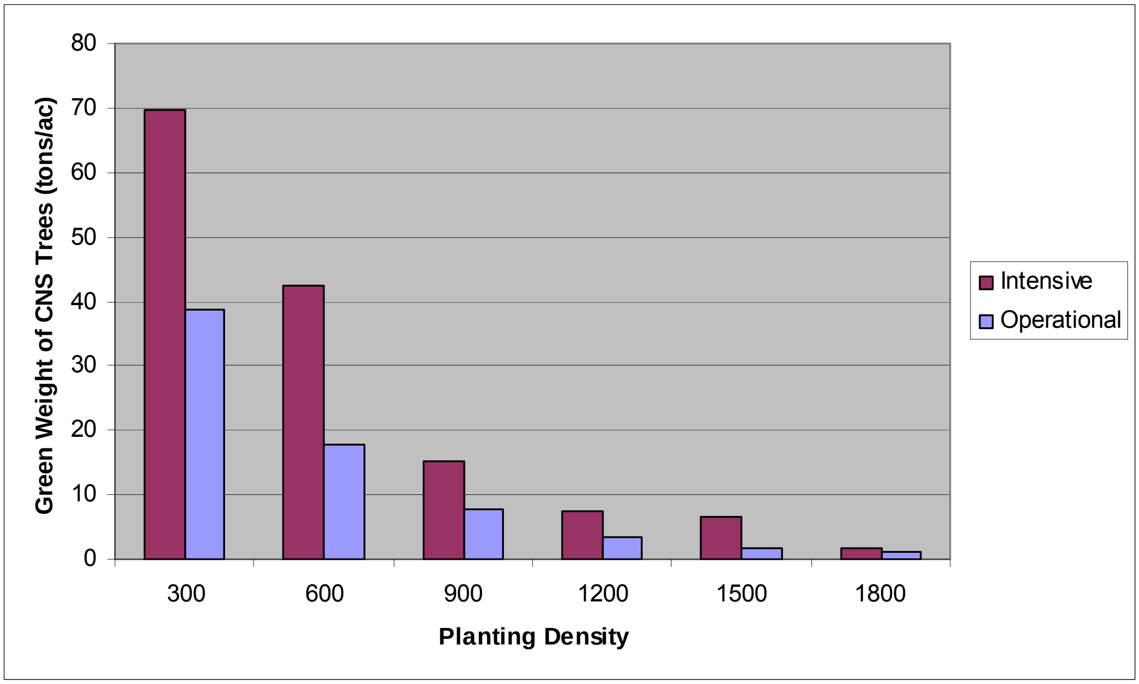


**Figure 20**. Average merchantable per-acre outside bark green weight (tons/ac) of chip-n-saw sized trees by planting density and management intensity for loblolly pine at age 12.

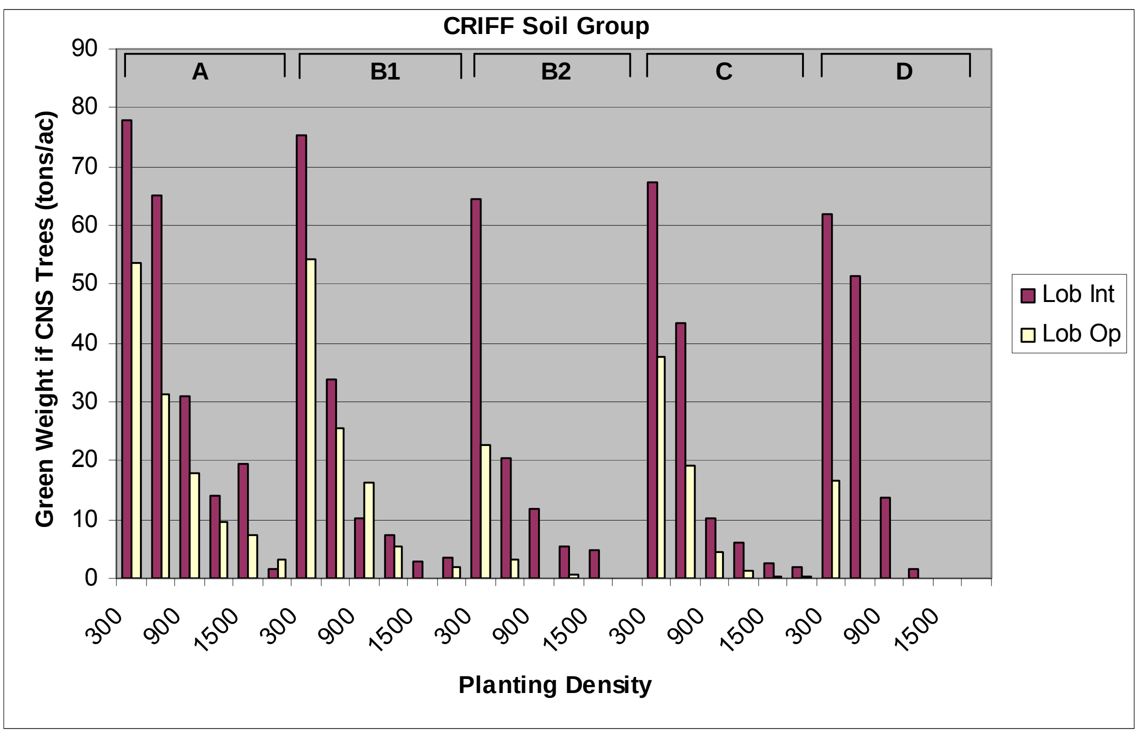


**Figure 21**. Merchantable per-acre outside bark green weight (tons/ac) of chip-n-saw sized trees by CRIFF soil group, planting density and management intensity for loblolly pine at age 12.

### 3.9 Stand Density Index

Stand Density Index (SDI) is a measure of the density of stands of trees that is independent of site index and age. Reineke (1933) proposed the index after noting that there was a limit to the number of trees of a given species that could be found in any pure stand of any given average DBH. He proposed using 10 inches as the index DBH. When the number of trees per acre and the quadratic mean DBH are plotted against each other in log-log form, the limiting relationship forms a straight line. For loblolly pine the limiting number of trees that can be found in a stand averaging 10 inches in DBH is 450. Intensively-managed, high-density loblolly pine stands that exceeded this maximum have been observed (Harrison, 2002), but once a stand reaches its limiting density the only way to achieve DBH growth is for trees to die. The slope of the log-log relationship is about –1.5. Reineke empirically derived it as –1.605.

Normally, stands of loblolly pine are in their late teens before they approach the limiting density line. Since some of these plots combine high initial trees per acre with intensive management they can be expected to approach the line at an earlier age. This is of particular interest to us since one of our objectives was to determine if the carrying capacity could be increased and also if the stand would crash with high management intensity before reaching merchantability for some of the high densities. While it is too early to test these trees for wood quality, a possible solution to large juvenile cores and large branches that cause lumber degrade would be to grow stands with relatively high-intensity management, but at high initial densities.

Table 13 shows the results of an analysis of variance of SDI. Management intensity and initial density were significant factors for SDI differences (Figure 22). Since both management intensity and initial density impacted the speed of stand development, it is not surprising that they were significant factors in SDI development. The effect of intensive management ranged from a 6 SDI unit decrease for the 1500 TPA density to a 40 SDI unit increase for the 1200 TPA density.

There was also a significant interaction between soil group and management intensity (Figure 23). As with other factors, the differences in SDI between management intensity treatments were significantly greater on the B2 and D soil groups.

**Table 13.** Analysis of variance results for loblolly pine average stand density index (SDI) at age 12.

| Source | Type III F | Pr > F |
|---|---|---|
| Soil | 1.67 | 0.2406 |
| Management | 23.25 | 0.0009* |
| Soil x Management | 5.48 | 0.0162* |
| Density | 85.01 | <0.0001* |
| Soil x Density | 0.95 | 0.5288 |
| Management x Density | 1.42 | 0.2232 |

*Significant at $\alpha = 0.05$.

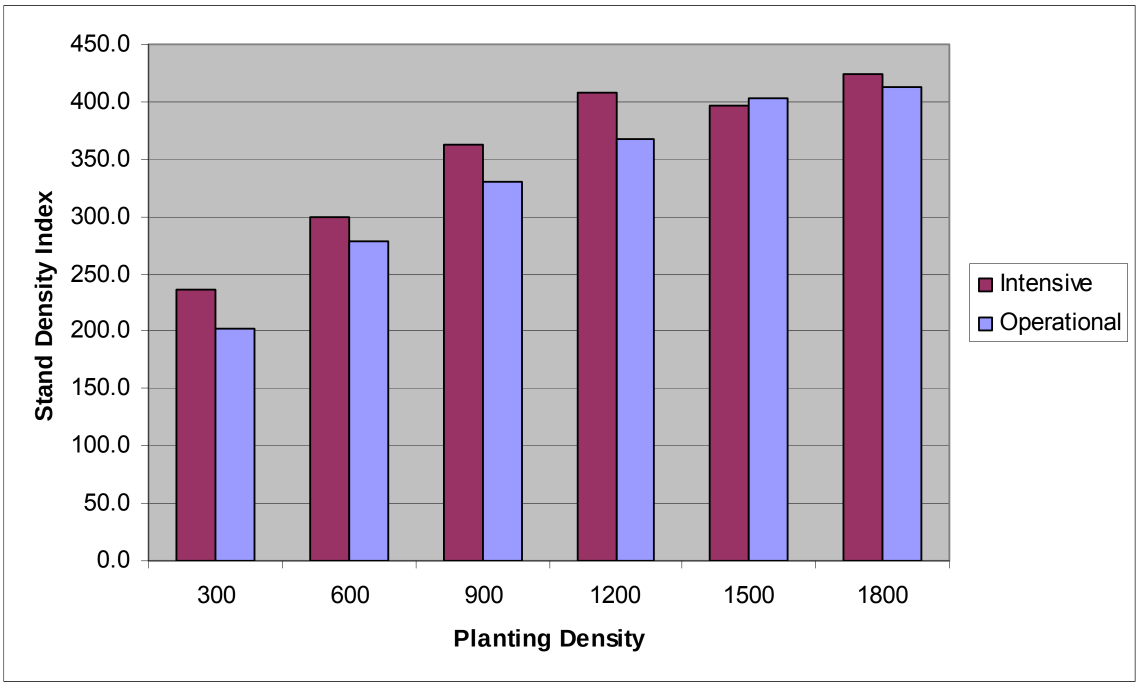


**Figure 22.** Average stand density index (SDI) for loblolly pine by planting density and management intensity for loblolly pine at age 12.

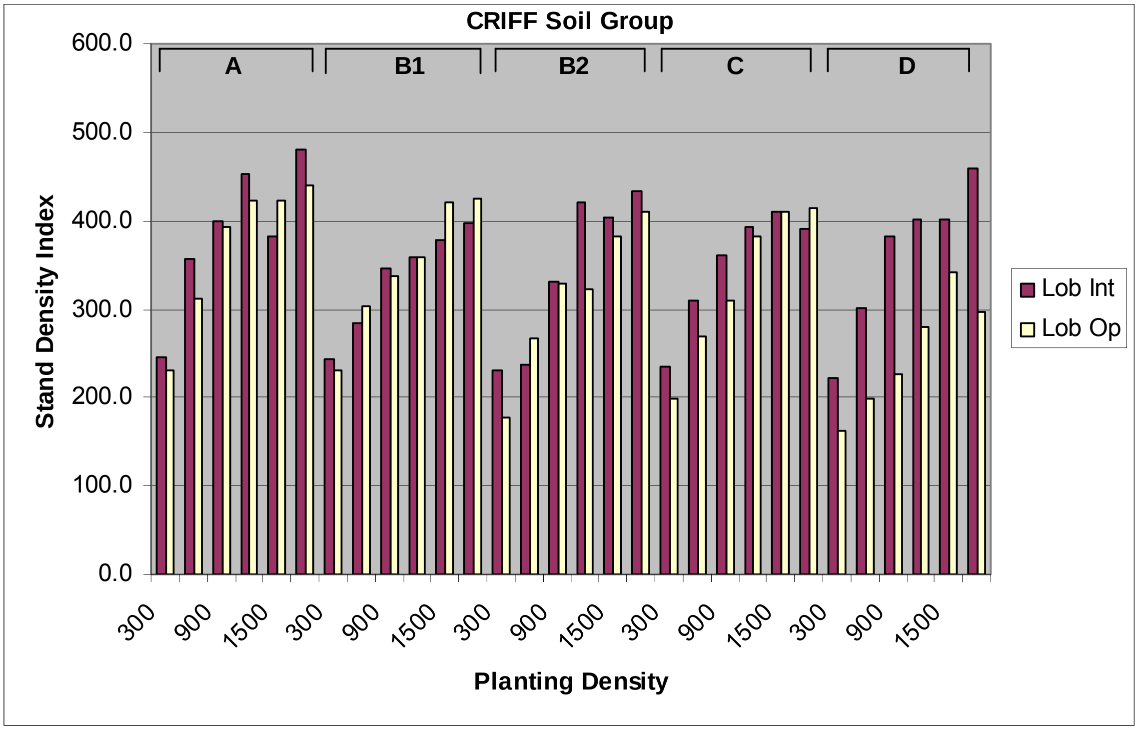


**Figure 23**. Average stand density index (SDI) by CRIFF soil group, planting density and management intensity for loblolly pine at age 12.

The percentage of the maximum SDI for a species that has been achieved in a stand has been suggested as a management tool by some researchers. For example, Dean and Baldwin (1993) state that loblolly stands begin to experience mortality when SDI values are at about 55% of the maximum value of 450. Their data was largely from non-intensively managed stands. Our experience with the B. F. Grant spacing study has been that those intensively managed stands do not experience significant mortality until at least 75% of maximum SDI (Harrison, 2002). The percentage of maximum SDI values were calculated for each plot and averaged for the different density x management treatment combinations by soil group (Figure 24). The intensive 1800 plots, especially on A and D soils, exceeded the expected limiting density by age 12.

Figure 25 shows the natural log of TPA plotted against natural log of Dq for selected loblolly pine treatments. It is interesting to note that, for a given density, the operational and more intensive management regimes began at different points but have proceeded along the same track up to the point where the more intensive regime has begun to reach its limiting density.

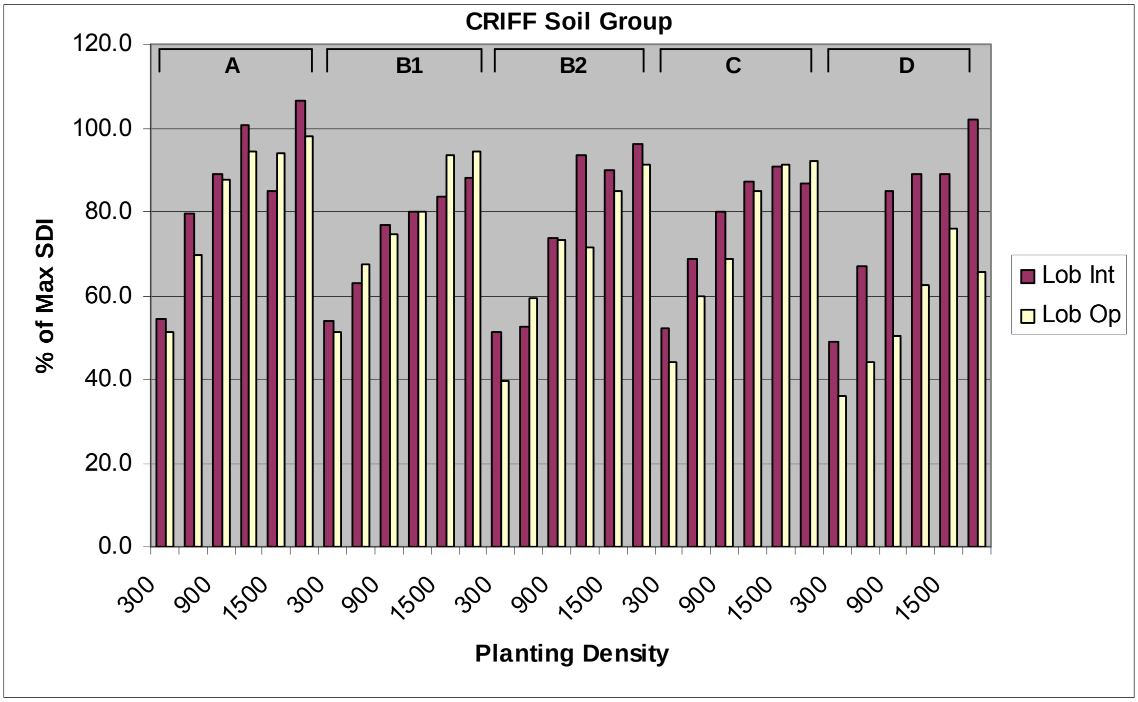


**Figure 24.** Average percentage of maximum stand density index (SDI) by CRIFF soil group, planting density and management intensity for loblolly pine at age 12.

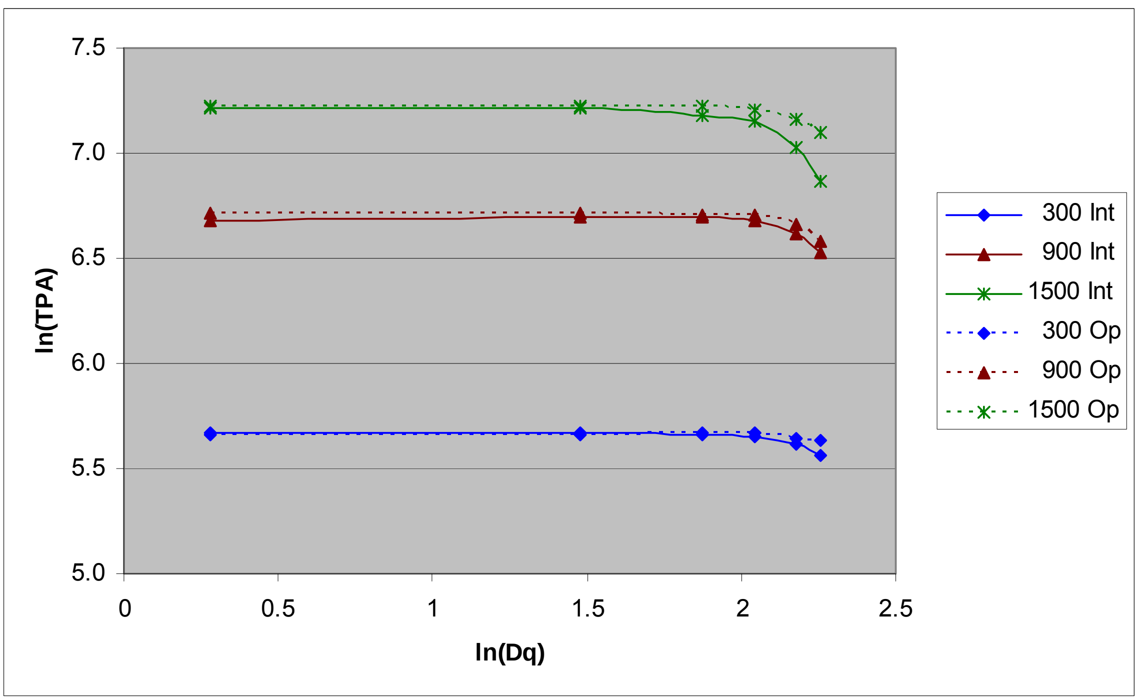


**Figure 25.** Natural log of trees per acre versus natural log of quadratic mean Dbh by planting density and management intensity for selected loblolly pine treatments.

### 3.10 Relative Spacing

Another limiting density value often calculated is relative spacing. Relative spacing is the average distance between trees expressed as a proportion of the dominant height.

Relative spacing typically declines over time since early in the life of the stand there is little mortality. Therefore, the numerator of the RS equation stays fixed and the denominator increases as trees grow in height. At some point, a combination of tree mortality and slowing height growth causes the RS proportion to approach an asymptotic value. RS asymptotes are species-specific and values for loblolly and slash pine have been empirically determined to be about 0.12.

Relative spacing values were calculated for each plot in the study and an analysis of variance was conducted on the RS proportions (Table 14). Management, initial density and their interaction significantly affected relative spacing. The average RS ratios by density and management intensity show that the intensively managed high density plots are approaching the published asymptote for loblolly pine (Figure 26). A significant soil type x density interaction was also observed and is illustrated in Figure 27.

**Table 14**. Analysis of variance results for loblolly pine average relative spacing at age 12.

| Source | Type III F | Pr > F |
|---|---|---|
| Soil | 1.46 | 0.2931 |
| Management | 18.06 | 0.0021* |
| Soil x Management | 4.42 | 0.0299* |
| Density | 217.20 | <0.0001* |
| Soil x Density | 1.36 | 0.1574 |
| Management x Density | 1.27 | 0.2808 |

*Significant at α = 0.05.

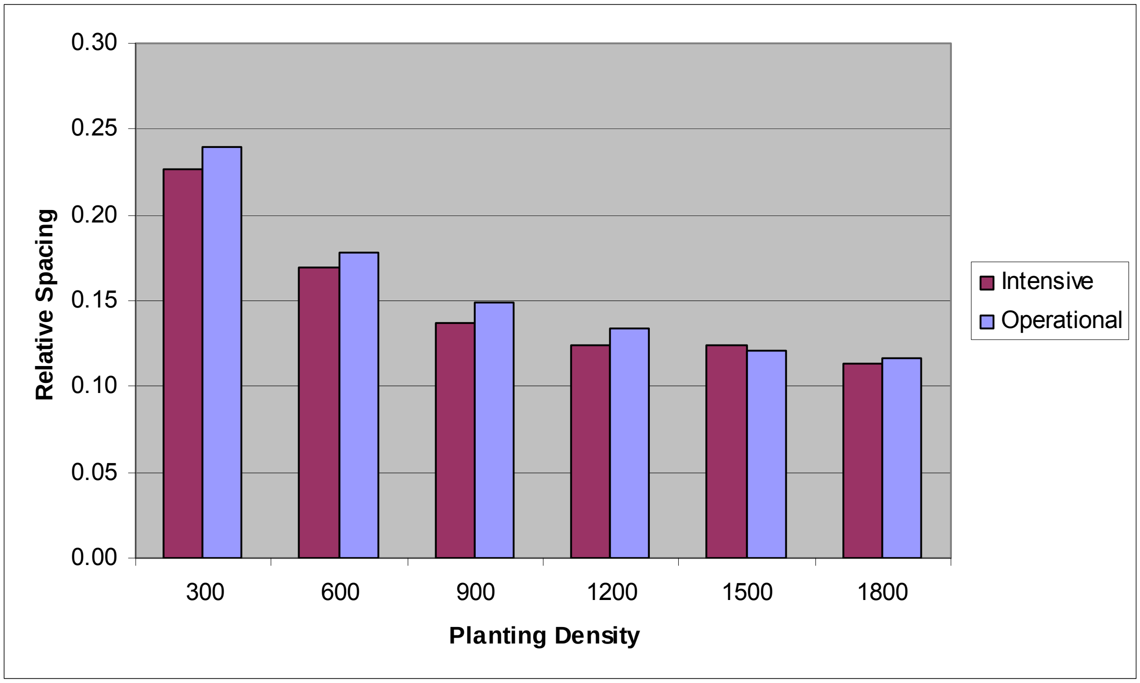


**Figure 26**. Average relative spacing (RS) by planting density and management intensity for loblolly pine at age 12.

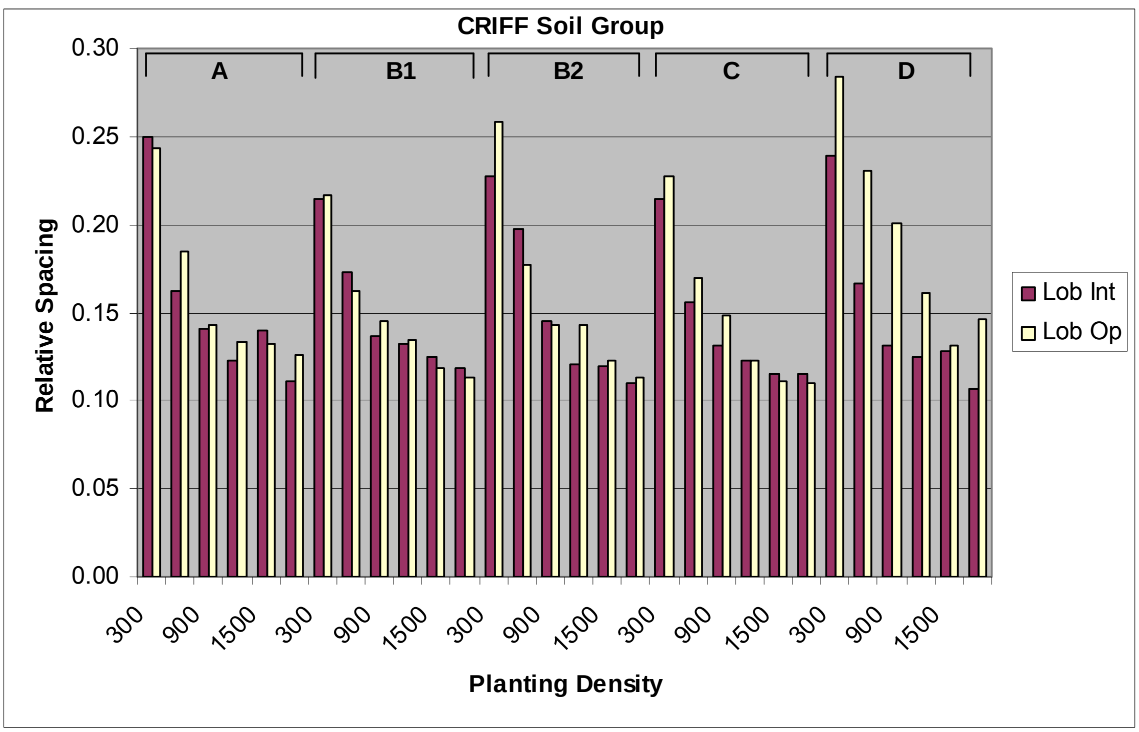


**Figure 27**. Average relative spacing (RS) by CRIFF soil group, planting density and management intensity for loblolly pine at age 12.

### 3.11 Crown Ratio

Crown ratio (or live crown ratio) is defined as the proportion of the total height of a tree that is covered by live branches. Crown ratio is a common indicator of tree vigor. Management intensity and density significantly impacted crown ratio for loblolly pine at age 12 (Table 15). Figure 28 illustrates that the operational treatment had consistently greater crown ratios by about 3.5% over the more intensive treatment. Crown ratio declined with increasing initial density although initial densities of 900 trees per acre and greater had similar values.

**Table 15.** Analysis of variance results for loblolly pine average crown ratio at age 12.

| Source | Type III F | Pr > F |
|---|---|---|
| Soil | 1.64 | 0.2473 |
| Management | 21.89 | 0.0012* |
| Soil x Management | 0.36 | 0.8283 |
| Density | 113.42 | <0.0001* |
| Soil x Density | 1.18 | 0.2818 |
| Management x Density | 0.46 | 0.8036 |

*Significant at $\alpha = 0.05$.

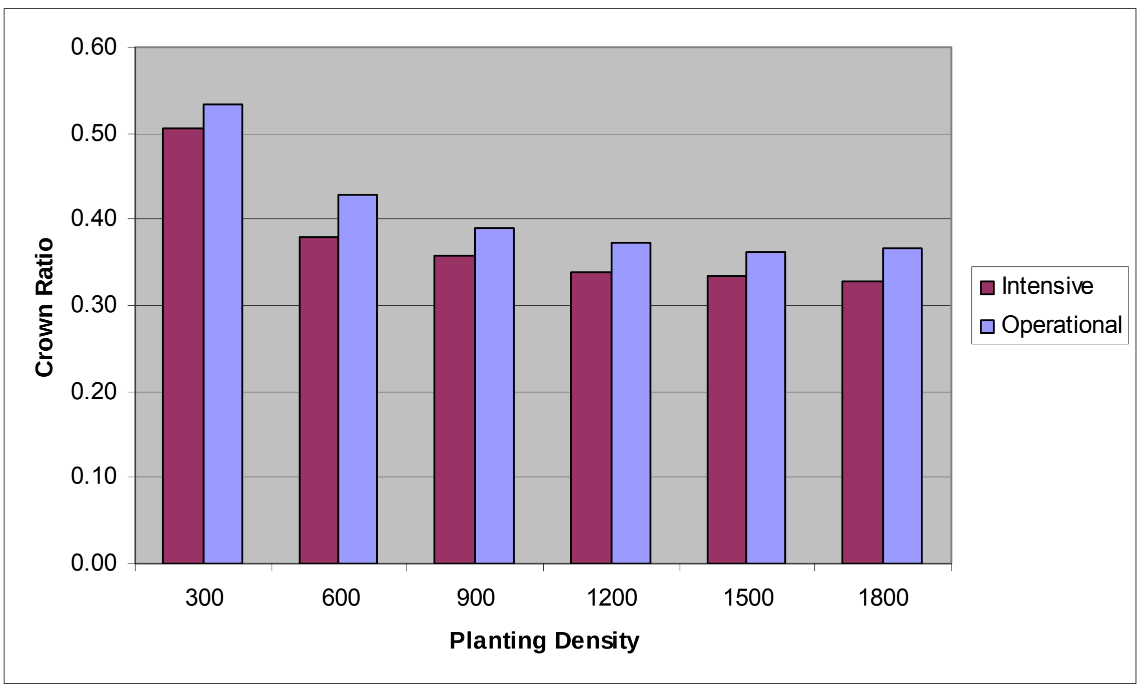


**Figure 28.** Average crown ratio by planting density and management intensity for loblolly pine at age 12.

### 3.12 Crown Length

Larson (1963) noted that live crown length is an important factor influencing stem form. In general, trees with longer crown lengths exhibit greater stem taper. Density significantly impacted crown length for loblolly pine at age 12 (Table 16). Figure 29 illustrates that crown length declined with increasing initial density. The 300 trees-per-acre initial density had 50% greater crown length compared to the average of the higher initial densities.

**Table 16.** Analysis of variance results for loblolly pine average crown length at age 12.

| Source | Type III F | Pr > F |
|---|---|---|
| Soil | 0.23 | 0.9170 |
| Management | 1.57 | 0.2413 |
| Soil x Management | 1.38 | 0.3156 |
| Density | 173.63 | <0.0001* |
| Soil x Density | 0.83 | 0.6700 |
| Management x Density | 1.01 | 0.4144 |

*Significant at α = 0.05.

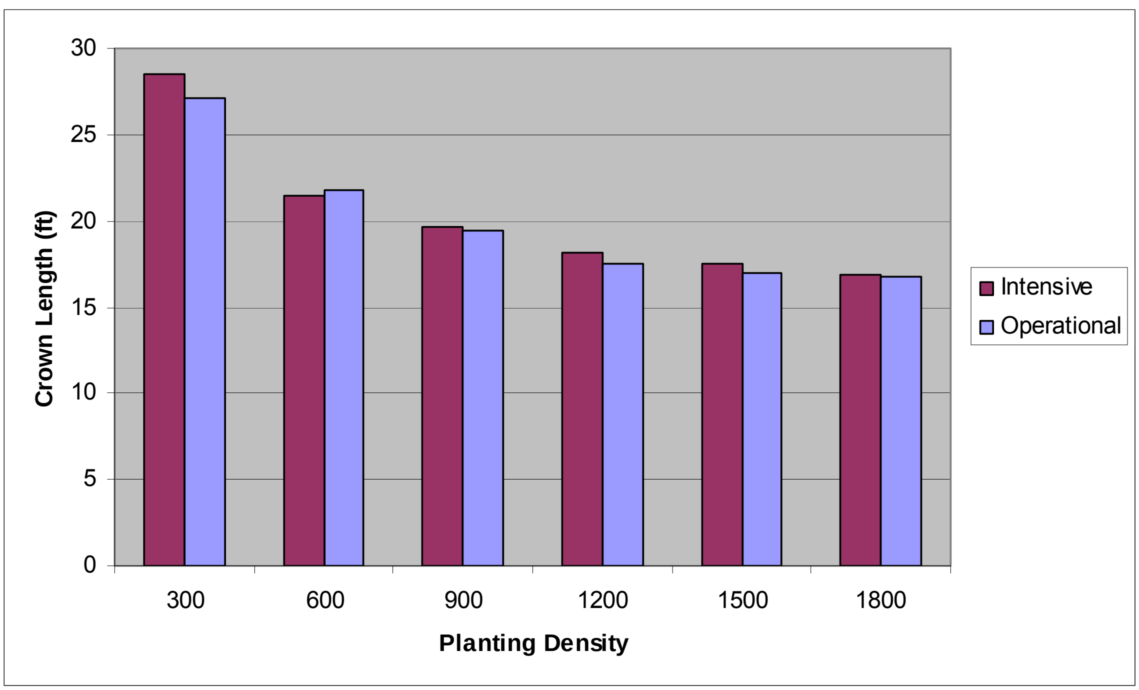


**Figure 29.** Average crown length by planting density and management intensity for loblolly pine at age 12.

# 4 SLASH PINE RESULTS

Recall that slash pine was established on nine of the seventeen locations at three initial densities: 300, 900 and 1500 trees per acre. Only seven of the original installations remained active at the time of the age-12 measurement. Also, slash pine plots at one location were impacted by wildfire. Increased mortality due to the fire are reflected in the results to follow, specifically in density-related stand characteristics. Analyses were run with and without the damaged plots. In general, significance of factors affecting slash pine performance was not affected.

Analysis of variance as described above was carried out for average DBH, average height, dominant height, percent survival, percent cronartium infection, per-acre basal area, per-acre total volume, per-acre total green weight, chip-n-saw green weight, stand density index, relative spacing, crown ratio and crown length. Table 17 shows the slash pine means by soil type, management intensity and initial density for all analysis variables. The number of installations comprising each mean is indicated.

**Table 17.** Slash pine means by CRIFF soil group, management intensity and initial density at age 12.

**CRIFF Soil Type B1 (2 Installations)**

| | Intensive | | | Operational | | |
|---|---|---|---|---|---|---|
| | 300 | 900 | 1500 | 300 | 900 | 1500 |
| Avg. DBH (in) | 8.7 | 6.4 | 5.4 | 8.2 | 6.0 | 5.3 |
| Avg. Height (ft) | 49.6 | 48.2 | 45.9 | 47.8 | 45.8 | 43.9 |
| Dom Height (ft) | 51.3 | 50.7 | 48.1 | 49.8 | 48.4 | 47.2 |
| % Survival | 86.9 | 69.3 | 62.8 | 83.8 | 76.6 | 64.1 |
| % Cron. | 28.0 | 23.3 | 11.6 | 23.2 | 15.5 | 9.7 |
| Basal Area ($ft^2$/ac) | 108 | 141 | 149 | 93 | 135 | 146 |
| Tot. Vol. ($ft^3$/ac) | 2534 | 3174 | 3179 | 2117 | 2922 | 3031 |
| Tot. Grn Wt (ton/ac) | 73 | 94 | 95 | 61 | 87 | 91 |
| CNS Wt (ton/ac) | 49.9 | 3.5 | 0.9 | 33.1 | 6.2 | 0.9 |
| Crown Ratio | 0.48 | 0.35 | 0.32 | 0.54 | 0.38 | 0.35 |
| Crown Length (ft) | 23.9 | 17.3 | 14.7 | 26.1 | 17.4 | 15.8 |

**CRIFF Soil Type B2 (2 Installations)**

| | Intensive | | | Operational | | |
|---|---|---|---|---|---|---|
| | 300 | 900 | 1500 | 300 | 900 | 1500 |
| Avg. DBH (in) | 9.0 | 6.3 | 5.7 | 7.5 | 5.7 | 4.6 |
| Avg. Height (ft) | 47.9 | 44.6 | 46.6 | 44.7 | 45.1 | 40.3 |
| Dom Height (ft) | 48.6 | 47.3 | 49.4 | 46.9 | 46.7 | 43.9 |
| % Survival | 61.3 | 60.4 | 61.9 | 78.1 | 84.4 | 77.8 |
| % Cron. | 31.6 | 29.4 | 27.7 | 25.8 | 24.5 | 28.5 |
| Basal Area ($ft^2$/ac) | 83 | 121 | 169 | 74 | 136 | 144 |
| Tot. Vol. ($ft^3$/ac) | 1912 | 2592 | 3720 | 1576 | 2876 | 2828 |
| Tot. Grn Wt (ton/ac) | 55 | 76 | 111 | 45 | 86 | 85 |
| CNS Wt (ton/ac) | 41.6 | 5.0 | 7.0 | 15.2 | 1.2 | 0.0 |
| Crown Ratio | 0.57 | 0.46 | 0.36 | 0.56 | 0.39 | 0.38 |
| Crown Length (ft) | 27.4 | 21.1 | 17.4 | 25.3 | 17.7 | 15.8 |

**CRIFF Soil Type C (3 Installations)**

| | Intensive | | | Operational | | |
|---|---|---|---|---|---|---|
| | 300 | 900 | 1500 | 300 | 900 | 1500 |
| Avg. DBH (in) | 8.6 | 6.2 | 5.3 | 7.6 | 5.8 | 5.0 |
| Avg. Height (ft) | 48.2 | 48.1 | 45.9 | 46.1 | 45.5 | 43.6 |
| Dom Height (ft) | 50.1 | 50.1 | 48.4 | 47.8 | 48.4 | 46.3 |
| % Survival | 72.1 | 53.8 | 60.2 | 90.0 | 62.8 | 49.0 |
| % Cron. | 24.6 | 13.2 | 7.3 | 9.2 | 8.3 | 5.0 |
| Basal Area ($ft^2$/ac) | 88 | 101 | 142 | 88 | 107 | 98 |
| Tot. Vol. ($ft^3$/ac) | 2009 | 2261 | 3026 | 1939 | 2319 | 1991 |
| Tot. Grn Wt (ton/ac) | 58 | 67 | 91 | 56 | 69 | 60 |
| CNS Wt (ton/ac) | 37.3 | 4.1 | 0.5 | 22.6 | 0.5 | 0.6 |
| Crown Ratio | 0.47 | 0.36 | 0.34 | 0.41 | 0.37 | 0.30 |
| Crown Length (ft) | 22.6 | 17.4 | 15.8 | 18.8 | 17.2 | 13.8 |

### 4.1 Average DBH

Table 18 shows the results of the analysis of variance for slash pine average DBH. Management intensity, density and their interaction significantly affected average DBH for slash pine. As shown in Figure 30, average DBH decreased with increasing density and the differences were more dramatic under the more intensive management scenario. The interaction comes from the larger gain from intensive management on the 300 initial density as compared to 900 or 1500, but the trend is the same for all initial densities. The gain in DBH for intensive management at 300 was approximately one inch compared with a gain of about 0.6 inches for the 900 and 1500 initial densities.

Figure 31 shows the average DBH development over time for slash pine treatments. The trends in DBH growth relative to planting density and management intensity are apparent and have been consistent through the life of the study.

**Table 18**. Analysis of variance results for slash pine average DBH at age 12.

| Source | Type III F | Pr > F |
|---|---|---|
| Soil | 0.28 | 0.7701 |
| Management | 43.77 | 0.0027* |
| Soil x Management | 4.62 | 0.0912 |
| Density | 663.07 | <0.0001* |
| Soil x Density | 0.27 | 0.8967 |
| Management x Density | 5.10 | 0.0162* |

*Significant at $\alpha = 0.05$.

### 4.2 Average Height and Dominant Height

Table 19 shows the results of the analysis of variance for slash pine average height. Management intensity and initial planting density were significant factors affecting average height. Figure 32 shows the average heights by initial density and management intensity. Average heights were 1.6 to 3.4 feet higher on the more intensively managed plots. Average heights were lower on the 1500 initial planting density plots for both operational and intensive management. There was no density x management interaction, but the average height of the 1500 TPA plots was approximately 1.7 feet less than the lower densities for intensively managed plots and more than three feet for the operational plots.

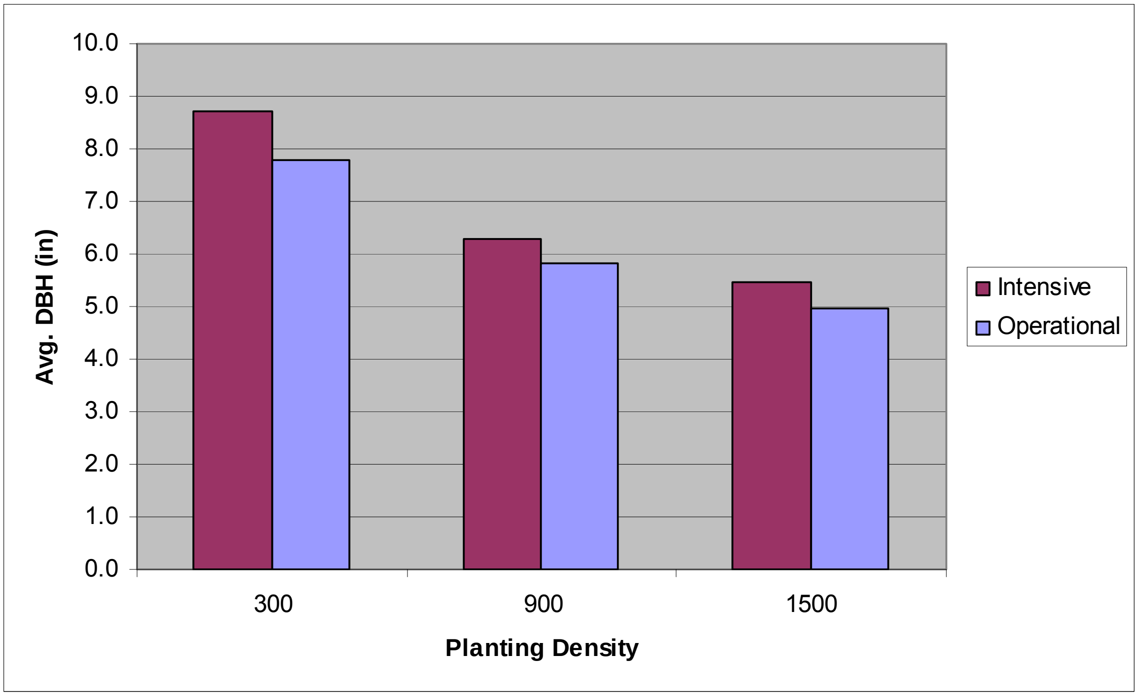


**Figure 30**. Average DBH by planting density and management intensity for slash pine at age 12.

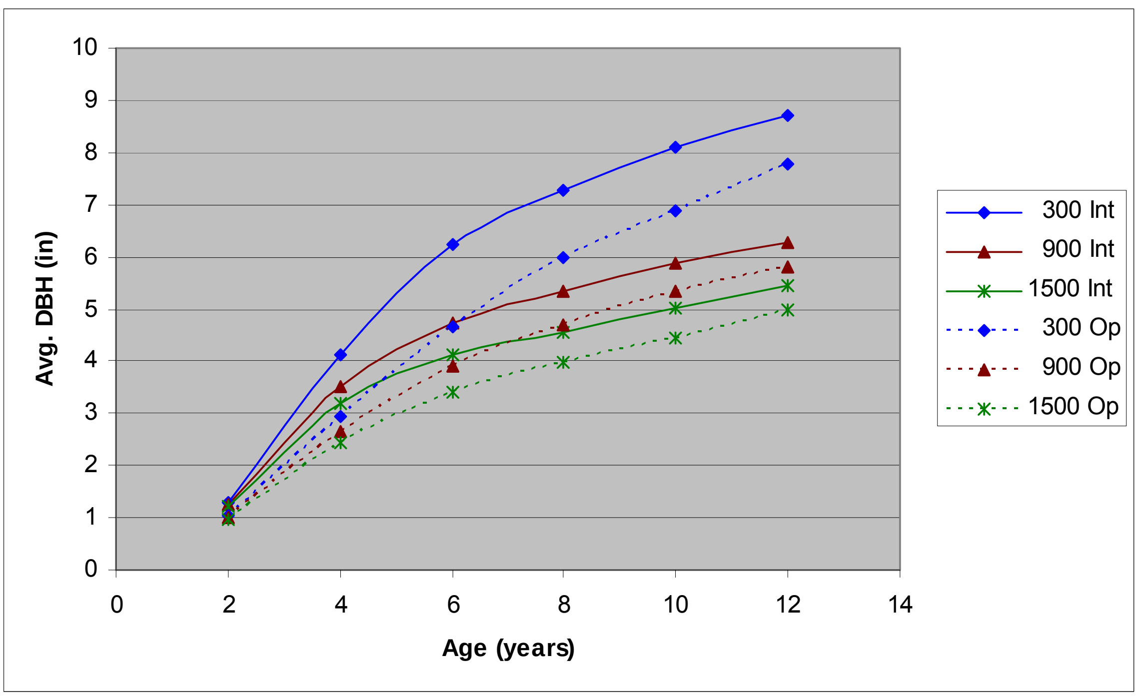


**Figure 31**. Average DBH growth by planting density and management intensity for slash pine treatments.

As discussed in the loblolly analysis, it is unusual to see planting density have a statistically or practically significant effect on average height. The trees with DBH values greater than the average DBH were designated as dominants and those average dominant heights were evaluated for the significance of planting density. For dominant height, management and initial density were significant factors at the 5% level. As shown in Figure 33, the differences in average dominant height across density, regardless of management, ranged from 0.5 to 2 feet. The average response to more intensive management was 2.1 feet.

**Table 19**. Analysis of variance results for slash pine average height at age 12.

| Source | Type III F | Pr > F |
|---|---|---|
| Soil | 0.27 | 0.7780 |
| Management | 12.09 | 0.0254* |
| Soil x Management | 0.13 | 0.8843 |
| Density | 16.63 | <0.0001* |
| Soil x Density | 0.49 | 0.7443 |
| Management x Density | 1.41 | 0.2664 |

*Significant at α = 0.05.

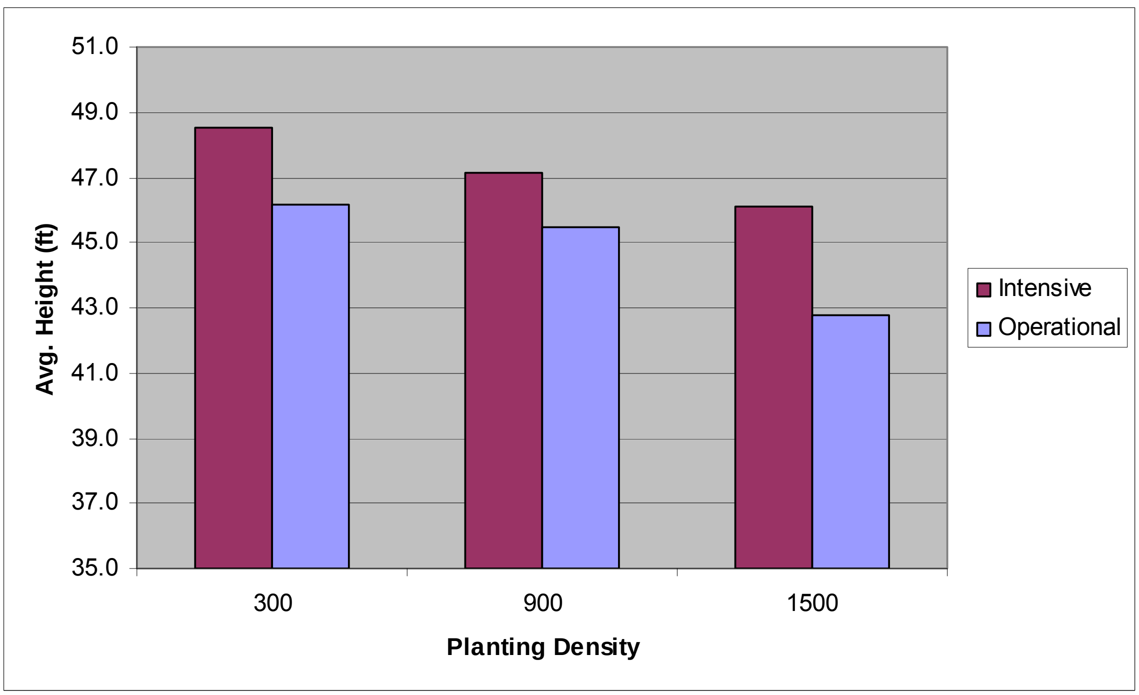


**Figure 32**. Average height by planting density and management intensity for slash pine at age 12.

Figure 34 shows the average dominant height growth from ages 2-12 for all slash pine treatments. Differences due to management intensity have remained consistent over time. The trend towards reduced height growth for the highest density is also apparent from ages 6-12.

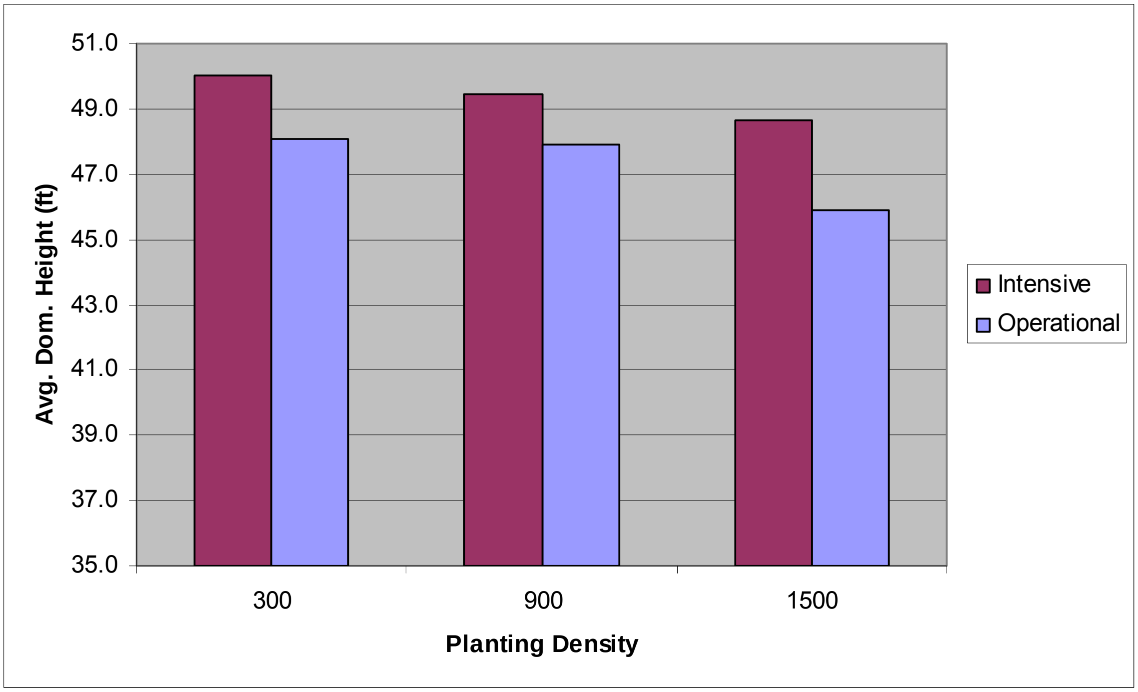


**Figure 33.** Average dominant height by planting density and management intensity for slash pine at age 12.

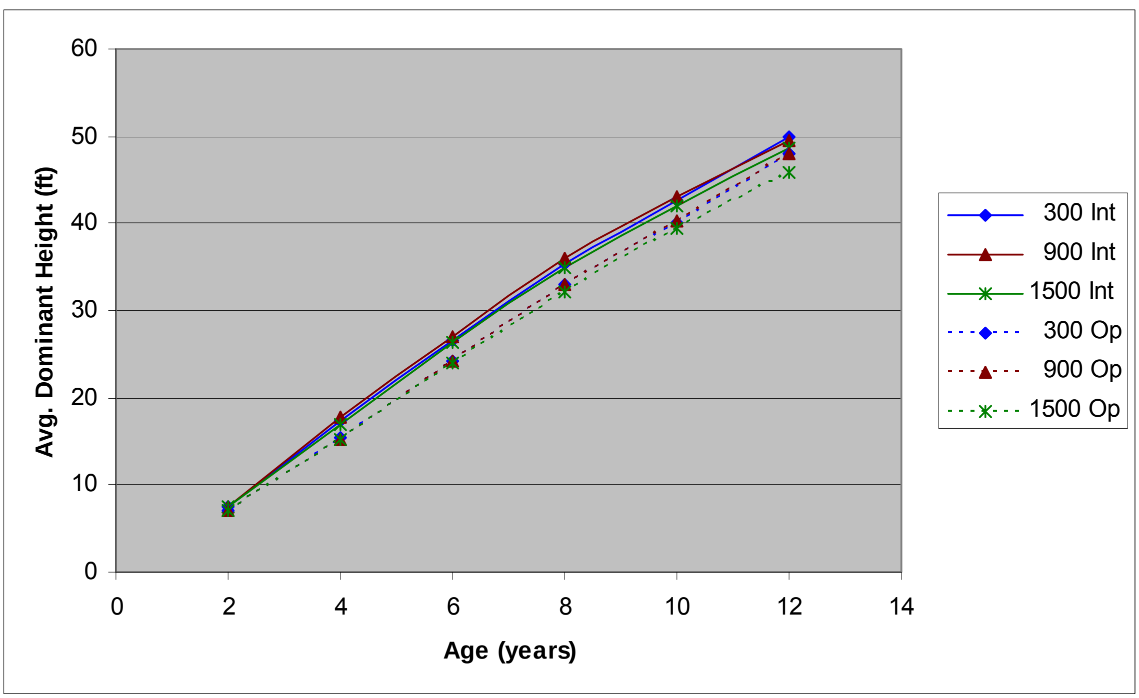


**Figure 34.** Average dominant height growth by planting density and management intensity for slash pine treatments.

## 4.3 Percent Survival

Table 20 shows the results of the analysis of variance for slash pine average percent survival. Initial density significantly affected survival through age 12. Compared to the 300 and 900 trees per acre plots, the highest density plots survived 5.3% and 17.4% less for intensive and operational treatments, respectively. Two slash pine plots with excessive mortality (<30% survival) were observed at age 12. Analyses were conducted with and without these plots that were affected by wildfire. The statistical significance of the various factors was not affected although the magnitude of differences was. All results reported here include the plots with excessive mortality.

CRIFF soil group significantly affected survival in the Age-8 analysis (Shiver and Harrison, 2004). The same trends are evident through age 12 but were not statistically significant (Figure 35). Figure 36 shows the average slash pine survival curves by initial density and management intensity.

**Table 20.** Analysis of variance results for slash pine average percent survival at age 12.

| Source | Type III F | Pr > F |
|---|---|---|
| Soil | 0.28 | 0.7671 |
| Management | 3.60 | 0.1308 |
| Soil x Management | 1.20 | 0.3899 |
| Density | 4.29 | 0.0281* |
| Soil x Density | 1.37 | 0.2794 |
| Management x Density | 0.82 | 0.4556 |

## 4.4 Percent Cronartium Infection

Table 21 shows the results of the analysis of variance for slash pine average percent cronartium infection. Initial density significantly affected the cronartium infection rate for slash pine. Figure 37 shows that there is a definite trend toward lower infection rates at higher densities. Although there was not a significant management x density interaction at age 12, the effect due to management intensity increased with decreasing trees per acre. The infection rate of the more intensively-managed plots exceeds that of the operational plots by 9.6%, 5.7% and 1.4% for the 300, 900 and 1500 trees per acre treatments, respectively.

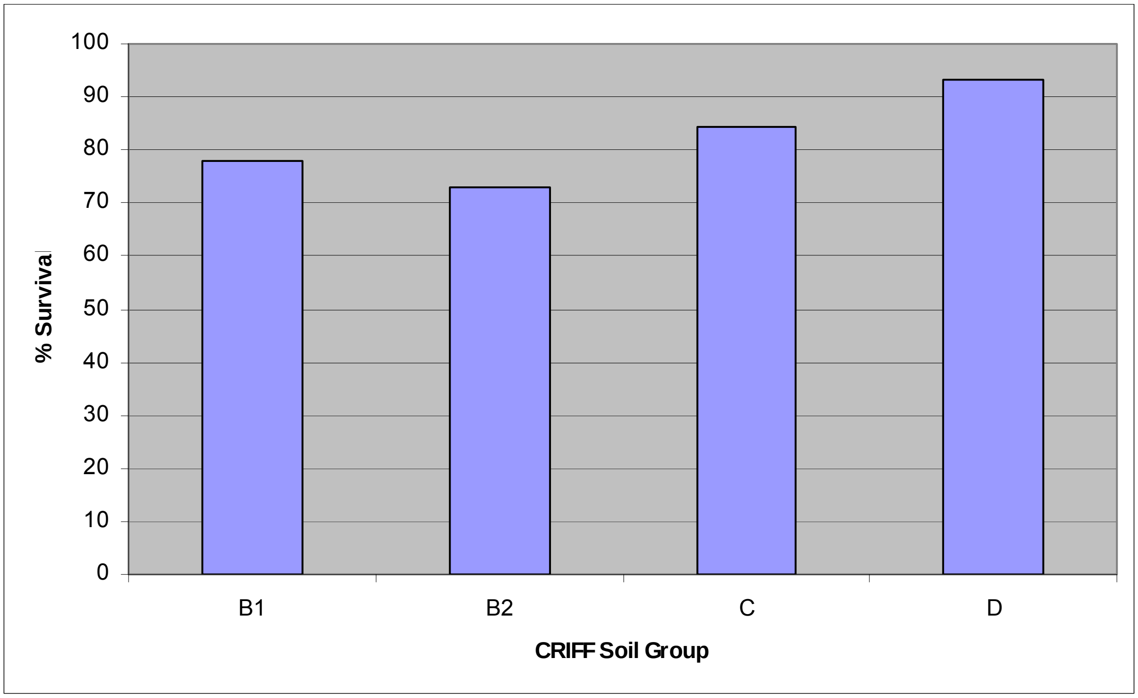


**Figure 35.** Average slash pine percent survival through age 12 by CRIFF soil group.

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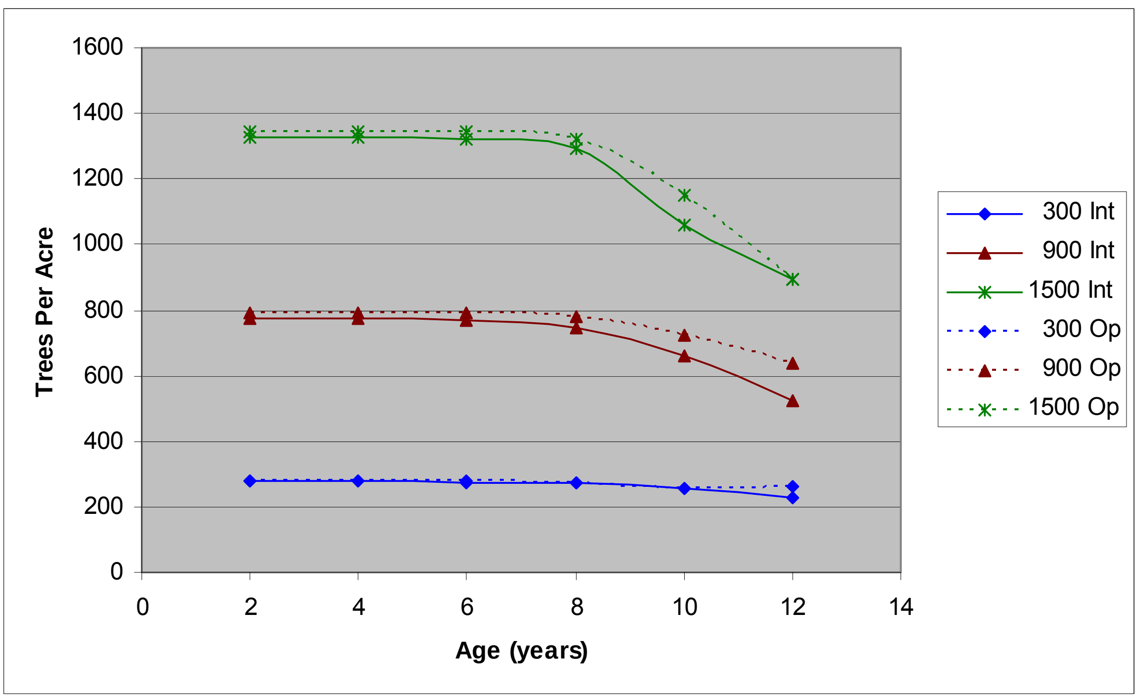


**Figure 36.** Trees per acre development by planting density and management intensity for slash pine treatments.

The CRIFF soil group was not a statistically-significant factor for cronartium infection rate at age 12 but consistent trends have emerged through the years. Figure 38 illustrates that the B2 soil type has the highest infection rates across all densities. On C soils, the effect of more intensive management on cronartium infection rate was greater than on other soil groups.

**Table 21.** Analysis of variance results for slash pine average percent cronartium infection at age 12.

| Source | Type III F | Pr > F |
|---|---|---|
| Soil | 3.63 | 0.1261 |
| Management | 4.56 | 0.0997 |
| Soil x Management | 0.29 | 0.7648 |
| Density | 6.70 | 0.0059* |
| Soil x Density | 1.49 | 0.2429 |
| Management x Density | 1.55 | 0.2369 |

*Significant at α = 0.05.

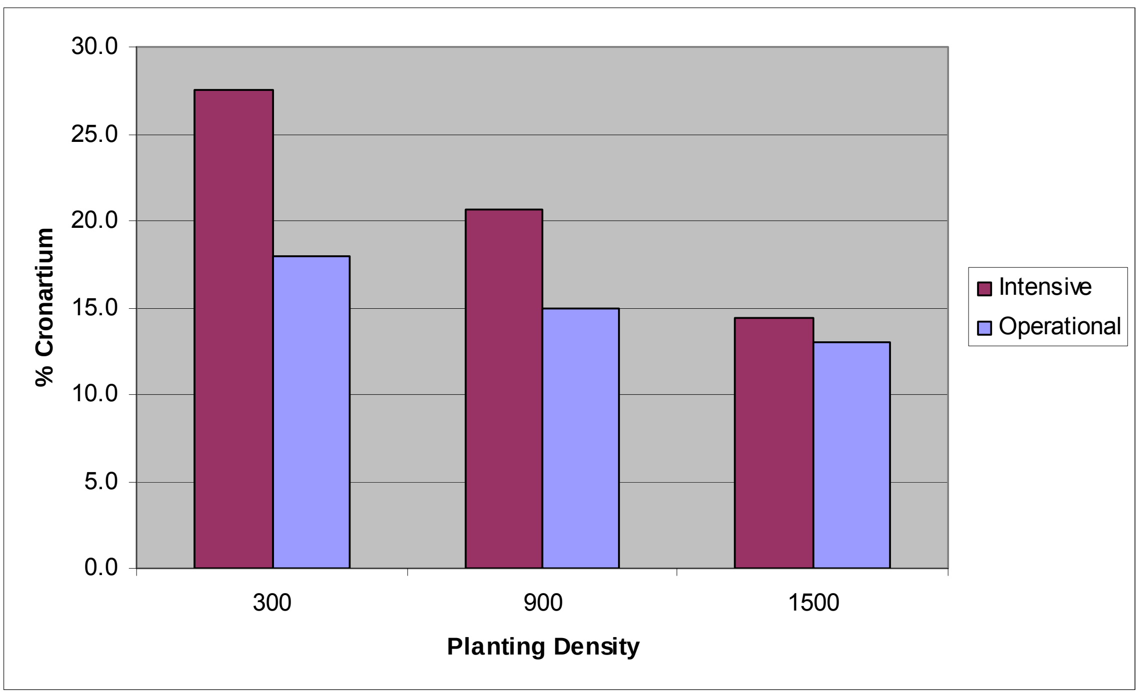


**Figure 37.** Average percent cronartium infection by planting density and management intensity for slash pine at age 12.

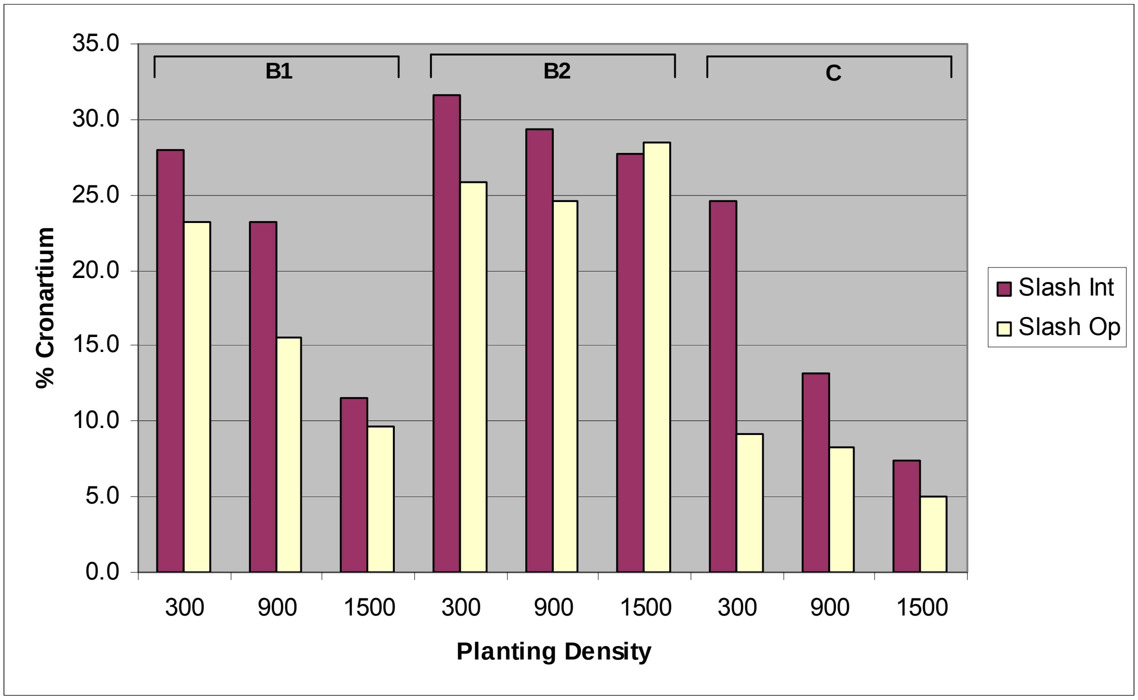


**Figure 38**. Average percent cronartium infection by CRIFF soil group, planting density and management intensity for slash pine at age 12.

### 4.5 Per-Acre Basal Area

Table 22 shows the results of the analysis of variance for slash pine per-acre basal area. Planting density significantly affected per-acre basal area and basal area increased with increasing initial density. Increasing initial density from 300 to 900 to 1500 increased basal area per acre substantially for both intensive and operational management. Figure 39 illustrates these trends. In contrast to previous analyses, management intensity did not have a significant effect on per-acre basal area. This may be due, in part, to the intensively-managed slash pine plots that experienced excessive mortality due to wildfire.

**Table 22**. Analysis of variance results for slash pine average per-acre basal area at age 12.

| Source | Type III F | Pr > F |
|---|---|---|
| Soil | 0.77 | 0.5201 |
| Management | 1.41 | 0.3003 |
| Soil x Management | 0.06 | 0.9385 |
| Density | 16.11 | <0.0001* |
| Soil x Density | 1.24 | 0.3255 |
| Management x Density | 1.53 | 0.2407 |

*Significant at α = 0.05.

Figure 40 shows average slash pine basal area growth from ages 2-12 for all treatments. It appears that significant slowing in basal area growth has occurred for the high-intensity and high-density treatments. Average basal area decreased from age 8 to 12 for the high-intensity 900 TPA treatment and for the 1500 trees per acre plots under both management treatments. This apparent anomaly can be at least partially attributed to catastrophic mortality discussed previously.

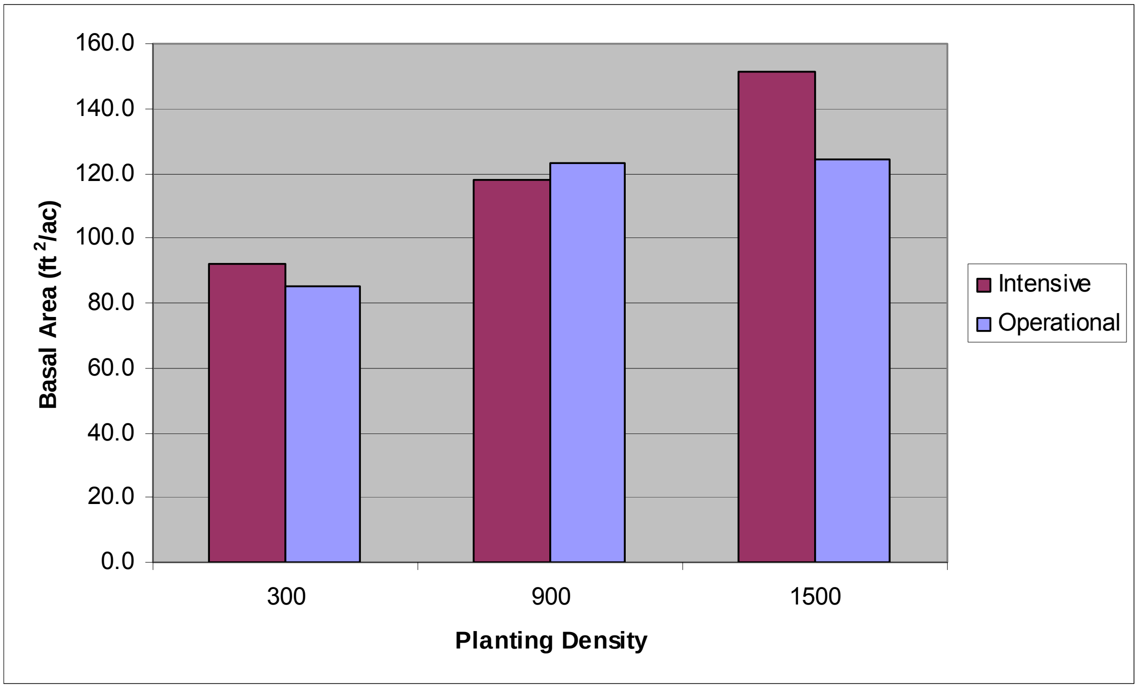


**Figure 39**. Average per-acre basal area ($ft^2$/ac) by planting density and management intensity for slash pine at age 12.

### 4.6 Per-Acre O.B. Volume

Table 23 shows the results of the analysis of variance for slash pine total volume. Planting density had the only significant effect on total per-acre volume. Figure 41 shows a nearly identical trend for volume as for basal area. An increase in management intensity resulted in increases in total per-acre stem volume for the 300 and 1500 densities but was not statistically significant. An increase in density from 300 to 1500 increased total stem volume per acre by 641 $ft^3$/ac on operationally-managed stands. On more intensively-managed stands, an increase in planted trees per acre from 300 to 1500 increased volume per acre at age 12 by 1137 $ft^3$/ac.

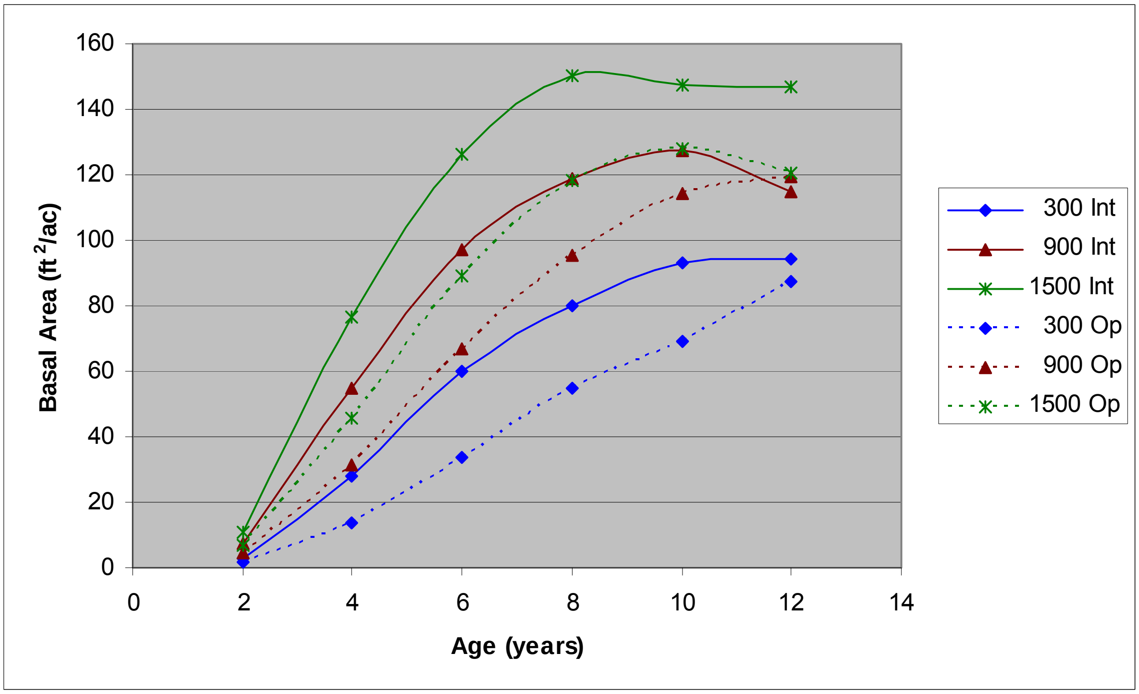


**Figure 40**. Average per-acre basal area growth ($ft^2/ac$) by planting density and management intensity for slash pine treatments.

**Table 23**. Analysis of variance results for slash pine average per-acre, total volume at age 12.

| Source | Type III F | Pr > F |
|---|---|---|
| Soil | 0.72 | 0.5400 |
| Management | 3.59 | 0.1309 |
| Soil x Management | 0.02 | 0.9808 |
| Density | 11.73 | 0.0004* |
| Soil x Density | 1.24 | 0.3268 |
| Management x Density | 1.96 | 0.1668 |

*Significant at $\alpha = 0.05$.

Figure 42 shows average slash pine total volume growth through age 12 for all treatments. As with per acre basal area, a slowdown in volume growth is apparent for the high intensity, 900 trees per acre density treatment plots and is attributable to excessive mortality to some extent.

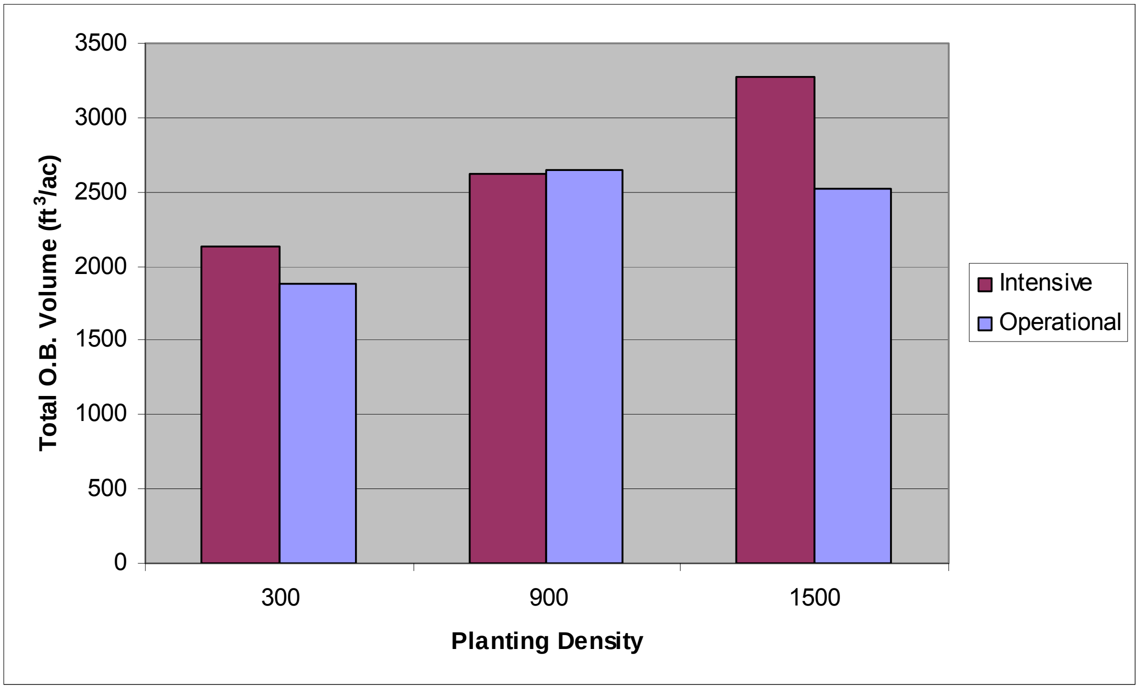


**Figure 41**. Average total per-acre outside bark volume ($ft^3/ac$) by planting density and management intensity for slash pine at age 12.

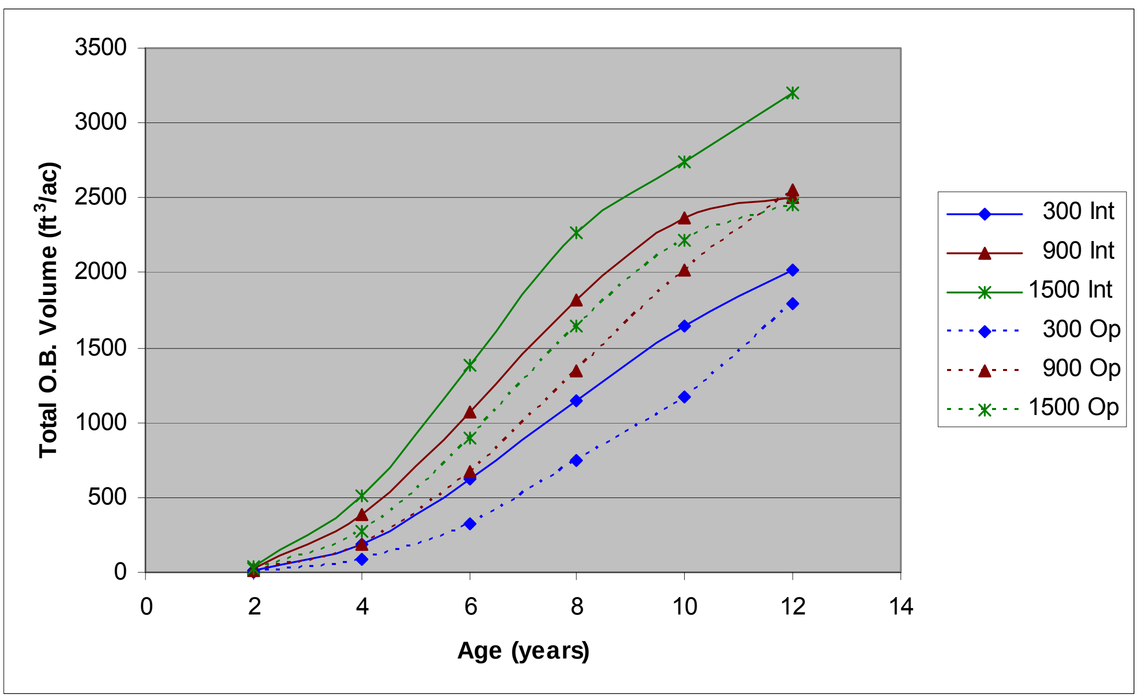


**Figure 42**. Total per-acre outside bark volume growth ($ft^3/ac$) by planting density and management intensity for slash pine treatments.

### 4.7 Per-Acre O.B. Green Weight

Table 24 shows the results of the analysis of variance for slash pine total green weight. Initial density had a significant effect on total, per-acre green weight. Figure 43 shows the per-acre green weights by density and management treatment. Green weight per acre increased as initial density increased from 300 to 1500 with weights going from about 58 tons/ac for 300 trees per acre to about 87 tons/ac for 1500 with operational management. Intensive management increased green weight by 2.7 tons/ac for the 300 and 900 density treatments and by 22.3 tons/ac for the 1500 trees per acre plots. Figure 44 shows the green weight development through age 12 for all slash pine treatments. Trends are similar to those observed for per-acre basal area and total volume.

**Table 24.** Analysis of variance results for slash pine average per-acre, total green weight at age 12.

| Source | Type III F | Pr > F |
|---|---|---|
| Soil | 0.70 | 0.5487 |
| Management | 3.37 | 0.1402 |
| Soil x Management | 0.02 | 0.9805 |
| Density | 13.60 | 0.0002* |
| Soil x Density | 1.19 | 0.3471 |
| Management x Density | 2.03 | 0.1572 |

*Significant at α = 0.05.

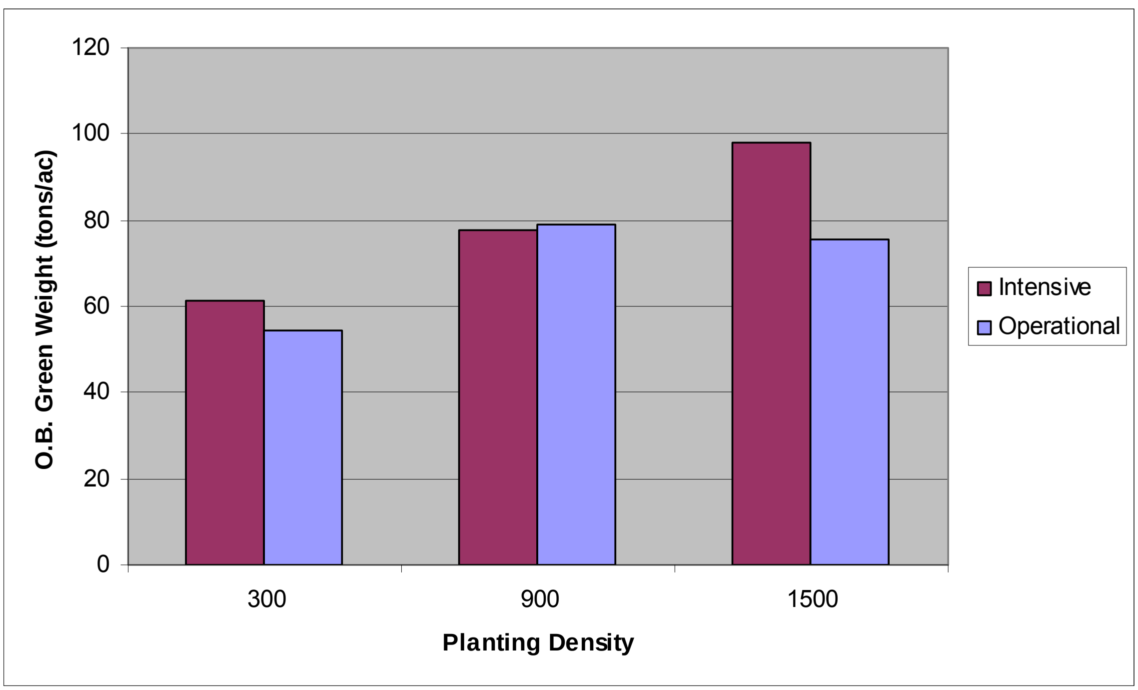


**Figure 43.** Average total per-acre outside bark green weight (tons/ac) by planting density and management intensity for slash pine at age 12.

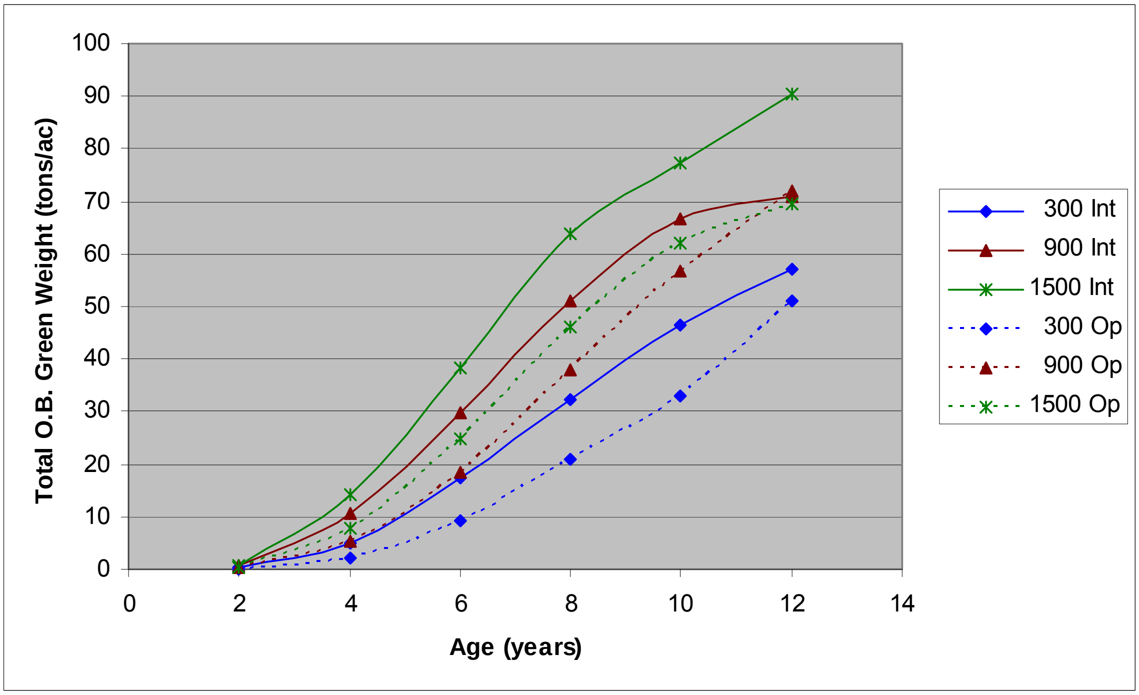


**Figure 44.** Average total per-acre outside bark green weight (tons/ac) by planting density and management intensity for slash pine treatments.

### 4.8 Per-Acre Chip-N-Saw Yield

Table 25 shows the results of the analysis of variance for per-acre merchantable green weight to a 6” top (o.b.) for trees greater than or equal to 8” DBH. As with loblolly pine, this quantity is intended to represent potential chip-n-saw yield but does not account for stem quality that would likely be worse at lower densities due to increased branch size. Management intensity and density had significant effects on chip-n-saw green weight. Figure 45 shows the per-acre green weights by density and management treatment. Only the 300 trees per acre plots had substantial chip-n-saw yields at age 12. Management intensity increased potential chip-n-saw yield by 18 tons/acre on the 300 trees per acre density plots.

**Table 25.** Analysis of variance results for slash pine average per-acre, merchantable green weight of chip-n-saw trees at age 12.

| Source | Type III F | Pr > F |
|---|---|---|
| Soil | 0.51 | 0.6369 |
| Management | 13.49 | 0.0213* |
| Soil x Management | 1.26 | 0.3757 |
| Density | 102.42 | <0.0001* |
| Soil x Density | 1.64 | 0.2030 |
| Management x Density | 7.67 | 0.0034* |

*Significant at α = 0.05.

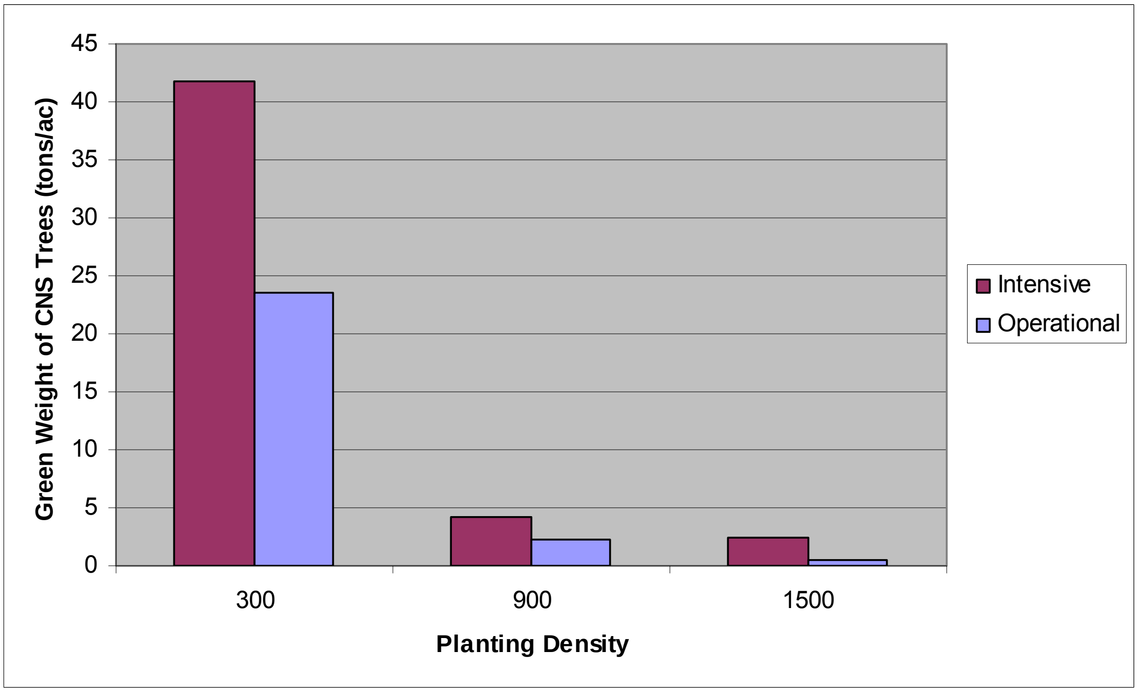


**Figure 45**. Average merchantable per-acre outside bark green weight of chip-n-saw trees (tons/ac) by planting density and management intensity for slash pine at age 12.

### 4.9 Stand Density Index

The stand density index (SDI) can be calculated for slash pine stands in exactly the same way it was calculated for loblolly stands. The only difference is in interpretation since slash pine has a theorized maximum stand density index of 400 as compared to 450 for loblolly. Table 26 shows the results of the analysis of variance for slash pine SDI. Only initial density had a significant effect on SDI. Figure 46 shows the SDI values by density and management. There was a slight increase in average SDI for intensive management at the 300 and 1500 trees per acre initial densities. By age 12 the combination of 1500 trees per acre initial density and intensive management resulted in an average SDI that approaches the published maximum value for slash pine. Figure 47 shows the percent of maximum SDI values by density and management that were obtained by calculating the plot SDI values divided by 400 and then averaged by density and management.

Figure 48 shows the natural log of TPA plotted against natural log of Dq for all slash pine treatments. As observed for loblolly pine, the operational and more intensive management regimes began at different points but have proceeded along the same track up to the point where the more intensive regime has begun to reach its limiting density.

**Table 26.** Analysis of variance results for slash pine average stand density index at age 12.

| Source | Type III F | Pr > F |
|---|---|---|
| Soil | 0.71 | 0.5464 |
| Management | 0.35 | 0.5854 |
| Soil x Management | 0.18 | 0.8420 |
| Density | 25.78 | <0.0001* |
| Soil x Density | 1.10 | 0.3829 |
| Management x Density | 0.31 | 0.2926 |

*Significant at α = 0.05.

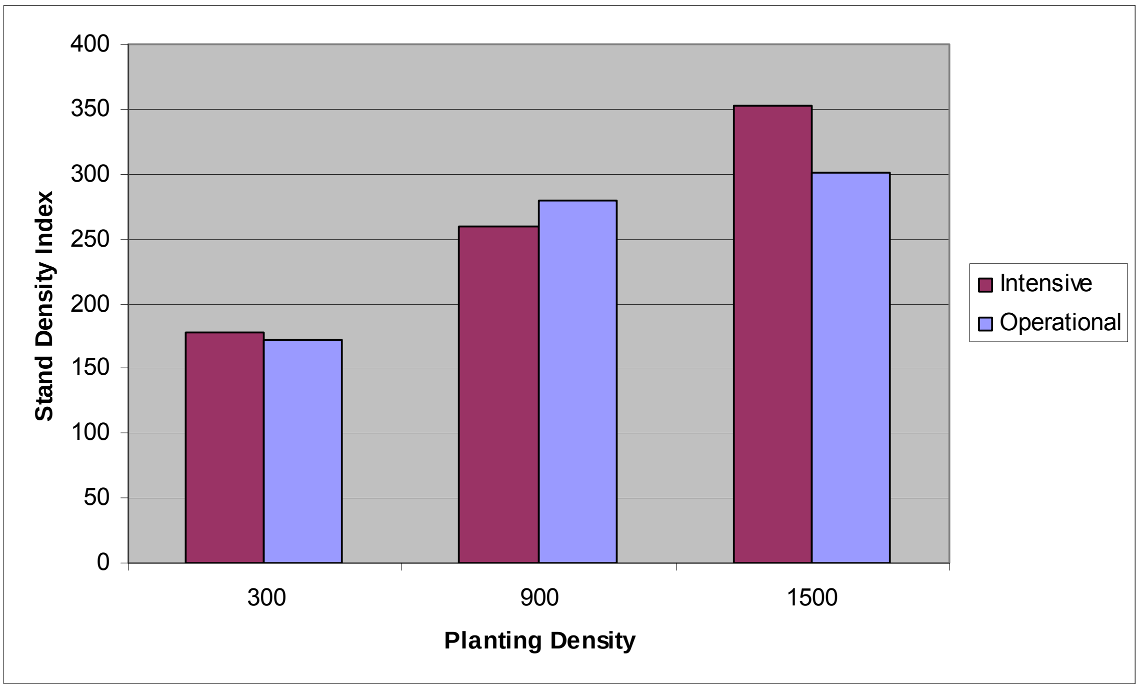


**Figure 46.** Average stand density index by planting density and management intensity for slash pine at age 12.

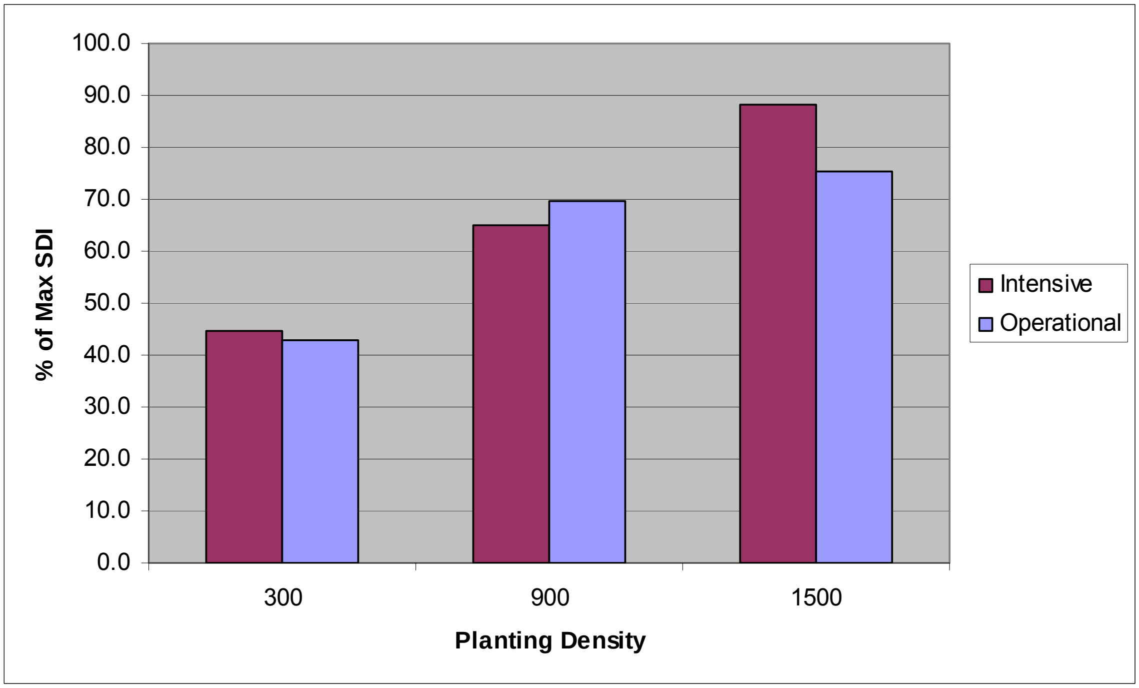


**Figure 47.** Average percentage of maximum stand density index by planting density and management intensity for slash pine at age 12.

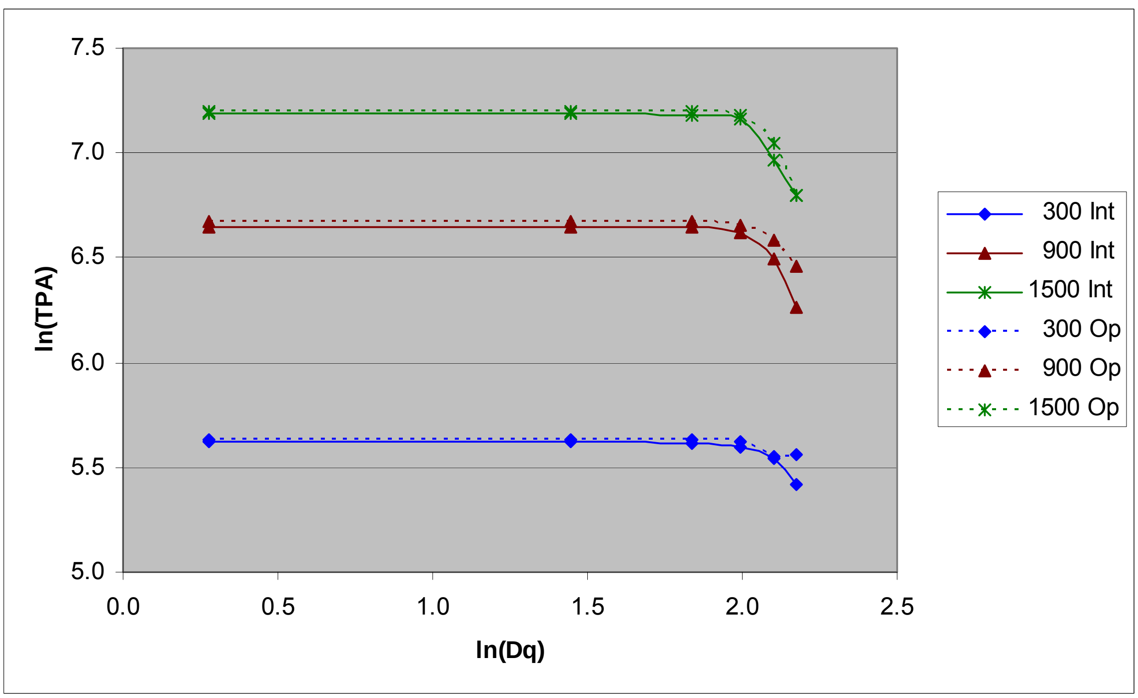


**Figure 48.** Natural log of trees per acre versus natural log of quadratic mean Dbh by planting density and management intensity for slash pine treatments

### 4.10 Relative Spacing

The other measure of limiting density calculated for these plots was relative spacing. Recall that the relative spacing decreases over the life of the stand in the absence of thinning to a lower asymptote that is typically around 0.12 for slash and loblolly pines. Table 27 shows the results of the analysis of variance for slash pine relative spacing. Initial density significantly affected relative spacing at age 12 (Figure 49). The average relative spacing of the operational 1500 trees per acre plots was greater than that of the more intensively-managed 1500 trees per acre plots. This apparent anomaly was, again, most likely attributable to catastrophic mortality on one slash pine plot.

**Table 27**. Analysis of variance results for slash pine average relative spacing at age 12.

| Source | Type III F | Pr > F |
|---|---|---|
| Soil | 0.50 | 0.6380 |
| Management | 0.01 | 0.9183 |
| Soil x Management | 0.45 | 0.6680 |
| Density | 16.34 | <0.0001* |
| Soil x Density | 0.73 | 0.5827 |
| Management x Density | 1.44 | 0.2614 |

*Significant at $\alpha = 0.05$.

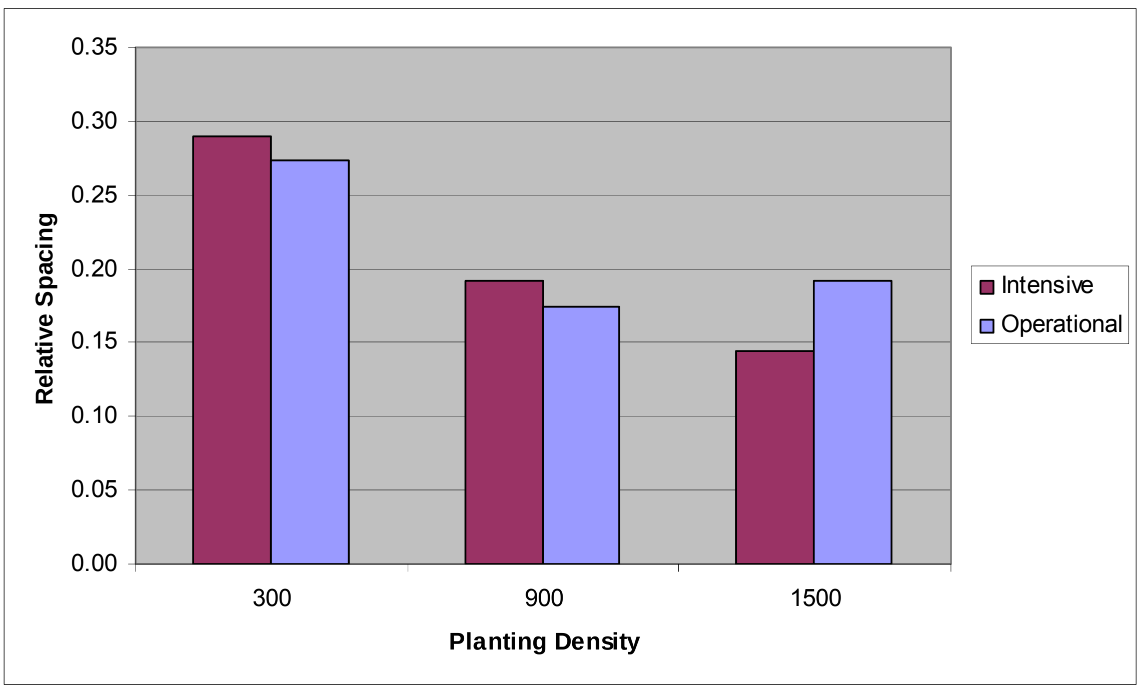


**Figure 49.** Average relative spacing by management intensity and density for slash pine at age 12.

### 4.11 Crown Ratio

Crown ratio (or live crown ratio) is defined as the proportion of the total height of a tree that is covered by live branches. Crown ratio is a common indicator of tree vigor. Initial density significantly impacted crown ratio for slash pine at age 12 (Table 28). Crown ratio declined with increasing initial density (Figure 50).

**Table 28.** Analysis of variance results for slash pine average crown ratio at age 12.

| Source | Type III F | Pr > F |
|---|---|---|
| Soil | 1.72 | 0.2884 |
| Management | 0.05 | 0.8315 |
| Soil x Management | 2.09 | 0.2393 |
| Density | 84.60 | <0.0001* |
| Soil x Density | 2.81 | 0.0534 |
| Management x Density | 0.11 | 0.8946 |

*Significant at α = 0.05.

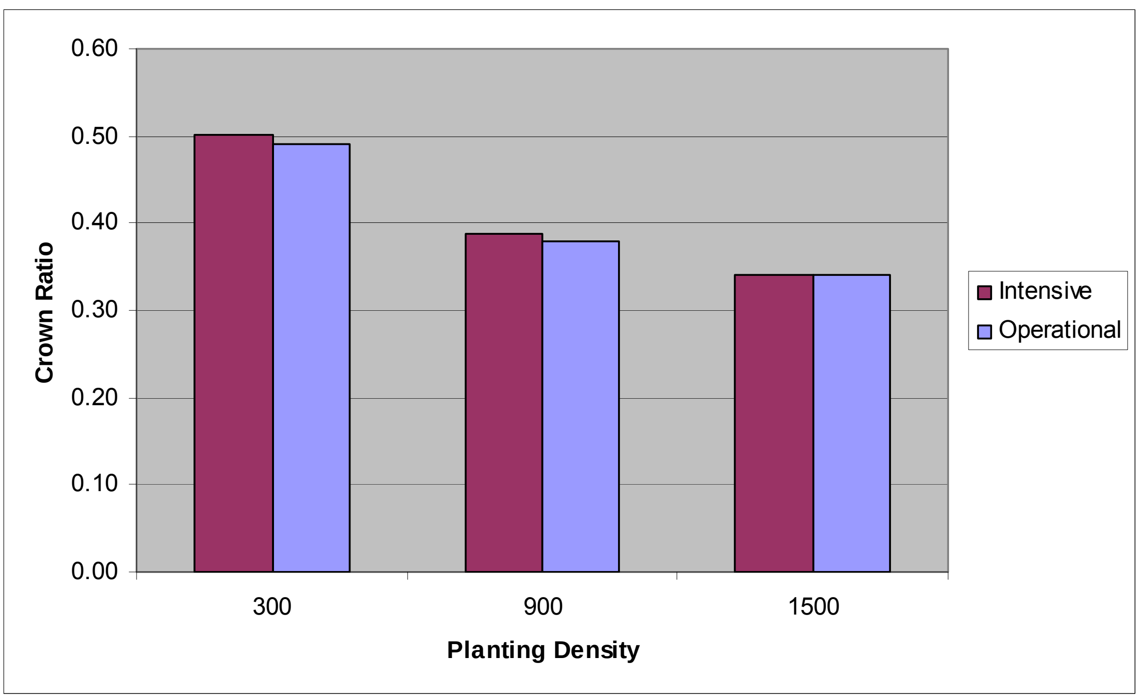


**Figure 50.** Average crown ratio by management intensity and density for slash pine at age 12.

### 4.12 Crown Length

As noted for loblolly pine, live crown length is an important factor influencing stem form (Larson, 1963). Density significantly impacted crown length for slash pine at age 12 (Table 29). Figure 51 illustrates that crown length declined with increasing initial density. The 300 trees per acre initial density had 41% greater crown length compared to the average of the higher initial densities.

**Table 29**. Analysis of variance results for slash pine average crown length at age 12.

| Source | Type III F | Pr > F |
|---|---|---|
| Soil | 1.72 | 0.2884 |
| Management | 0.05 | 0.8315 |
| Soil x Management | 2.09 | 0.2393 |
| Density | 84.60 | <0.0001* |
| Soil x Density | 2.81 | 0.0534 |
| Management x Density | 0.11 | 0.8946 |

*Significant at α = 0.05.

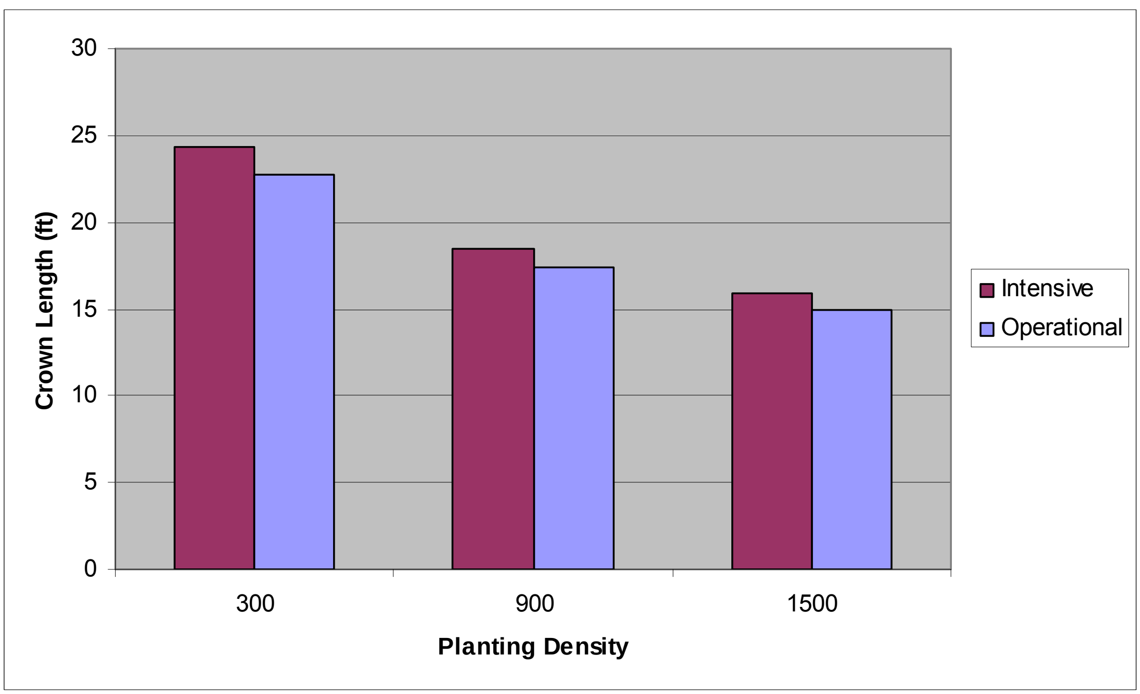


**Figure 51.** Average crown length by management intensity and density for slash pine at age 12.

# 5 SPECIES COMPARISON

## 5.1 Comparison of Species Across all Soil Groups

A graphical comparison was carried out to assess differences in tree and stand characteristics of loblolly and slash pine. Figures 52-63 show the average DBH, height, dominant height, survival percentage, cronartium infection percentage, per-acre basal area, per-acre total volume, per-acre total green weight, merchantable green weight of chip-n-saw sized trees, stand density index, relative spacing, crown ratio and crown length by species, initial density and management intensity level across soil groups.

There were minimal differences in the DBH values for the two species when paired by management intensity and initial density. There was a slight advantage, about 0.8 inches, to loblolly at the 300 density with intensive management. For all other pairs the differences were 0.1- 0.2 inches (Figure 52).

The intensively managed loblolly pine plots had consistently greater average heights (6-8 feet) than all other treatments (Figure 53). The intensively managed loblolly stands had average heights about six feet taller than operational loblolly at the same density. The operational loblolly plots were slightly taller than the slash intensively managed at all initial densities. The intensive slash pine plots had average heights only 2-3 feet taller than the operational slash pine plots. On an average tree size basis it appears that the gains in loblolly from more intensive management come primarily from an average height response. The same trends that are evident for average height are also evident when only the average height of dominants is evaluated (Figure 54).

In all cases, operational treatment plots had better survival than the more intensively managed plots (Figure 55). Loblolly pine survived better than slash pine in most comparisons by 12% on the average, but intensive slash had comparable survival to intensive loblolly at the 1500 initial density. The higher cronartium infection levels associated with slash pine for both operational and intensively-managed stands discussed next may be responsible for the slightly lower survival of slash pine compared to loblolly.

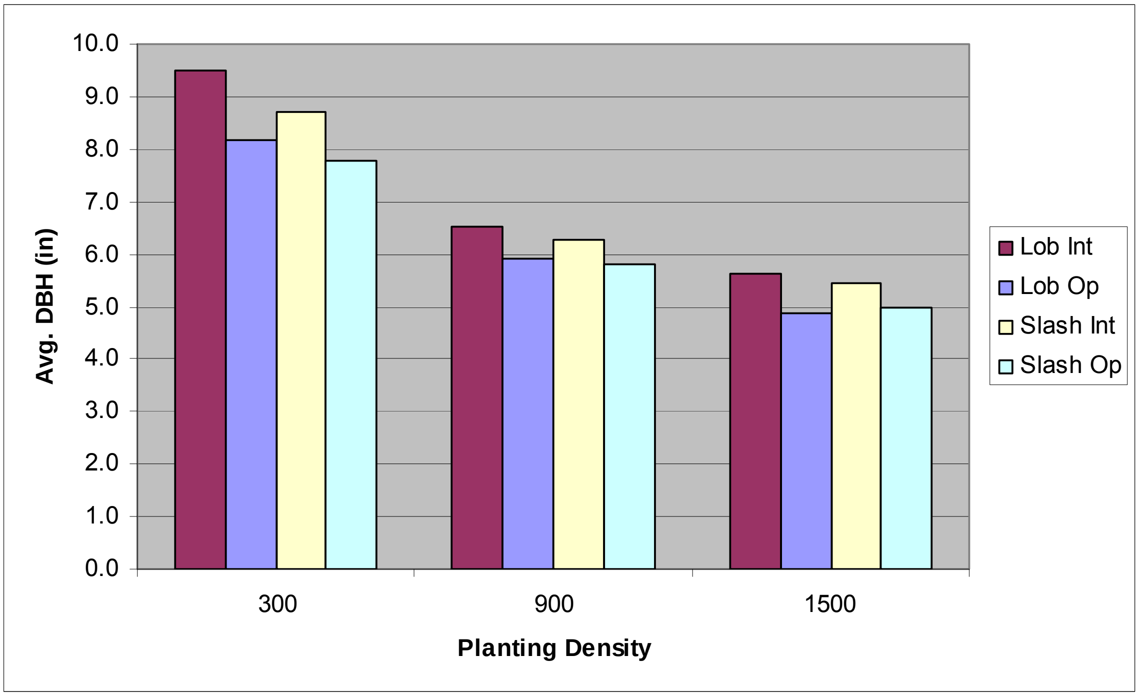


**Figure 52**. Average DBH by species, management intensity and density at age 12.

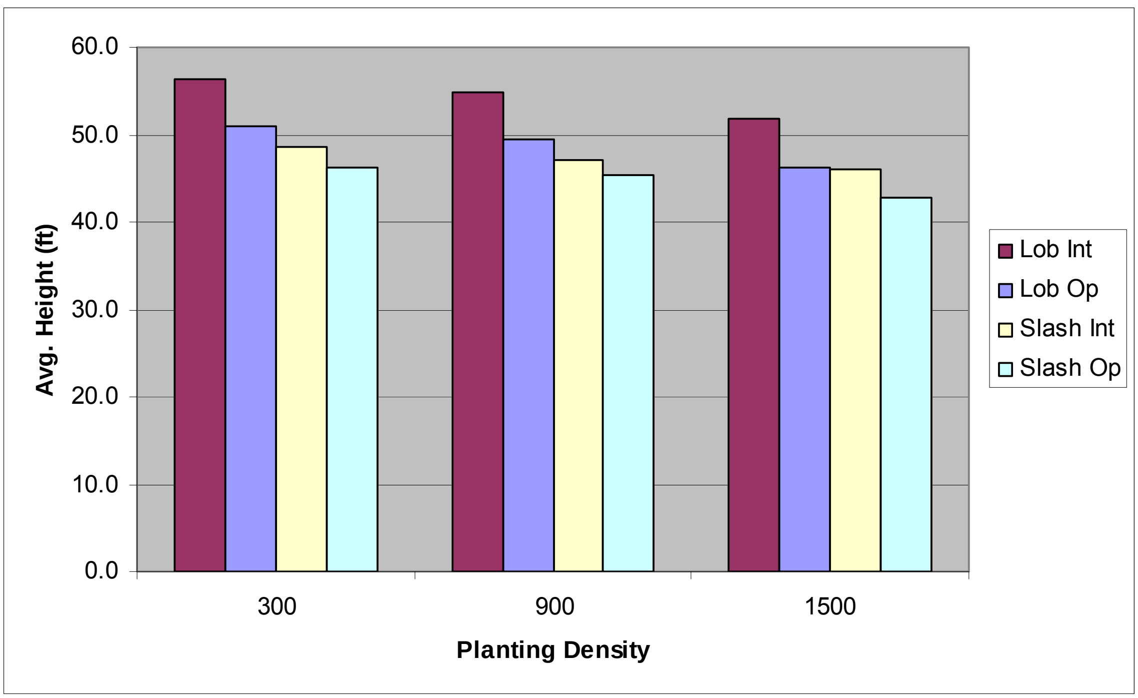


**Figure 53**. Average height by species, management intensity and density at age 12.

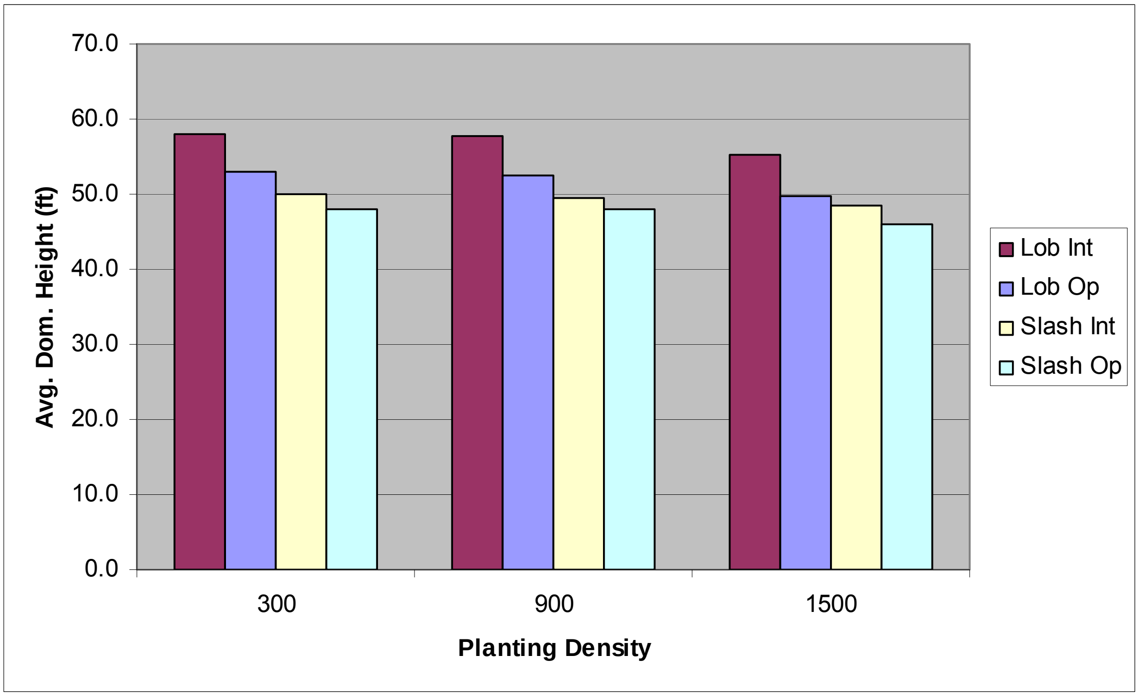


**Figure 54.** Average dominant height by species, management intensity and density at age 12.

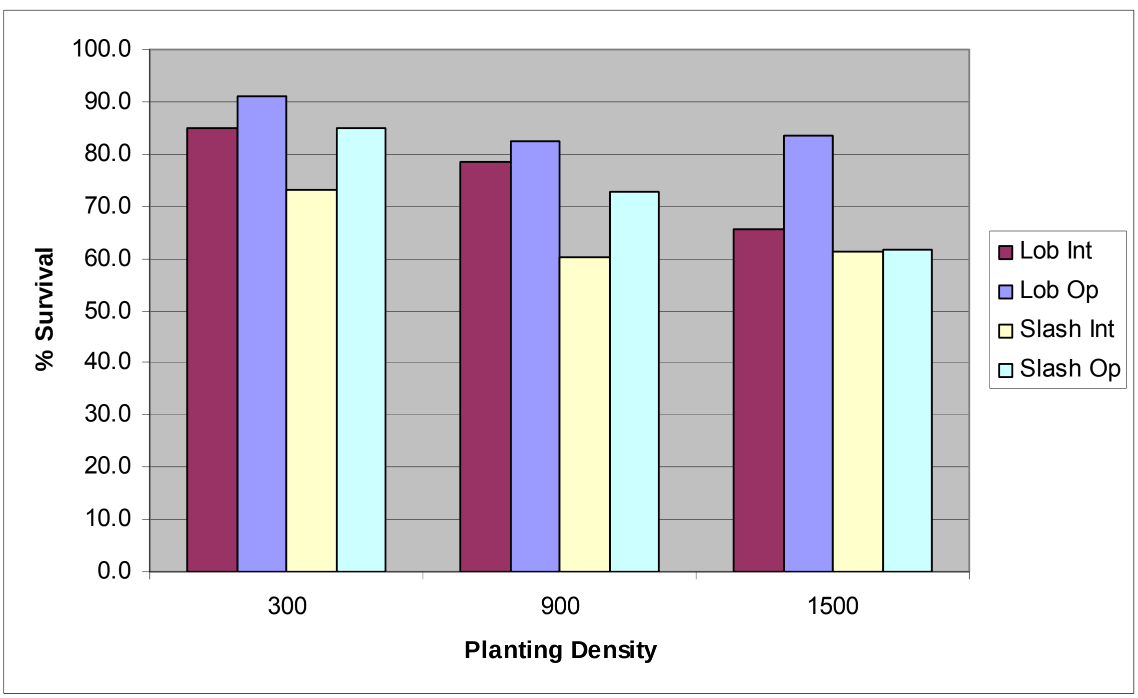


**Figure 55.** Average percent survival by species, management intensity and density at age 12.

As has been reported in many previous studies, treatments that accelerated pine growth also tended to increase the cronartium infection rate. The effect of management intensity is also evident in this study (Figure 56). It is also noteworthy that the slash pine plots typically had higher cronartium infection levels than loblolly. In fact, for the 1500 initial density, the operational slash pine plots had higher infection levels than the intensively managed loblolly plots by 1.6%. Infection rates for both species also tended to increase with decreasing planting density.

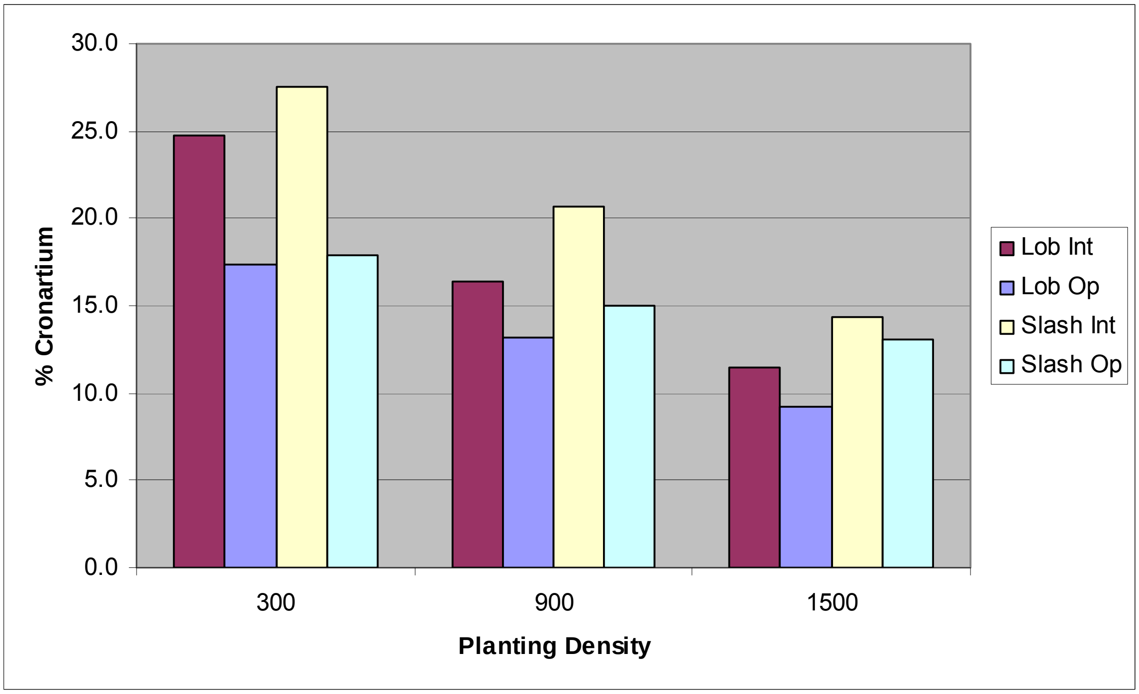


**Figure 56**. Average percent cronartium infection by species, management intensity and density at age 12.

For all treatments and species, per-acre basal area increased with increasing initial density (Figure 57). The operational loblolly pine plots had consistently more basal area (18-42 $ft^2$/ac) than operational slash pine plots across all initial densities. Loblolly pine had more basal area by about 42 $ft^2$/ac than slash pine on intensively managed plots for the two lower initial densities. On the intensively-managed plots with 1500 TPA initial density, slash pine had about 22 $ft^2$/ac lower basal area per acre than loblolly.

The trends for per-acre, outside bark volume were the same as those seen for per-acre basal area, but the differences were accentuated because of the loblolly height advantage (Figure 58). Volume increased with increasing management intensity and initial density. Loblolly pine had more volume by 493-1280 $ft^3$/ac at all spacings for the operational treatments. Loblolly pine had greater volumes than slash pine by 1050 to 1770 $ft^3$/ac on the intensive treatments at all spacings.

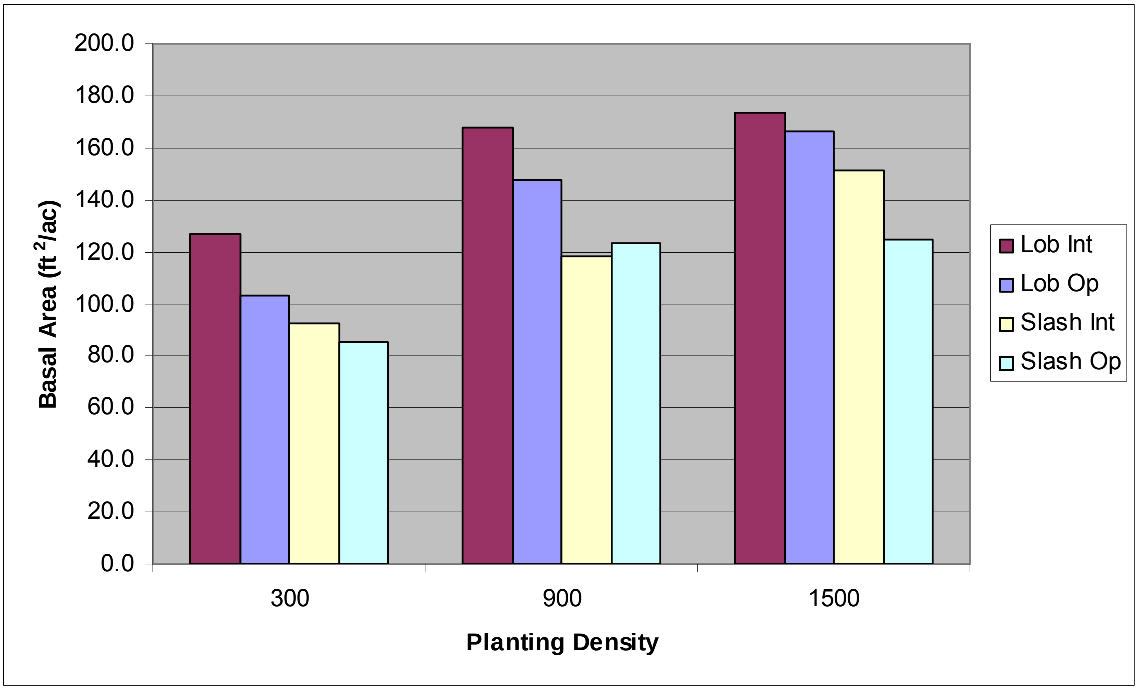


**Figure 57**. Average per-acre basal area by species, management intensity and density at age 12.

The trends for total green weight were similar to the trends for total volume (Figure 59). The advantage for loblolly pine in terms of green weight was 29-47 tons/ac for intensively managed stands and was 13-32 tons/ac for operational stands depending on the initial density.

Figure 60 shows the merchantable green weight (tons/acre) for chip-n-saw sized trees by species, management intensity and initial density. For each initial density, intensively-managed loblolly pine had nearly twice the chip-n-saw yield of intensively-managed slash pine at age 12. Operational loblolly pine plots also had nearly as much or more chip-n-saw yield than intensively-managed slash pine.

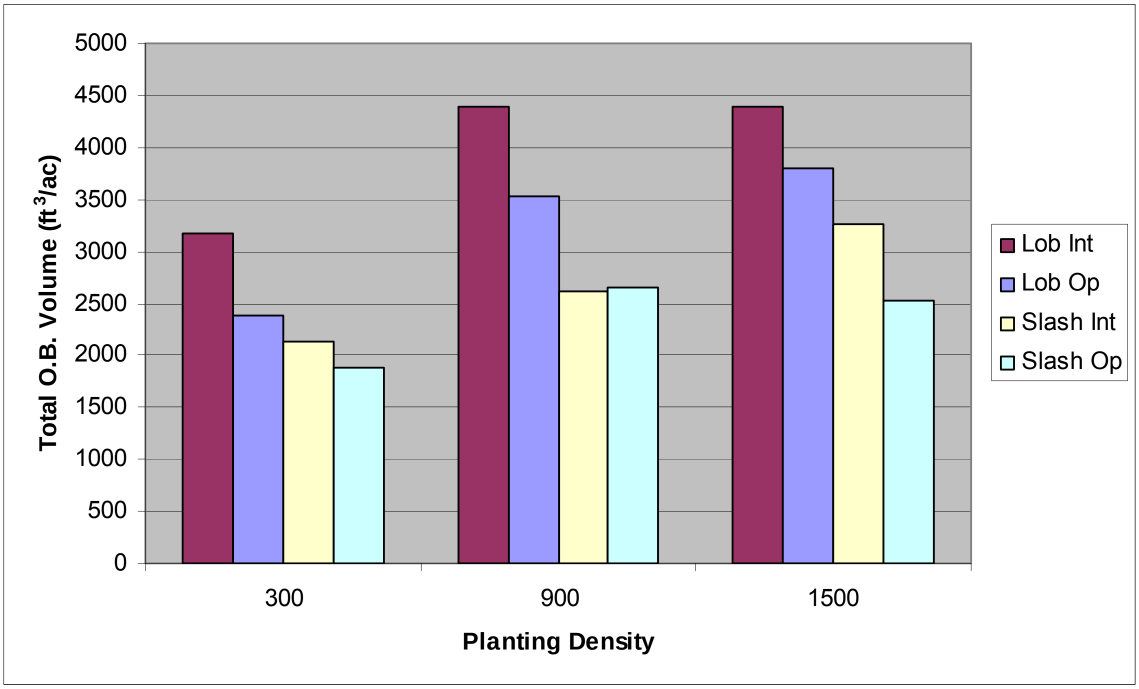


**Figure 58**. Average total per-acre outside bark volume ($ft^3/ac$) by species, management intensity and density at age 12.

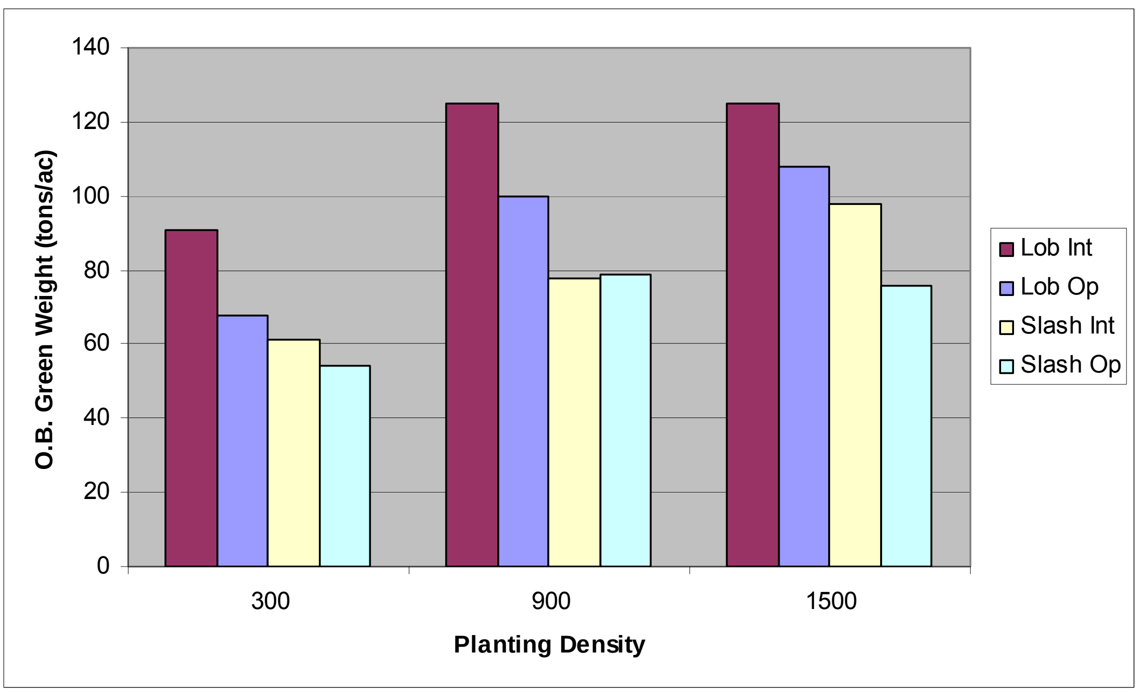


**Figure 59**. Average total per-acre outside bark green weight (tons/ac) by species, management intensity and density at age 12.

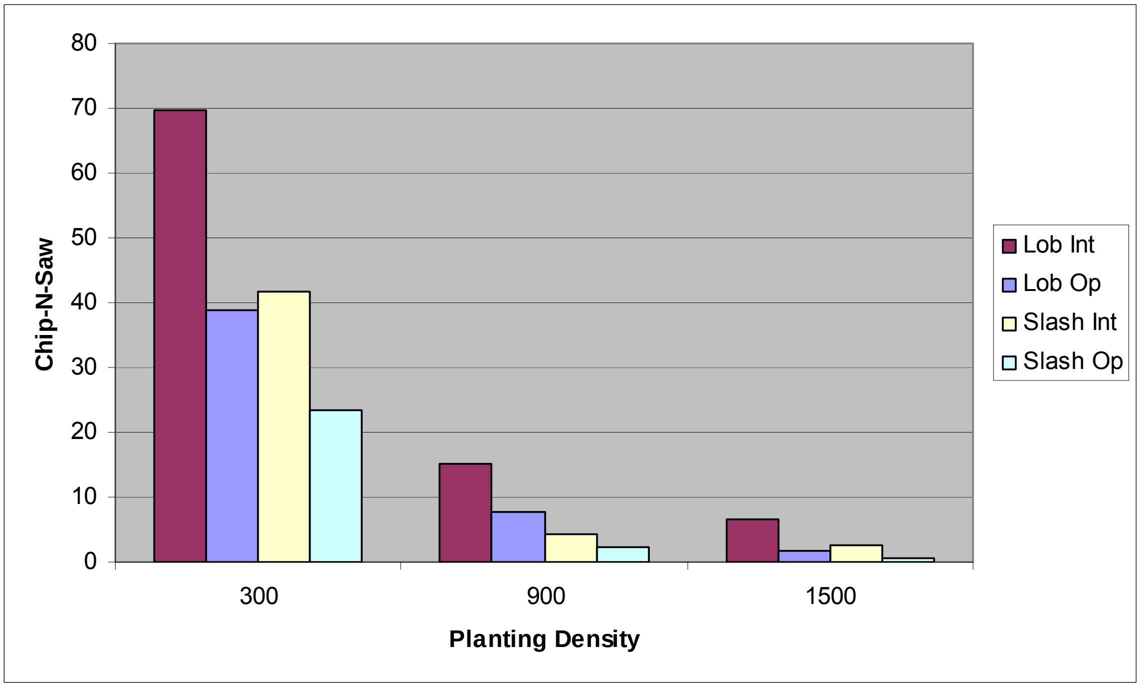


**Figure 60**. Average merchantable per-acre outside bark green weight of chip-n-saw trees (tons/ac) by species, planting density and management intensity at age 12.

The comparison of the stand density index for the two species looks very similar to the comparison of basal area per acre (Figure 61). Loblolly had a higher stand density index than slash when compared on a management intensity and initial density basis. The differences, however, were not large.

Average relative spacing is lower for loblolly than for slash pine at age 12 (Figure 62). It is somewhat surprising, but operational loblolly stands have lower relative spacing than slash pine stands at the same initial density. This must be related to the combination of faster early height growth and slightly better survival for loblolly pine.

Figure 63 shows average crown ratios by treatment for slash and loblolly pine. Operational slash pine plots had the highest crown ratios across the density classes while intensive loblolly pine had the lowest crown ratios.

Figure 64 shows average crown lengths by treatment for slash and loblolly pine. For all densities, intensive loblolly pine had the highest crown lengths followed by operational loblolly, intensive slash and operational slash pine.

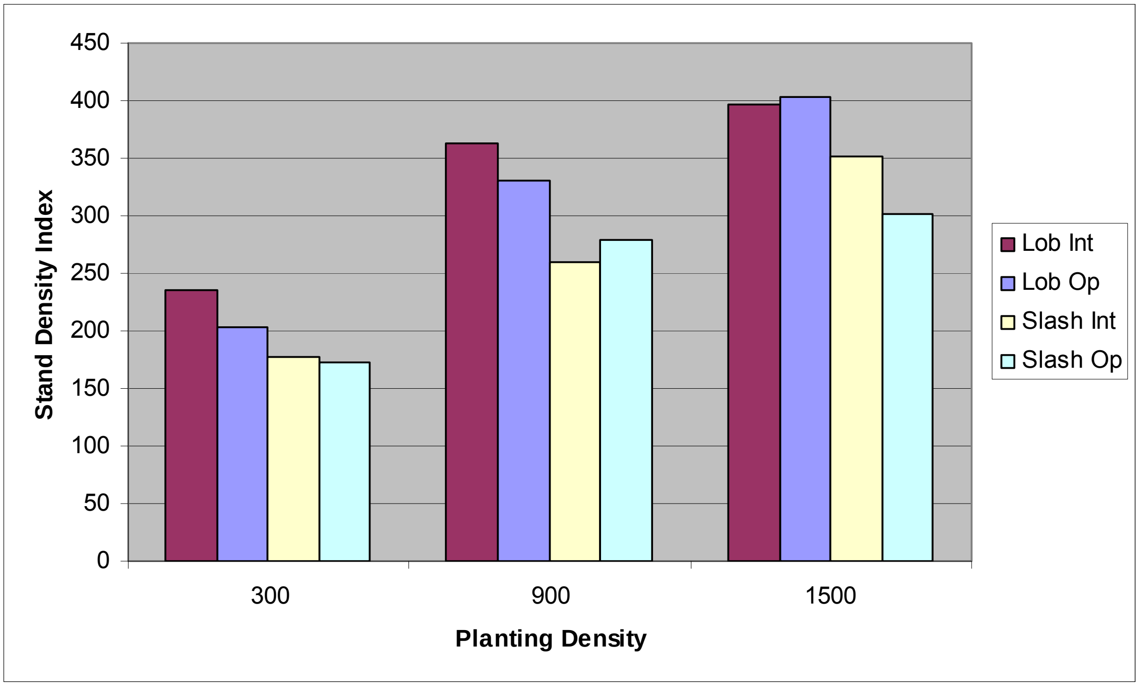


**Figure 61**. Average stand density index by species, management intensity and density at age 12.

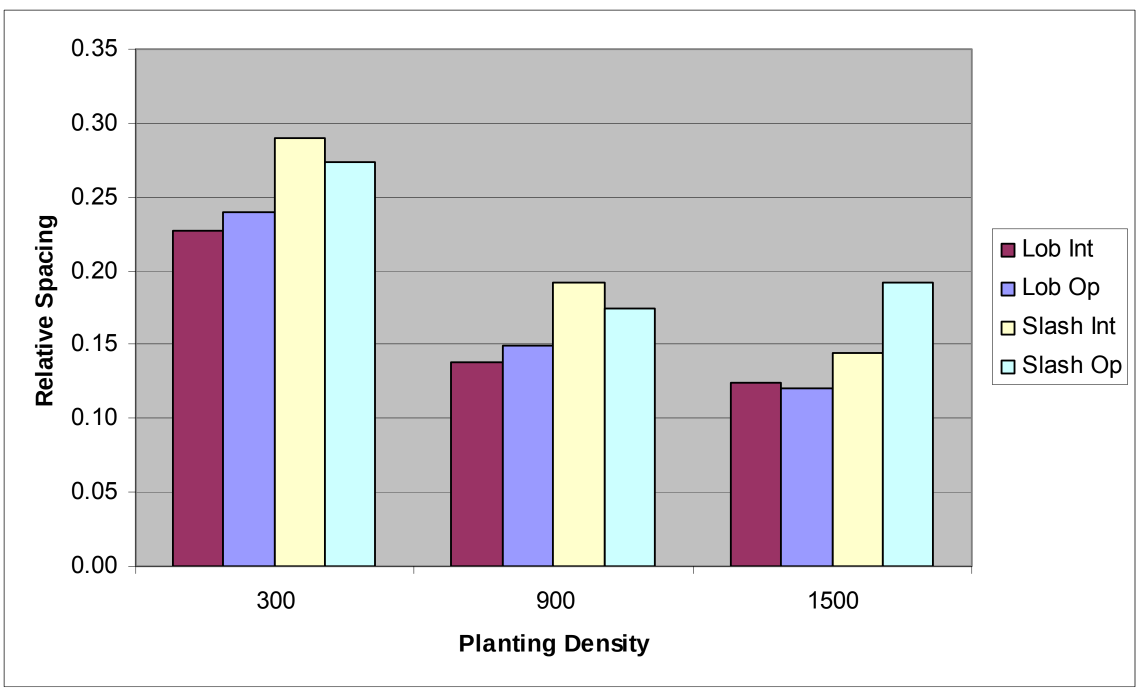


**Figure 62.** Average relative spacing by species, management intensity and density at age 12.

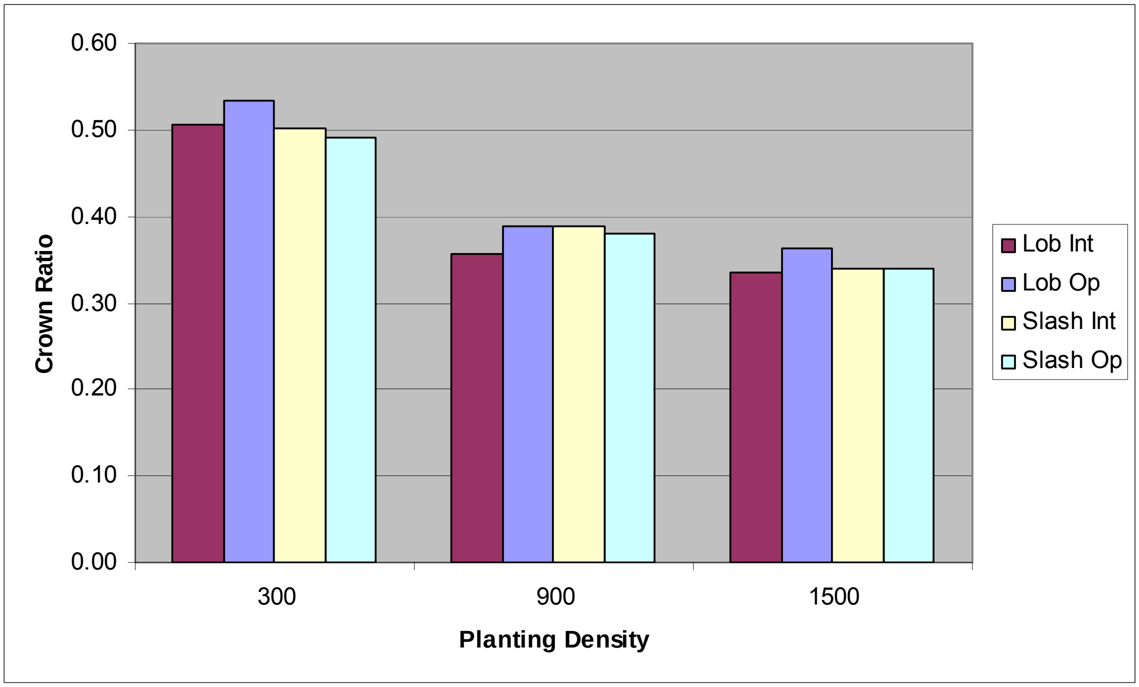


**Figure 63**. Average crown ratio by species, management intensity and density at age 12.

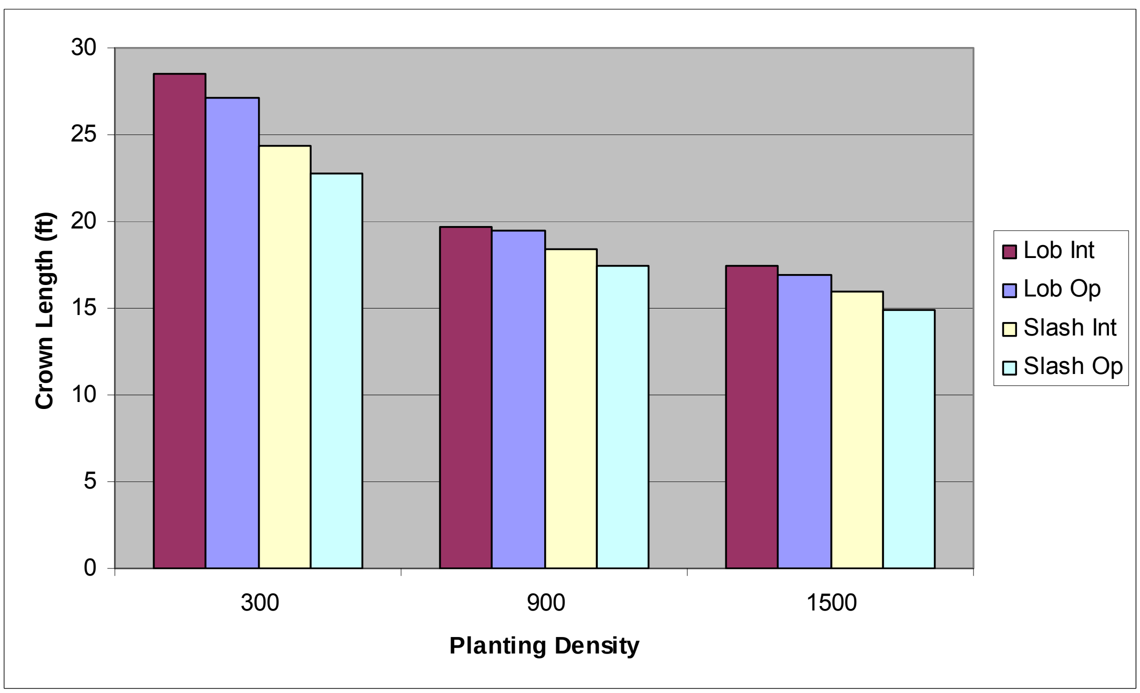


**Figure 64**. Average crown length by species, management intensity and density at age 12.

### 5.2 Comparison of Species by Soil Group

Differences between slash and loblolly pine average tree and stand characteristics for the Culture/ Density study can be clarified, somewhat, by an analysis of the differences on a soil group basis. Unfortunately there were no slash installations established on CRIFF A group soils and the slash pine installations on D group soils have been lost. The graphs here reflect only B1 and B2 nonspodosols and C group spodosols. The breakdown by CRIFF soil group is

| CRIFF Group | Number of Installations |
|---|---|
| B1 | 2 |
| B2 | 2 |
| C | 3 |
| Total | 7 |

Figure 65 shows the average DBH by CRIFF soil group, species, management treatment and initial density. On all soil groups the 300 initial density when combined with high intensity management resulted in larger average DBH values for loblolly as compared to slash pine. On the 900 density there was very little difference in average DBH between species for high intensity. On the operationally-managed plots, there was very little difference in average DBH by species for B1, B2 and C group soils across densities.

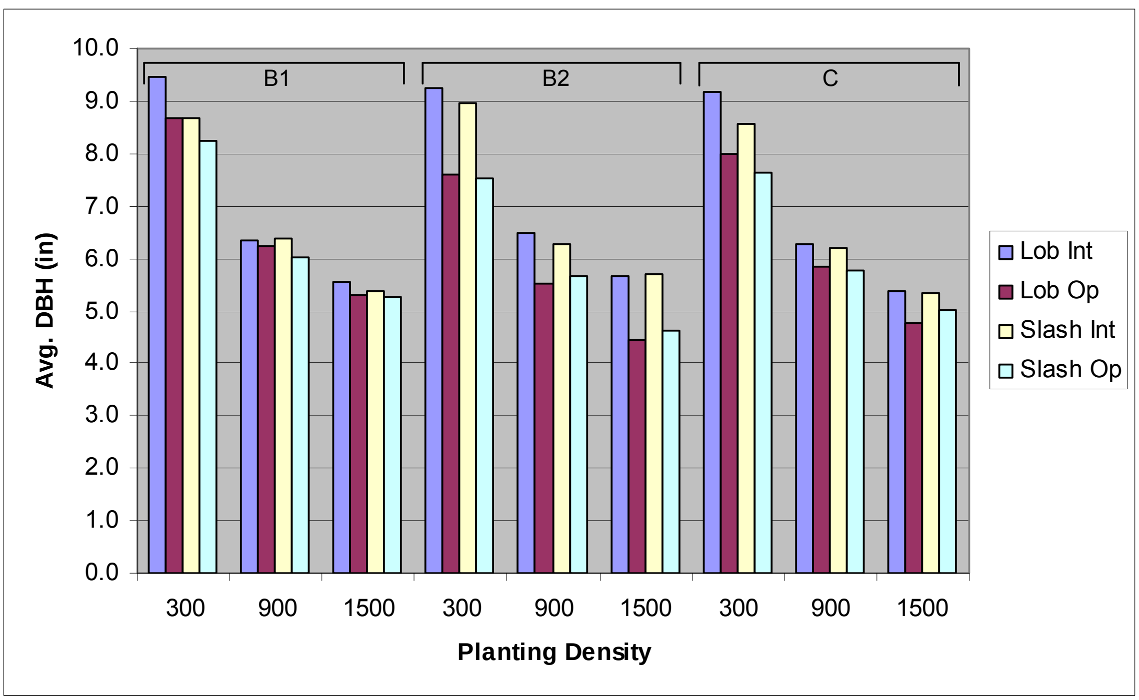


**Figure 65**. Average DBH (in) by CRIFF soil group, species, management intensity and density at age 12.

Loblolly pine had consistently taller average heights than slash pine for all soil and treatment groups (Figure 66). For intensively managed plots this difference was from 5 to 14 feet taller for loblolly. Soil group seemed to have little effect on average heights for either species, though intensively-managed plots were slightly more variable than operationally-managed plots. On the B1 and C soil groups, the operational loblolly pine plots were about 6 feet taller than operationally-managed slash pine plots at all densities. On the B2 soils, operational loblolly plots averaged about 3 feet taller heights than operational slash. The same general trends hold for average dominant height as for average height (Figure 67).

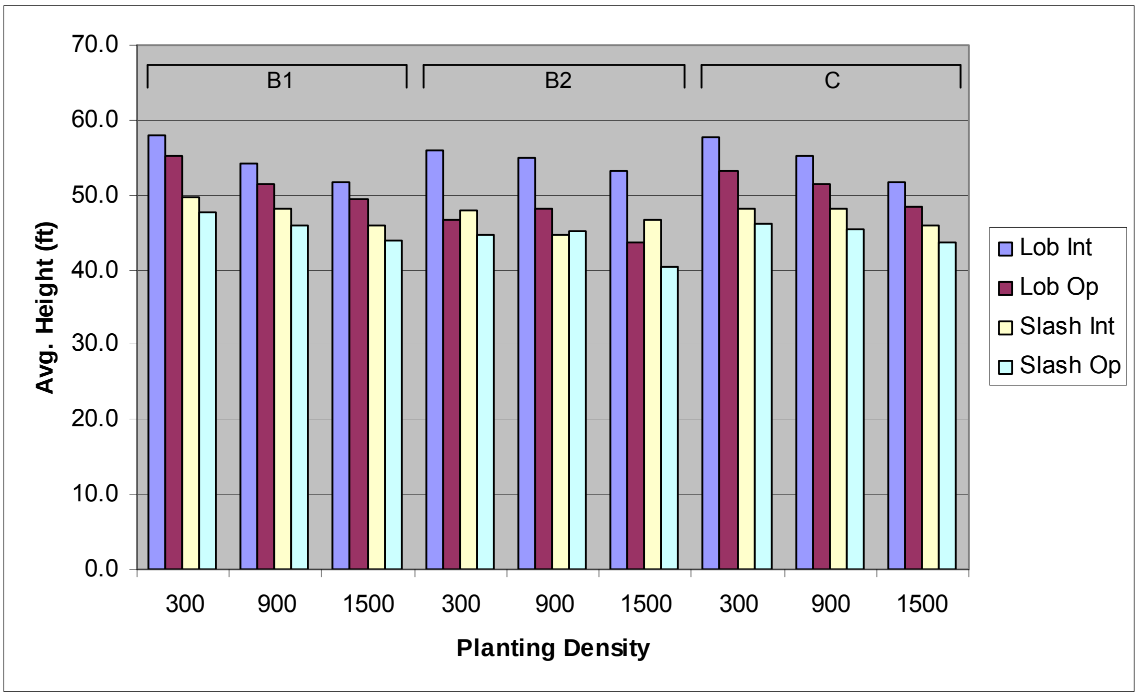


**Figure 66.** Average height (ft) by CRIFF soil group, species, management intensity and density at age 12.

Survival trends for the two species by CRIFF soil group, management intensity, and density are shown in Figure 68. Survival for both species was uniformly good on the spodosols, CRIFF group C. On B1 soils, survival averaged 80% for loblolly and 74% for slash across management and density treatments. On B2 soils, intensively managed slash pine had very poor survival at 61% across all treatments. Loblolly pine averaged 82% survival on the B2 soil group.

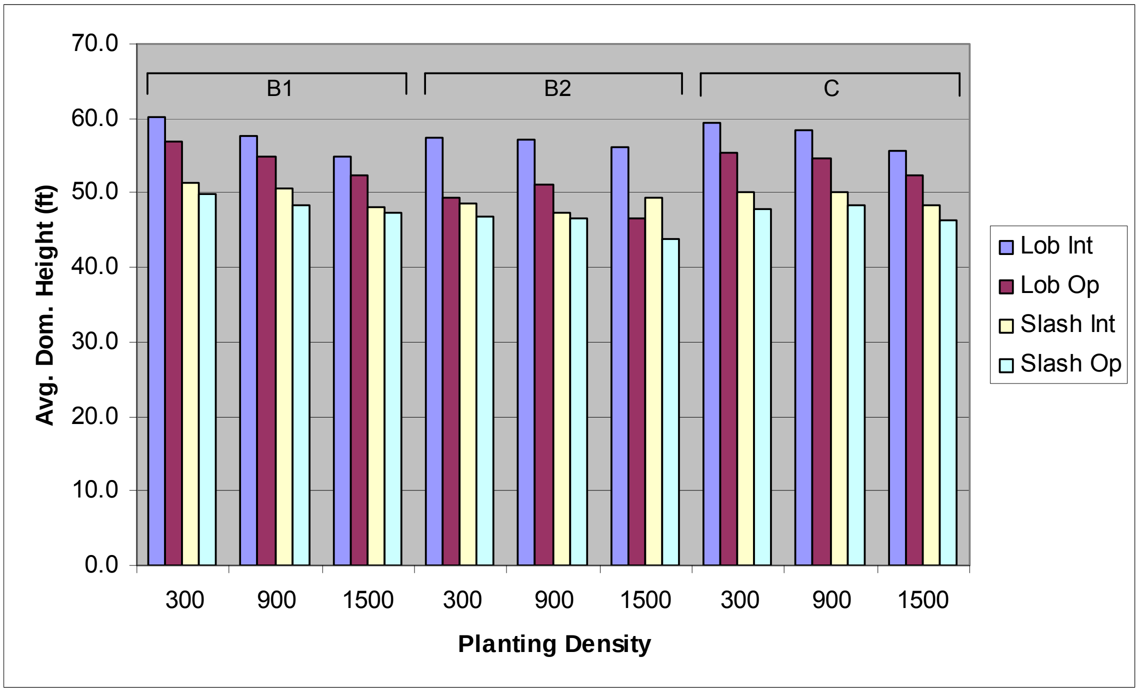


**Figure 67**. Average dominant height (ft) by CRIFF soil group, species, management intensity and density at age 12.

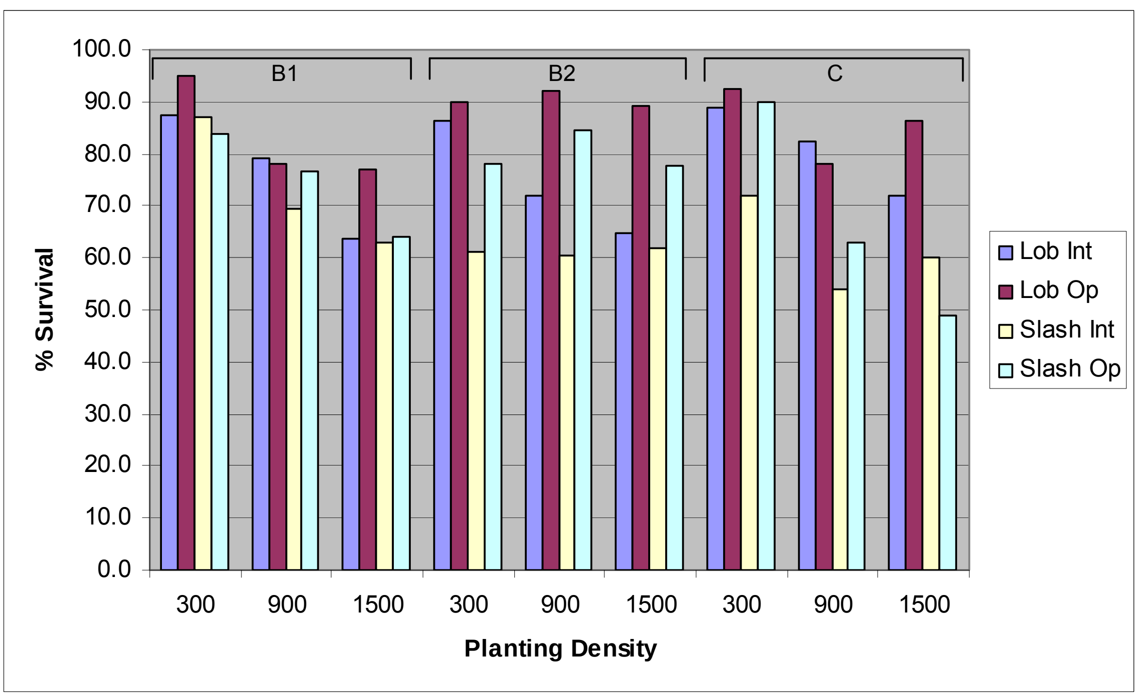


**Figure 68**. Average percent survival by CRIFF soil group, species, management intensity and density at age 12.

Cronartium infection rates were lower on the CRIFF group C spodosols than on the nonspodosol soils (Figure 69). The trend of lower infection levels as density increased is evident on all soil groups, though for slash pine with intensive management, infection levels were high across all densities and all soil groups except C. The B2 soil group had the highest infection rates. Rates from 24-32% may have contributed to the higher mortality rate for slash pine on B2 soils mentioned earlier. Loblolly infection rates were increased by a combination of low initial density (300 trees per acre) and high management intensity, but either raising density or lowering management intensity decreased infection levels noticeably.

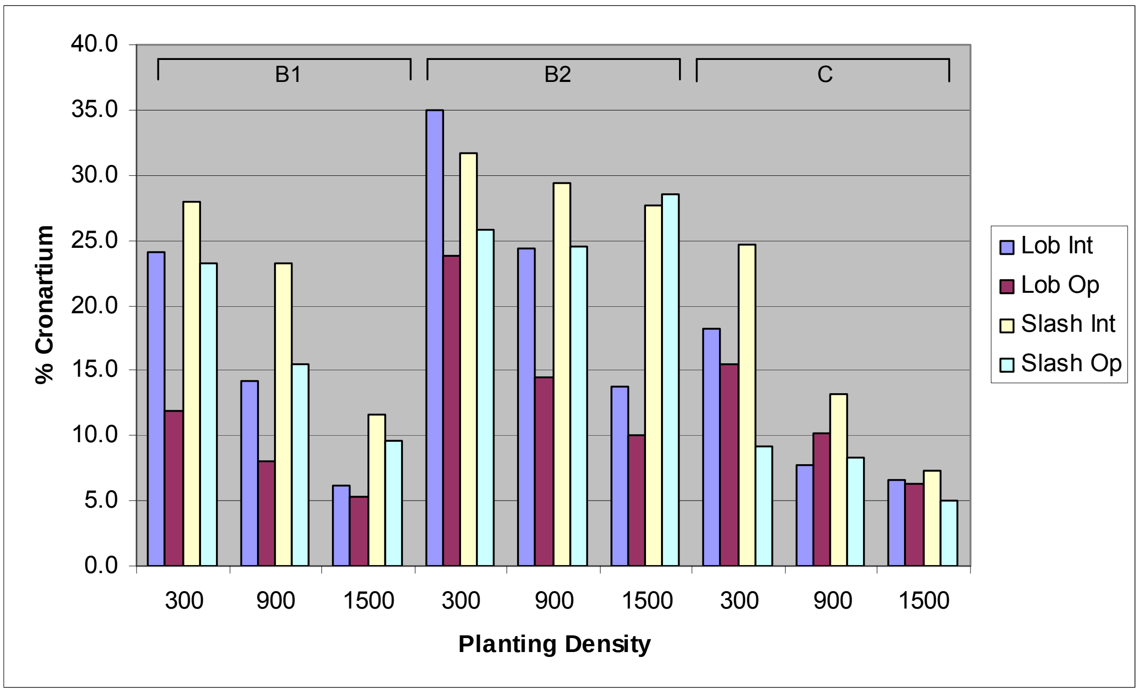


**Figure 69**. Average percent cronartium by CRIFF soil group, species, management intensity and density at age 12.

Loblolly pine had consistently more per-acre basal area than slash pine (Figure 70). On all soil groups, intensively managed loblolly resulted in 21ft$^2$/ac more basal area per acre than slash pine. On the operationally-managed plots, loblolly pine averaged 24ft$^2$/ac more basal area per acre than slash pine.

Loblolly pine with intensive management had more volume than slash pine with intensive management in every soil group and density class (Figure 71). The advantage to loblolly ranged from 892 ft$^3$/ac on the B1 group soils to 1600 ft$^3$/ac on soil group C.

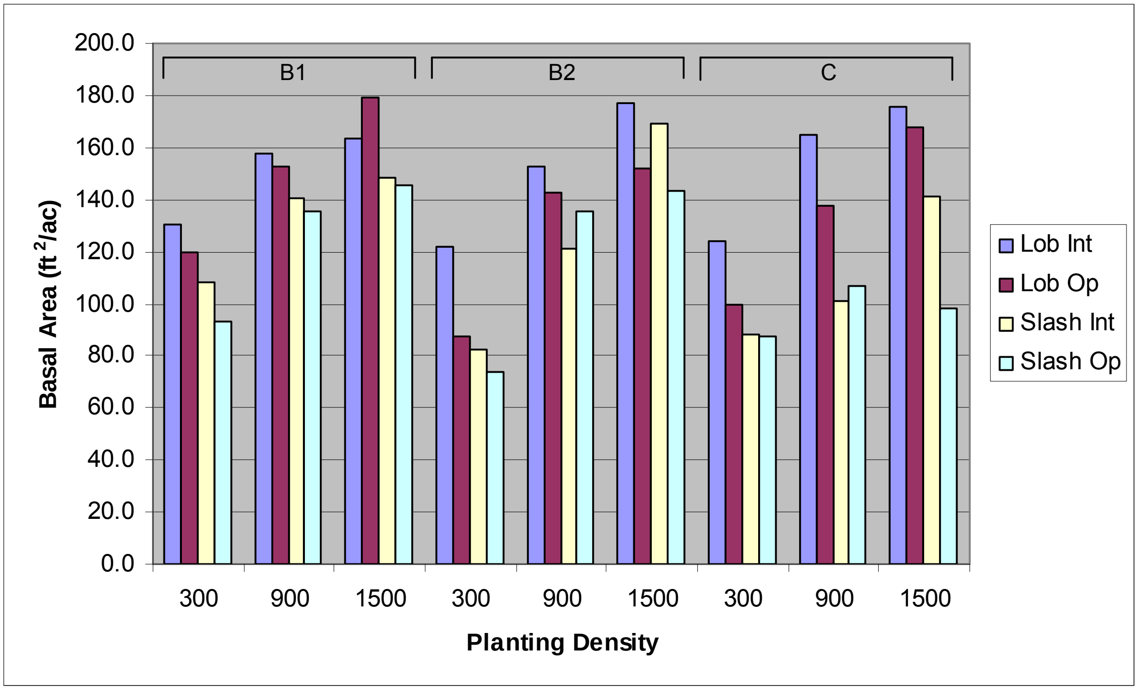


**Figure 70**. Per-acre basal area ($ft^2$/ac) by CRIFF soil group, species, management intensity and density at age 12.

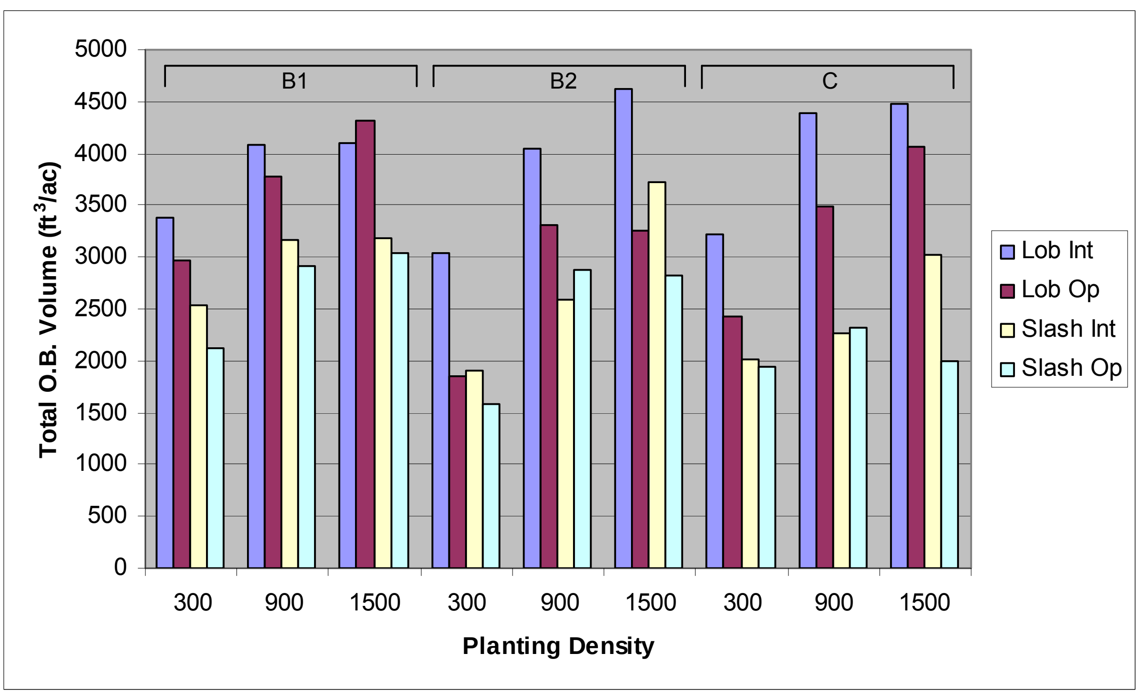


**Figure 71**. Per-acre total outside bark volume ($ft^3$/ac) by CRIFF soil group, species, management intensity and density at age 12.

The trends for total green weight were nearly identical to total volume (Figure 72). The advantage of using intensively managed loblolly rather than intensively managed slash ranged from 22-43 tons/ac at age 12. The advantages of loblolly on the operationally-managed plots ranged from 8-33 tons/ac.

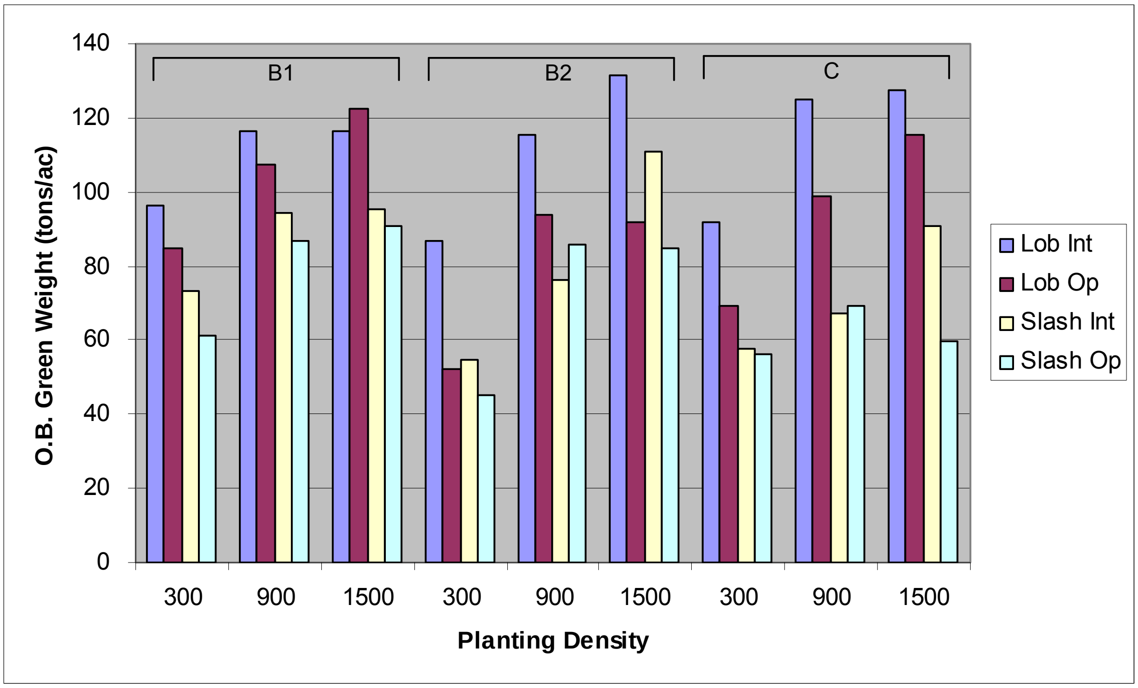


**Figure 72**. Per-acre total outside bark green weight (tons/ac) by CRIFF soil group, species, management intensity and density at age 12.

The stand density index (SDI) comparison for species across soil groups, management intensities, and initial densities at age 12 followed a pattern almost identical to total green weight and total outside bark volume. Loblolly had higher SDI values than slash pine for all soil groups and all initial densities for intensively managed plots.

Because slash pine has a lower maximum SDI value (400) than loblolly (450), the average percentage of maximum SDI values were often higher for slash pine than for loblolly (Figure 73). Most of the 1500 initial density slash pine plots with intensive management were at or near their maximum density at age 12. This indicates that by the next measurement there will either be DBH stagnation, increased mortality or a redefinition of the maximum possible density for slash pine. Intensively managed loblolly plots were also approaching their maximum values.

Since loblolly pine has, on average, less mortality and better height growth, the relative spacing values for slash pine are higher than for loblolly when compared for the same initial density management intensity, and soil group (Figure 74).

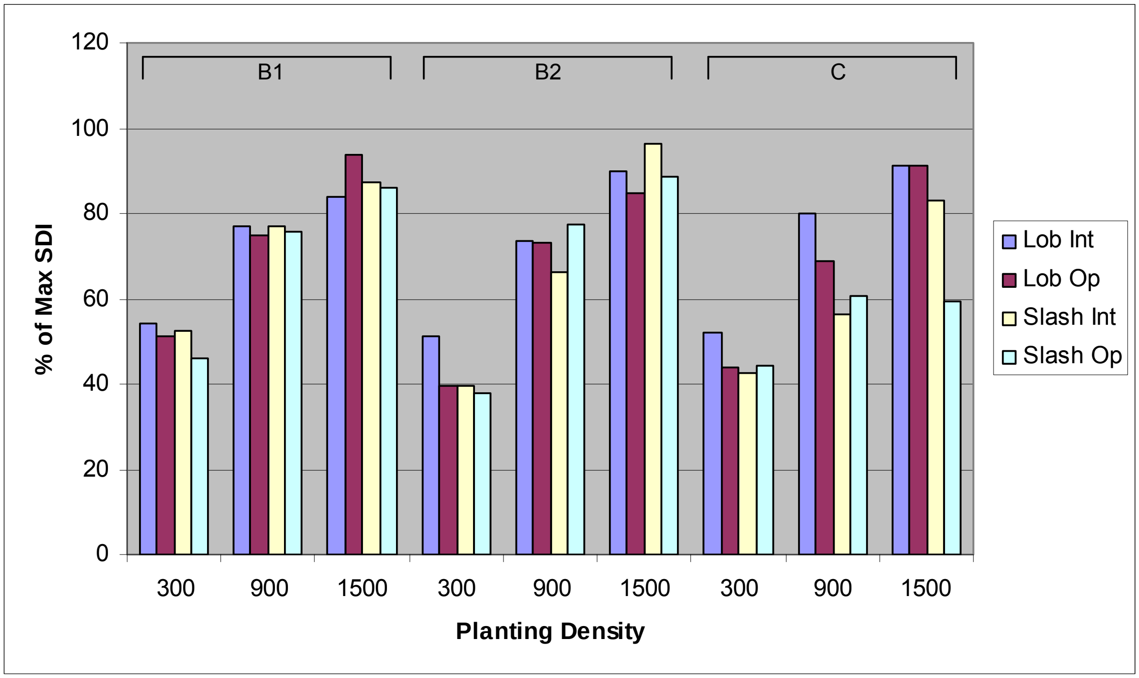


**Figure 73.** Percentage of Maximum Stand Density Index by CRIFF soil group, species, management intensity and density at age 12.

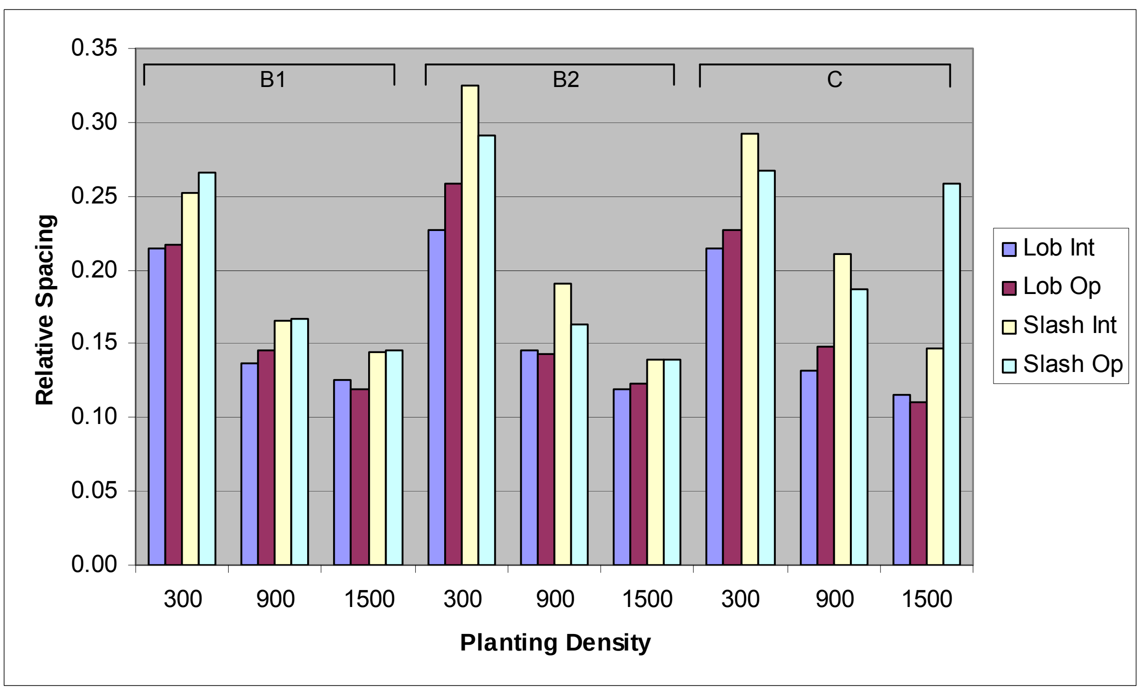


**Figure 74.** Average relative spacing by CRIFF soil group, species, management intensity and density at age 12.

# 6 DISCUSSION AND CONCLUSIONS

The data reported on here are from 12-year-old plantations. Growth rates for both the operational and more intensive treatments have resulted in per-acre basal areas, total volumes, and total green weights greater than normally seen in much older stands with more traditional silviculture. These stand characteristics describe tree dimension as well as stand density and provide interesting criteria to examine differences due to management treatment regime, planting density, species and soil group.

As with numerous studies reported in the literature, more intensive management has resulted in larger average DBH for all spacing treatments and soil groups. An examination of the average DBH for the different spacing treatments shows that the additional competition control and fertilization has accelerated the onset of intra-species competition on the intensive treatment plots. The inverse relationship between average DBH and initial density has become evident for both species and management treatments.

More intensive management has significantly increased height growth at all spacing treatment levels. The increase is particularly true for loblolly pine where intensive management adds more than 5 feet, but is also significant for slash pine. The significant gains from intensive management are significant for dominant height as well as for average height of all trees. Gains are of similar magnitude for dominant height. Somewhat surprising is the finding that initial density affected average height and average dominant height for loblolly and slash pine. Densities of 1200 trees per acre and higher had significantly shorter heights for both species.

On the negative side, more intensive management has increased mortality and the cronartium infection rate compared to the operational treatment. Increased mortality is most likely due to increased intra-species competition due to accelerated growth. The relationship between increased growth and increased cronartium infection has been well-documented and therefore it does not come as a surprise in this study. Slash pine had higher infection rates, in general, than loblolly pine. Perhaps the gains in rust resistance due to tree improvement reflected by populations on this study for loblolly pine have surpassed those of slash pine. The differences in cronartium infection rates for both species seem to be soil related with infection rates much greater on the B2 soil group.

Trends for per-acre basal area, total volume and total green weight were similar for slash and loblolly pine. Each attribute increased with increasing initial density. It is surprising to see intensively-managed slash pine with 1500 initial trees per acre exhibiting a dramatic slowdown in basal area growth by age 8. The basal area growth rate of intensively-managed, high-density loblolly pine basal has also decreased, but not nearly to the extent that slash pine has. This will have significant influence on future modeling efforts with these data.

Many of the plots in this study are now approaching their theoretical maximum densities, but they are approaching at a much earlier age than they would under normal management. It will be interesting to see if they establish new maximum densities as has happened with these species grown in South America and South Africa. If not, we can expect either stagnation or severe mortality in these plots perhaps as early as the next planned remeasurement in two years.

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