# PMRC COASTAL PLAIN CULTURE / DENSITY STUDY:

# AGE 10 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 contain loblolly pine and nine installations also include slash pine at three densities. Both the operational and intensive treatments consisted of chemical site preparation and bedding followed by a fall herbicide treatment applied in five-foot bands over the planted rows. 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. These plots also were sprayed for tip moths during 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 growing season.

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, percent survival, percent cornartium infection, per-acre basal area, per-acre outside bark total volume, per acre total outside bark green weight, stand density index, relative spacing and dominant height for each species.

For loblolly pine, the cultural treatment or management intensity factor and the density factor 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 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 response to more intensive management was about 3 ft greater on the B2 and D soil groups as compared to the other soil groups. Management intensity, density and the soil x density interaction significantly impacted loblolly pine survival through age 10. Operational treatment plots survived better than more intensively managed plots by about 5%. Cronartium infection levels increased with decreasing density. There was also a significant management x density interaction with the 1200 trees per acre and higher treatments having similar infection levels regardless of management and the lower density treatments having higher infection levels on more intensively managed treatments. 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 per-acre basal area, the soil x management factor was also significant. As with other analysis variables, the response to more intensive management was greater on the B2 and D soil groups. For the limiting density variables, stand density index (SDI) and relative spacing (RS), the significant factors are density and management intensity. More intensive management and higher densities result in significantly higher SDI and lower RS values.

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 densities. Management intensity and density were significant factors for average slash pine height. Intensively managed treatments were taller by about 2.3 ft compared to operational treatments. Though density was statistically significant, there was only about a 1 ft difference in average height from 300 to 1500 trees per acre. For average dominant height only management intensity was significant and the difference was about 2.4 ft in favor of the intensive management treatment. No significant factors were found to affect slash pine survival through age 10. Survival by CRIFF soil group ranged from 73.1% on B2 soil to 93.4% on D soils. The density factor significantly affected the cronartium infection rate. Percent infection decreased with increasing density; ranging from 24.2% on 300 TPA plots to 13% on 1500 TPA plots. The spodosol installations, CRIFF C and D, 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, management and planting density had significant effects. The more intensively managed treatments and the higher densities resulted in higher values of all three stand characteristics. For stand density index (SDI) the only significant factor was density with higher densities resulting in significantly higher SDI's. For relative spacing, management intensity, planting density and their interaction were significant factors. As with loblolly pine, the higher densities result in lower RS values. The significant interaction largely results from differences in the B2 soil group. The lower survival rates and higher fusiform rust infection rates result in higher relative spacing values for this group than for the others.

The average DBH, average height, survival, cronartium infection level, basal area, total green weight, total volume, stand density index, and relative spacing 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 0.6" greater DBH at the 300 density with intensive management. For all other treatment/species pairs, the largest difference was about 0.2" Loblolly was 6-8 feet taller than slash pine on the intensive treatments and 4-5 feet taller on the operational plots. In fact, the operational loblolly was taller than intensively-managed slash by an average of 2.7 ft. Both species had good survival, but loblolly had better overall survival by 4-5 percent. The intensively managed slash pine plots had the highest level of cronartium infection. This was at least partially due to the high level of cronartium infection on the slash pine plots located 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 11-14 $ft^2$/ac. On the intensively-managed plots, loblolly had 12-25 $ft^2$/ac more basal area than slash pine. The same trends apply when analyzed by soil group except for the CRIFF D soils. On these well-drained spodosols, operational slash pine had more basal area than loblolly across all densities. Intensively-managed slash had more basal area than loblolly on the 1500 TPA initial density. 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 300-600 $ft^3$/ac for the operational treatments and 660 to 1040 $ft^3$/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 20-27 tons/ac for intensively managed stands and was 8-14 tons/ac for operational stands depending on the initial density. As with basal area, operational slash pine had slightly more yield than loblolly on the D group soils at the higher densities.

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# 1 INTRODUCTION

Industrial forest landowners in the Southeastern U.S. have experienced increasing pressure to maximize per-acre volume production from slash and loblolly 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 researchers have reported significant gains in yield due to tree improvement and more intensive management practices. When contemplating the regeneration of a slash or loblolly pine plantation, forest managers in the Southeastern U.S. 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.
- Describe and compare the development of stand leaf area index (LAI) produced by the various combinations of cultural intensity and stand density.

This report contains the findings of the study though age ten for slash and loblolly pine for the first two objectives.

# 2 METHODS

Seventeen installations were established in the 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.

**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.

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. These plots also were sprayed for tip moths during 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 NH4$NO_3$ 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 growing season. 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 to keep the plots as completely free of competing vegetation as possible. 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.

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 treatments, 8 feet for the 600 and 900 tpa plots and 12 feet for the 300 tpa treatment. Table 2 shows the spacings and plot sizes for the density subplots. 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 17 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.

| Factor | | df |
|---|---|---|
| SOIL | | 4 |
| INST(SOIL) | [error (soil)] | 12 |
| MANAGEMENT | | 1 |
| MANAGEMENT*SOIL | | 4 |
| MANAGEMENT*INST(SOIL) | [error (a)] | 12 |
| DENSITY | | 5 |
| DENSITY*SOIL | | 20 |
| DENSITY*CULTURE | | 5 |
| DENSITY*CULTURE*SOIL | } [error (b)] | 20 |
| DENSITY*INST(SOIL) | } [error (b)] | 60 |
| DENSITY*CULTURE*INST(SOIL) | } [error (b)] | 60 |
| | Corrected total | 203 |

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

# 3 LOBLOLLY PINE RESULTS

After the tenth growing season, diameters of all trees and heights on every other tree were measured. A tree was considered a dominant tree if it was in the upper 50% of diameters on the plot. Each tree 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):

$$VOB = 0.00145519\, DBH^{1.826051}\, HT^{1.221965}$$
$$GWOB = 0.0740959\, DBH^{1.829983}\, HT^{1.247669}$$

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

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

*DBH* = diameter at breast height (in)

*HT* = total tree height (ft)

Analysis of variance as described above was carried out for average DBH, average height, average dominant height, percent survival, percent cornartium infection, per-acre basal area, total per-acre total volume, total per acre green weight, stand density index and relative spacing. Table 4 shows the loblolly pine means by soil type, management intensity and initial density.

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

**CRIFF Soil Type A**

| Management | Plant Density | Avg. DBH (in) | Avg. Height (ft) | Avg. Dom. Height | % Surv | % Cron | Basal Area ($ft^2$/ac) | Total Vol ($ft^3$/ac) | Total Grn. Wt (tons/ac) |
|---|---|---|---|---|---|---|---|---|---|
| Intensive | 300 | 9.3 | 47.1 | 49.0 | 80.8 | 35.3 | 116.6 | 2409 | 68 |
| | 600 | 7.5 | 49.9 | 51.6 | 85.8 | 34.5 | 160.6 | 3634 | 103 |
| | 900 | 6.5 | 48.7 | 50.9 | 80.6 | 27.9 | 171.4 | 3883 | 110 |
| | 1200 | 5.8 | 47.9 | 50.5 | 84.2 | 22.6 | 189.8 | 4291 | 122 |
| | 1500 | 5.6 | 46.5 | 49.4 | 61.7 | 23.4 | 160.1 | 3598 | 102 |
| | 1800 | 5.0 | 45.5 | 47.8 | 80.4 | 15.3 | 200.3 | 4368 | 124 |
| Operational | 300 | 7.9 | 42.9 | 45.0 | 90.4 | 23.1 | 95.1 | 1802 | 51 |
| | 600 | 6.7 | 42.9 | 45.1 | 83.3 | 22.6 | 123.5 | 2441 | 69 |
| | 900 | 5.9 | 44.6 | 47.7 | 90.3 | 24.3 | 159.0 | 3309 | 94 |
| | 1200 | 5.4 | 43.7 | 46.7 | 83.1 | 16.5 | 164.3 | 3415 | 97 |
| | 1500 | 4.9 | 41.2 | 44.4 | 79.0 | 18.7 | 163.5 | 3221 | 91 |
| | 1800 | 4.9 | 41.4 | 44.3 | 71.9 | 12.4 | 171.3 | 3375 | 95 |

**CRIFF Soil Type B1**

| Management | Plant Density | Avg. DBH (in) | Avg. Height (ft) | Avg. Dom. Height | % Surv | % Cron | Basal Area ($ft^2$/ac) | Total Vol ($ft^3$/ac) | Total Grn. Wt (tons/ac) |
|---|---|---|---|---|---|---|---|---|---|
| Intensive | 300 | 8.9 | 51.7 | 54.1 | 91.3 | 26.6 | 119.9 | 2736 | 78 |
| | 600 | 6.8 | 50.5 | 52.1 | 81.3 | 12.8 | 126.4 | 2943 | 84 |
| | 900 | 5.9 | 48.5 | 50.9 | 90.1 | 14.3 | 156.8 | 3542 | 100 |
| | 1200 | 5.5 | 48.6 | 50.8 | 83.8 | 5.8 | 169.6 | 3940 | 112 |
| | 1500 | 5.0 | 46.2 | 49.2 | 74.4 | 6.2 | 157.6 | 3509 | 99 |
| | 1800 | 4.9 | 46.2 | 49.8 | 69.8 | 2.9 | 168.2 | 3796 | 107 |
| Operational | 300 | 7.9 | 48.8 | 50.6 | 96.3 | 11.0 | 101.5 | 2206 | 63 |
| | 600 | 6.5 | 47.1 | 50.1 | 88.8 | 9.8 | 124.1 | 2721 | 77 |
| | 900 | 5.8 | 45.4 | 48.7 | 80.7 | 7.0 | 135.9 | 2920 | 83 |
| | 1200 | 5.1 | 44.2 | 47.6 | 78.8 | 9.5 | 139.4 | 2994 | 85 |
| | 1500 | 4.8 | 43.1 | 46.5 | 83.8 | 5.2 | 160.8 | 3352 | 95 |
| | 1800 | 4.5 | 41.8 | 45.7 | 78.3 | 5.8 | 157.0 | 3235 | 91 |

**CRIFF Soil Type B2**

| Management | Plant Density | Avg. DBH (in) | Avg. Height (ft) | Avg. Dom. Height | % Surv | % Cron | Basal Area ($ft^2$/ac) | Total Vol ($ft^3$/ac) | Total Grn. Wt (tons/ac) |
|---|---|---|---|---|---|---|---|---|---|
| Intensive | 300 | 8.6 | 50.3 | 51.8 | 88.3 | 31.7 | 108.9 | 2425 | 69 |
| | 600 | 6.6 | 49.2 | 51.0 | 85.4 | 25.1 | 126.6 | 2879 | 82 |
| | 900 | 6.0 | 49.6 | 51.3 | 78.1 | 24.5 | 144.2 | 3384 | 96 |
| | 1200 | 5.5 | 49.7 | 52.1 | 84.7 | 16.1 | 175.1 | 4178 | 119 |
| | 1500 | 5.3 | 49.6 | 52.6 | 74.0 | 11.4 | 174.0 | 4211 | 119 |
| | 1800 | 4.7 | 46.1 | 49.5 | 81.0 | 11.3 | 178.8 | 4064 | 115 |
| Operational | 300 | 7.0 | 42.8 | 45.2 | 90.8 | 24.9 | 75.7 | 1460 | 41 |
| | 600 | 5.8 | 44.2 | 46.4 | 93.8 | 22.1 | 105.5 | 2173 | 61 |
| | 900 | 5.1 | 44.9 | 47.3 | 92.0 | 13.3 | 123.1 | 2634 | 75 |
| | 1200 | 4.4 | 40.2 | 43.2 | 86.1 | 12.6 | 116.2 | 2292 | 65 |
| | 1500 | 4.2 | 41.1 | 44.1 | 91.7 | 10.6 | 139.5 | 2797 | 79 |
| | 1800 | 3.9 | 39.9 | 43.1 | 91.3 | 9.3 | 146.2 | 2889 | 81 |

**CRIFF Soil Type C**

| Management | Plant Density | Avg. DBH (in) | Avg. Height (ft) | Avg. Dom. Height | % Surv | % Cron | Basal Area ($ft^2/ac$) | Total Vol ($ft^3/ac$) | Total Grn. Wt (tons/ac) |
|---|---|---|---|---|---|---|---|---|---|
| Intensive | 300 | 8.5 | 51.0 | 53.0 | 92.5 | 19.4 | 111.1 | 2531 | 72 |
| | 600 | 6.8 | 51.8 | 54.6 | 92.3 | 11.9 | 142.6 | 3471 | 99 |
| | 900 | 5.8 | 49.5 | 52.4 | 90.0 | 9.1 | 153.9 | 3661 | 104 |
| | 1200 | 5.3 | 47.6 | 50.7 | 88.3 | 4.2 | 166.6 | 3864 | 110 |
| | 1500 | 4.9 | 46.8 | 50.2 | 85.4 | 6.3 | 175.1 | 4042 | 114 |
| | 1800 | 4.7 | 46.5 | 49.9 | 74.0 | 5.6 | 164.9 | 3785 | 107 |
| Operational | 300 | 7.3 | 46.9 | 48.6 | 93.3 | 14.8 | 84.3 | 1786 | 51 |
| | 600 | 6.3 | 49.0 | 51.2 | 92.0 | 13.7 | 122.3 | 2811 | 80 |
| | 900 | 5.3 | 46.5 | 49.6 | 92.3 | 9.3 | 133.7 | 3015 | 85 |
| | 1200 | 4.7 | 43.3 | 46.7 | 94.0 | 6.7 | 142.7 | 3032 | 86 |
| | 1500 | 4.4 | 43.7 | 47.0 | 90.8 | 6.7 | 148.6 | 3217 | 91 |
| | 1800 | 4.2 | 43.1 | 46.9 | 86.1 | 6.6 | 153.1 | 3315 | 94 |

**CRIFF Soil Type D**

| Management | Plant Density | Avg. DBH (in) | Avg. Height (ft) | Avg. Dom. Height | % Surv | % Cron | Basal Area ($ft^2/ac$) | Total Vol ($ft^3/ac$) | Total Grn. Wt (tons/ac) |
|---|---|---|---|---|---|---|---|---|---|
| Intensive | 300 | 8.7 | 50.0 | 51.5 | 90.6 | 8.1 | 112.1 | 2482 | 71 |
| | 600 | 6.9 | 51.9 | 53.8 | 85.6 | 5.3 | 134.2 | 3250 | 92 |
| | 900 | 6.1 | 50.2 | 52.8 | 89.6 | 4.6 | 169.7 | 4028 | 114 |
| | 1200 | 5.2 | 47.6 | 49.9 | 87.5 | 3.7 | 161.6 | 3701 | 105 |
| | 1500 | 4.8 | 45.6 | 48.2 | 87.8 | 3.6 | 168.5 | 3777 | 107 |
| | 1800 | 4.5 | 44.9 | 48.3 | 86.4 | 3.8 | 181.7 | 4031 | 114 |
| Operational | 300 | 7.0 | 43.6 | 44.5 | 89.4 | 5.4 | 72.3 | 1399 | 40 |
| | 600 | 5.5 | 40.8 | 43.5 | 92.5 | 4.6 | 94.4 | 1813 | 51 |
| | 900 | 4.8 | 39.4 | 41.8 | 84.9 | 4.1 | 101.6 | 1903 | 54 |
| | 1200 | 4.3 | 38.4 | 41.4 | 91.7 | 6.2 | 117.3 | 2207 | 62 |
| | 1500 | 3.9 | 37.8 | 41.4 | 95.6 | 2.6 | 128.3 | 2405 | 68 |
| | 1800 | 3.9 | 37.0 | 40.7 | 85.1 | 3.8 | 137.2 | 2609 | 73 |

## 3.1 Average DBH

Table 5 shows the results of the analysis of variance for average DBH for loblolly pine. The management intensity factor was 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 type.

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

| Source | Type III F | Pr > F |
|---|---|---|
| Soil | 3.37 | 0.0541 |
| Management | 131.00 | <0.0001* |
| Soil x Management | 3.49 | 0.0495* |
| Density | 1187.80 | <0.0001* |
| Soil x Density | 1.01 | 0.4570 |
| Management x Density | 15.50 | <0.0001* |

*Significant at α = 0.05.

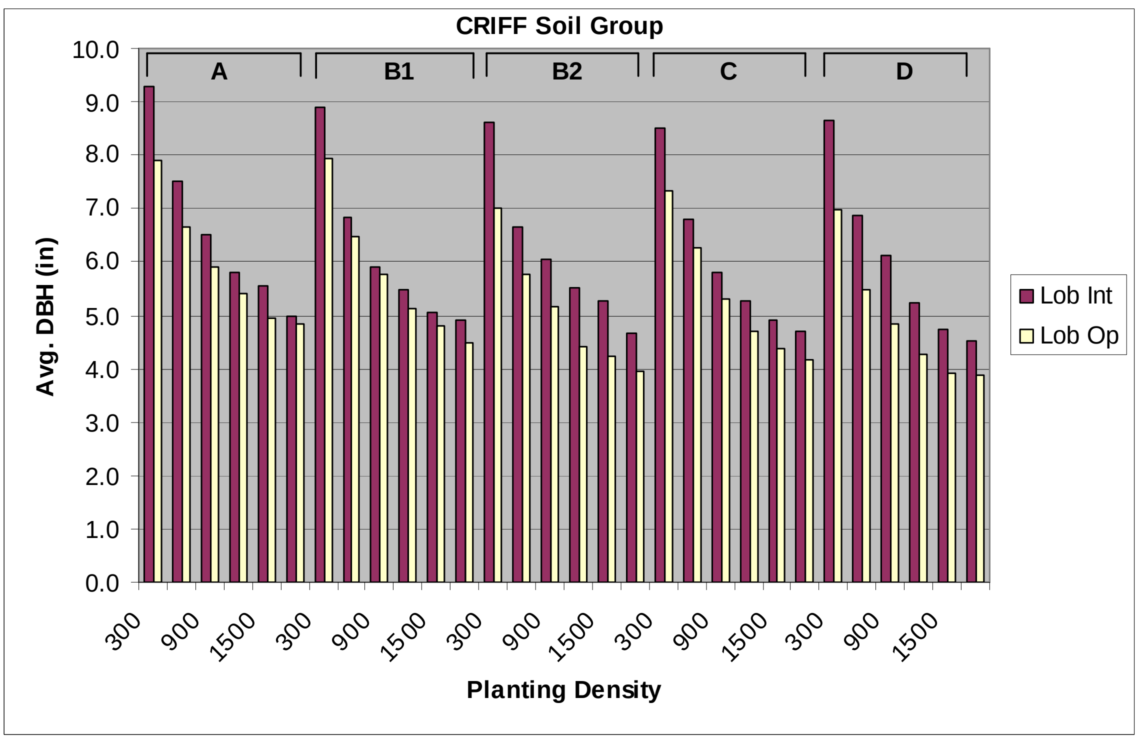


**Figure 1**. Average DBH by CRIFF soil group, planting density and management intensity for loblolly pine at age ten.

Several factors deserve mention as a result of this analysis and graph. The increase in DBH due to management intensity 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 600-1200 TPA and 0.5” for the 1800 TPA treatment.

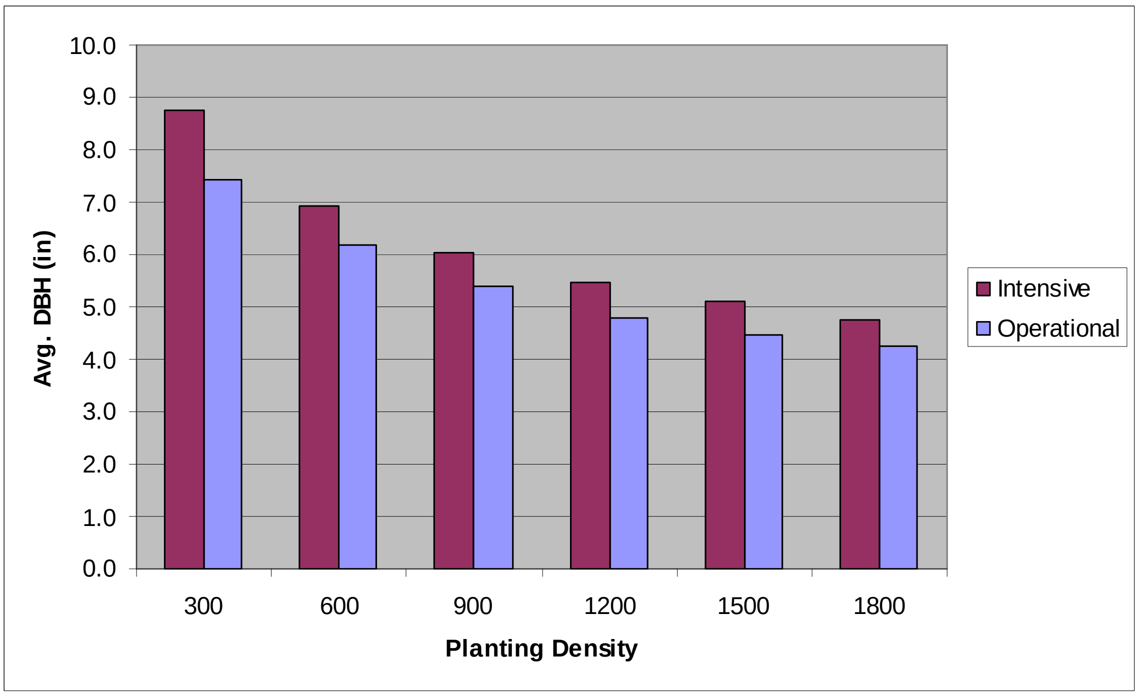


**Figure 2**. Average DBH by planting density and management intensity for loblolly pine at age ten.

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 competition effect of the 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 10.

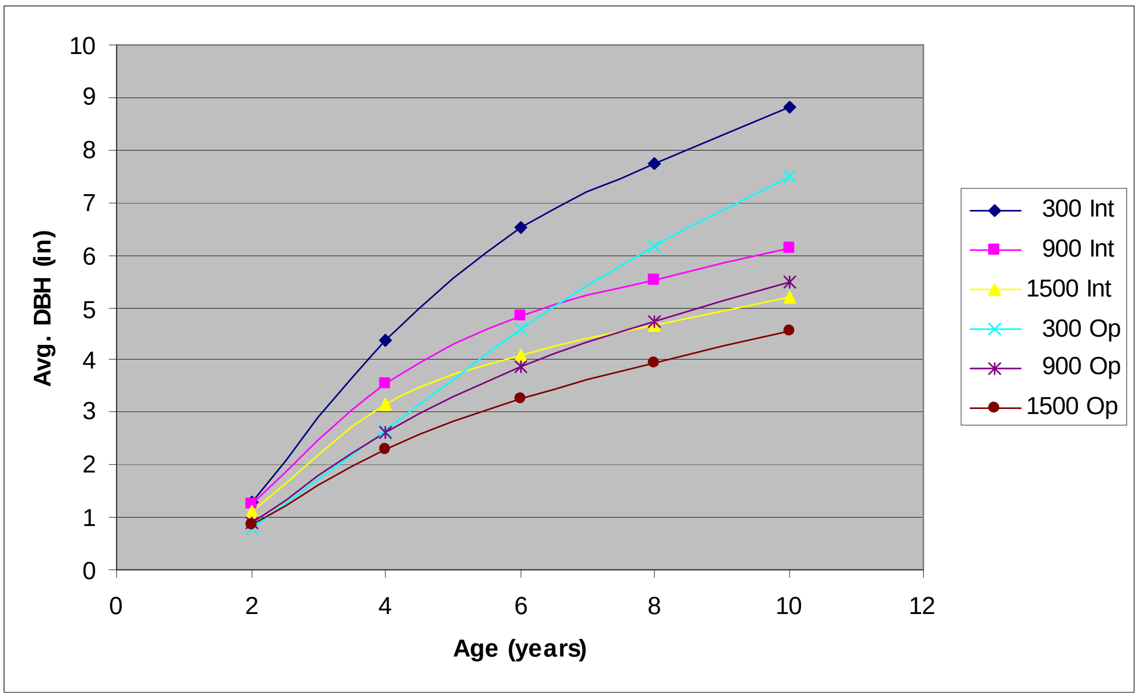


**Figure 3.** Average DBH growth by planting density and management intensity for selected loblolly pine treatments at age ten.

### 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 acre) had the highest average heights for both management treatment groups. It is unusual to see initial density as a significant factor for average height. In the range of densities that we normally manage loblolly pine, density is not significant. This study, however, extends that 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 height among the 300, 600 and 900 TPA densities, but there was a trend toward lower average height for as initial density increases. 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 only 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 ten.

| Source | Type III F | Pr > F |
|---|---|---|
| Soil | 0.89 | 0.5023 |
| Management | 129.32 | <0.0001* |
| Soil x Management | 4.48 | 0.0249* |
| Density | 26.60 | <0.0001* |
| Soil x Density | 1.63 | 0.0563 |
| Management x Density | 0.50 | 0.7749 |

*Significant at $\alpha = 0.05$.

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 3.9 feet for the A, B1 and C soil groups. The increase in height due to more intensive management was 6.9 feet and 8.9 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 ten compared to previous years. The differences due to management intensity have remained consistent from ages 6 through 10.

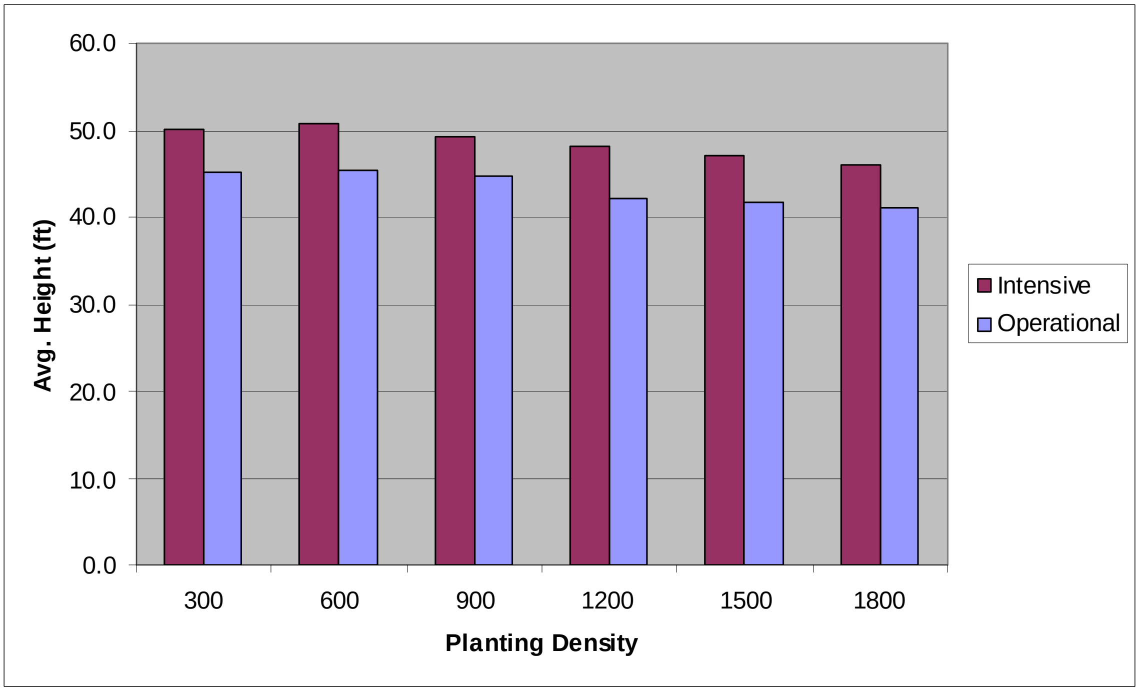


**Figure 4**. Average height by planting density and management intensity for loblolly pine at age ten.

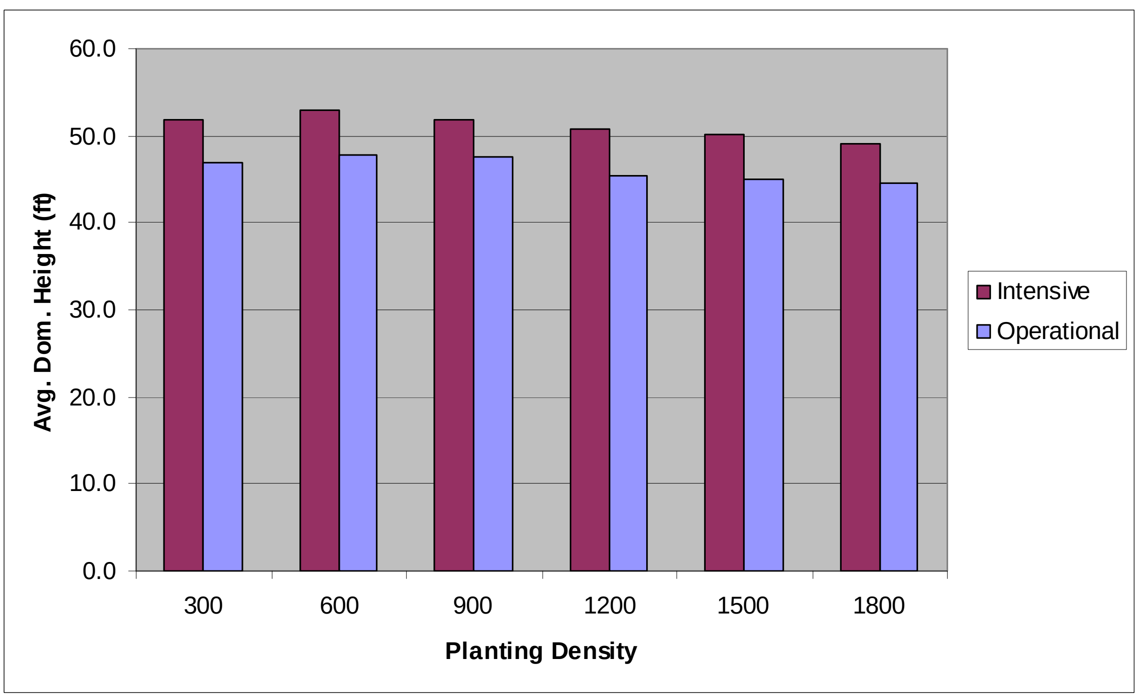


**Figure 5**. Average dominant height by planting density and management intensity for loblolly pine at age ten.

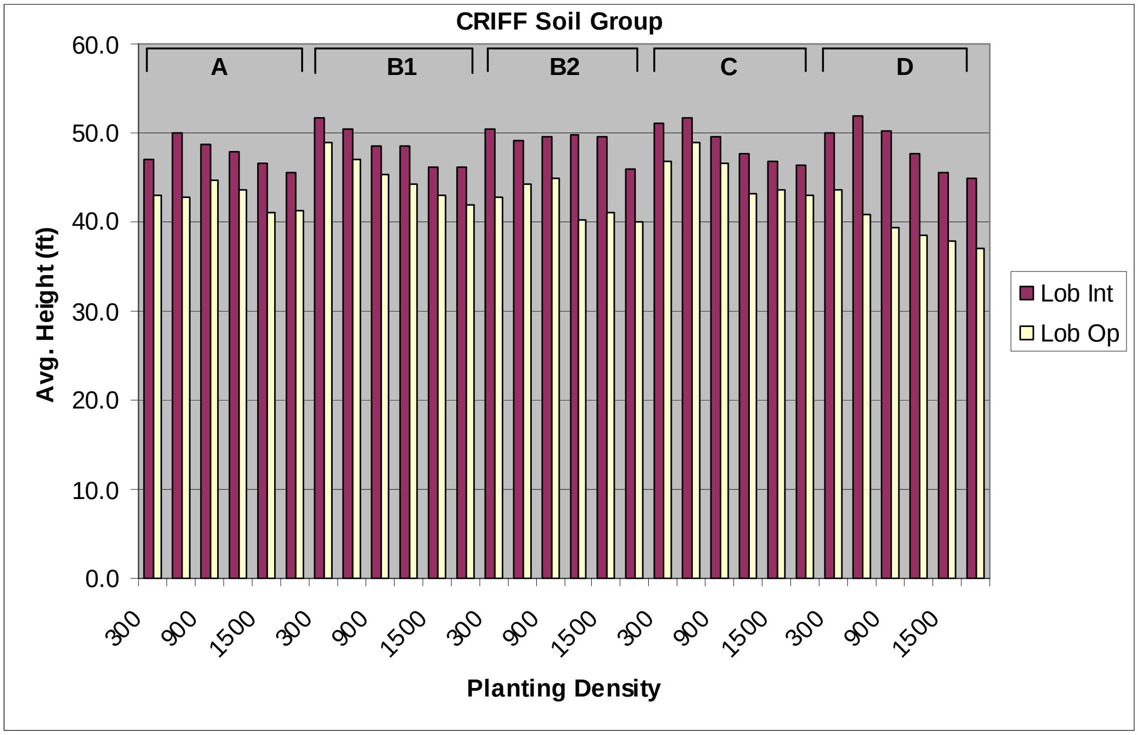


**Figure 6**. Average height by CRIFF soil group, planting density and management intensity for loblolly pine at age ten.

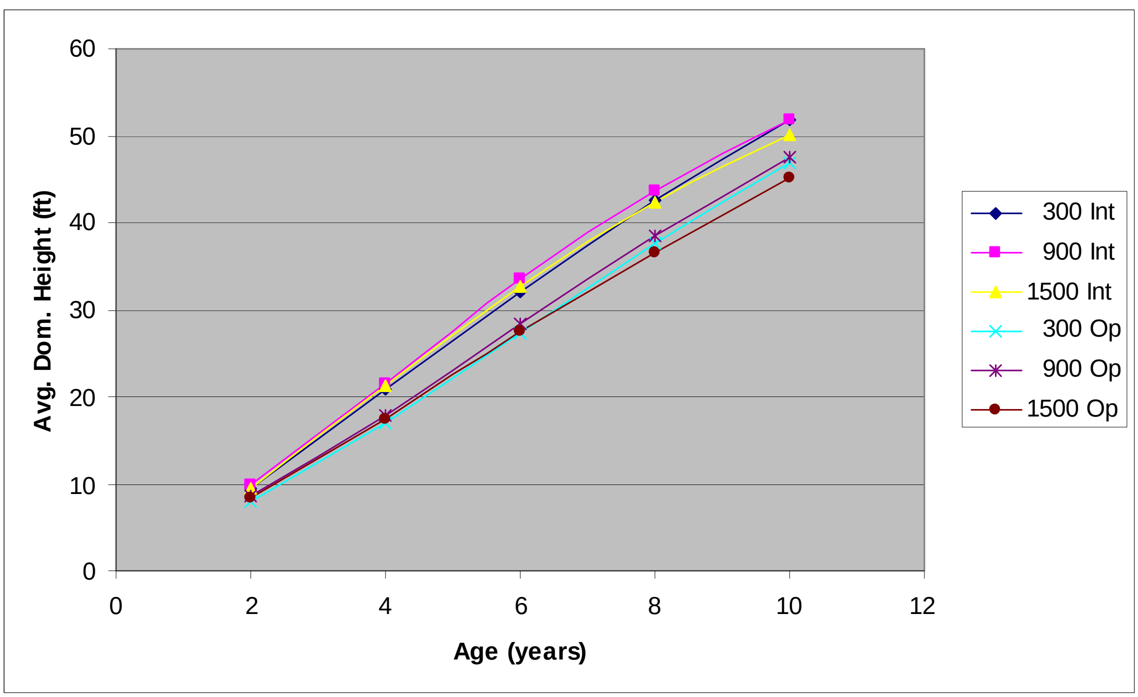


**Figure 7**. Average dominant height growth by planting density and management intensity for selected loblolly pine treatments at age ten.

### 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 77-92% for loblolly pine. This was primarily the survival from age one to age ten 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 5%. The differences due to management for the 1500 and 1800 TPA treatments were skewed, somewhat, by individual plots that had experienced excessive mortality (39-50%) by age ten.

A significant Soil x Density effect was also observed at age ten (Table 7). Figure 9 illustrates that the interaction may be attributable to the differences among soil group between the average survival of initial densities 300-1200 TPA and the average survival of the 1500 and 1800 TPA densities. Survival differences between these two groups range from 11.6% on soil group A to 0.3% on soil group D.

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

| Source | Type III F | Pr > F |
|---|---|---|
| Soil | 0.75 | 0.5786 |
| Management | 12.16 | 0.0058* |
| Soil x Management | 0.96 | 0.4707 |
| Density | 9.05 | <0.0001* |
| Soil x Density | 1.71 | 0.0404* |
| Management x Density | 2.09 | 0.0714 |

*Significant at $\alpha = 0.05$.

Figure 10 shows survival curves (ages 2-10 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.

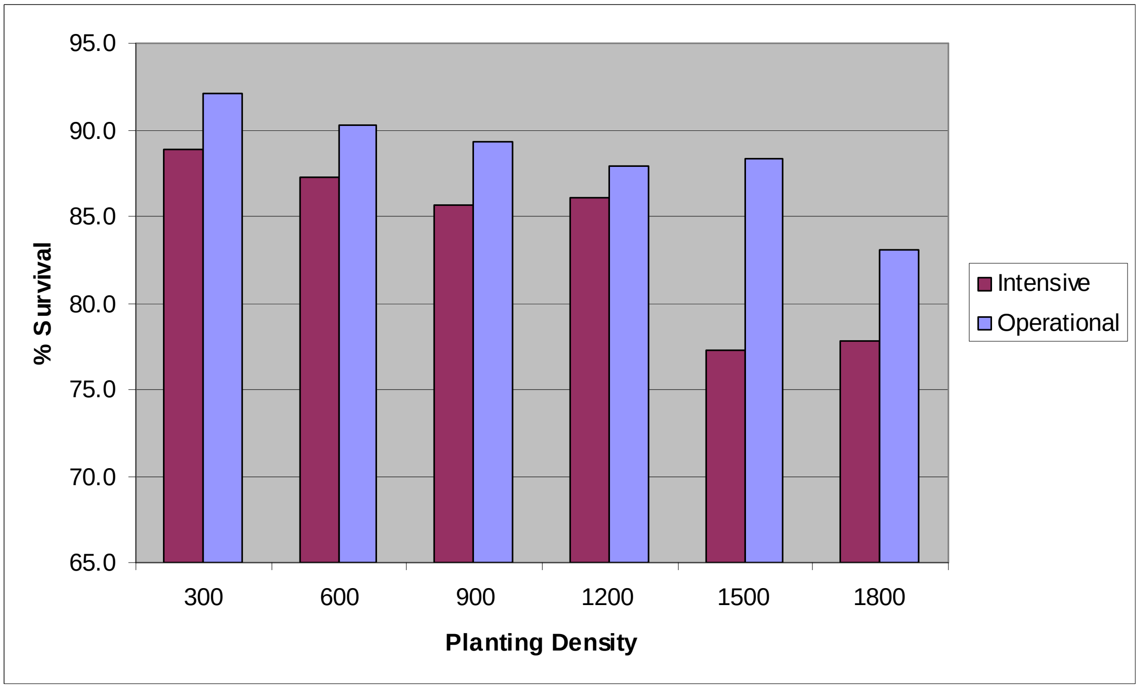


**Figure 8.** Percent survival by planting density and management intensity for loblolly pine at age ten.

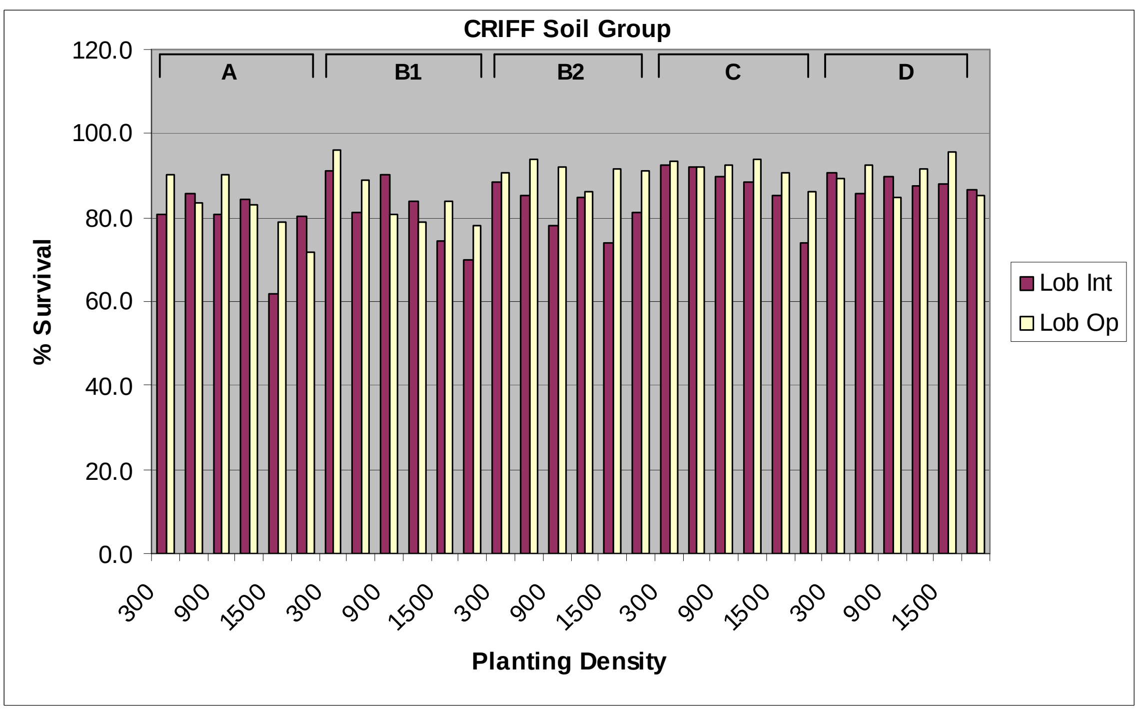


**Figure 9.** Percent survival by CRIFF soil group, planting density and management intensity for loblolly pine at age ten.

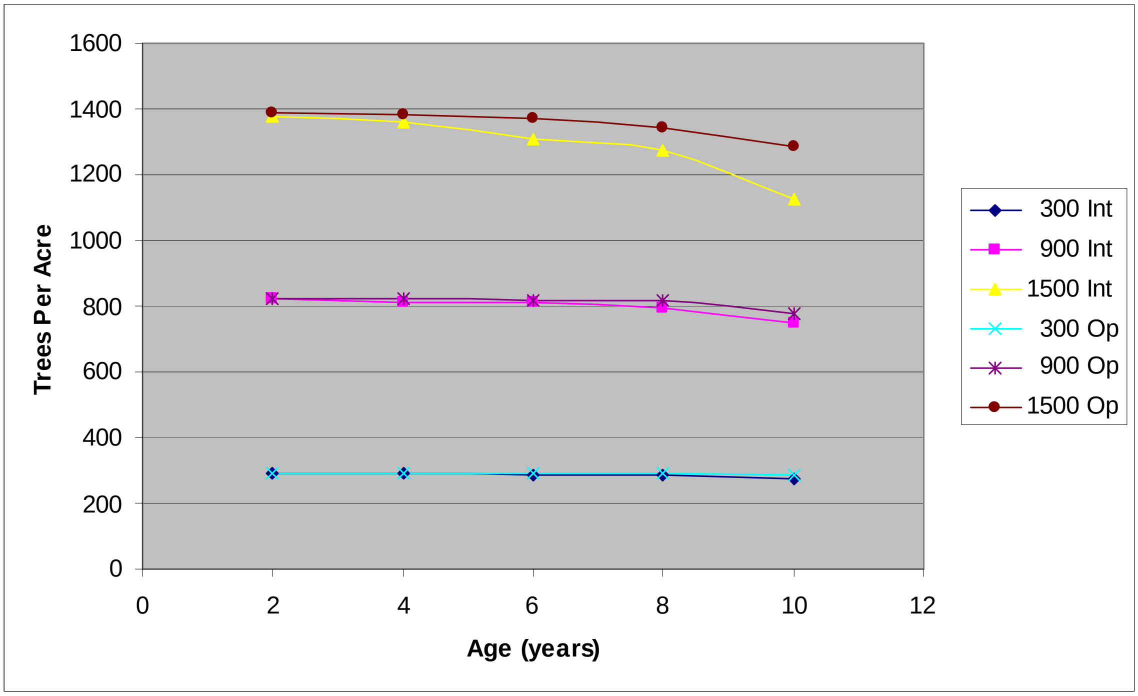


**Figure 10.** Trees per acre development by planting density and management intensity for selected loblolly pine treatments.

### 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 24% for all densities and management regimes. Management intensity, initial density and their interaction 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. Though soil type was not significant at the 5% level, it was at the 10% level. 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 ten.

| Source | Type III F | Pr > F |
|---|---|---|
| Soil | 3.08 | 0.0680 |
| Management | 7.54 | 0.0206* |
| Soil x Management | 1.83 | 0.1994 |
| Density | 24.22 | <0.0001* |
| Soil x Density | 1.55 | 0.0764 |
| Management x Density | 2.59 | 0.0293* |

*Significant at α = 0.05.

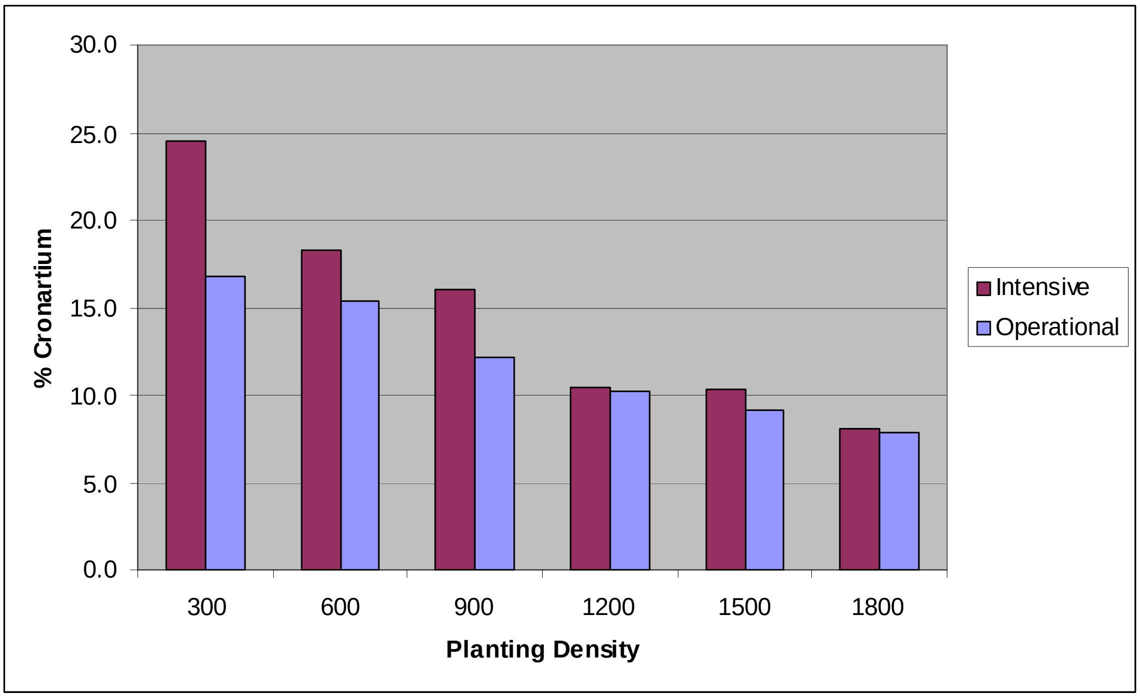


**Figure 11.** Average percent cronartium infection by planting density and management intensity for loblolly pine at age ten.

### 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.

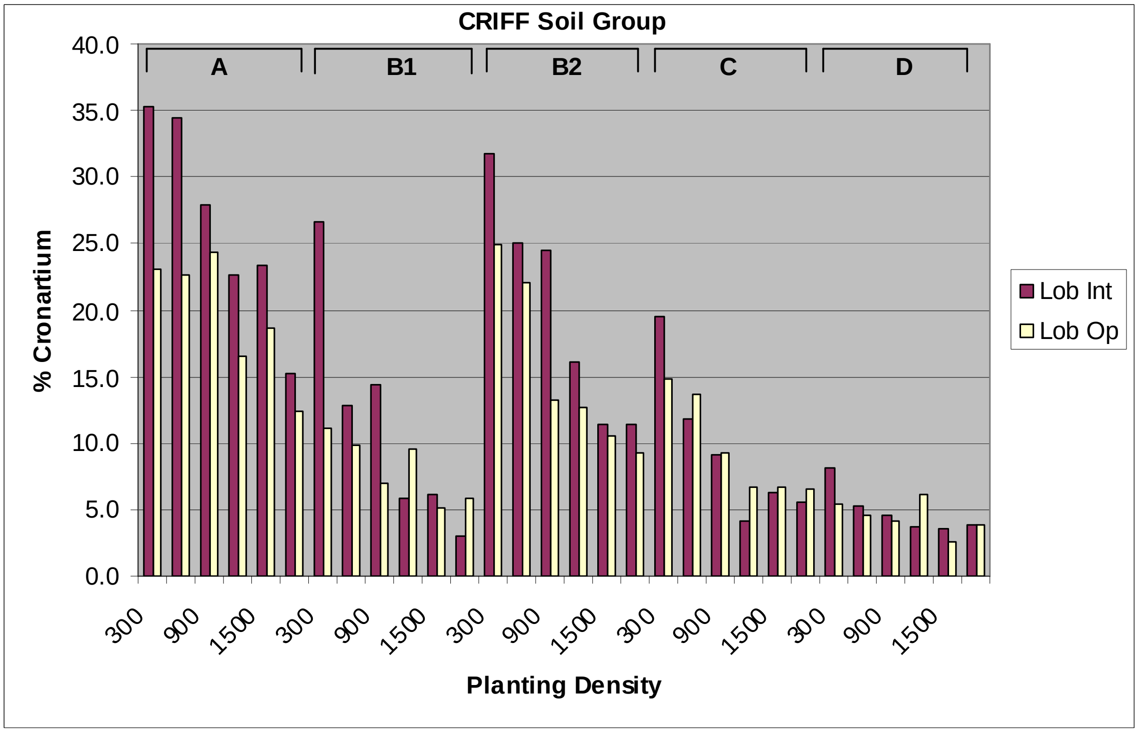


**Figure 12**. Average percent cronartium infection by CRIFF soil group, planting density and management intensity for loblolly pine at age ten.

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

| Source | Type III F | Pr > F |
|---|---|---|
| Soil | 1.56 | 0.2590 |
| Management | 113.82 | <0.0001* |
| Soil x Management | 4.37 | 0.0266* |
| Density | 117.18 | <0.0001* |
| Soil x Density | 1.46 | 0.1088 |
| Management x Density | 1.37 | 0.2420 |

*Significant at α = 0.05.

There is very little difference in per acre basal area for intensively-managed plots at age ten for densities of 1200 and greater. 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 20-35 $ft^2$/ac (14-32%) 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 ten is extremely high for the intensively managed plots. The 1200 and greater initial density plots averaged 173 ft$^2$/ac across all soil types.

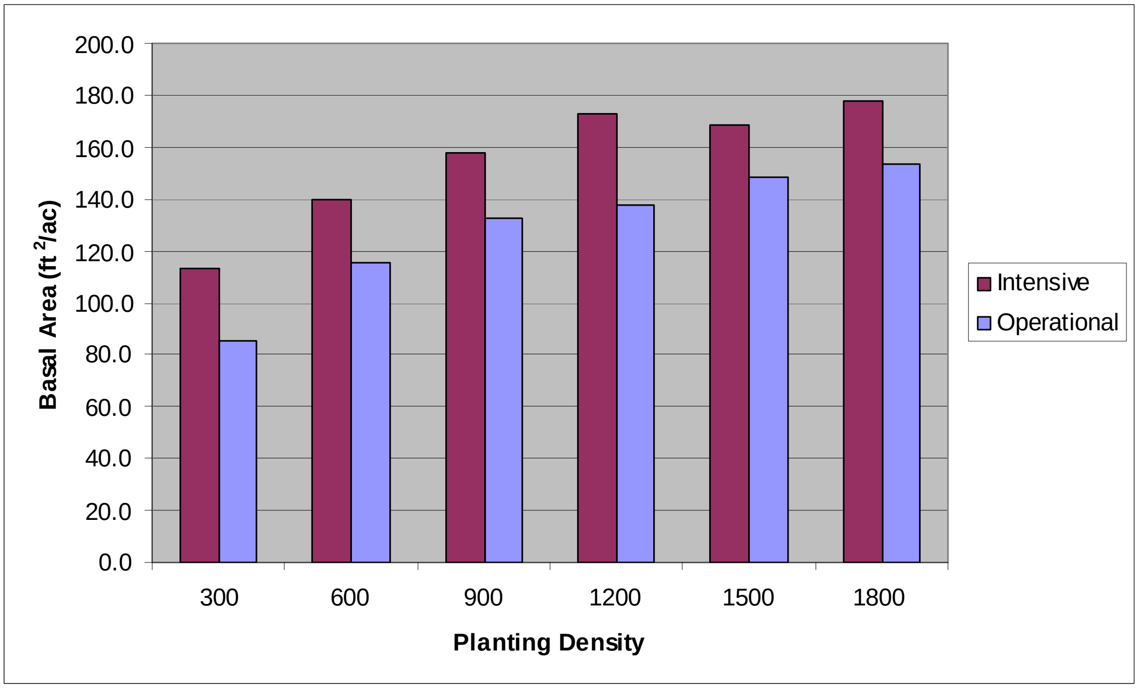


**Figure 13**. Average per-acre basal area (ft$^2$/ac) by planting density and management intensity for loblolly pine at age ten.

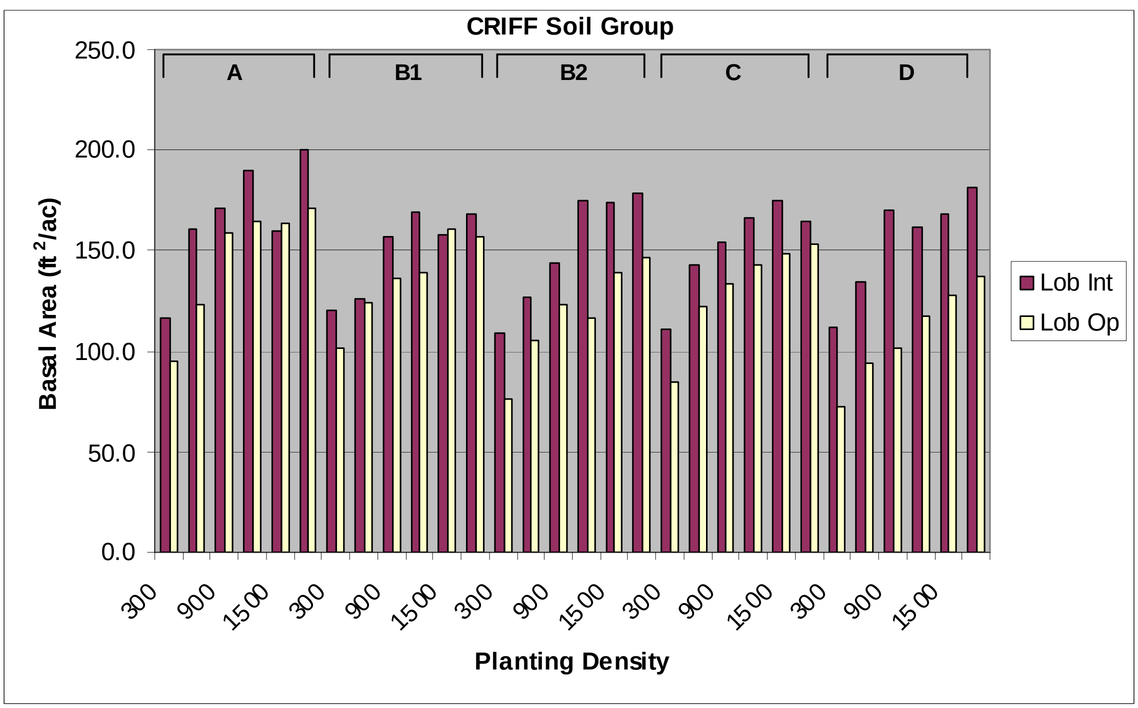


**Figure 14**. Average per-acre basal area (ft$^2$/ac) by CRIFF soil group, planting density and management intensity for loblolly pine at age ten.

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 ten.

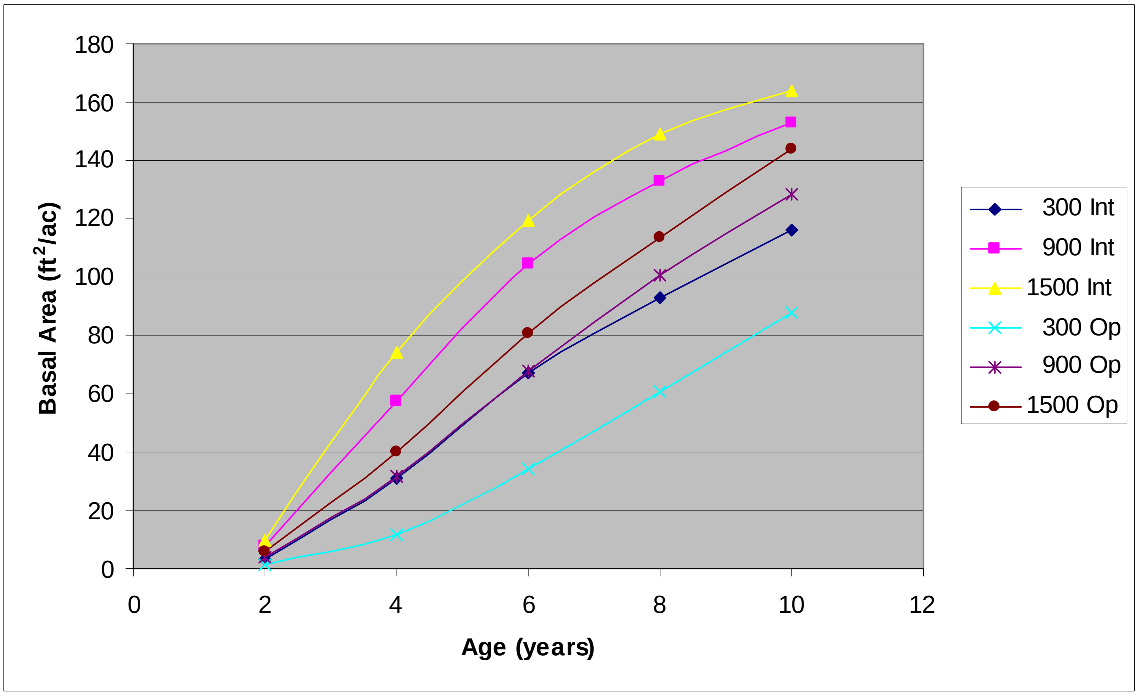


**Figure 15**. Average per-acre basal area growth (ft$^2$/ac) by planting density and management intensity for selected loblolly pine treatments.

### 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 ten. The average increase in volume over all densities was 882 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 ten.

| Source | Type III F | Pr > F |
|---|---|---|
| Soil | 0.63 | 0.6493 |
| Management | 107.10 | <0.0001* |
| Soil x Management | 3.39 | 0.0534 |
| Density | 70.57 | <0.0001* |
| Soil x Density | 1.35 | 0.1594 |
| Management x Density | 1.28 | 0.2754 |

*Significant at $\alpha$ = 0.05.

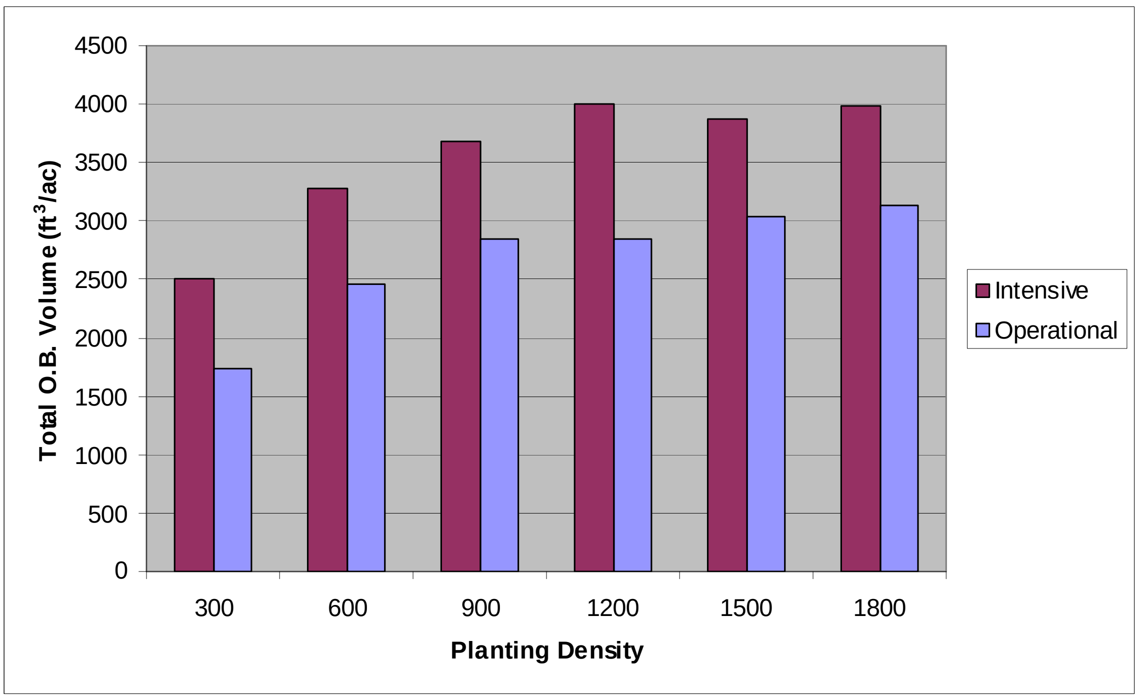


**Figure 16.** Average total per-acre outside bark volume ($ft^3$/ac) by planting density and management intensity for loblolly pine at age 10.

### 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.

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 7.6 tons/ac/yr. This represents a 26% increase in MAI of 6 tons/ac/year observed at age eight on the operationally-managed plots (Shiver and Harrison, 2004).

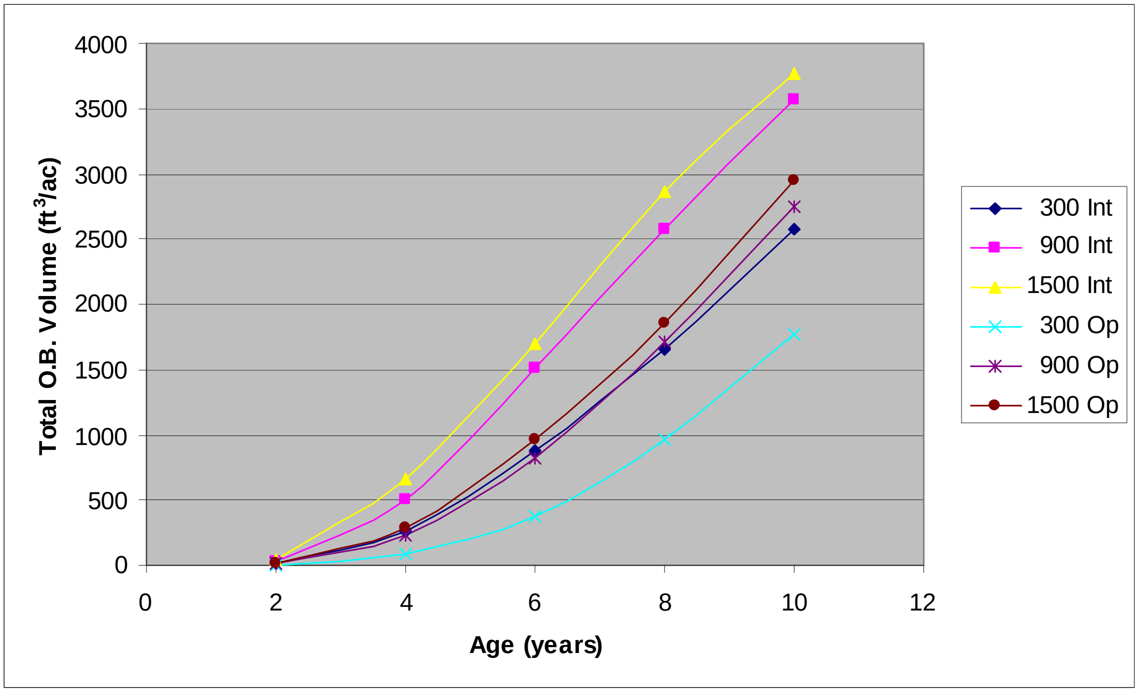


**Figure 17.** Total per-acre outside bark volume growth ($ft^3$/ac) by planting density and management intensity for selected loblolly pine treatments.

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

| Source | Type III F | Pr > F |
|---|---|---|
| Soil | 0.63 | 0.6512 |
| Management | 107.03 | <0.0001* |
| Soil x Management | 3.37 | 0.0542 |
| Density | 68.71 | <0.0001* |
| Soil x Density | 1.35 | 0.1596 |
| Management x Density | 1.28 | 0.2781 |

*Significant at α = 0.05.

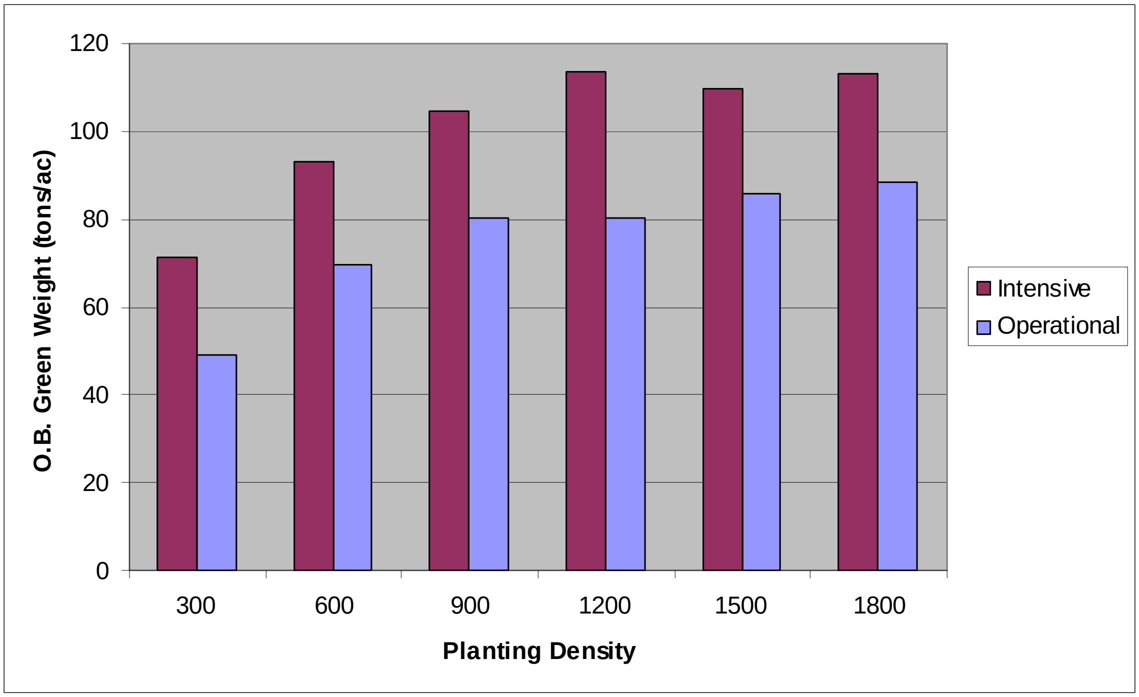


**Figure 18**. Average total per-acre outside bark green weight (tons/ac) by planting density and management intensity for loblolly pine at age ten.

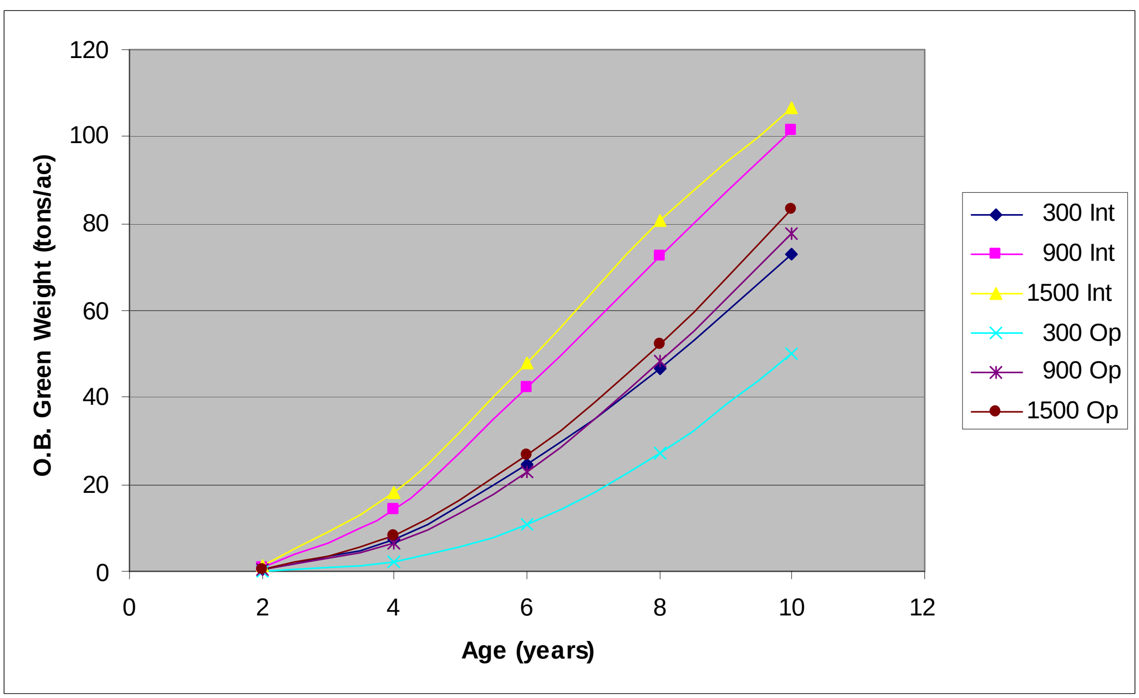


**Figure 19**. Average total per-acre outside bark green weight (tons/ac) by planting density and management intensity for loblolly pine at age ten.

### 3.8 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. We have actually had a few stands slightly exceed this in our spacing study (up to about 475), but not for long. 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.

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.

Table 12 shows the results of an analysis of variance of SDI. Management intensity and initial density were significant factors for SDI differences (Figure 20). 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 29 SDI unit increase for the 1500 TPA density to a 65 SDI unit increase for the 1200 TPA density.

There was also a significant interaction between soil group and management intensity (Figure 21). As with other factors, the differences in SDI between management intensity treatments were significantly greater on the B2 and D soil groups.

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

| Source | Type III F | Pr > F |
|---|---|---|
| Soil | 0.90 | 0.4989 |
| Management | 88.28 | <0.0001* |
| Soil x Management | 4.31 | 0.0277* |
| Density | 248.11 | <0.0001* |
| Soil x Density | 1.46 | 0.1073 |
| Management x Density | 1.51 | 0.1925 |

*Significant at $\alpha = 0.05$.

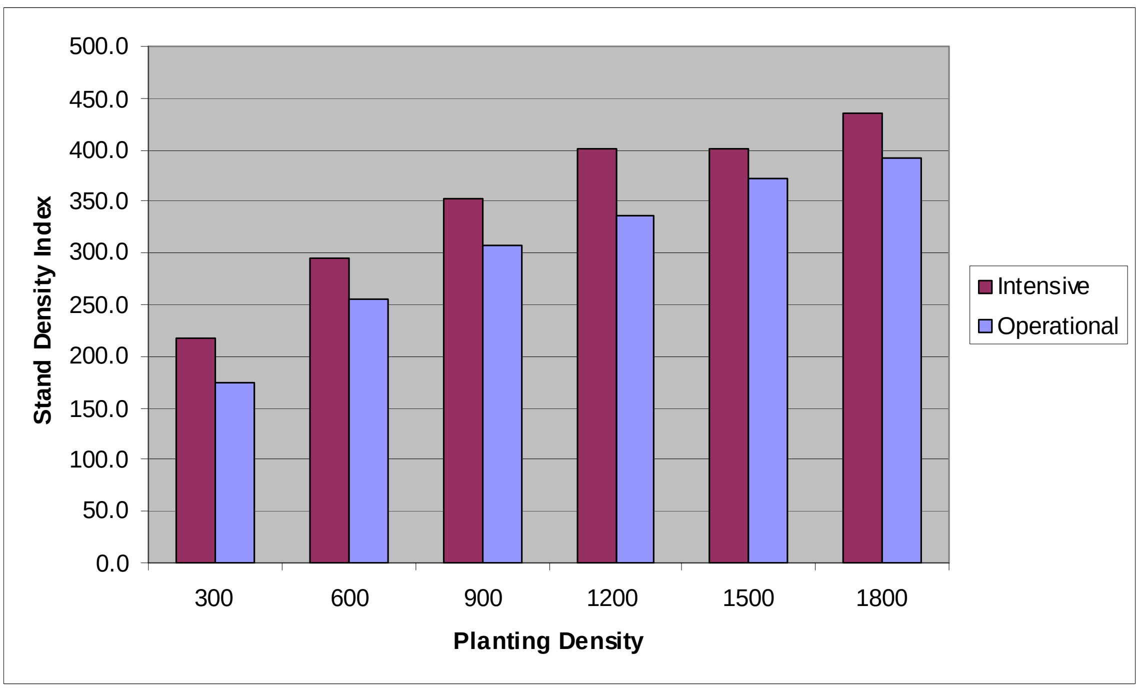


**Figure 20**. Average stand density index (SDI) for loblolly pine by planting density and management intensity for loblolly pine at age ten.

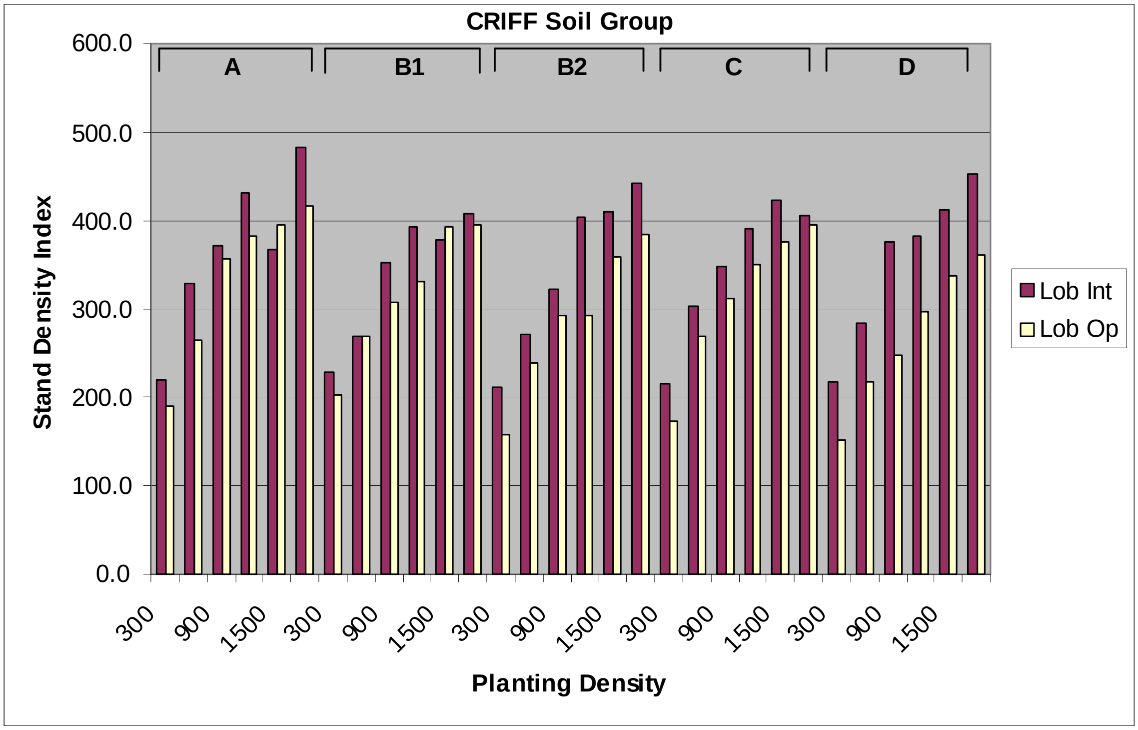


**Figure 21**. Average stand density index (SDI) by CRIFF soil group, planting density and management intensity for loblolly pine at age ten.

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. 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 22). The intensive 1800 plots, especially on A, B2 and D soils, approached or exceeded the expected limiting density by age ten.

Figure 23 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.

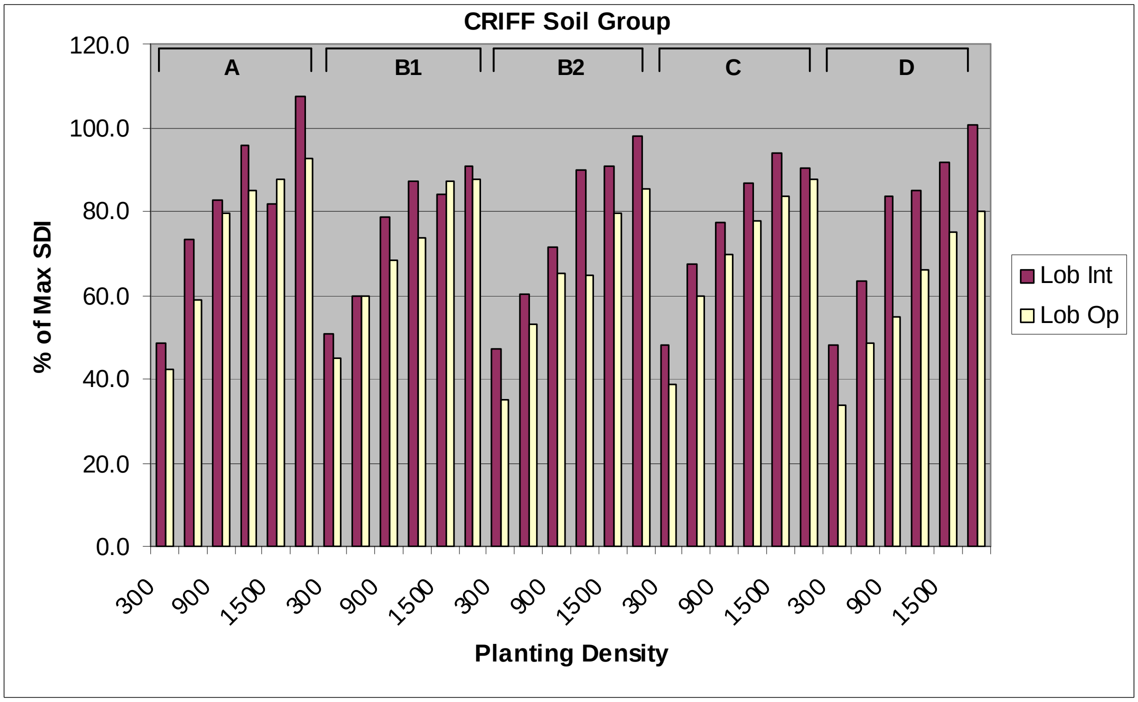


**Figure 22**. Average percentage of maximum stand density index (SDI) by CRIFF soil group, planting density and management intensity for loblolly pine at age ten.

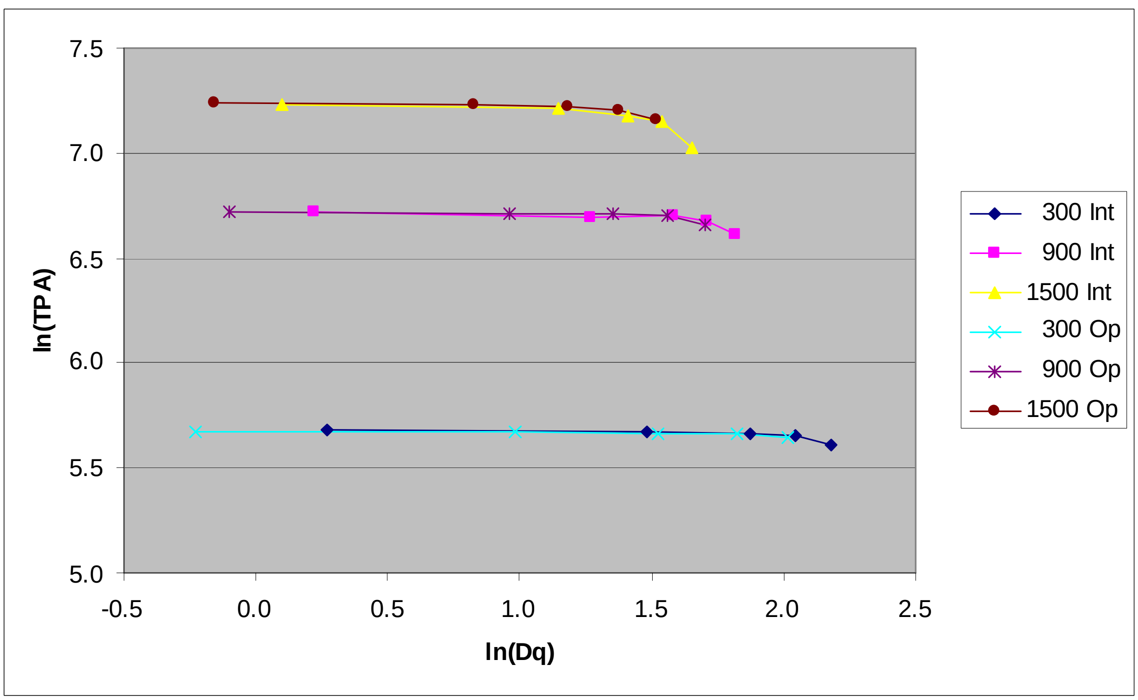


**Figure 23**. Average percentage of maximum stand density index (SDI) by planting density and management intensity for loblolly pine at age ten.

### 3.9 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. 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.

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 slash and loblolly 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 13). Management, initial density and their interaction significantly affected relative spacing. The average RS proportions by density and management intensity show that the intensively managed high density plots are approaching the published asymptote for loblolly pine (Figure 24). A significant soil type x density interaction was also observed and is illustrated in Figure 25.

**Table 13**. Analysis of variance results for loblolly pine average relative spacing at age ten.

| Source | Type III F | Pr > F |
|---|---|---|
| Soil | 1.11 | 0.4061 |
| Management | 28.76 | 0.0003* |
| Soil x Management | 2.24 | 0.1371 |
| Density | 537.55 | <0.0001* |
| Soil x Density | 1.89 | 0.0186* |
| Management x Density | 2.46 | 0.0388* |

*Significant at $\alpha = 0.05$.

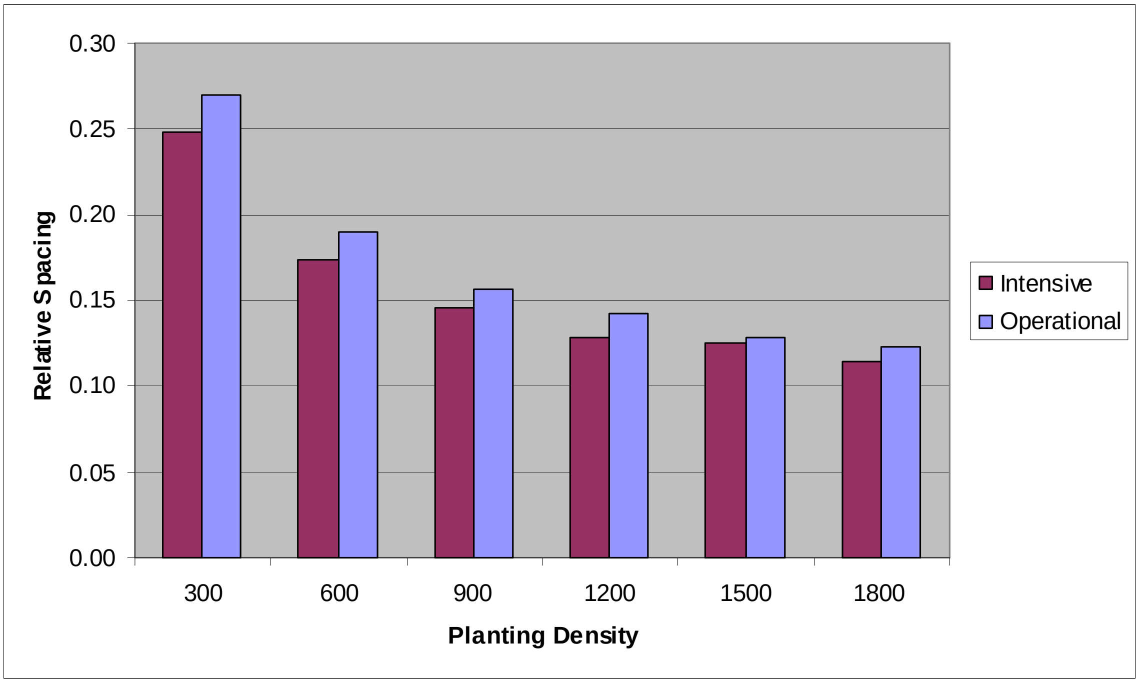


**Figure 24**. Average relative spacing (RS) by planting density and management intensity for loblolly pine at age ten.

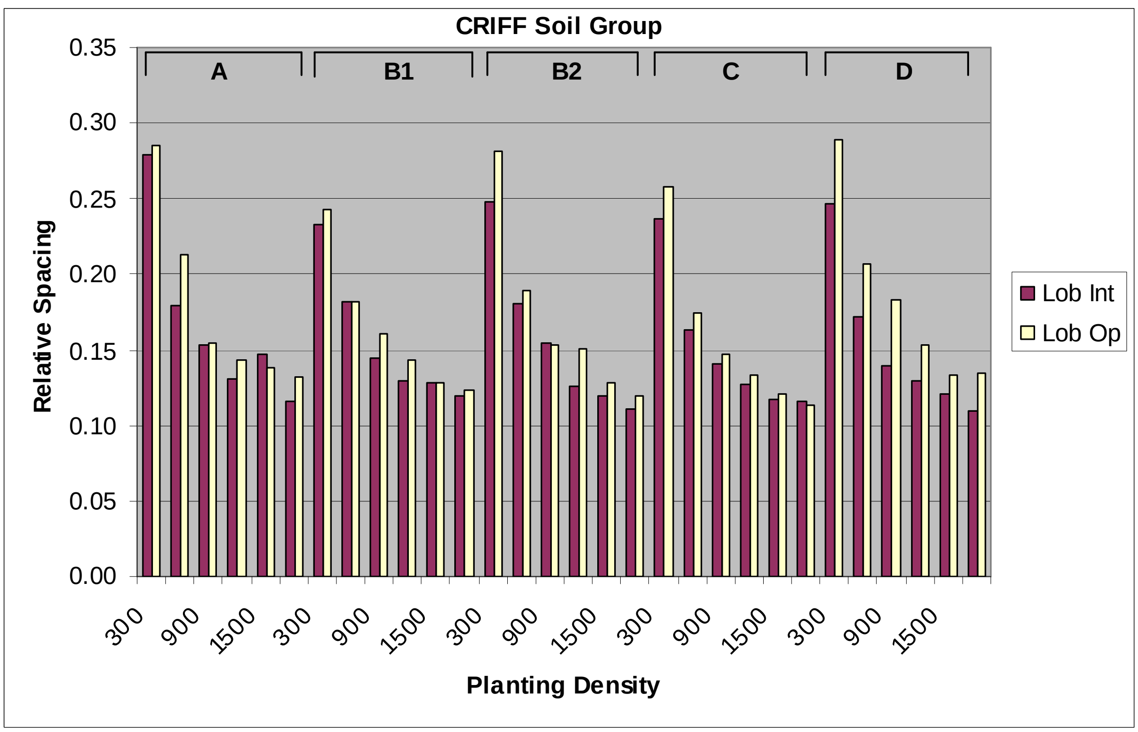


**Figure 25**. Average relative spacing (RS) by CRIFF soil group, planting density and management intensity for loblolly pine at age ten.

# 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. 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):

$$VOB = 0.00456\, DBH^{2.0726}\, HT^{0.8114}$$

$$GWOB = 0.1763\, DBH^{1.9604}\, HT^{0.9761}$$

where VOB = total stem volume outside bark (o.b.) in cubic feet,
GWOB = total stem green weight (o.b.) in lbs,
DBH = tree diameter at breast height (in), and
HT = total tree height (ft).

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, stand density index and relative spacing. Table 14 shows the slash pine means by soil type, management intensity and initial density.

**Table 14**. Slash pine means by CRIFF soil group, management intensity and initial density at age ten.

**CRIFF Soil Type B1**

| Management | Plant Density | Avg. DBH (in) | Avg. Height (ft) | Dom. Height (ft) | % Surv | % Cron | Basal Area/ac ($ft^2$/ac) | Total Vol/ac ($ft^3$/ac) | Total Wt/ac (tons/ac) |
|---|---|---|---|---|---|---|---|---|---|
| Intensive | 300 | 8.2 | 43.7 | 45.3 | 88.8 | 33.0 | 98.5 | 2074 | 59 |
| | 900 | 5.9 | 42.8 | 45.4 | 75.5 | 23.5 | 132.3 | 2708 | 80 |
| | 1500 | 5.1 | 40.9 | 42.8 | 69.4 | 12.5 | 145.6 | 2819 | 84 |
| Operational | 300 | 7.6 | 41.5 | 43.2 | 85.6 | 21.0 | 80.2 | 1612 | 46 |
| | 900 | 5.6 | 40.3 | 42.2 | 78.1 | 16.7 | 119.0 | 2294 | 67 |
| | 1500 | 4.8 | 38.4 | 41.2 | 69.4 | 9.7 | 128.8 | 2390 | 71 |

**CRIFF Soil Type B2**

| Management | Plant Density | Avg. DBH (in) | Avg. Height (ft) | Dom. Height (ft) | % Surv | % Cron | Basal Area/ac ($ft^2$/ac) | Total Vol/ac ($ft^3$/ac) | Total Wt/ac (tons/ac) |
|---|---|---|---|---|---|---|---|---|---|
| Intensive | 300 | 8.3 | 41.7 | 43.0 | 63.8 | 36.8 | 74.0 | 1522 | 43 |
| | 900 | 6.0 | 39.3 | 42.0 | 62.5 | 37.2 | 113.6 | 2189 | 63 |
| | 1500 | 5.3 | 41.4 | 43.6 | 67.8 | 23.3 | 158.5 | 3133 | 92 |
| Operational | 300 | 6.9 | 38.4 | 40.3 | 78.8 | 28.7 | 62.7 | 1181 | 33 |
| | 900 | 5.3 | 38.9 | 40.0 | 84.9 | 24.4 | 117.0 | 2183 | 64 |
| | 1500 | 4.3 | 35.6 | 39.0 | 80.9 | 27.9 | 127.9 | 2263 | 67 |

**CRIFF Soil Type C**

| Management | Plant Density | Avg. DBH (in) | Avg. Height (ft) | Dom. Height (ft) | % Surv | % Cron | Basal Area/ac ($ft^2$/ac) | Total Vol/ac ($ft^3$/ac) | Total Wt/ac (tons/ac) |
|---|---|---|---|---|---|---|---|---|---|
| Intensive | 300 | 8.0 | 40.6 | 42.2 | 85.4 | 24.6 | 92.0 | 1827 | 51 |
| | 900 | 5.7 | 40.8 | 43.6 | 84.7 | 11.7 | 139.7 | 2754 | 81 |
| | 1500 | 4.9 | 39.7 | 41.8 | 77.3 | 7.0 | 157.4 | 2991 | 89 |
| Operational | 300 | 7.1 | 39.8 | 41.2 | 92.1 | 9.5 | 77.4 | 1517 | 43 |
| | 900 | 5.3 | 39.1 | 41.1 | 84.7 | 9.1 | 122.0 | 2314 | 68 |
| | 1500 | 4.5 | 38.1 | 40.6 | 81.7 | 4.2 | 139.2 | 2554 | 76 |

**CRIFF Soil Type D**

| Management | Plant Density | Avg. DBH (in) | Avg. Height (ft) | Dom. Height (ft) | % Surv | % Cron | Basal Area/ac ($ft^2$/ac) | Total Vol/ac ($ft^3$/ac) | Total Wt/ac (tons/ac) |
|---|---|---|---|---|---|---|---|---|---|
| Intensive | 300 | 8.1 | 42.4 | 44.5 | 95.0 | 19.7 | 102.4 | 2105 | 60 |
| | 900 | 5.8 | 41.4 | 43.9 | 91.7 | 21.6 | 152.8 | 3038 | 89 |
| | 1500 | 4.8 | 40.6 | 42.4 | 89.4 | 17.5 | 174.5 | 3374 | 100 |
| Operational | 300 | 7.0 | 37.9 | 40.2 | 90.0 | 26.4 | 72.6 | 1349 | 38 |
| | 900 | 5.3 | 40.2 | 41.2 | 95.8 | 6.5 | 133.7 | 2548 | 75 |
| | 1500 | 4.2 | 36.3 | 39.1 | 98.8 | 9.5 | 147.2 | 2582 | 77 |

### 4.1 Average DBH

Table 15 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 26, 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 1 inch compared with a gain of about 0.6 inches for the 900 and 1500 initial densities.

Figure 27 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 15**. Analysis of variance results for slash pine average DBH at age ten.

| Source | Type III F | Pr > F |
|---|---|---|
| Soil | 0.26 | 0.8516 |
| Management | 52.01 | 0.0020* |
| Soil x Management | 2.35 | 0.2134 |
| Density | 974.20 | <0.0001* |
| Soil x Density | 0.32 | 0.9190 |
| Management x Density | 10.47 | 0.0006* |

*Significant at $\alpha = 0.05$.

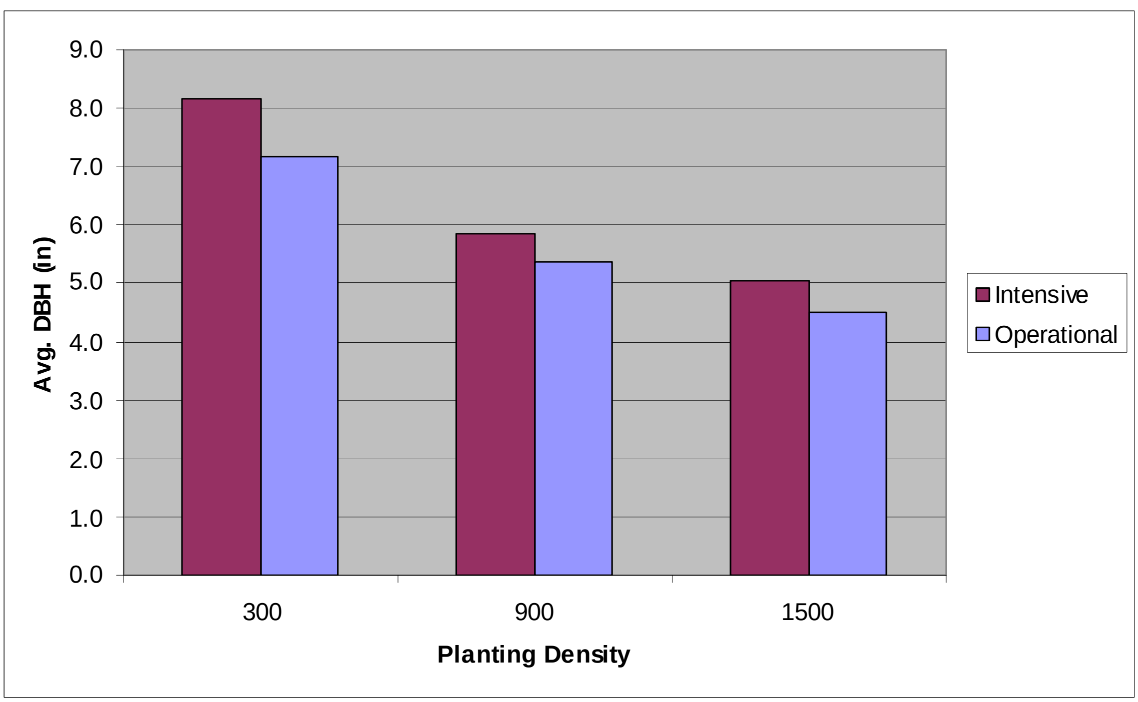


**Figure 26**. Average DBH by planting density and management intensity for slash pine at age ten.

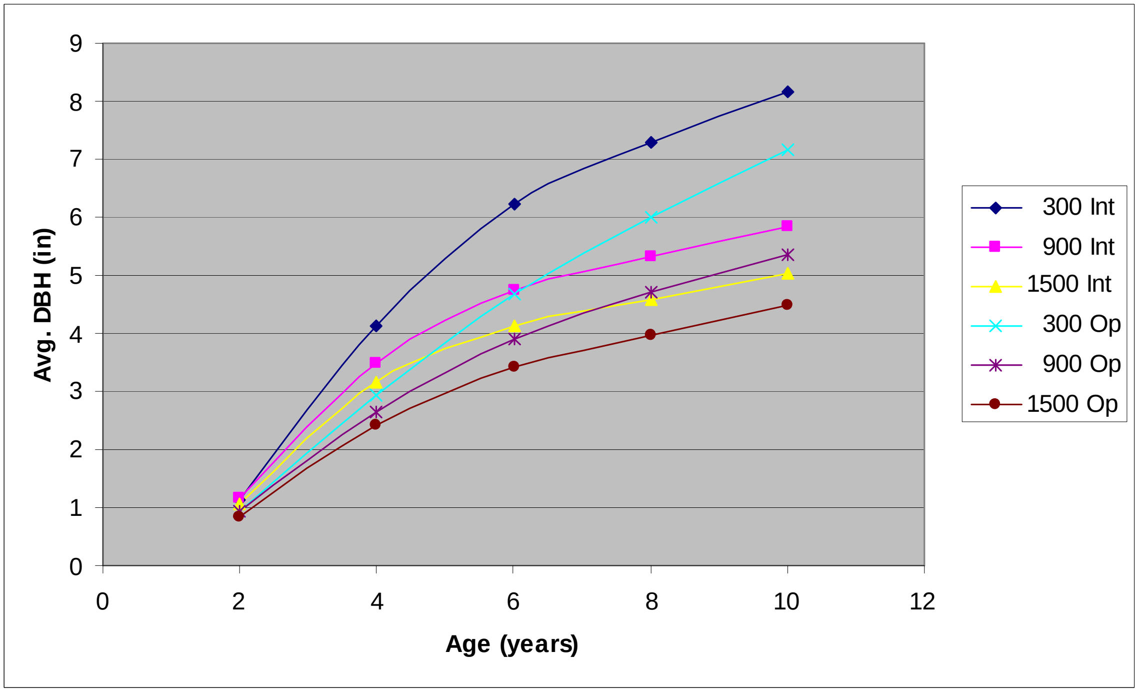


**Figure 27**. Average DBH growth by planting density and management intensity for slash pine treatments.

## 4.2 Average Height

Table 16 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 28 shows the average heights by initial density and management intensity. Average heights were 1.5 to 3.2 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 one foot less than the lower densities for intensively managed plots and more than two feet for the operational plots.

As discussed in the loblolly analysis, it is unusual to see planting density have an 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 29, the differences in average dominant height across density, regardless of management, were approximately one foot. The average response to more intensive management was 2.4 feet.

**Table 16**. Analysis of variance results for slash pine average height at age ten.

| Source | Type III F | Pr > F |
|---|---|---|
| Soil | 0.33 | 0.8053 |
| Management | 14.46 | 0.0191* |
| Soil x Management | 0.57 | 0.6656 |
| Density | 7.99 | 0.0025* |
| Soil x Density | 0.59 | 0.7384 |
| Management x Density | 0.61 | 0.2225 |

*Significant at α = 0.05.

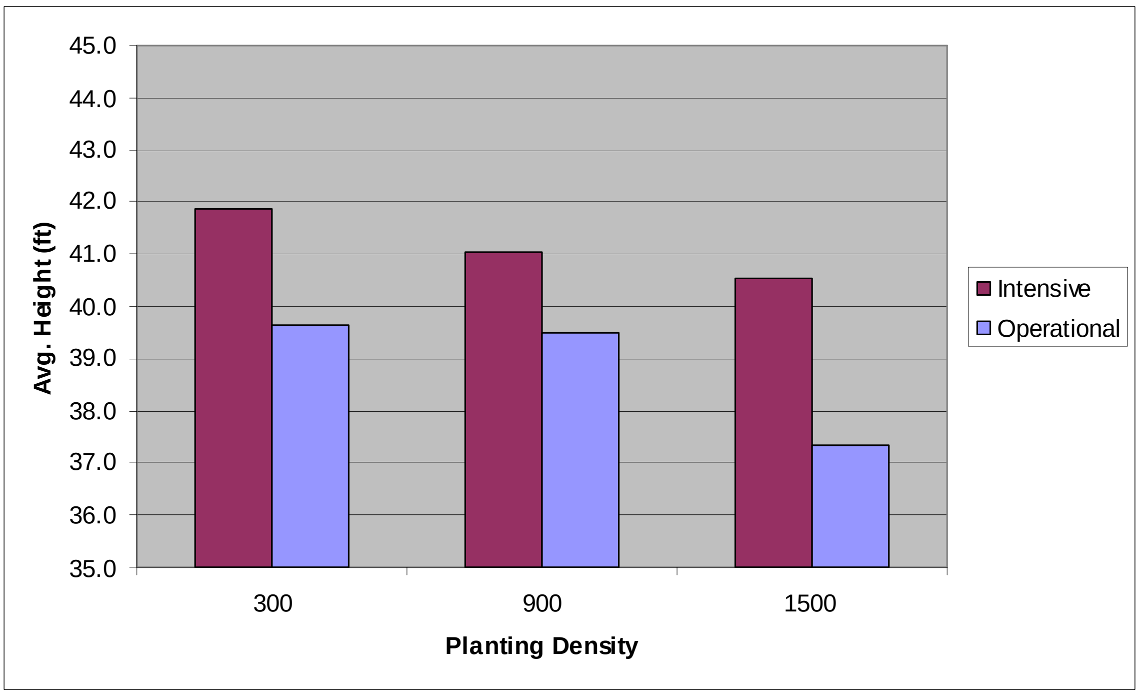


**Figure 28**. Average height by planting density and management intensity for slash pine at age ten.

Figure 30 shows the average dominant height growth from ages 2-10 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 6-10.

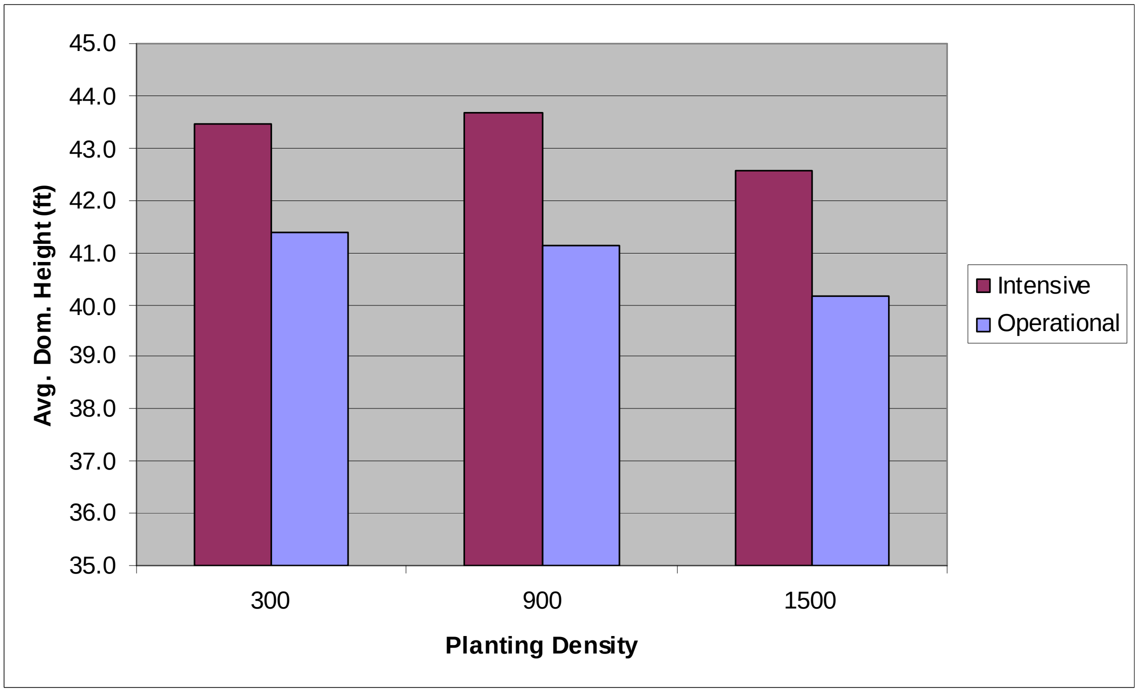


**Figure 29**. Average dominant height by planting density and management intensity for slash pine at age ten.

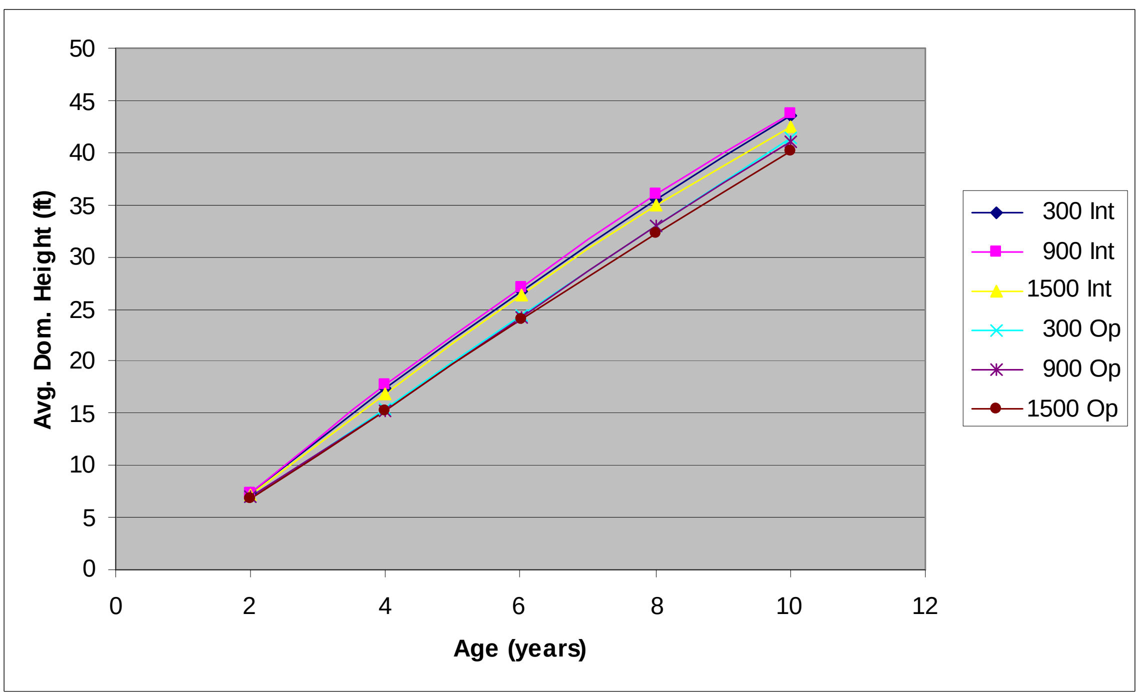


**Figure 30**. Average dominant height growth by planting density and management intensity for slash pine treatments.

### 4.3 Percent Survival

Table 17 shows the results of the analysis of variance for slash pine average percent survival. There were no significant factors that affected survival through age ten. CRIFF soil group significantly affected survival in the Age-8 analysis (Shiver and Harrison, 2004). The same trends are evident through age ten but were not statistically significant (Figure 31). Figure 32 shows the average slash pine survival curves.

**Table 17**. Analysis of variance results for slash pine average percent survival at age ten.

| Source | Type III F | Pr > F |
|---|---|---|
| Soil | 1.50 | 0.3432 |
| Management | 4.86 | 0.0923 |
| Soil x Management | 2.37 | 0.2117 |
| Density | 1.90 | 0.1737 |
| Soil x Density | 1.58 | 0.2004 |
| Management x Density | 0.07 | 0.9350 |

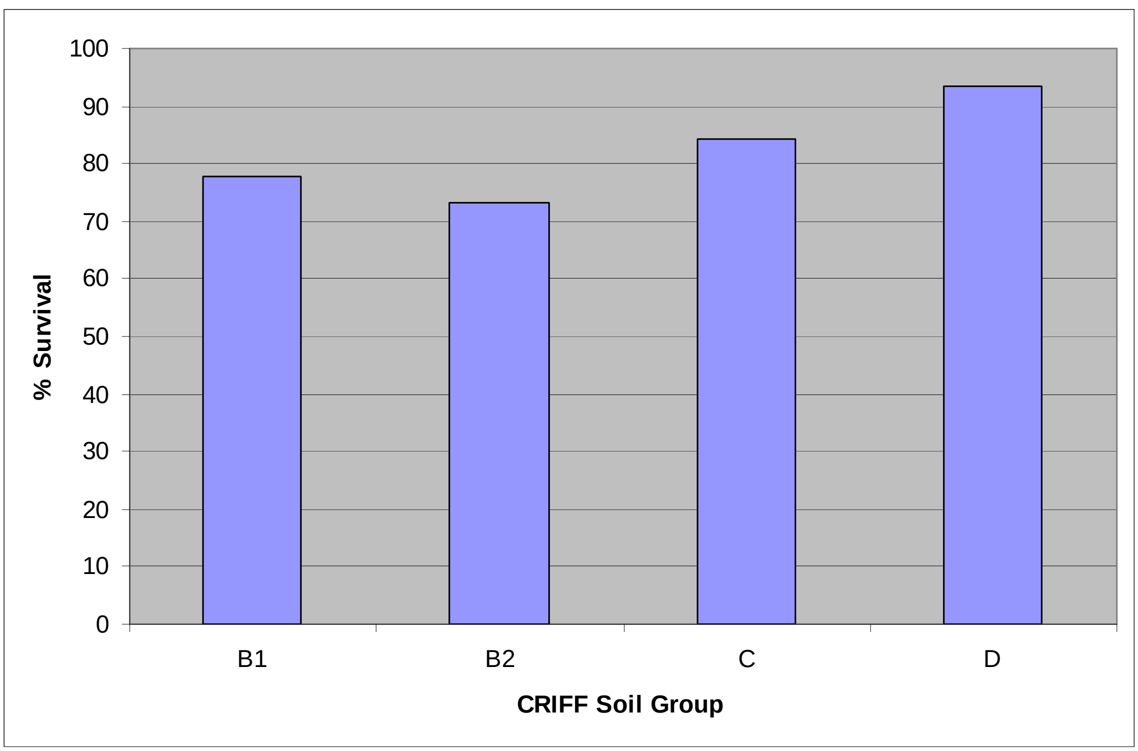


**Figure 31**. Trees per acre by CRIFF soil group for slash pine at age ten

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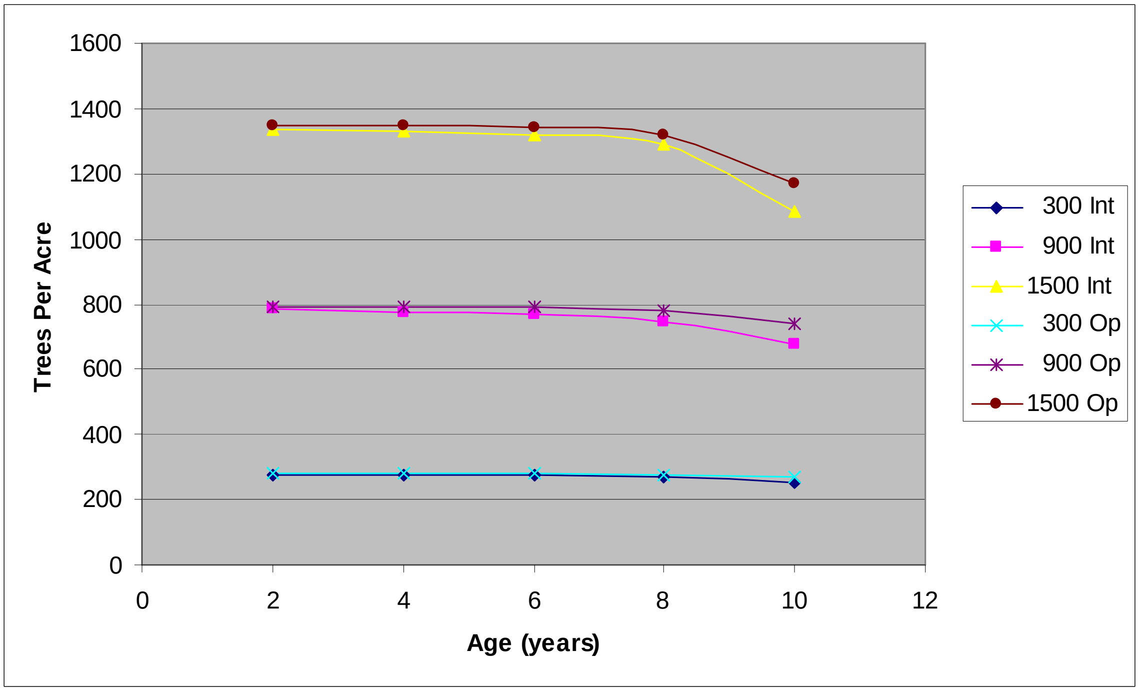


**Figure 32**. Trees per acre development by planting density and management intensity for slash pine treatments.

### 4.4 Percent Cronartium Infection

Table 18 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 33 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 ten, 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 9.9%, 7.7% and 1.6% for the 300, 900 and 1500 trees per acre treatments, respectively.

The CRIFF soil group was not a statistically-significant factor for cronartium infection rate at age ten but consistent trends have emerged through the years. Figure 34 illustrates that the B2 soil type has the highest infection rates across all densities. For most of the soil types, intensive management increased the infection rate on the 300 initial trees per acre plots, but this is reversed for the spodosols with no underlying argillic horizon (the D soils). On D soils, the more intensive treatments resulted in higher infection rates on the higher densities. From a management point of view, there is a trend that is stronger for intensively managed stands than for more operationally managed stands for infection rates to decrease as density increases from 300 to 900 to 1500.

**Table 18**. Analysis of variance results for slash pine average percent cronartium infection at age ten.

| Source | Type III F | Pr > F |
|---|---|---|
| Soil | 6.50 | 0.0512 |
| Management | 6.08 | 0.0693 |
| Soil x Management | 0.04 | 0.9898 |
| Density | 8.32 | 0.0020* |
| Soil x Density | 0.39 | 0.8805 |
| Management x Density | 1.47 | 0.2507 |

*Significant at $\alpha = 0.05$.

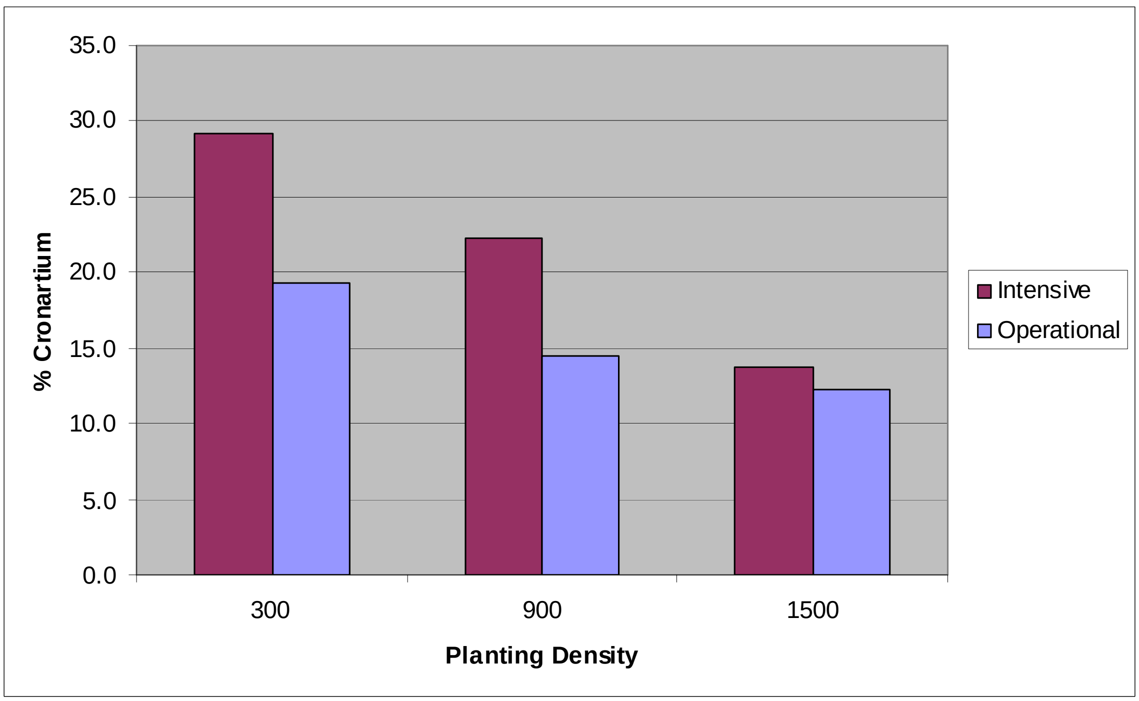


**Figure 33**. Average percent cronartium infection by planting density and management intensity for slash pine at age ten.

### 4.5 Per-Acre Basal Area

Table 19 shows the results of the analysis of variance for slash pine per-acre basal area. Management intensity and planting density significantly affected per-acre basal area. Basal area increased with increasing initial density and with increasing management intensity. The differences between intensive and operational treatments averaged about 17ft$^2$/ac, or approximately 68% of the basal area response observed at age eight. Increasing initial density from 300 to 900 to 1500 increased basal area per acre substantially for both intensive and operational management. Figure 35 illustrates these trends.

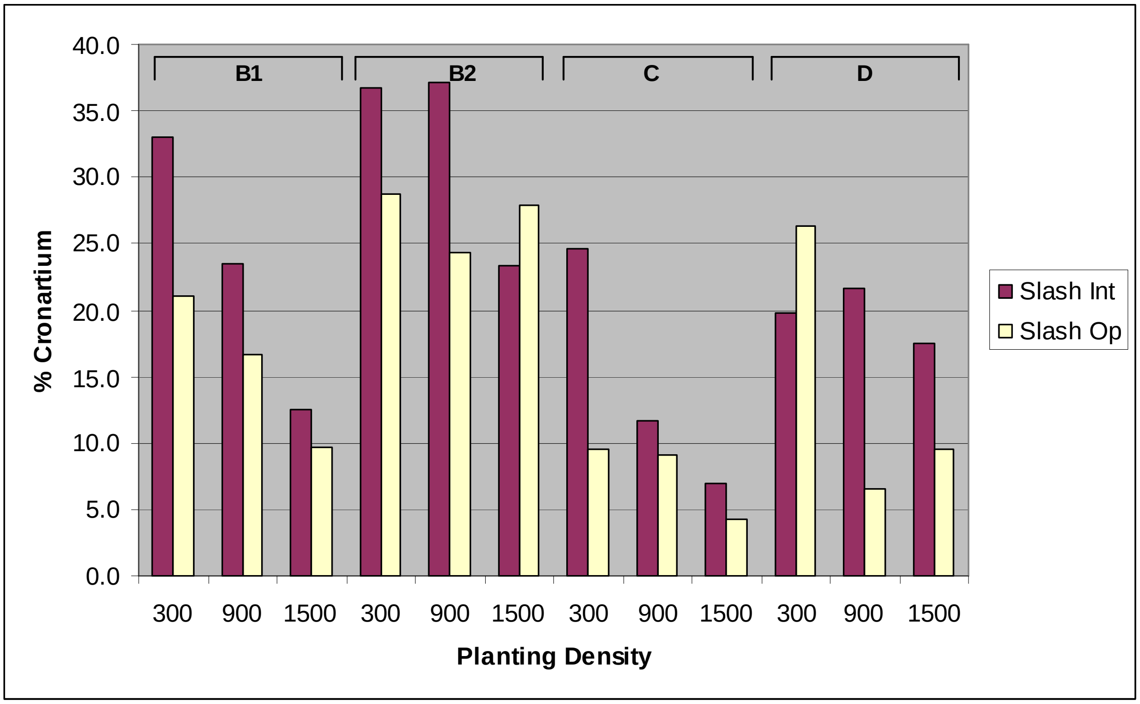


**Figure 34**. Average percent cronartium infection by CRIFF soil group, planting density and management intensity for slash pine at age ten.

**Table 19**. Analysis of variance results for slash pine average per-acre basal area at age ten.

| Source | Type III F | Pr > F |
|---|---|---|
| Soil | 1.11 | 0.4423 |
| Management | 22.85 | 0.0088* |
| Soil x Management | 0.37 | 0.7770 |
| Density | 197.92 | <0.0001* |
| Soil x Density | 2.01 | 0.1074 |
| Management x Density | 1.45 | 0.2566 |

*Significant at α = 0.05.

Figure 36 shows average slash pine basal area growth from ages 2-10 for all treatments. It appears that significant slowing in basal area growth has occurred for the high-intensity treatments. In fact, average basal area decreased slightly from age eight to ten for the high-intensity 1500 TPA treatment.

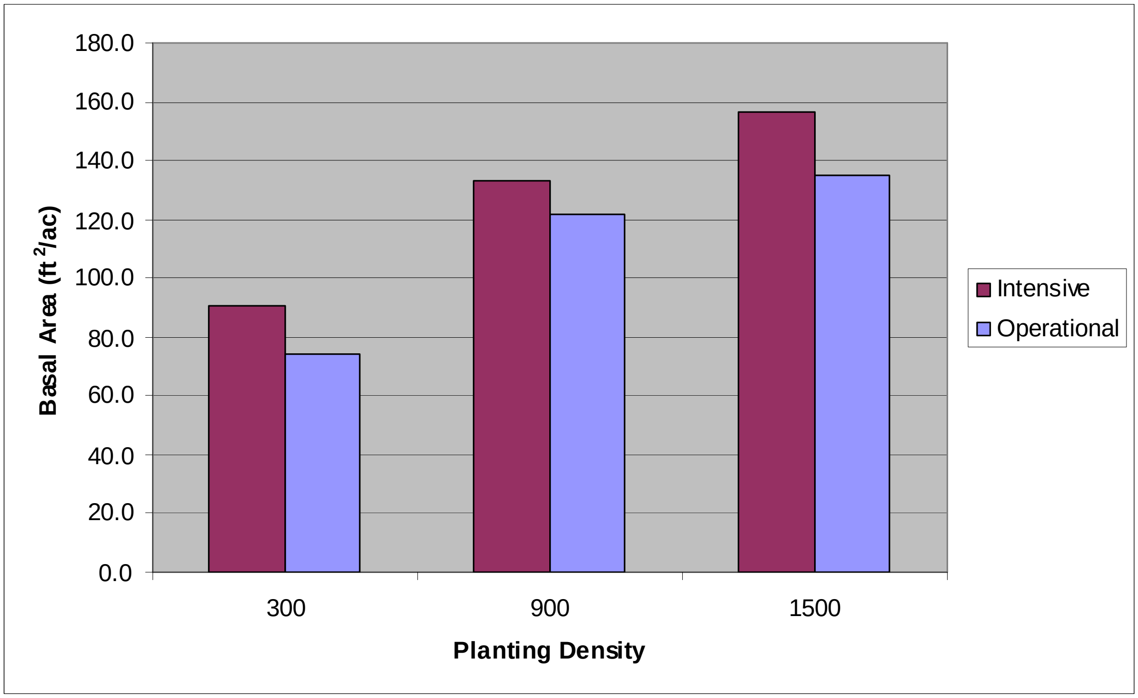


**Figure 35**. Average per-acre basal area (ft$^2$/ac) by planting density and management intensity for slash pine at age ten.

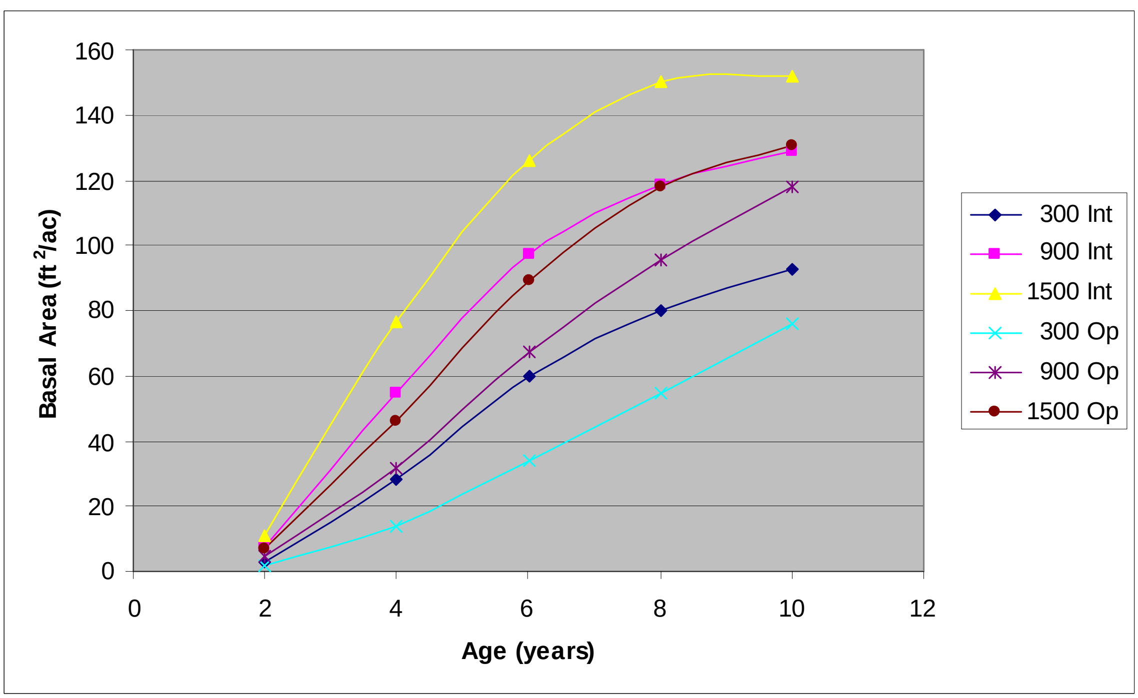


**Figure 36**. Average per-acre basal area growth (ft$^2$/ac) by planting density and management intensity for slash pine treatments.

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

Table 20 shows the results of the analysis of variance for slash pine total volume. Management intensity and planting density had significant effects on total per-acre volume. Figure 37 shows a nearly identical trend for volume as for basal area. An increase in management intensity resulted in large increases in total per-acre stem volume across densities. Those increases averaged 330 to 587ft$^3$/ac at age ten. Likewise, an increase in density from 300 to 1500 increased total stem volume per acre by 1008 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 ten by 1184 ft$^3$/ac.

**Table 20**. Analysis of variance results for slash pine average per-acre, total volume at age ten.

| Source | Type III F | Pr > F |
|---|---|---|
| Soil | 0.61 | 0.6453 |
| Management | 25.28 | 0.0073* |
| Soil x Management | 0.35 | 0.7917 |
| Density | 125.51 | <0.0001* |
| Soil x Density | 2.01 | 0.1069 |
| Management x Density | 1.85 | 0.1813 |

*Significant at α = 0.05.

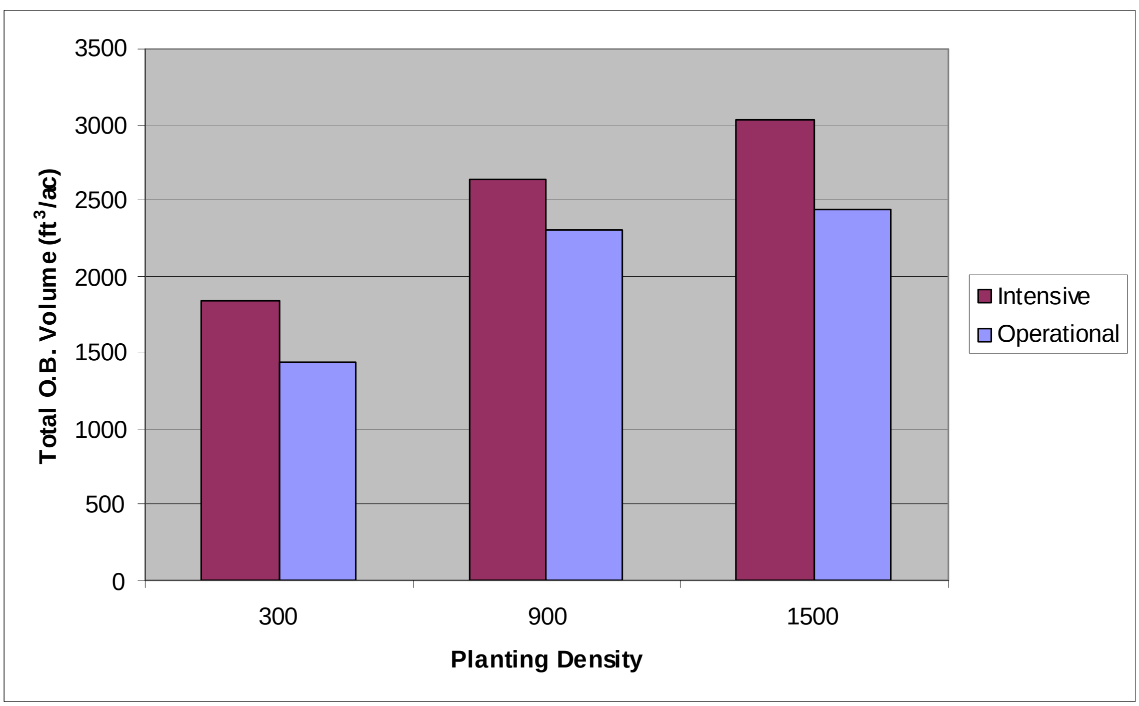


**Figure 37**. Average total per-acre outside bark volume (ft$^3$/ac) by planting density and management intensity for slash pine at age ten.

Figure 38 shows average slash pine total volume growth through age 10 for all treatments. As with per acre basal area, a slowdown in volume growth is apparent for the high intensity, 1500 trees per acre density treatment plots.

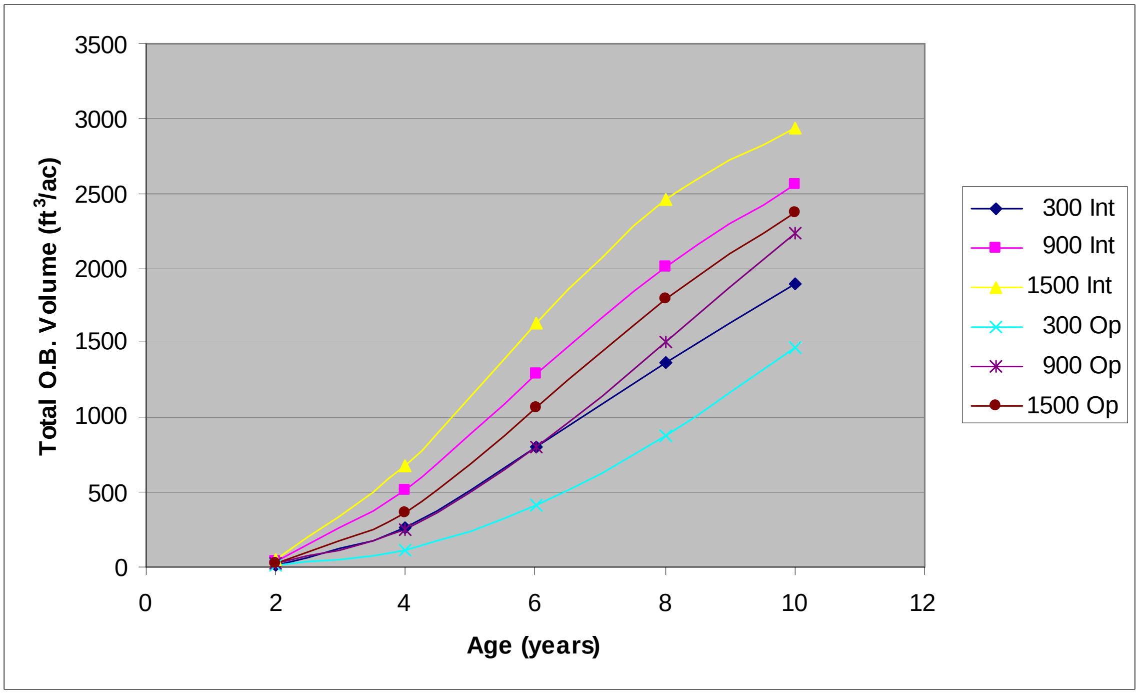


**Figure 38**. Total per-acre outside bark volume growth ($ft^3/ac$) by planting density and management intensity for slash pine treatments.

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

Table 21 shows the results of the analysis of variance for slash pine total green weight. Management intensity and density had significant effects on total, per-acre green weight. Figure 39 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 41 tons/ac for 300 trees per acre to about 72 tons/ac for 1500 with operational management. Intensive management increased green weight by 13 tons/ac over all density treatments.

Figure 40 shows the green weight development through age 10 for all slash pine treatments.

**Table 21.** Analysis of variance results for slash pine average per-acre, total green weight at age ten.

| Source | Type III F | Pr > F |
|---|---|---|
| Soil | 0.60 | 0.6457 |
| Management | 23.75 | 0.0082* |
| Soil x Management | 0.36 | 0.7882 |
| Density | 134.57 | <0.0001* |
| Soil x Density | 1.89 | 0.1281 |
| Management x Density | 1.96 | 0.1640 |

*Significant at α = 0.05.

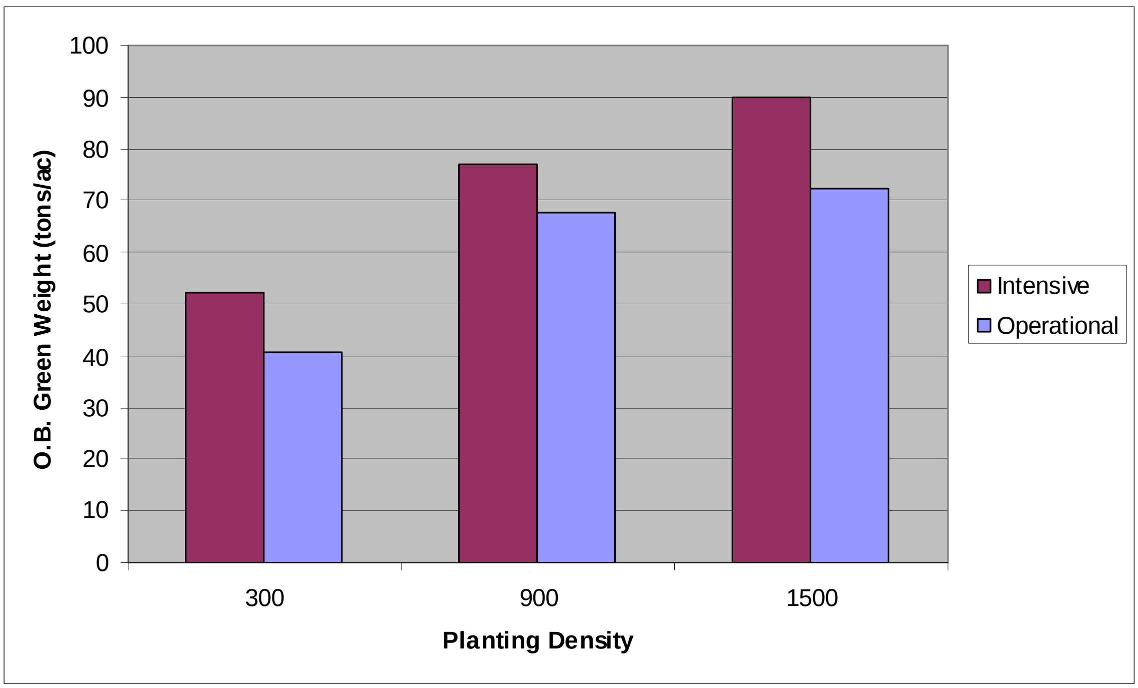


**Figure 39.** Average total per-acre outside bark green weight (tons/ac) by planting density and management intensity for slash pine at age ten.

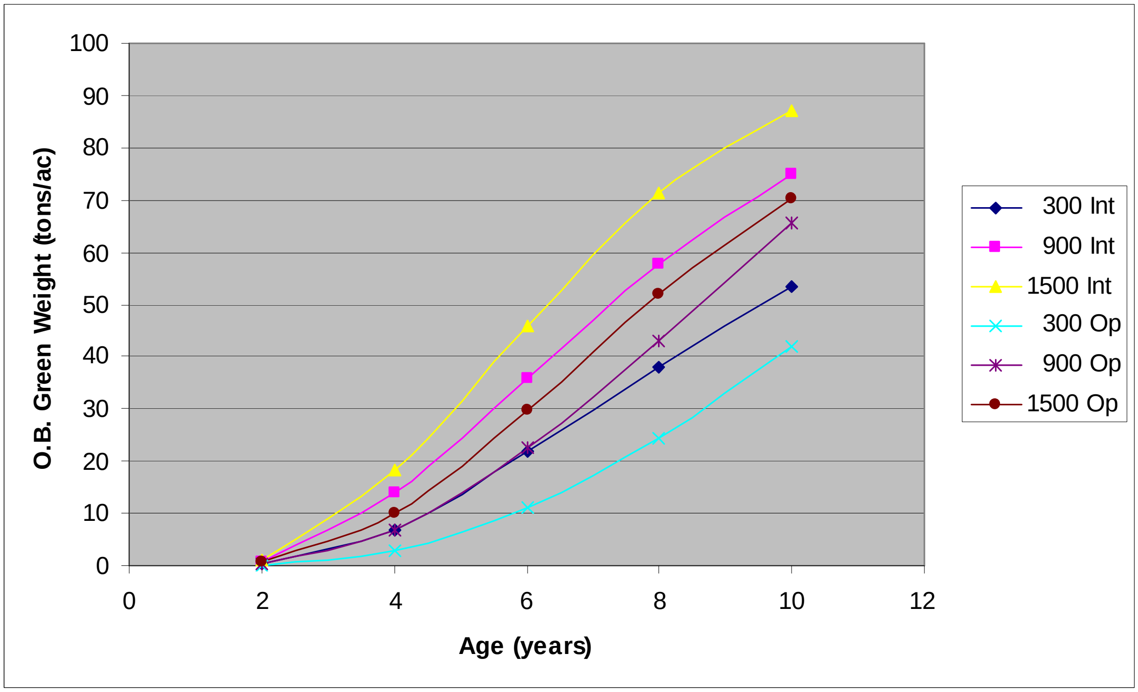


**Figure 40**. Average total per-acre outside bark green weight (tons/ac) by planting density and management intensity for slash pine at age ten.

### 4.8 Stand Density Index

The stand density index 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. SDI values were calculated for every plot. Table 22 shows the results of the analysis of variance for slash pine SDI. Management intensity and initial density had significant effects on SDI. Figure 41 shows the SDI values by density and management. There is a slight increase in average SDI for intensive management at each of the initial densities. By age ten 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 42 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 43 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 22**. Analysis of variance results for slash pine average stand density index at age ten.

| Source | Type III F | Pr > F |
| --- | --- | --- |
| Soil | 1.42 | 0.3613 |
| Management | 13.67 | 0.0209* |
| Soil x Management | 0.59 | 0.6555 |
| Density | 284.89 | <0.0001* |
| Soil x Density | 1.77 | 0.1521 |
| Management x Density | 0.99 | 0.3868 |

*Significant at α = 0.05.

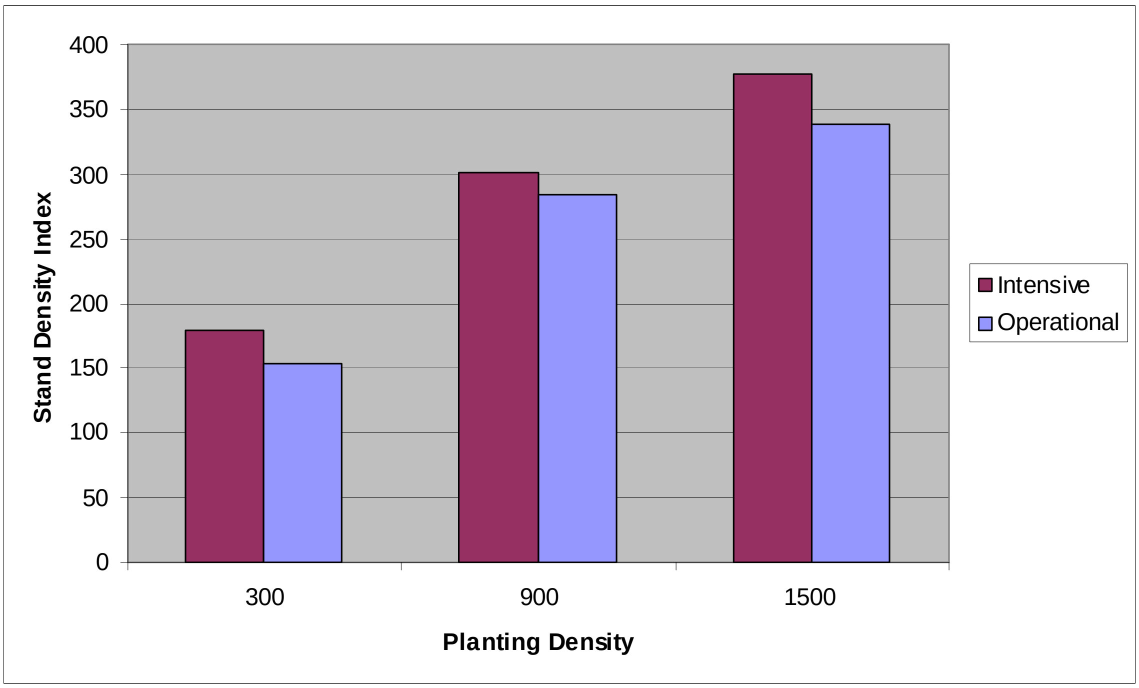


**Figure 41**. Average stand density index by planting density and management intensity for slash pine at age ten.

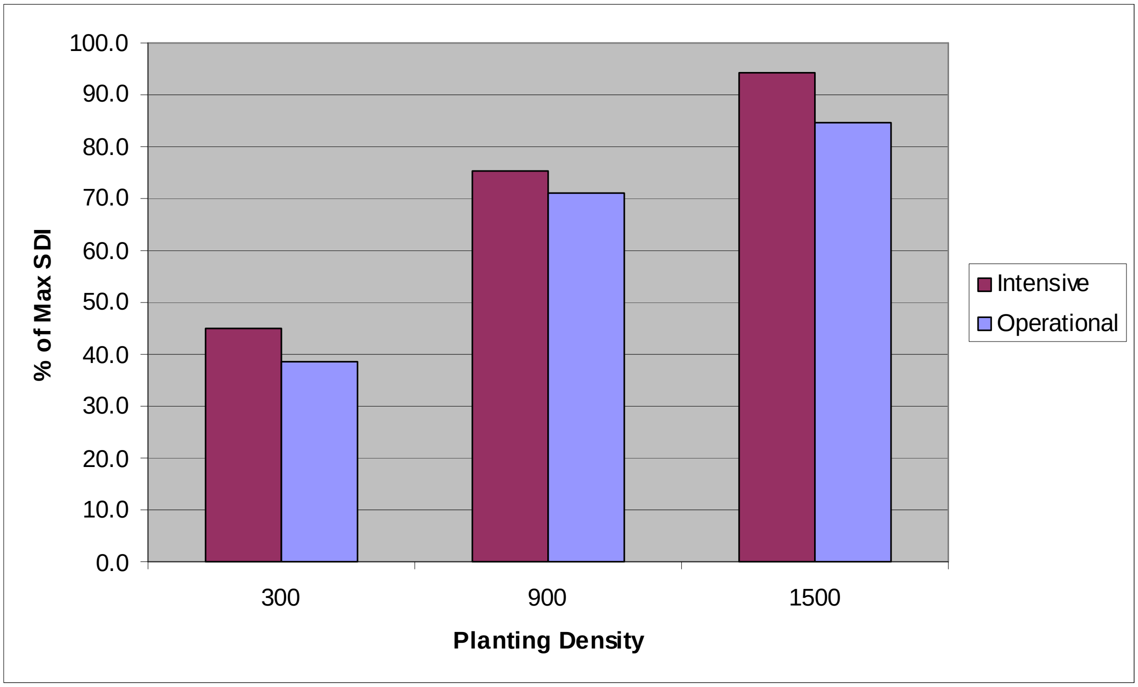


**Figure 42**. Average percentage of maximum stand density index by planting density and management intensity for slash pine at age ten.

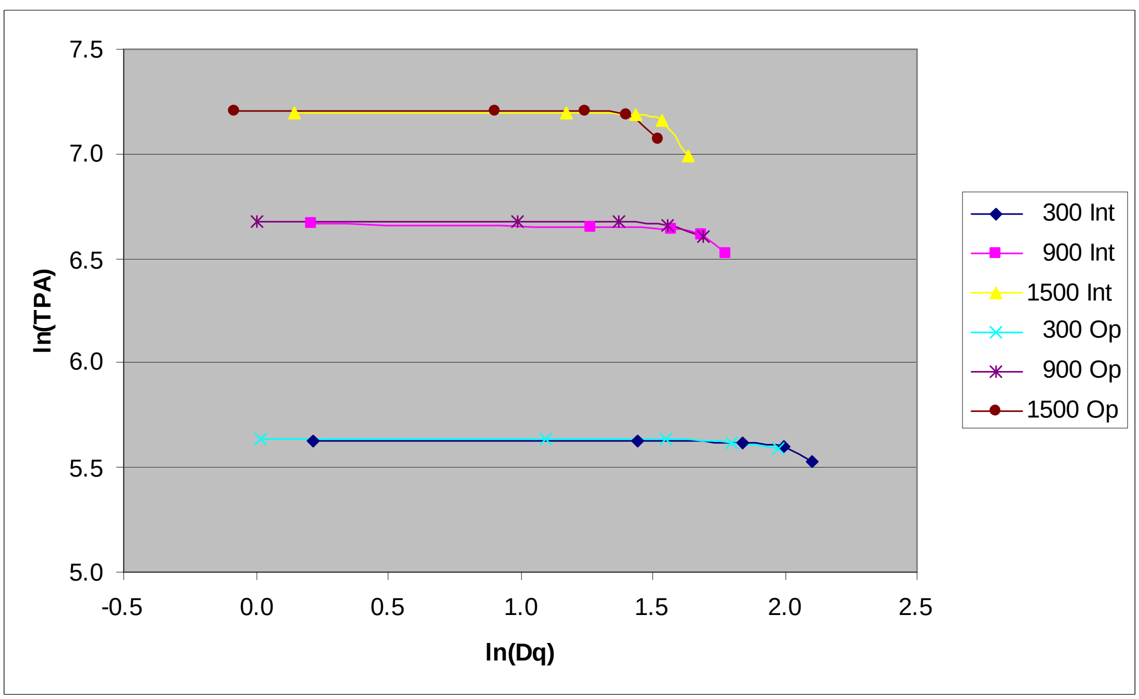


**Figure 43**. Average percentage of maximum stand density index by planting density and management intensity for slash pine at age ten.

### 4.9 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. Relative spacing was calculated for each of the plots in the study and subjected to the same analysis of variance as the other variables examined. Table 23 shows the results of the analysis of variance for slash pine relative spacing. Initial density significantly affected relative spacing at age 10 (Figure 44). Examination of Figure 45 leads to the conclusion that relative spacing values across soil classes for the same initial densities are similar with the exception of soil type B2. The B2 soil class is the soil with higher mortality than the others and this shows up in relative spacing as a higher value at the same age. Values for slash pine are down to about 0.15 for the 1500 density, but are not as low as loblolly pine at the same age. This is likely due, at least in part, to the taller heights observed for loblolly pine.

**Table 23**. Analysis of variance results for slash pine average relative spacing at age ten.

| Source | Type III F | Pr > F |
|---|---|---|
| Soil | 1.58 | 0.3260 |
| Management | 0.47 | 0.5305 |
| Soil x Management | 0.86 | 0.5304 |
| Density | 427.58 | <0.0001* |
| Soil x Density | 2.53 | 0.0510 |
| Management x Density | 0.00 | 0.9982 |

*Significant at $\alpha = 0.05$.

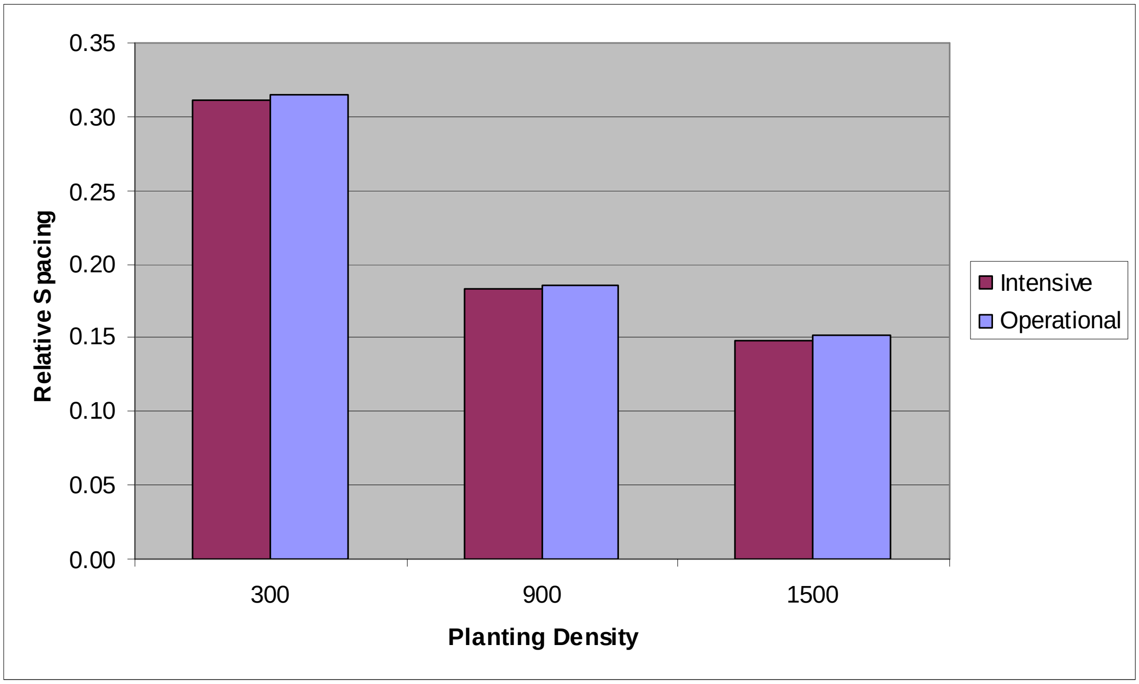


**Figure 44.** Average relative spacing by management intensity and density for slash pine at age ten.

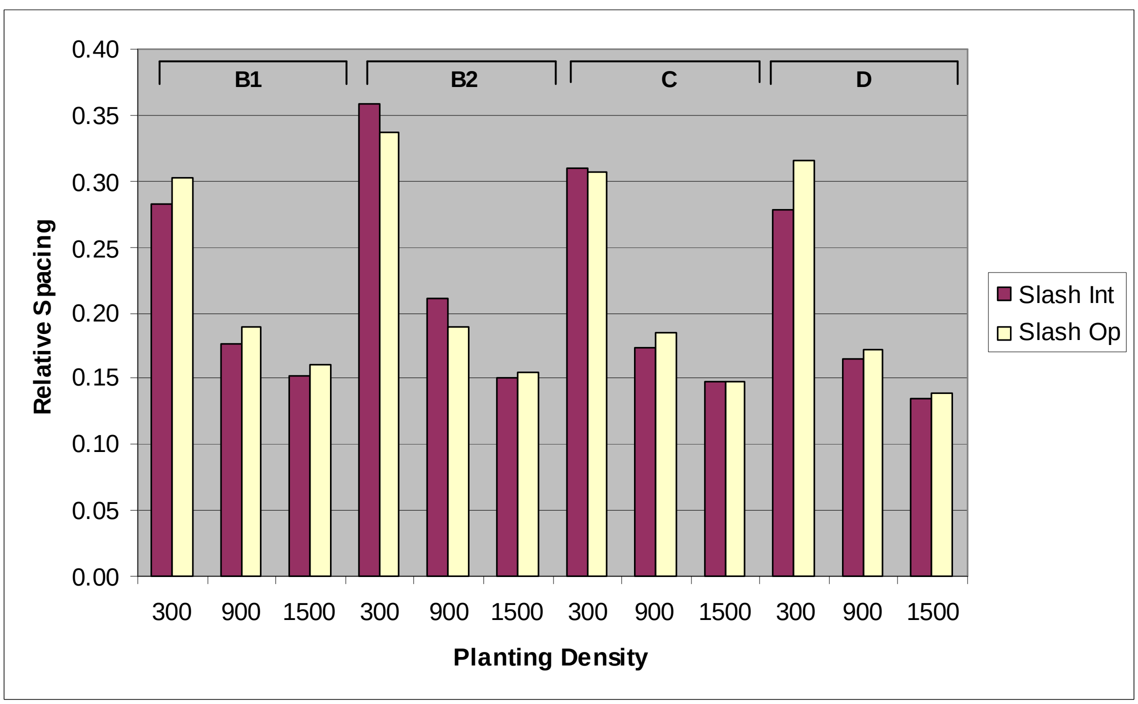


**Figure 45.** Average relative spacing by CRIFF soil group, management intensity and density for slash pine at age ten.

# 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 slash and loblolly pine. Figures 46-55 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, stand density index and relative spacing 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 0.6", to loblolly at the 300 density with intensive management. For all other pairs the largest difference was about 0.2" (Figure 46).

The intensively managed loblolly pine plots had consistently greater average heights (6-8 feet) than all other treatments (Figure 47). The intensively managed loblolly stands had average heights about 5 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 2.5-3 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 48).

In all cases, operational treatment plots had better survival than the more intensively managed plots (Figure 49). Loblolly pine survived better than slash pine in most comparisons by 4-5 % on the average, but intensive slash had comparable survival to intensive loblolly at the 1500 initial density. The higher cronaritum 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.

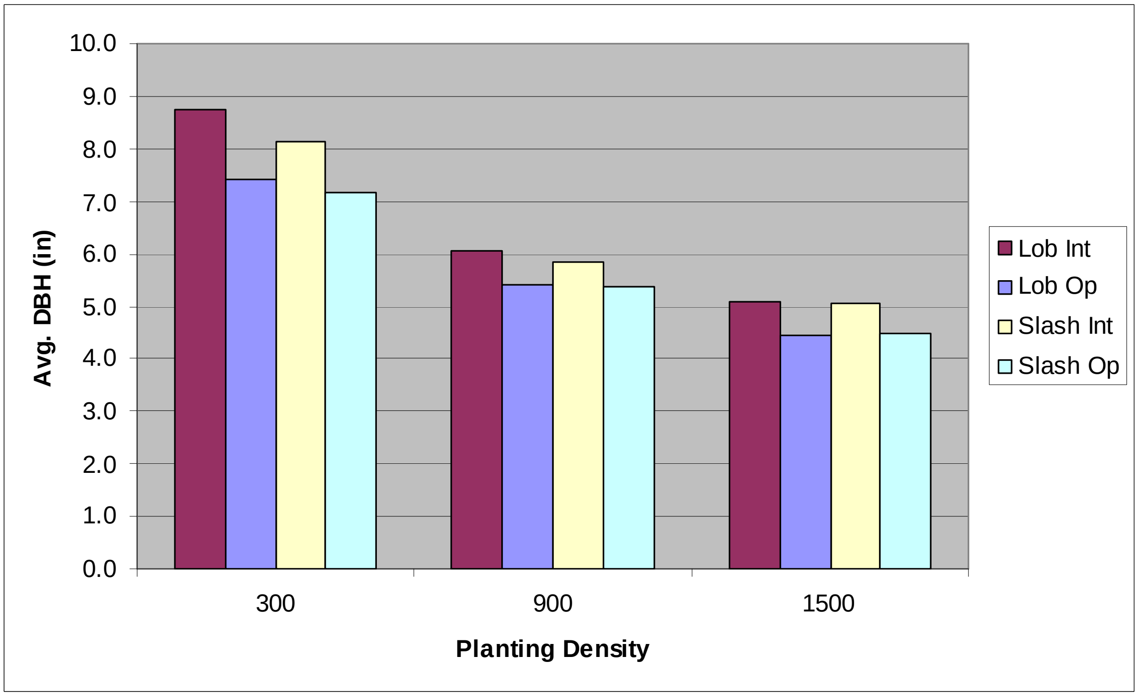


**Figure 46**. Average DBH by species, management intensity and density at age ten.

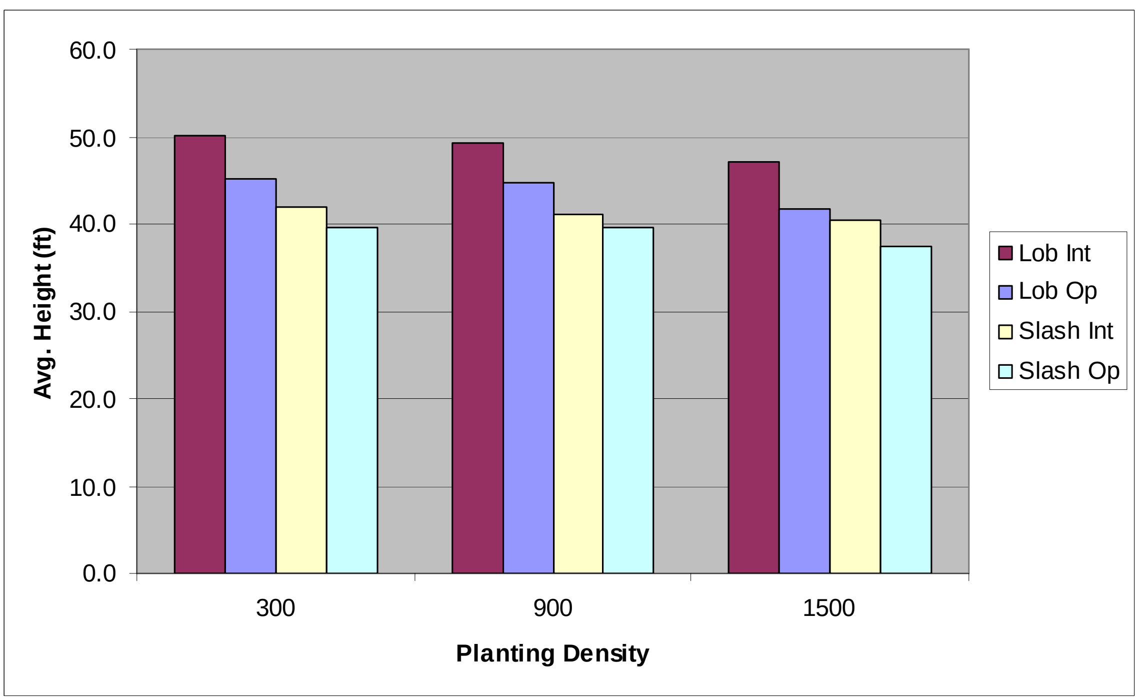


**Figure 47**. Average height by species, management intensity and density at age ten.

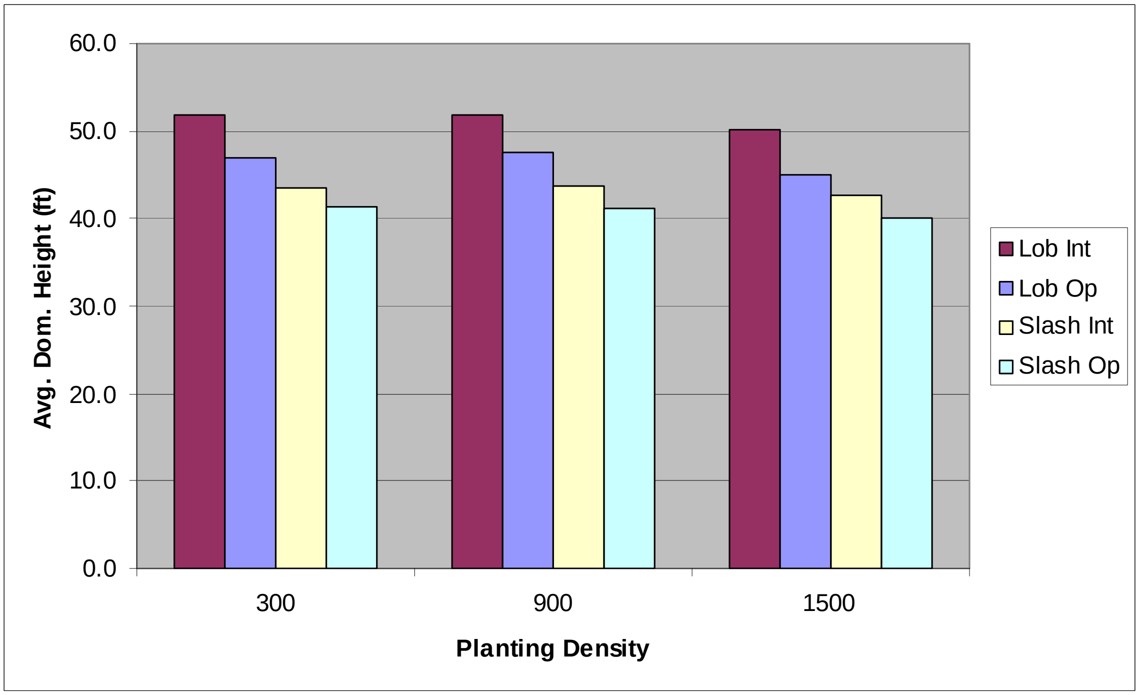


**Figure 48.** Average dominant height by species, management intensity and density at age ten.

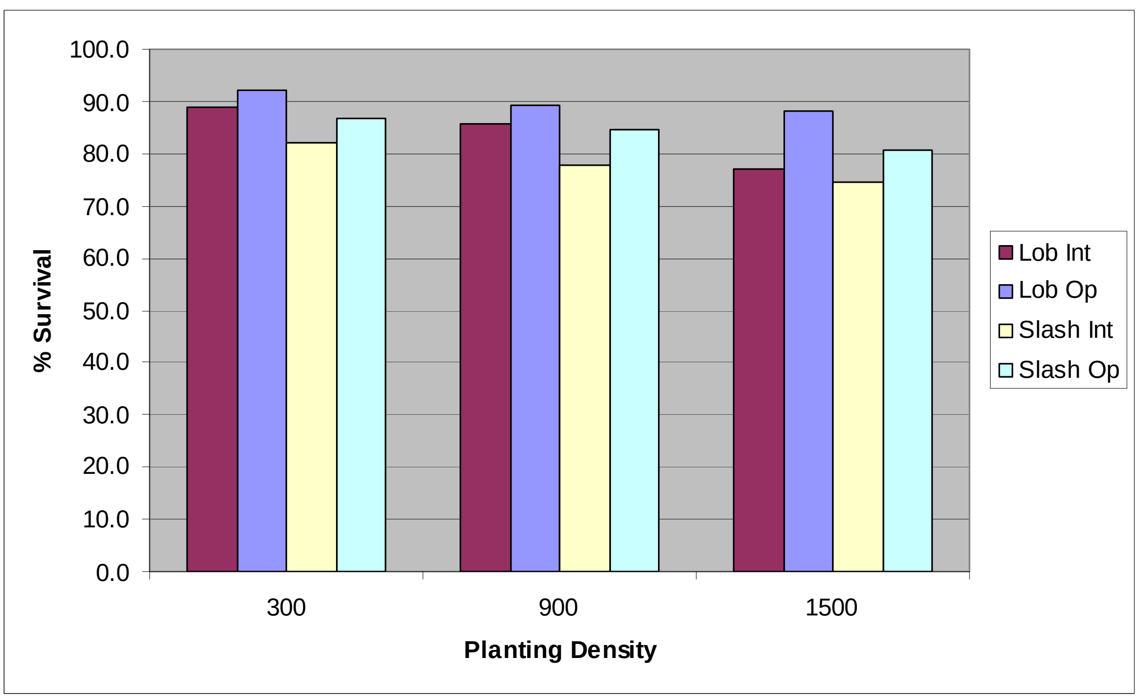


**Figure 49.** Average percent survival by species, management intensity and density at age ten.

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 50). 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 3.4%. Infection rates for both species also tended to increase with decreasing planting density.

For all treatments and species, per-acre basal area increased with increasing initial density (Figure 51). The operational loblolly pine plots had consistently more basal area (11-14 $ft^2$/ac) than operational slash pine plots across all initial densities. Loblolly pine had more basal area by about 24$ft^2$/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 12$ft^2$/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 52). Volume increased with increasing management intensity and initial density. Loblolly pine had more volume by 300-600 $ft^3$/ac at all spacings for the operational treatments. Loblolly pine had greater volumes than slash pine by 660 to 1040 $ft^3$/ac on the intensive treatments at all spacings.

The trends for total green weight were similar to the trends for total volume (Figure 53). The advantage for loblolly pine in terms of green weight was 20-27 tons/ac for intensively managed stands and was 8-14 tons/ac for operational stands depending on the initial density.

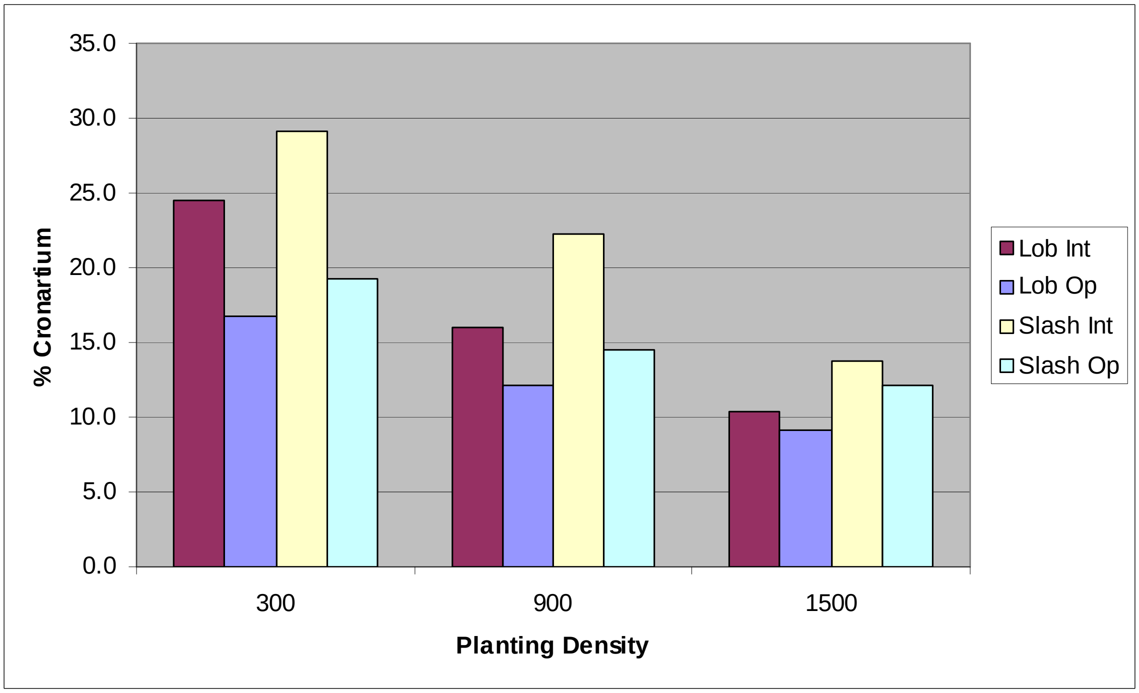


**Figure 50**. Average percent cronartium infection by species, management intensity and density at age ten.

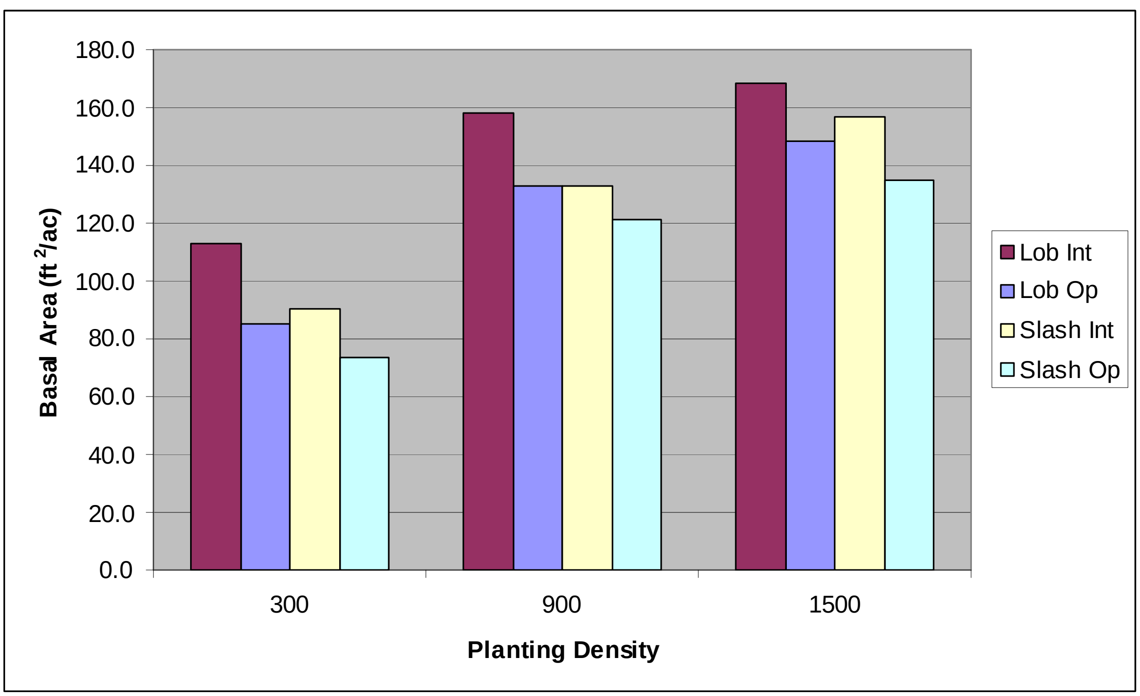


**Figure 51**. Average per-acre basal area by species, management intensity and density at age ten.

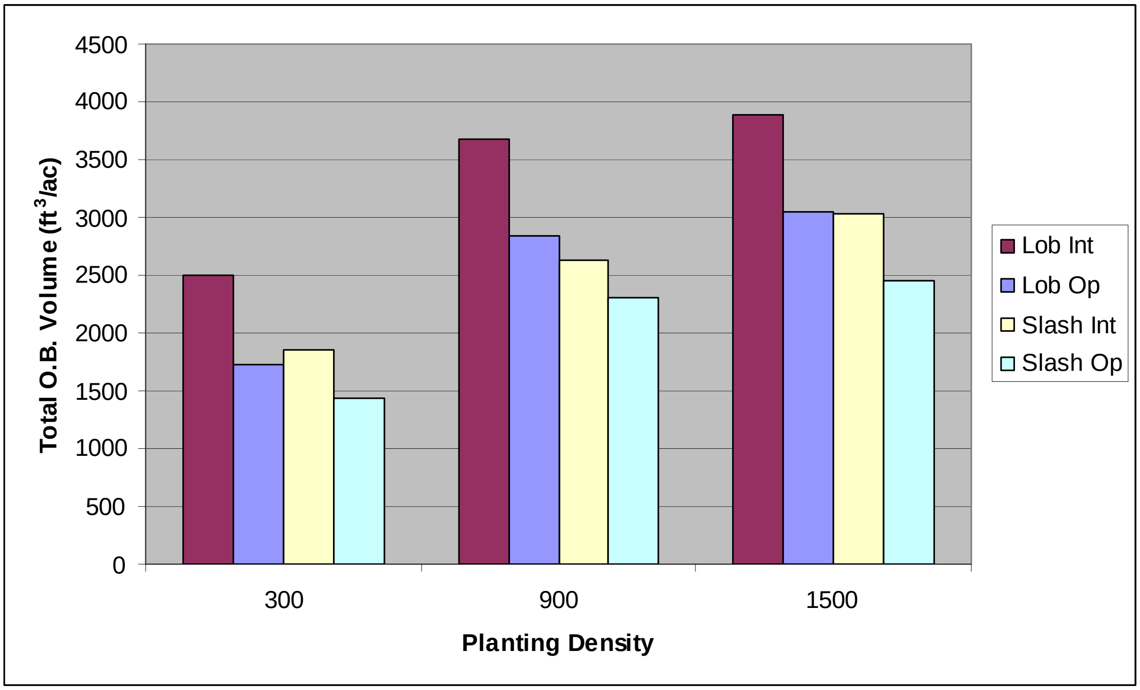


**Figure 52**. Average total per-acre outside bark volume ($ft^3/ac$) by species, management intensity and density at age ten.

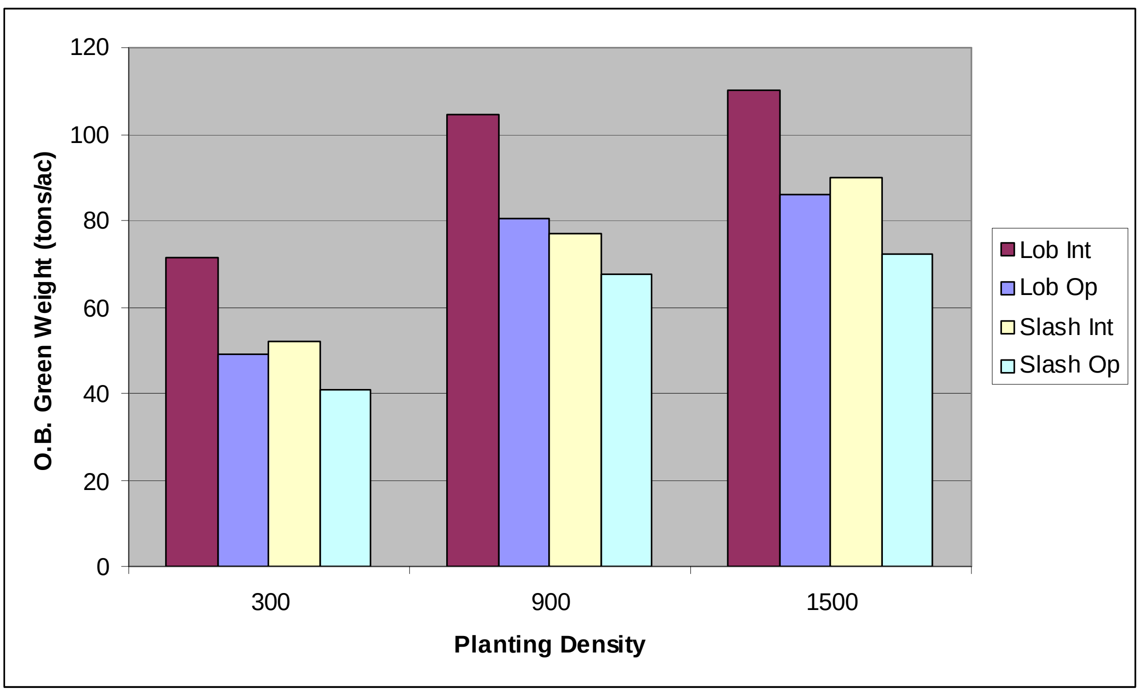


**Figure 53**. Average total per-acre outside bark green weight (tons/ac) by species, management intensity and density at age ten.

The comparison of the stand density index for the two species looks very similar to the comparison of basal area per acre (Figure 54). 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.

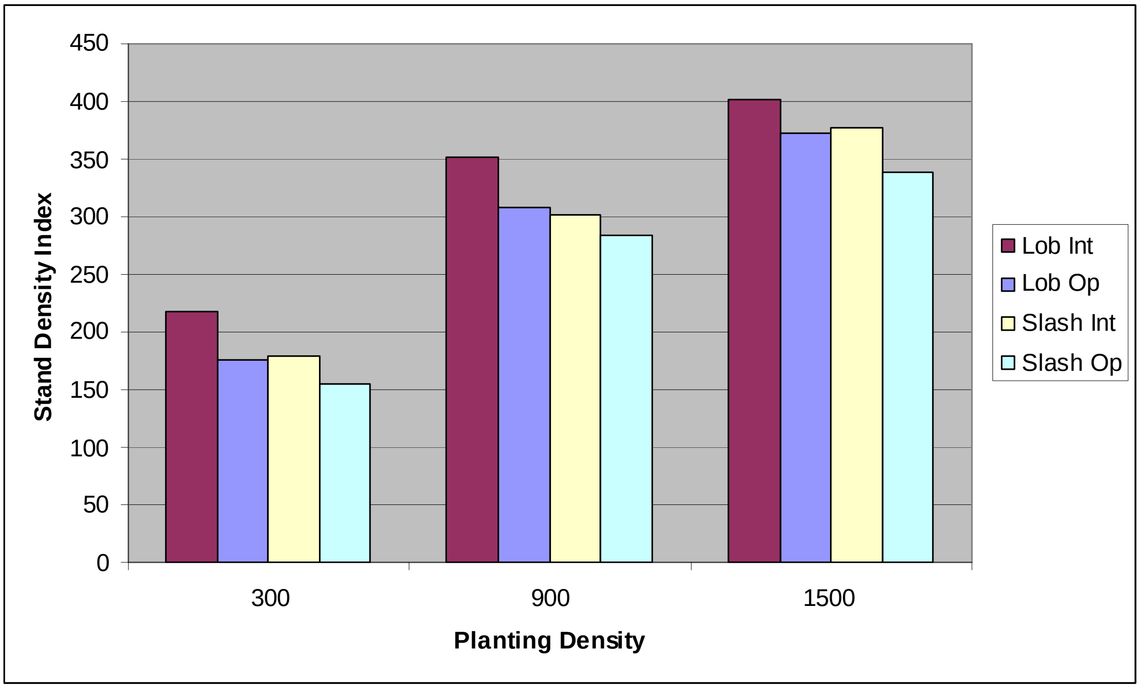


**Figure 54**. Average stand density index by species, management intensity and density at age ten.

Average relative spacing is lower for loblolly than for slash pine at age ten (Figure 55). 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.

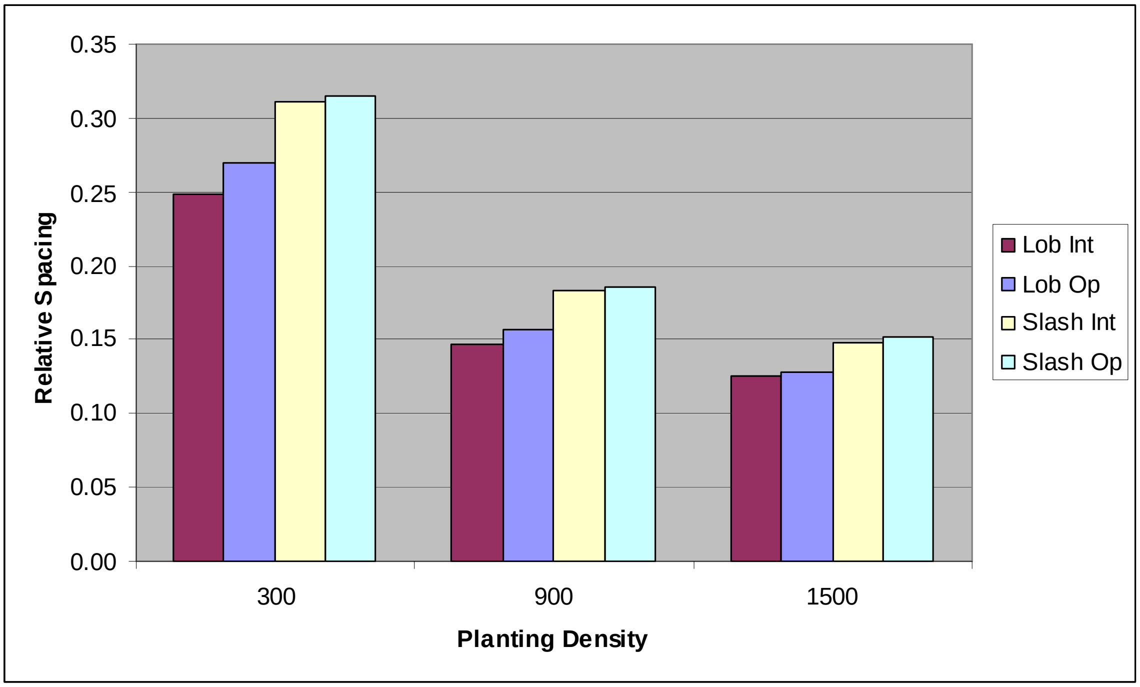


**Figure 55.** Average relative spacing by species, management intensity and density at age ten.

### 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 on CRIFF A group soils so the graphs here reflect only B1 and B2 nonspodosols and C and D group spodosols. The breakdown by CRIFF soil group is

| CRIFF Group | Number of Installations |
|---|---|
| B1 | 3 |
| B2 | 2 |
| C | 3 |
| D | 1 |
| Total | 9 |

So, in the results it is important to remember that CRIFF groups D and B2 do not have as much replication as do B1 and C.

Figure 56 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 management except on the D group soils where the advantage again went to loblolly pine by about 0.4". On the operationally-managed plots, there was very little difference in average DBH by species for B1, B2 and C group soils across densities. For D group soils, spodosols with no underlying argillic, slash pine average DBH values tended to be slightly higher than loblolly DBH values across densities. Across both soil group and management intensity, slash tended to compare better with loblolly for average DBH as initial density increased.

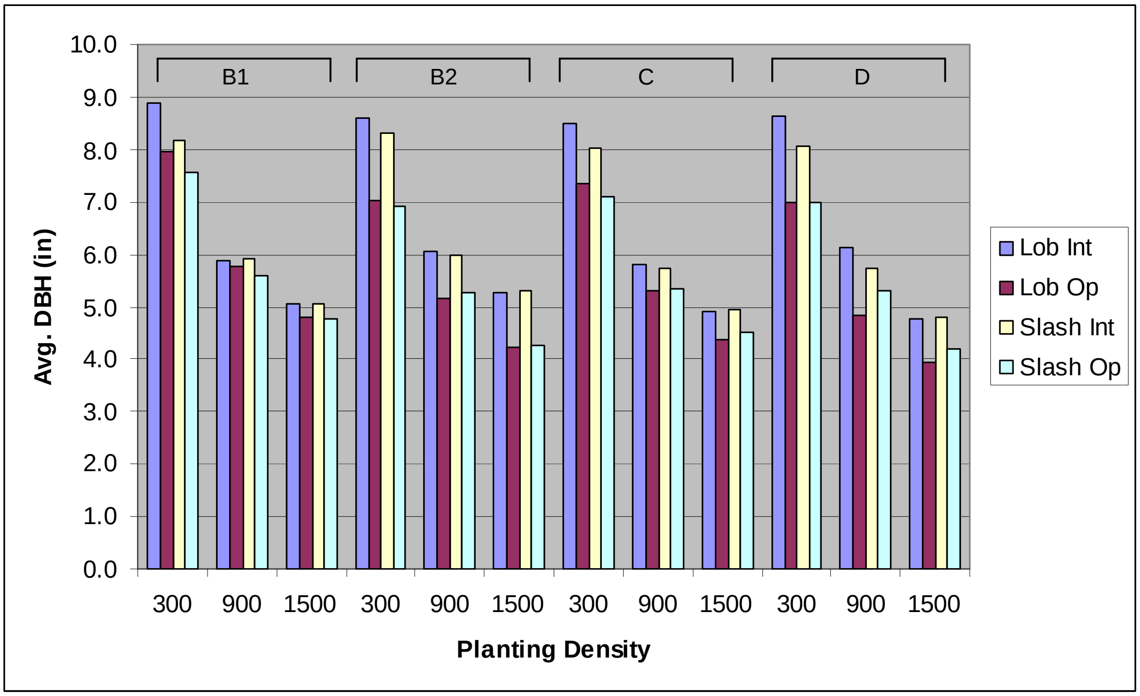


**Figure 56**. Average DBH (in) by CRIFF soil group, species, management intensity and density at age ten.

Loblolly pine had consistently taller average heights than slash pine for all soil and treatment groups (Figure 57). For intensively managed plots this difference was from 4 to 10 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 and D soils, operational loblolly plots averaged about 9 feet taller heights than operational slash. The same general trends hold for average dominant height as for average height (Figure 58).

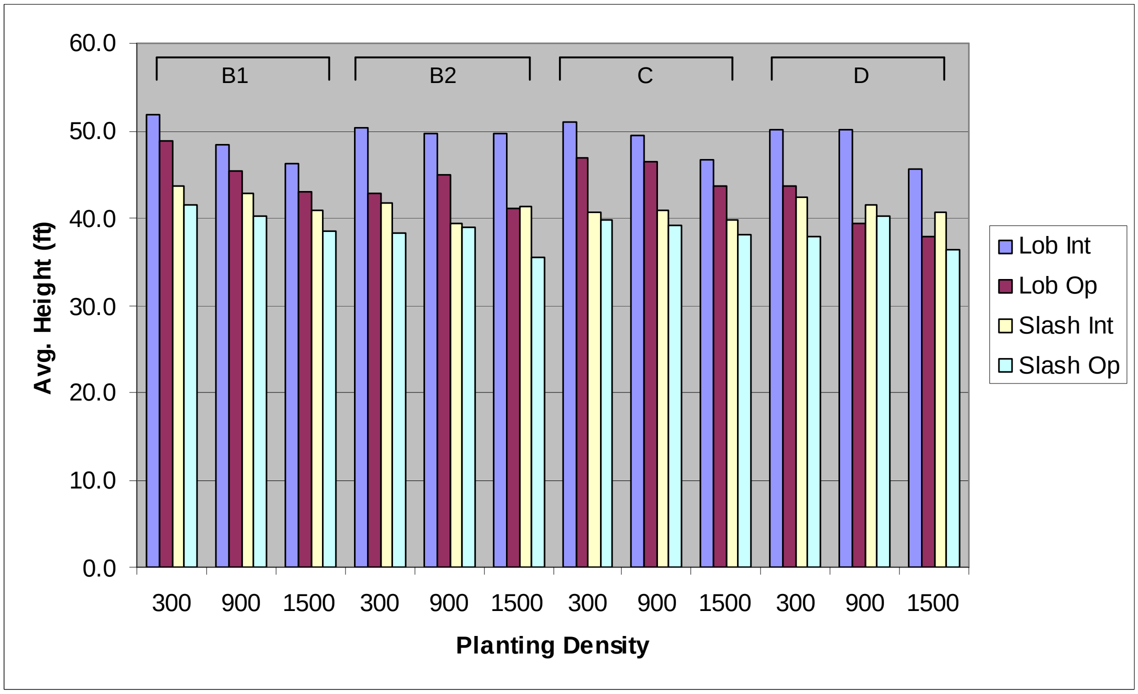


**Figure 57**. Average height (ft) by CRIFF soil group, species, management intensity and density at age ten.

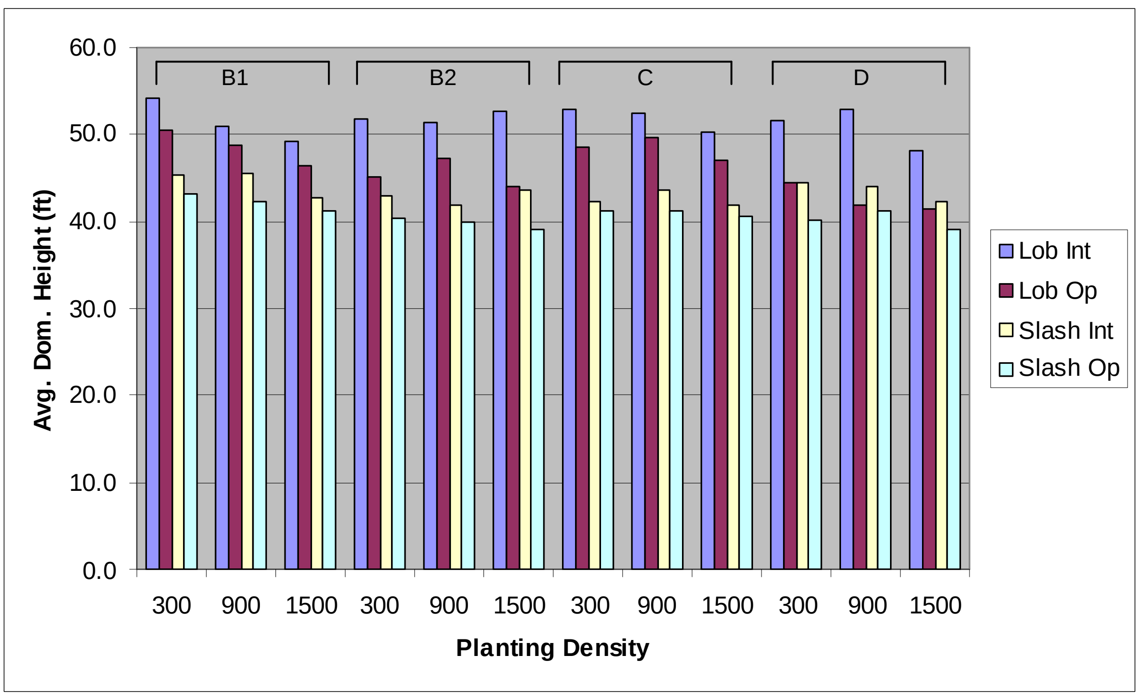


**Figure 58**. Average dominant height (ft) by CRIFF soil group, species, management intensity and density at age ten.

Survival trends for the two species by CRIFF soil group, management intensity, and density are shown in Figure 59. Survival for both species was uniformly good on the spodosols, CRIFF groups C and D. On B1 soils, survival averaged 86% for loblolly and 78% for slash across management and density treatments. On B2 soils, intensively managed slash pine had very poor survival at 65% across all treatments. Loblolly pine averaged 86% survival on the B2 soil group.

Cronartium infection rates were lower on the spodosols, CRIFF groups C and D, than on the nonspodosol soils (Figure 60). 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 23-37% 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.

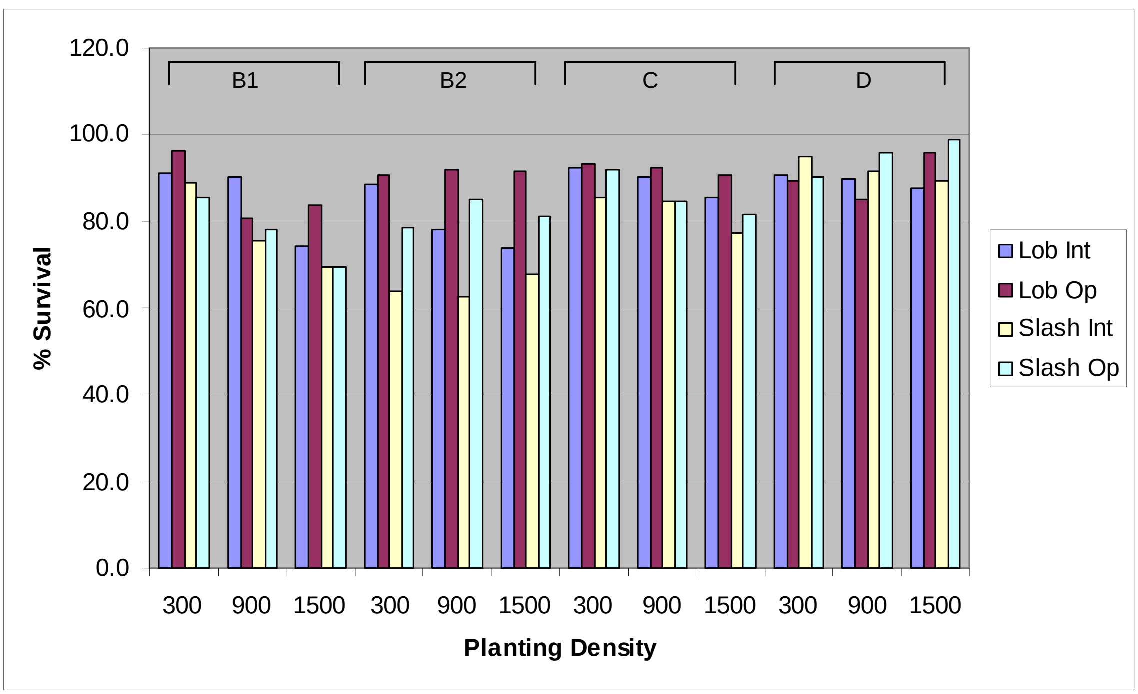


**Figure 59**. Average percent survival by CRIFF soil group, species, management intensity and density at age ten.

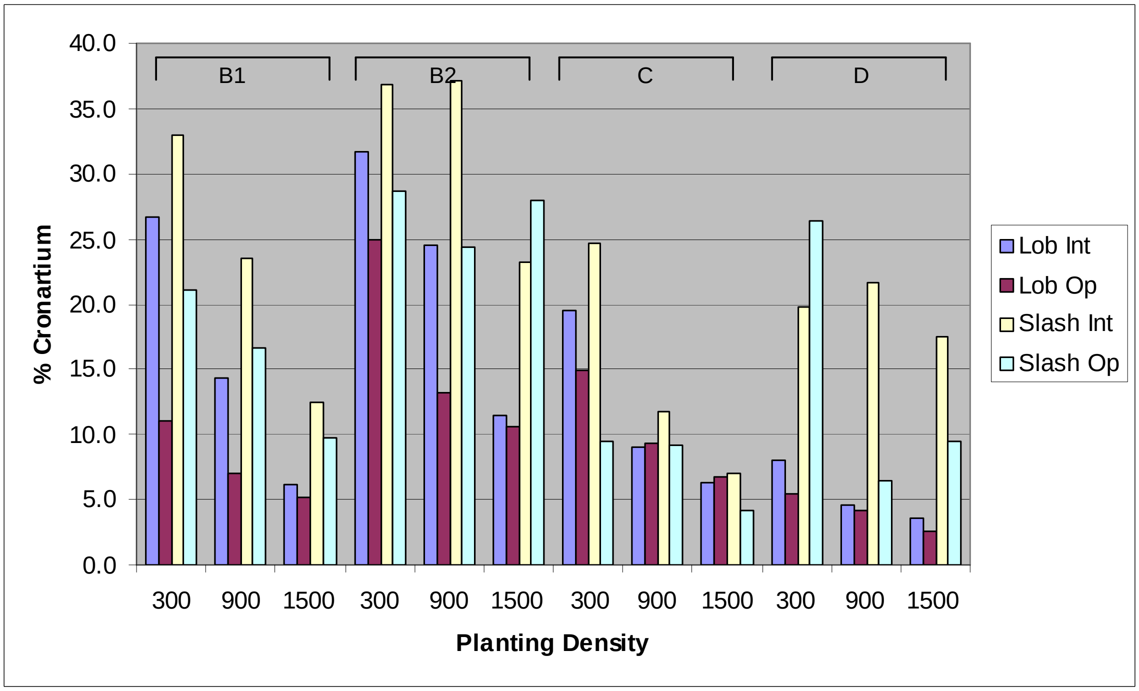


**Figure 60**. Average percent cronartium by CRIFF soil group, species, management intensity and density at age ten.

Loblolly pine had consistently more per-acre basal area than slash pine with the exception of the D soil group (Figure 61). On the other 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 14ft$^2$/ac more basal area per acre than slash pine. Slash pine had consistently more per-acre basal area than loblolly with operational management on the D soil group and for the intensively-managed 1500 initial density.

Loblolly pine with intensive management had more volume than slash pine with intensive management in every soil group and density class (Figure 62). The advantage to loblolly ranged from 590ft$^3$/ac on the D-group soils to 1059ft$^3$/ac on soil group B2. Slash pine had more total volume on the operational plots on the D soil group with 900 and 1500 initial trees per acre.

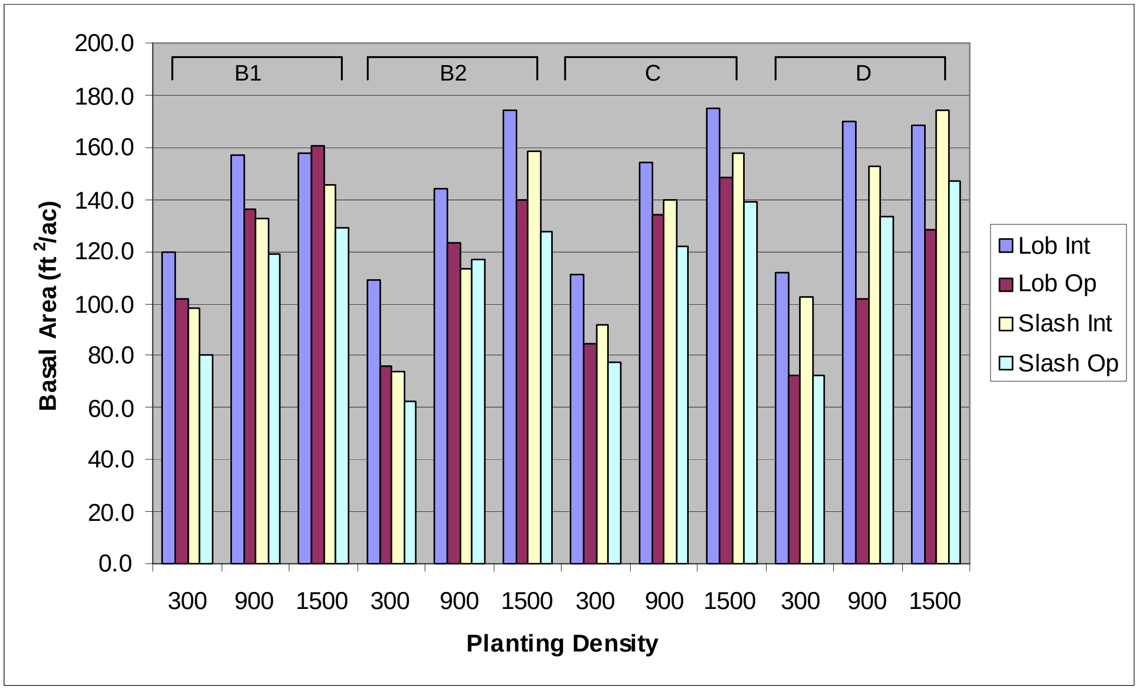


**Figure 61**. Per-acre basal area ($ft^2/ac$) by CRIFF soil group, species, management intensity and density at age ten.

The trends for total green weight were nearly identical to total volume (Figure 63). The advantage of using intensively managed loblolly rather than intensively managed slash ranged from 6-32 tons/ac at age ten. The advantages of loblolly on the operationally-managed plots, with the exception of the D group soils, ranged from 7-24 tons/ac. On D group soils the slash advantage was 21 tons/ac on the 900 and 9 tons/ac 1500 initial density.

The stand density index (SDI) comparison for species across soil groups, management intensities, and initial densities at age ten 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 except for the 1500 tree per acre initial density on soil group D. The SDI values for the two species were closer for operationally-managed plots and slash pine had higher SDI values for all densities on D group soils.

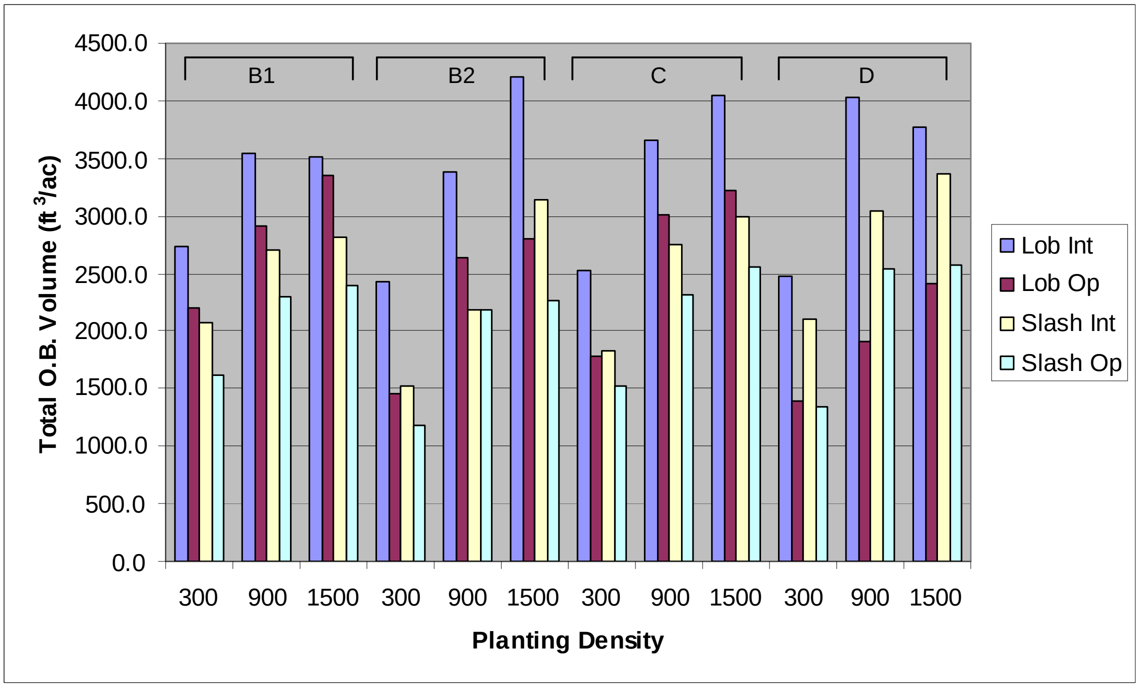


**Figure 62**. Per-acre total outside bark volume ($ft^3/ac$) by CRIFF soil group, species, management intensity and density at age ten.

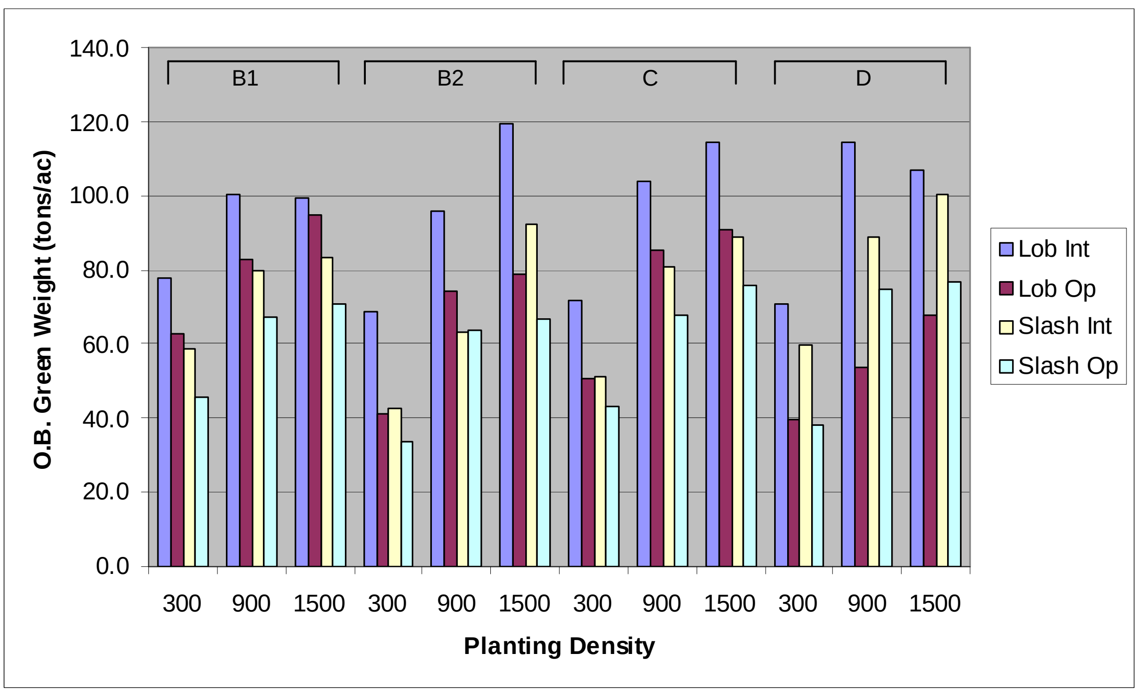


**Figure 63**. Per-acre total outside bark green weight (tons/ac) by CRIFF soil group, species, management intensity and density at age ten.

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 64). Most of the 1500 initial density slash pine plots with intensive management were at or near their maximum density at age ten. 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 65).

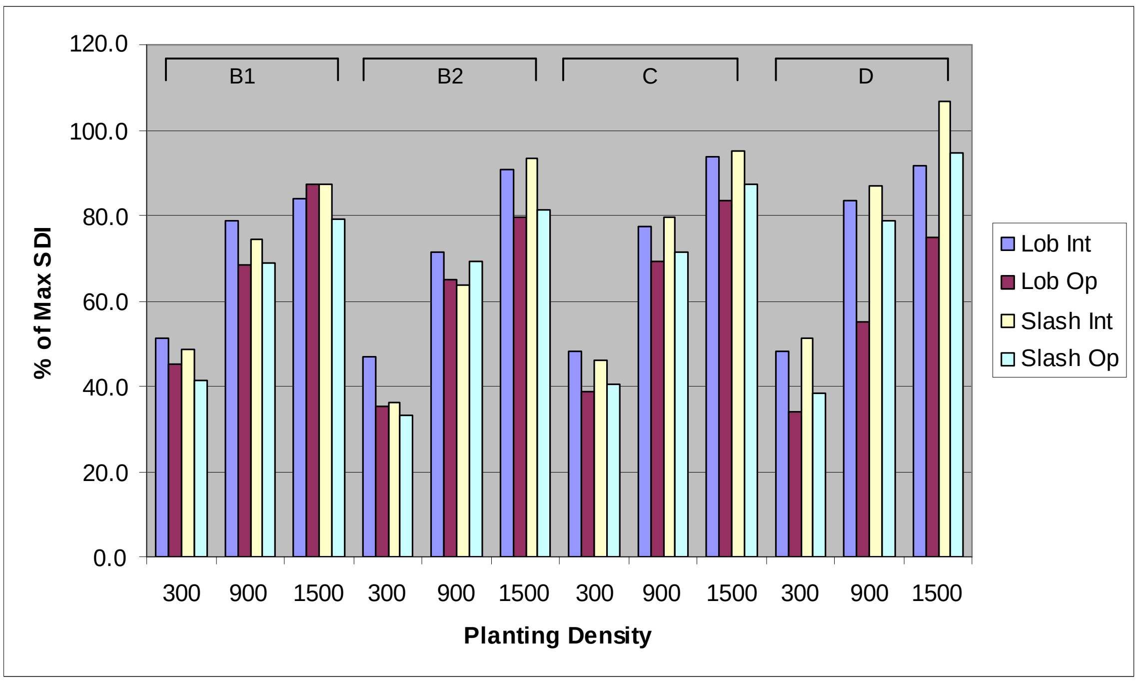


**Figure 64.** Percentage of Maximum Stand Density Index by CRIFF soil group, species, management intensity and density at age ten.

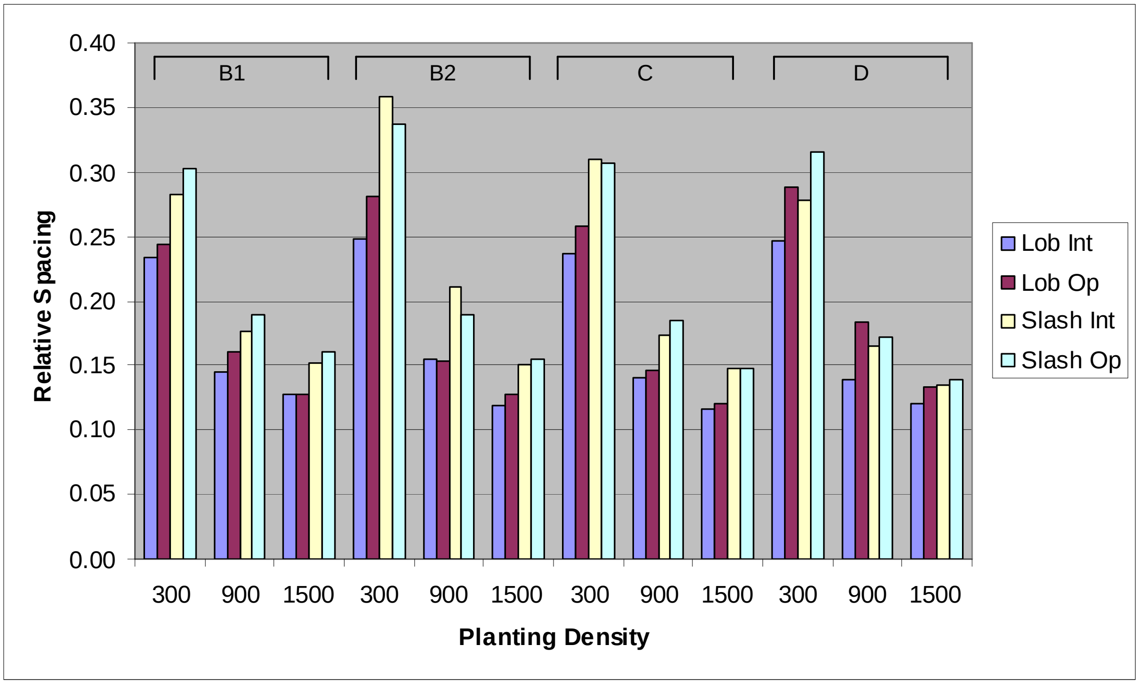


**Figure 65.** Average relative spacing by CRIFF soil group, species, management intensity and density at age ten.

# 6 DISCUSSION

The data reported on here are from 10-year-old plantations. Accelerated growth for both the operational and more intensive treatments has resulted in per-acre basal areas, total volumes, and total green weights normally seen in much older stands. 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's for all spacing treatments and soil groups. An examination of the average DBH's for the different spacing treatments shows that the additional weed control and fertilization has accelerated the onset of inter-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 inter-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. What is surprising is that slash pine had higher infection rates, in general, than loblolly pine. Perhaps the gains in rust resistance due to tree improvement 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. Both quantities 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 10. The 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.

In comparing slash and loblolly pine, it appears that the D group soils are legitimate slash pine sites if intensive management is not planned. On those soils, slash pine produced as much or more volume and weight as loblolly pine across the three densities. If, however, intensive management was used, loblolly still outperformed slash pine on all soil groups at age ten.

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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