PMRC COASTAL PLAIN CULTURE / DENSITY STUDY:

AGE 8 ANALYSIS

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PMRC Technical Report 2004 - 1
May 20, 2004

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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 was also a significant density x management interaction 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 more differences in average DBH across densities. 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. There were no significant differences in survival due to any of the factors or interactions. 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. The trends for per-acre basal area, per-acre green weight and per-acre total stem volume were similar. The management intensity factor, the density factor and their interaction had significant effects on these per-acre values, though the interaction for basal area was only significant at the 10% level of significance. 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. The interaction apparently results from virtually no difference or even a slight decline on operational treatments as the density increased from 900 to 1200. The 1500 and 1800 densities continue to increase on operational treatments so this may just be an anomaly in these data. 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 lower densities than at the 900 or 1500 densities. Management intensity and density were significant factors for average slash pine height. Intensively managed treatments were taller by about 2.6 ft compared to operational treatments. Though density was significant statistically 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 2.7 ft in favor of the intensive management treatment. Soil group was the only significant factor for slash pine survival. The CRIFF B2 average survival was significantly lower than survival of any other soil group. The density and soil group factors significantly affected the cronartium infection rate. The spodosol installations, CRIFF class C and D had lower infection levels than the nonspodosol soils, particularly the C group soils. On the nonspodosol soils, 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. For relative spacing both planting density and density by soil class 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. Average dbh's within each treatment combination were nearly equal for slash and loblolly pine. Loblolly was 5-7 feet taller than slash pine on the intensive treatments and 1-3 feet taller on the operational plots. Both species had good survival, but loblolly had better overall survival by 2-4 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. Per-acre basal areas for both species were nearly equal on the operational treatment plots. Across soil classes, slash pine had comparable per-acre basal area to loblolly with intensive management and 1500 trees per acre initial density treatments. On lower densities, however, the loblolly had more basal area per acre. Loblolly pine had more total, per-acre stem volume than slash pine for all planting densities on the intensively managed plots. On operational plots, slash pine volumes were higher on the D group soils and on the 1500 initial density C group soils, but loblolly had more volume on all other density and soil group combinations. The same pattern held true for total per acre green weight.

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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 8 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 gallberry) (*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 a 5-foot band 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 qts. Garlon 4 and 2 qts. 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 $NH4NO_3$ 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. 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 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)		60
DENSITY*CULTURE*INST(SOIL)		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 eighth 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):

$$GWOB = 0.0740959\,DBH^{1.829983}\,HT^{1.247669}$$

$$VOB = 0.00145519\,DBH^{1.826051}\,HT^{1.221965}$$

where *VOB* = total stem volume outside bark (o.b.)

GWOB = total stem green weight (o.b.)

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, and total per acre green weight. 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 eight.

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	6.85	33.2	39.7	98.3	18.6	76.4	1064	35
	600	5.55	33.1	43.5	98.3	9.8	101.1	1470	47
	900	4.82	32.5	43.6	97.2	10.0	113.5	1651	52
	1200	4.43	31.7	42.6	96.7	4.1	128.2	1848	58
	1500	4.04	31.1	42.0	96.5	3.2	133.2	1917	60
	1800	3.92	30.8	40.7	95.3	3.8	149.2	2146	67
Operational	300	5.16	27.5	37.0	97.5	12.1	43.7	516	17
	600	4.40	26.6	36.4	91.7	9.6	59.9	707	23
	900	3.94	26.2	38.5	90.3	7.6	72.6	869	28
	1200	3.55	25.1	38.2	91.1	7.4	79.0	901	29
	1500	3.47	26.2	36.2	93.5	6.9	97.2	1172	38
	1800	3.13	25.1	36.5	92.4	7.3	94.6	1113	36

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	7.9	43.3	44.7	96.3	19.9	99.8	1997	52
	600	6.3	43.2	45.0	98.3	12.3	130.5	2733	70
	900	5.5	42.5	44.4	95.8	10.5	142.8	3007	76
	1200	5.0	42.1	44.1	93.9	4.2	161.0	3416	85
	1500	4.5	40.0	42.1	92.5	2.9	158.5	3276	80
	1800	4.4	39.9	42.3	89.1	3.8	175.5	3629	89
Operational	300	6.7	38.3	40.3	97.5	15.9	74.3	1366	35
	600	5.5	36.9	39.1	91.3	10.5	94.2	1740	43
	900	4.9	36.1	38.9	88.9	8.5	108.5	2026	50
	1200	4.4	33.8	36.3	87.5	11.6	113.1	2022	49
	1500	4.2	35.0	37.6	87.5	8.6	128.5	2374	57
	1800	3.8	33.7	36.6	87.1	9.0	129.6	2369	56

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	7.6	41.2	42.9	92.1	30.2	87.9	1695	44
	600	6.0	40.6	41.9	89.2	25.1	108.9	2150	54
	900	5.4	40.9	42.0	81.9	24.5	120.1	2438	61
	1200	5.0	40.5	42.8	90.6	14.3	154.0	3152	78
	1500	4.7	41.0	43.3	85.6	11.1	158.0	3330	82
	1800	4.2	38.9	40.9	88.2	10.2	157.4	3198	78
Operational	300	5.7	33.2	35.6	92.5	25.4	51.8	863	21
	600	4.9	35.0	36.9	94.2	21.6	76.1	1363	33
	900	4.5	36.0	38.0	94.1	12.2	96.2	1803	44
	1200	3.8	32.0	34.5	87.5	14.3	87.1	1513	36
	1500	3.7	33.3	35.4	93.3	11.8	106.4	1921	45
	1800	3.4	32.2	34.6	93.3	9.1	112.7	1989	46

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	7.3	40.3	42.0	95.0	20.1	84.8	1615	42
	600	6.1	42.8	45.3	97.0	12.5	120.4	2526	64
	900	5.2	40.9	43.1	96.3	8.3	131.3	2708	68
	1200	4.7	39.8	42.4	95.8	4.9	145.2	2993	74
	1500	4.4	39.7	42.4	94.8	6.6	155.9	3240	79
	1800	4.1	38.8	41.6	91.5	6.5	156.5	3221	78
Operational	300	6.0	36.4	38.2	95.3	14.2	57.2	1035	26
	600	5.3	38.9	40.9	94.3	12.8	91.2	1787	44
	900	4.6	37.6	40.0	98.5	8.3	106.4	2092	51
	1200	4.0	34.6	37.4	97.8	6.9	108.6	2023	49
	1500	3.8	35.2	37.8	96.5	6.4	118.3	2243	53
	1800	3.6	34.6	37.6	96.1	6.2	128.1	2426	58

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	7.8	42.6	43.9	91.9	10.2	92.7	1832	48
	600	6.3	44.5	46.2	91.9	4.7	122.4	2631	67
	900	5.7	44.7	46.7	90.6	5.2	146.7	3225	82
	1200	4.8	41.3	43.2	89.6	4.6	141.1	2959	73
	1500	4.4	39.6	41.7	92.8	4.5	153.1	3147	77
	1800	4.2	40.6	43.4	90.5	3.9	165.0	3505	86
Operational	300	5.7	35.5	37.1	89.4	5.4	48.8	853	21
	600	4.7	34.2	36.6	92.5	6.1	69.3	1232	30
	900	4.2	32.8	35.4	87.0	5.4	77.0	1343	32
	1200	3.6	31.8	34.5	92.5	6.5	85.0	1488	35
	1500	3.3	31.3	34.0	95.6	2.6	92.5	1611	37
	1800	3.3	31.0	33.9	86.4	3.8	102.6	1845	43

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 a = 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 eight.

Source	Type III F	Pr > F
Soil	3.22	0.0559
Management	301.72	<0.0001*
Soil x Management	4.79	0.0175*
Density	837.85	<0.0001*
Soil x Density	1.39	0.1393
Management x Density	22.25	<0.0001*

*Significant at a = 0.05.

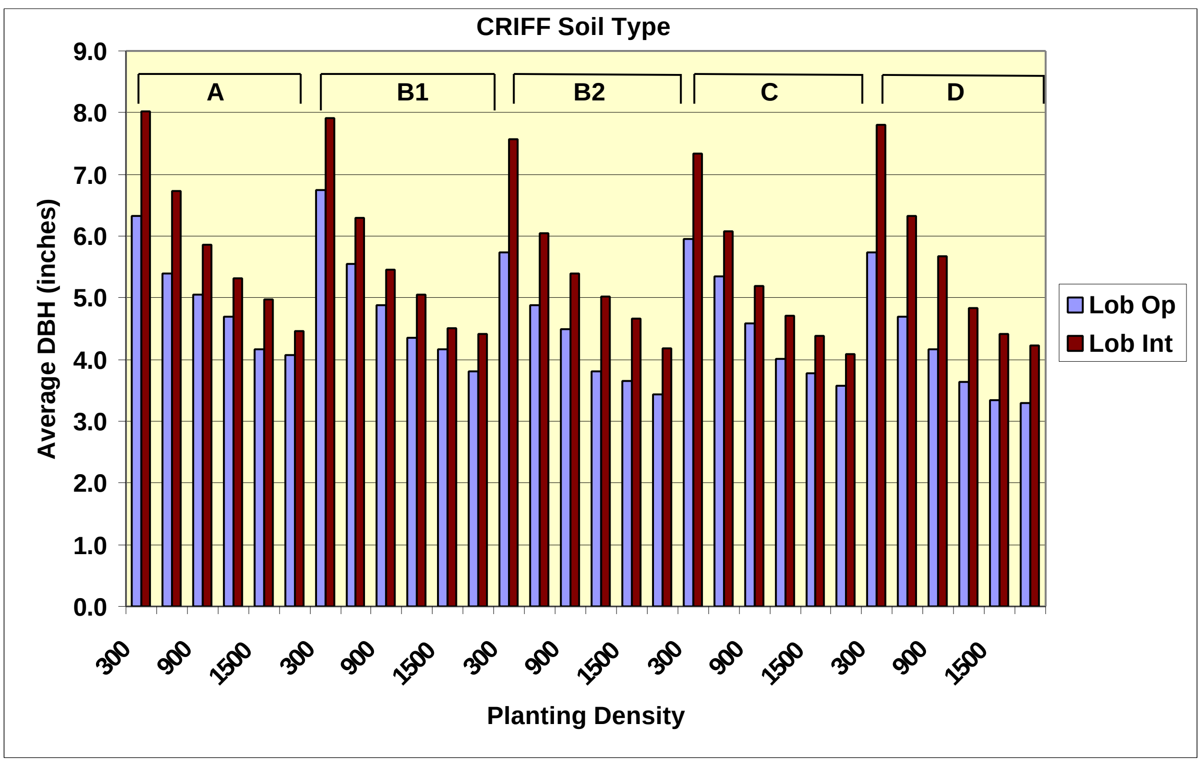

Figure 1. Average dbh by planting density, management intensity, and CRIFF soil type for loblolly pine at age eight.

Several factors deserve mention as a result of this analysis and graph. First of all 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. However, the effect of management intensity is more acute at the lower densities, particularly for CRIFF soils A, B1, and C. Recall that these are the three soil groups with argillic horizons at reasonably shallow depths. 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 interspecific 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.

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 a = 0.05 level with the intensive culture treatment heights averaging five to seven feet taller across the different densities. The density factor also significantly affected average height, but the differences appear very small (Figure 2). The 600 and 900 trees per acre densities had the highest average heights for both management treatment groups. Figure 2 shows the average heights by management intensity and initial density.

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 (1200, 1500, and 1800 per acre). There are no significant differences in height between the 600 and 900 densities, but there is a trend toward lower average height for both lower initial densities and higher initial densities. 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 height by planting density and management intensity is shown in Figure 3. The trend across densities is the same regardless of the management intensity. Differences between intensive and operational are slightly less, by about a foot, for average dominant height as compared to average height.

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

Source	Type III F	Pr > F
Soil	0.53	0.7133
Management	121.84	<.0001*
Soil x Management	2.16	.1404
Density	12.53	<.0001*
Soil x Density	1.82	.1750
Management x Density	0.80	0.5530

*Significant at a = 0.05.

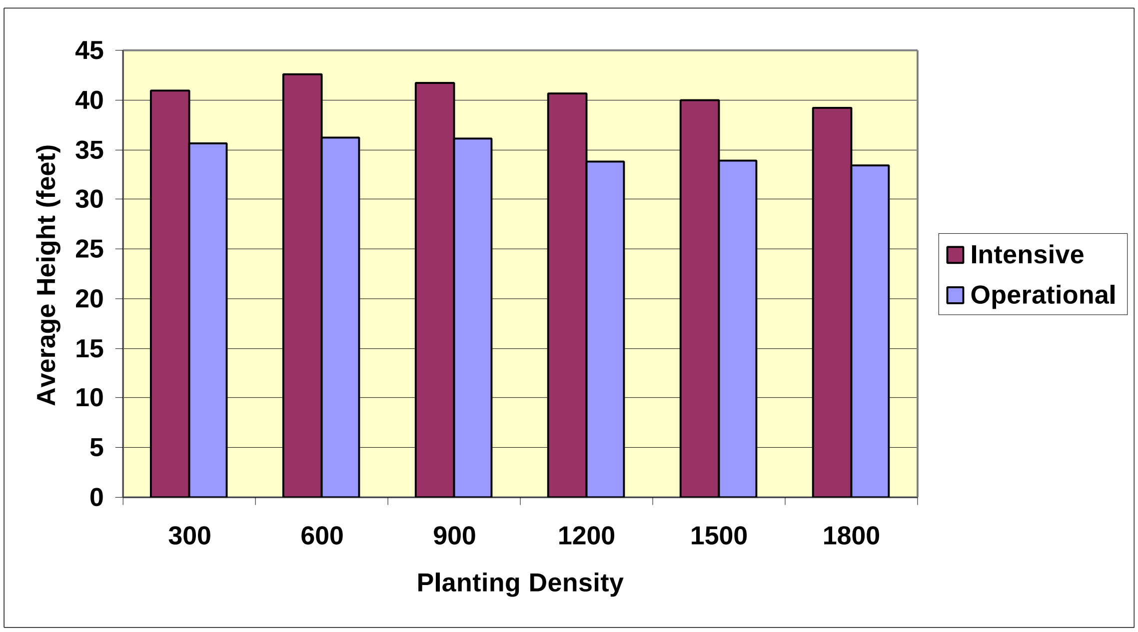

Figure 2. Average height by planting density and management intensity for loblolly pine at age eight.

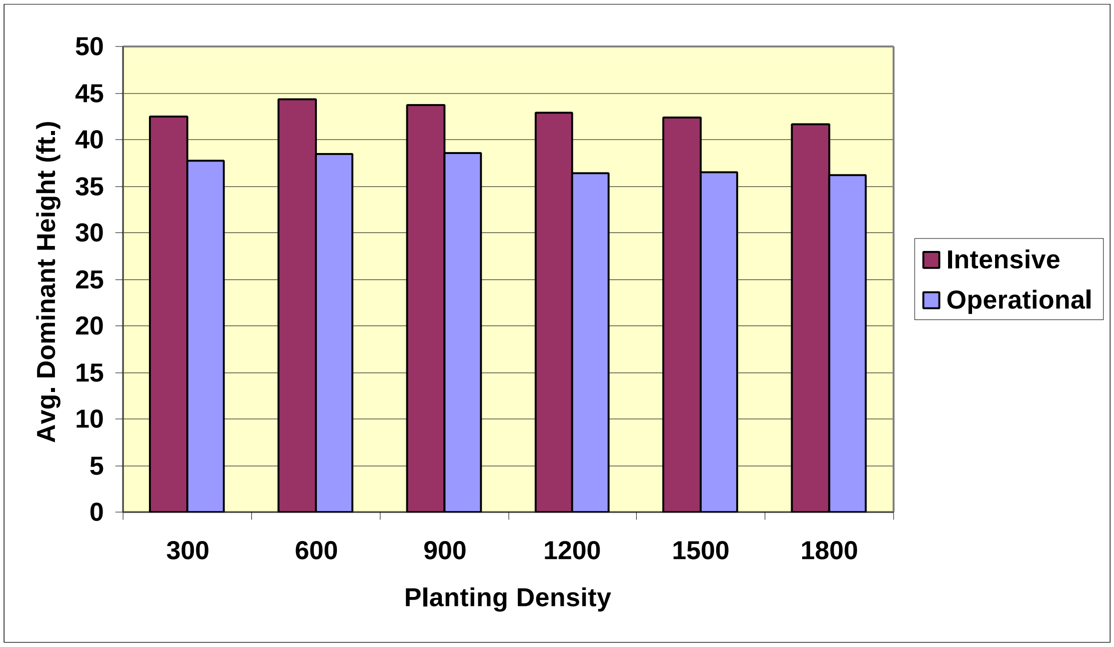

Figure 3. Average dominant height by planting density and management intensity for loblolly pine at age eight.

3.3 Percent Survival

Table 7 shows the results of the analysis of variance for average percent survival. Average survival by treatment was in excess of 89% for loblolly pine. This is primarily the survival from age one to age eight since trees were double planted and one tree was randomly removed after the first growing season when both survived. There were no significant differences in survival rates due to any factor included in the analysis of variance. Figure 4 shows the average survival percentages by initial density and management intensity. Though the differences appear large in the histogram, each unit change on the y-axis is only 1% survival.

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

Source	Type III F	Pr > F
Soil	1.32	0.3209
Management	0.29	0.6001
Soil x Management	1.47	0.2754
Density	1.91	0.0963
Soil x Density	1.40	0.1313
Management x Density	1.68	0.1428

*Significant at a = 0.05.

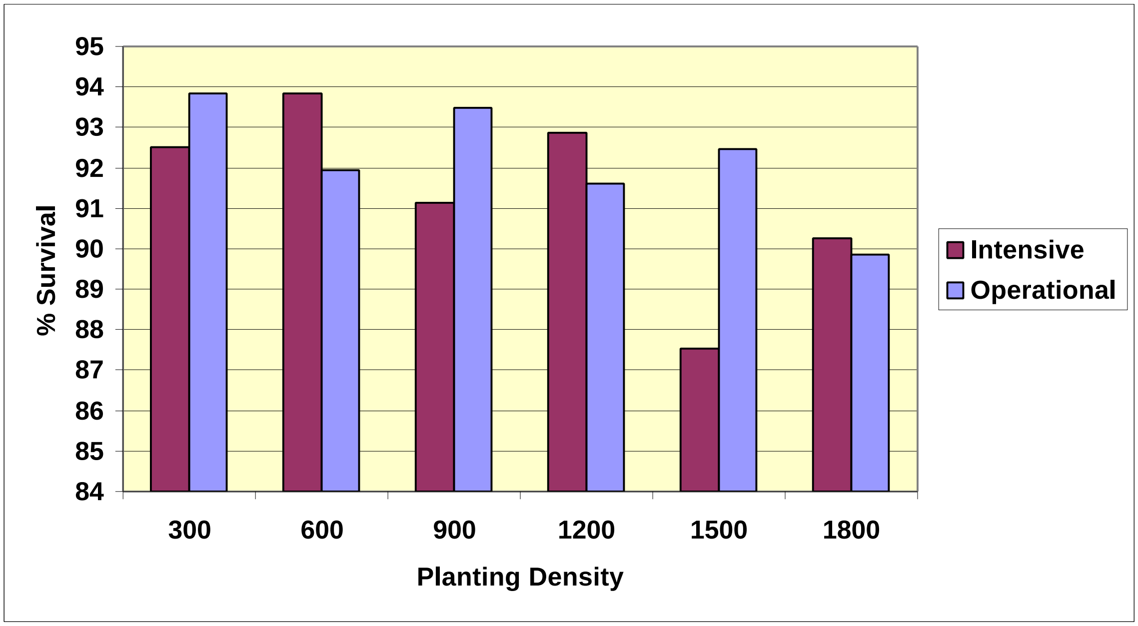

Figure 4. Percent survival by planting density and management intensity for loblolly pine at age eight.

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 7 to 23% for all densities and management regimes. Density and the management intensity x density interaction significantly affected the cronartium infection rate. As shown in Figure 5, 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 6 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 in 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, but only for 300, 600, and 900 initial trees per acre. For the B1 soil group and for the two spodosol soils, CRIFF C and D, only the 300 trees per acre initial density is noticeably higher in infection level for intensively managed versus operational managed plots. Regardless of soil group, there is a marked trend toward lower infection levels as initial density increases, at least up to 1200 trees per acre.

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

Source	Type III F	Pr > F
Soil	3.05	0.0644
Management	3.10	0.1060
Soil x Management	1.81	0.1969
Density	24.80	<0.0001*
Soil x Density	1.40	0.1319
Management x Density	2.98	0.0141

*Significant at a = 0.05.

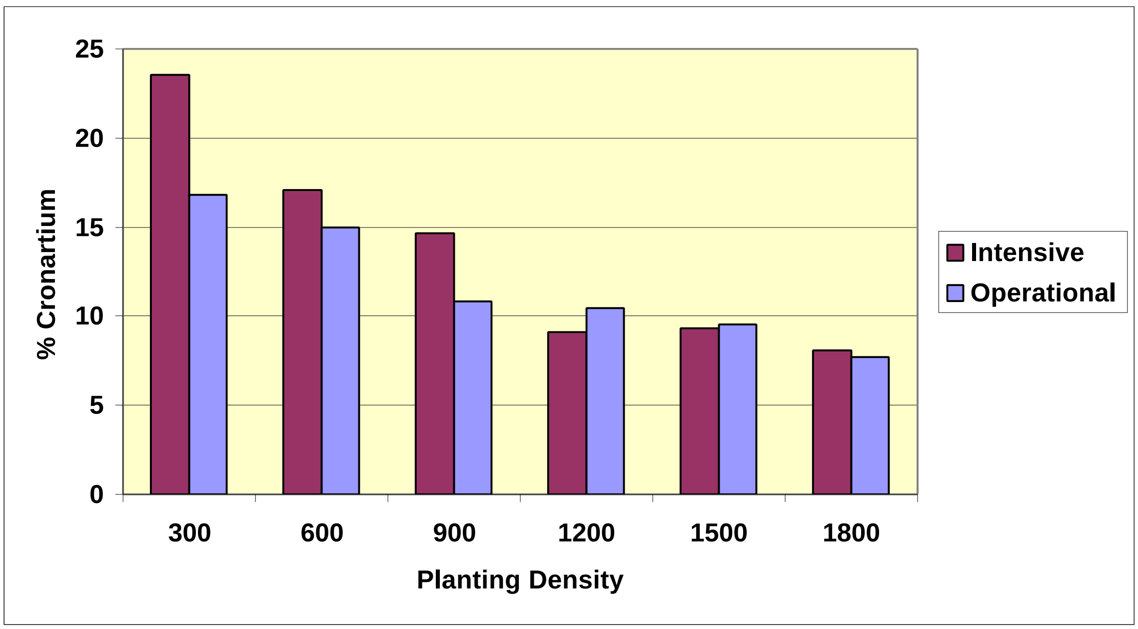

Figure 5. Average percent cronartium infection by planting density and management intensity for loblolly pine at age eight.

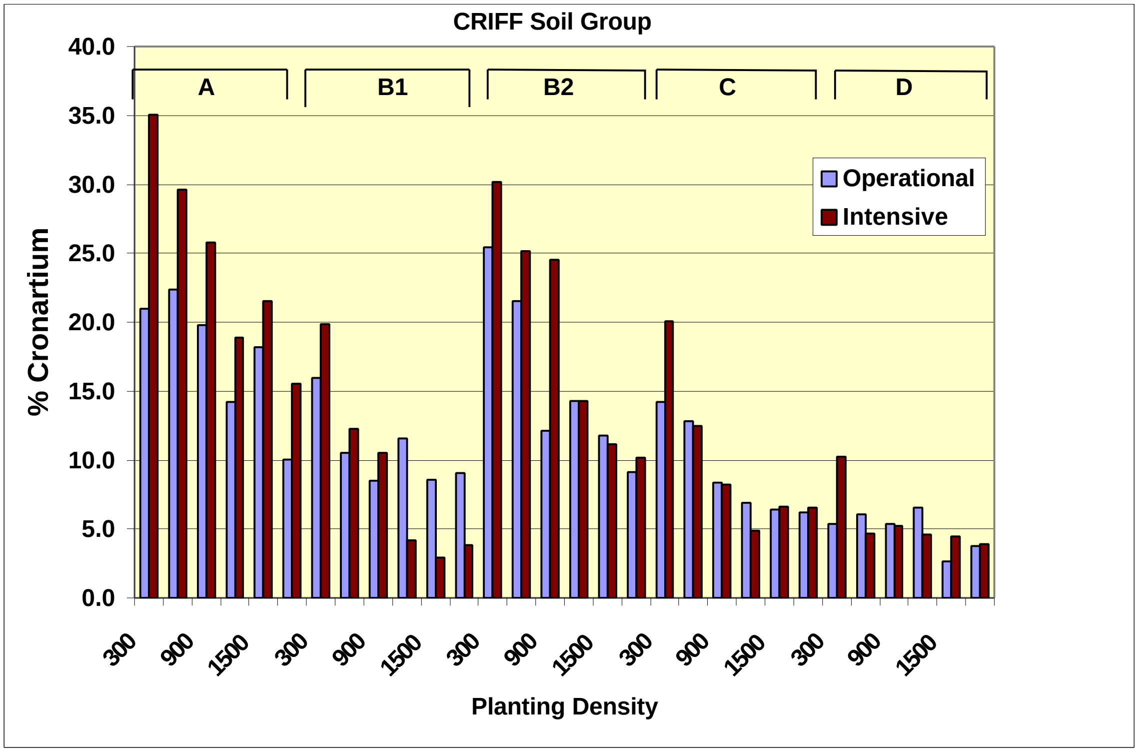

Figure 6. Average percent cronartium infection by planting density, management intensity, and CRIFF soil group for loblolly pine at age eight.

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. Basal area increased with increasing density, especially up to an initial density of 1200 trees per acre.

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

Source	Type III F	Pr > F
Soil	1.98	0.1676
Management	175.32	0.0001*
Soil x Management	2.11	0.1480
Density	131.60	0.0001*
Soil x Density	1.15	0.3061
Management x Density	1.97	0.0878

*Significant at a = 0.05.

There is very little difference in per acre basal area for intensively managed plots at age eight 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.

The difference in basal area per acre by management intensity given an initial density varies somewhat, but averages 30-40 ft^2/ac more on the intensively managed plots. The level of basal area per acre exhibited by these plots at age eight is extremely high for the intensively managed plots. The 1200 and greater initial density plots average more than 150 ft^2/ac with the 1800 density plots averaging 166 ft^2/ac across all soil types.

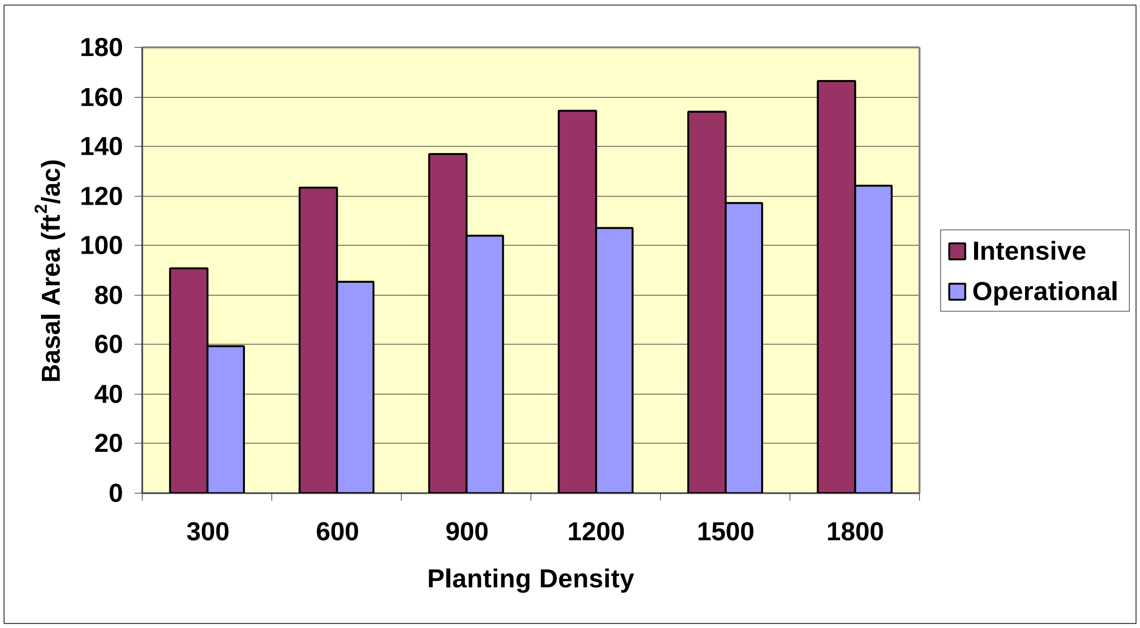

Figure 7. Average per-acre basal area (ft^2/ac) by planting density and management intensity for loblolly pine at age eight.

3.6 Per-Acre O.B. Volume

Table 10 shows the results of the analysis of variance for per-acre total stem volume. The results show very similar trends as seen for per-acre basal area. Management, density and their interaction significantly affected per-acre volume (Figure 8). The interaction is a result of less volume being added on the 300 trees per acre plots as a result of intensive management than on the other initial densities. The 300 trees per acre initial density does not have enough trees to fully occupy the sites and therefore the added resources from the intensive management does not add as much volume as it does on higher densities. The addition of intensive management to the 1200 initial trees per acre and higher plots adds more than 1000 ft^3/ac in total volume at age eight.

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

Source	Type III F	Pr > F
Soil	0.97	0.4624
Management	141.41	0.0001*
Soil x Management	1.70	0.2204
Density	80.80	0.0001*
Soil x Density	1.10	0.3523
Management x Density	3.84	0.0028*

*Significant at a = 0.05.

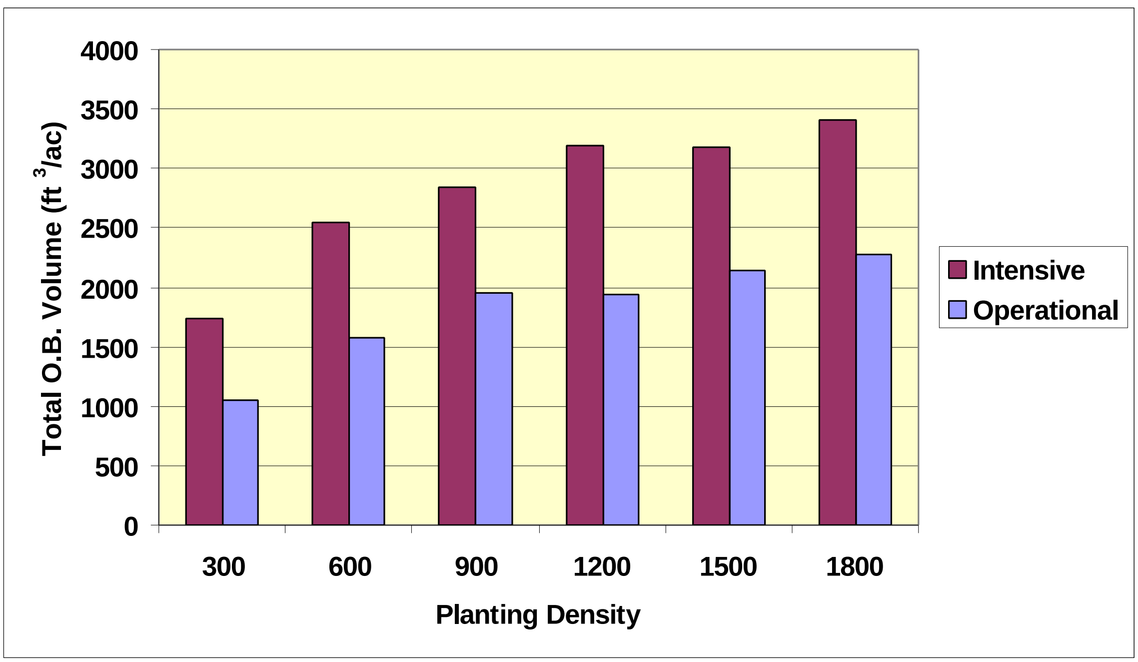

Figure 8. Average total per-acre outside bark volume (ft^3/ac) by planting density and management intensity for loblolly pine at age eight.

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 basal area. Management, density and their interaction significantly affected per-acre green weight (Figure 9). With the exception of an initial density of 300 trees per acre the intensive management added 25 to slightly more than 30 tons/ac at age eight. The higher densities combined with the more intensive management results in growth of about 10 tons/ac/yr. The corresponding value for the operational plots is about 6 tons/ac/yr.

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

Source	Type III F	Pr > F
Soil	0.96	0.4661
Management	147.09	0.0001*
Soil x Management	1.69	0.2220
Density	79.02	0.0001*
Soil x Density	1.10	0.3525
Management x Density	3.84	0.0028*

*Significant at a = 0.05.

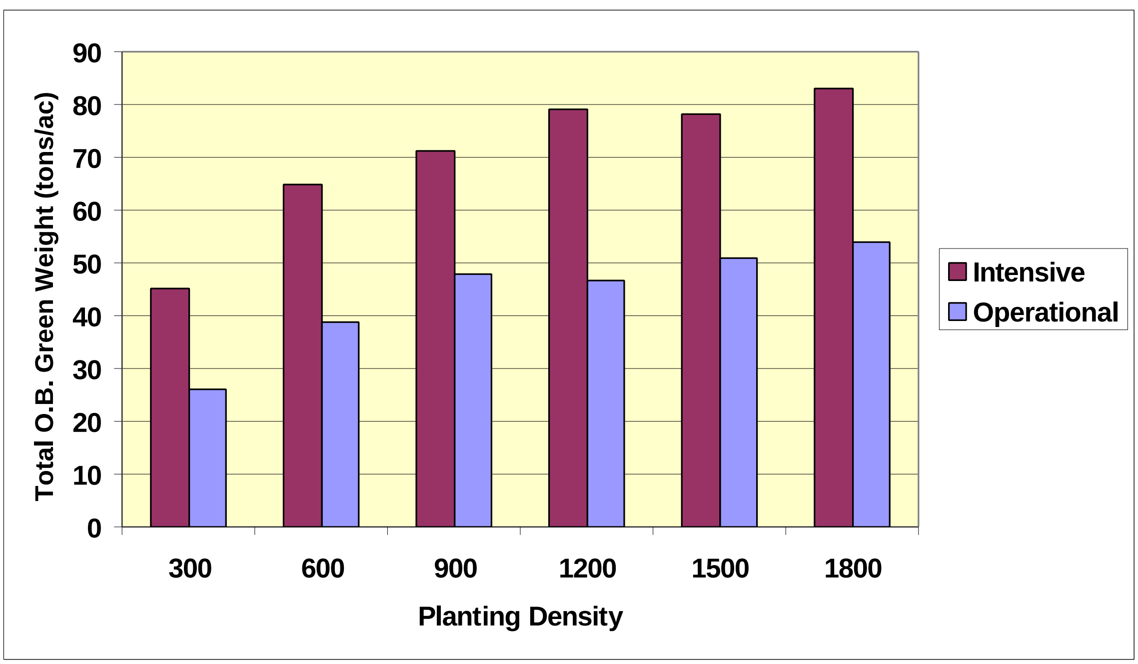

Figure 9. Average total per-acre outside bark green weight (tons/ac) by planting density and management intensity for loblolly pine at age eight.

3.8 Stand Density Index

Stand Density Index 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 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:

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

where SDI = stand density index,
N = 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, density, and their interaction were significant factors for SDI differences (Figure 10). Since both management intensity and initial density impact the speed of stand development, it is not surprising that they are significant factors. The effect of intensive management is surprisingly constant at about a 75 SDI unit increase across density with the exception of the 300 initial density.

Table 12. Analysis of variance results for loblolly pine average stand density index at age eight.

Source	Type III F	Pr > F
Soil	1.63	0.2365
Management	152.84	0.0001*
Soil x Management	2.12	0.1461
Density	268.94	0.0001*
Soil x Density	1.10	0.3601
Management x Density	2.97	0.0144*

*Significant at a = 0.05.

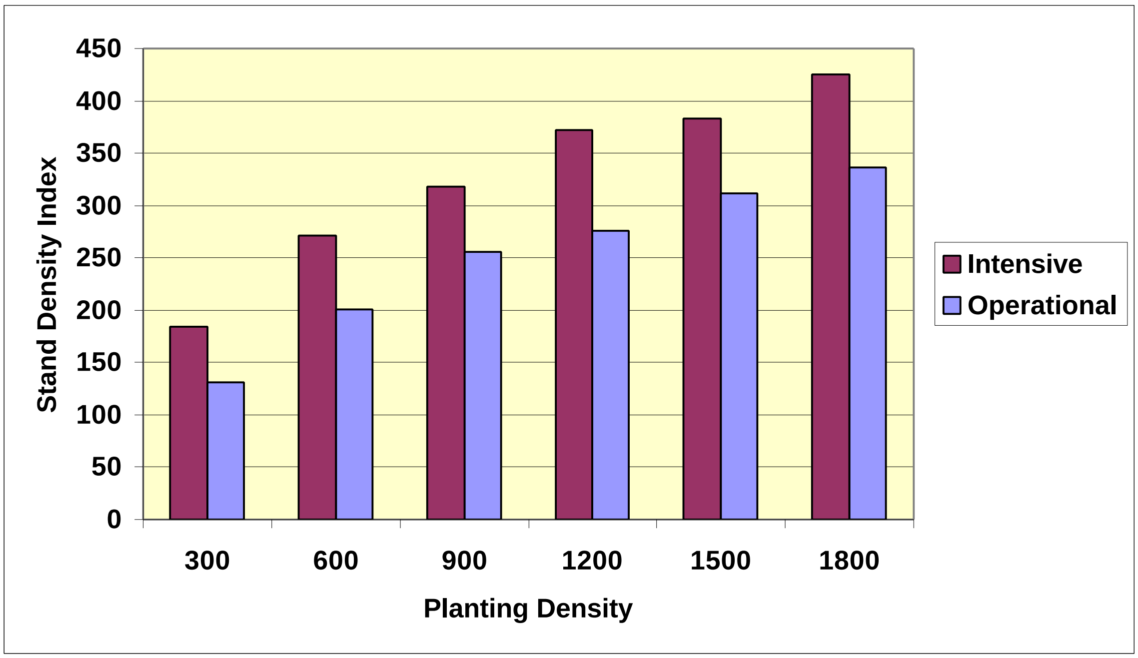

Figure 10. Average stand density index (SDI) for loblolly pine by planting density and management intensity for loblolly pine at age eight.

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 % max SDI values were calculated for each plot and averaged for the different density x treatment combinations (Figure 11). The intensive 1800 plots are approaching the limiting density at age eight, though mortality has been minimal in those plots through age eight.

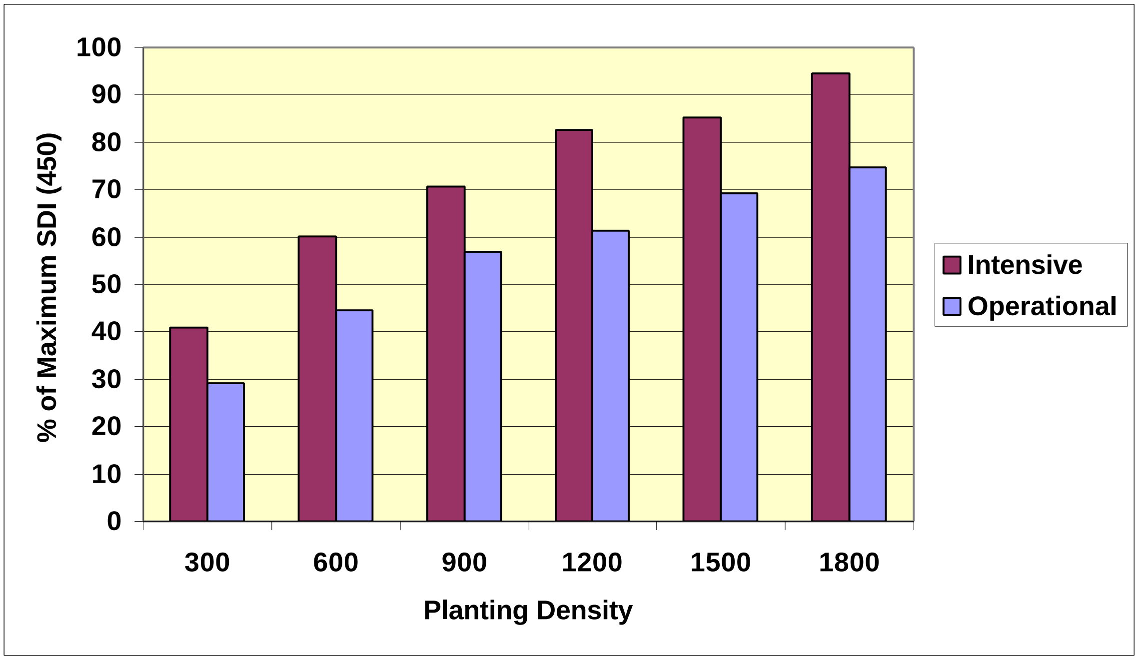

Figure 11. Average percentage of maximum stand density index (SDI) by planting density and management intensity for loblolly pine at age eight.

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 = SQRT[43560/N]/Hd

where SQRT = square root

N = 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 asymptote to some low value. RS asymptotes are species specific and values for slash and loblolly have been empirically determined to be about 0.12. RS values were calculated for each plot in the study and an analysis of variance was conducted on the RS proportions (Table 13). 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 12).

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

Source	Type III F	Pr > F
Soil	1.33	0.3198
Management	42.32	0.0001*
Soil x Management	1.07	0.4171
Density	504.52	0.0001*
Soil x Density	1.41	0.1300
Management x Density	2.16	0.0626

*Significant at a = 0.05.

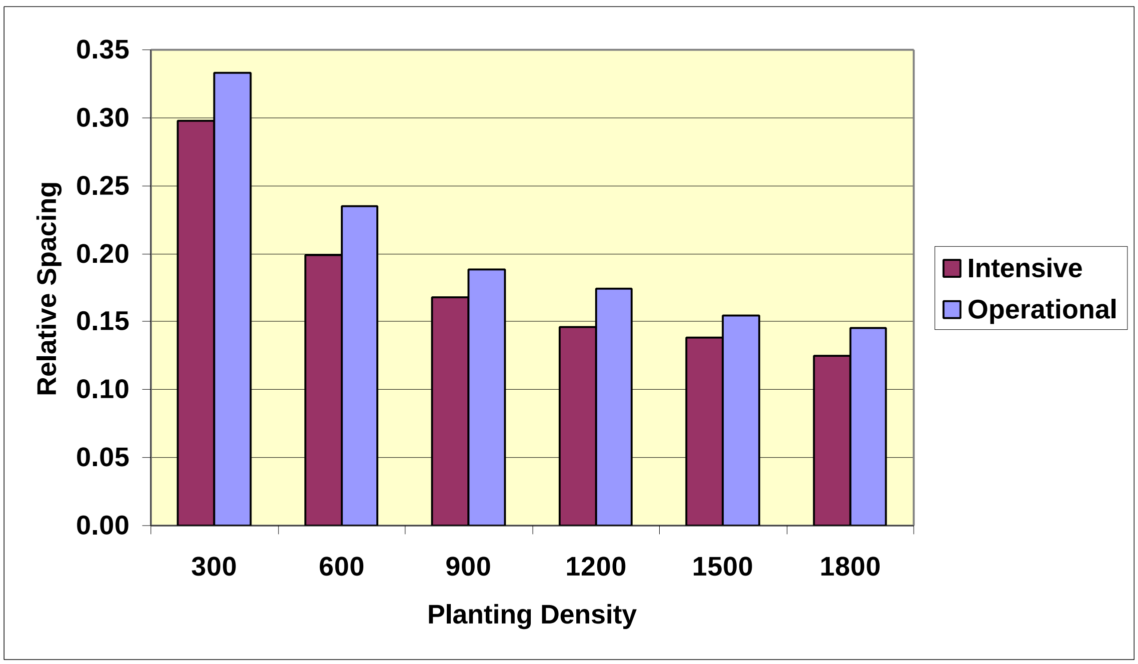

Figure 12. Average relative spacing (RS) by planting density and management intensity for loblolly pine at age eight.

4 SLASH PINE RESULTS

Recall that slash pine was established on nine of the seventeen locations at three densities: 300, 900, and 1500 initial trees per acre. On each of the slash plots, individual tree outside bark cubic foot volumes and green weights for each tree 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 cornartium 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 six.

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	7.4	35.6	37.2	97.1	33.0	88.7	1488	38
	900	5.4	36.2	38.6	90.3	20.1	134.1	2435	60
	1500	4.5	33.6	35.3	93.3	13.0	158.9	2755	66
Operational	300	6.4	32.4	33.8	87.1	15.4	59.1	927	23
	900	4.8	31.5	33.2	84.4	22.0	97.1	1569	38
	1500	4.1	29.8	32.1	85.4	12.7	124.6	1991	47

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	7.3	32.3	33.6	68.1	37.9	61.0	948	24
	900	5.4	30.6	32.4	66.7	34.4	97.5	1506	36
	1500	4.9	33.1	34.9	75.3	23.8	153.6	2589	63
Operational	300	5.6	29.7	31.3	83.1	29.3	44.2	655	16
	900	4.6	31.1	31.9	88.5	24.0	93.6	1495	36
	1500	3.7	28.5	31.1	86.9	29.4	102.6	1612	38

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	7.1	32.8	34.3	89.6	18.8	75.1	1175	29
	900	5.2	33.7	35.8	90.6	8.9	124.1	2115	52
	1500	4.4	32.6	34.4	92.3	8.2	152.1	2579	62
Operational	300	5.8	31.8	33.0	95.8	7.7	54.0	853	21
	900	4.7	31.7	33.1	92.7	10.9	101.4	1663	40
	1500	4.1	31.1	32.9	95.6	3.7	132.0	2178	51

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	7.4	35.4	37.2	95.0	18.4	86.7	1448	37
	900	5.3	34.9	36.7	93.8	21.1	131.4	2301	56
	1500	4.5	34.2	35.5	91.9	14.3	154.7	2734	66
Operational	300	5.9	32.2	33.9	91.3	27.4	52.8	837	21
	900	4.6	33.0	34.0	95.8	6.5	102.3	1726	41
	1500	3.8	30.6	32.6	98.8	8.9	121.4	1980	46

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 13, 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 is about 1.2 inches compared with a gain of about 0.6 inches for the 900 and 1500 initial densities.

Table 15. Analysis of variance results for slash pine average dbh at age eight.

Source	Type III F	Pr > F
Soil	0.50	0.6997
Management	104.36	0.0002*
Soil x Management	2.46	0.1782
Density	620.19	<0.0001*
Soil x Density	1.76	0.1462
Management x Density	19.51	<0.0001*

*Significant at a = 0.05.

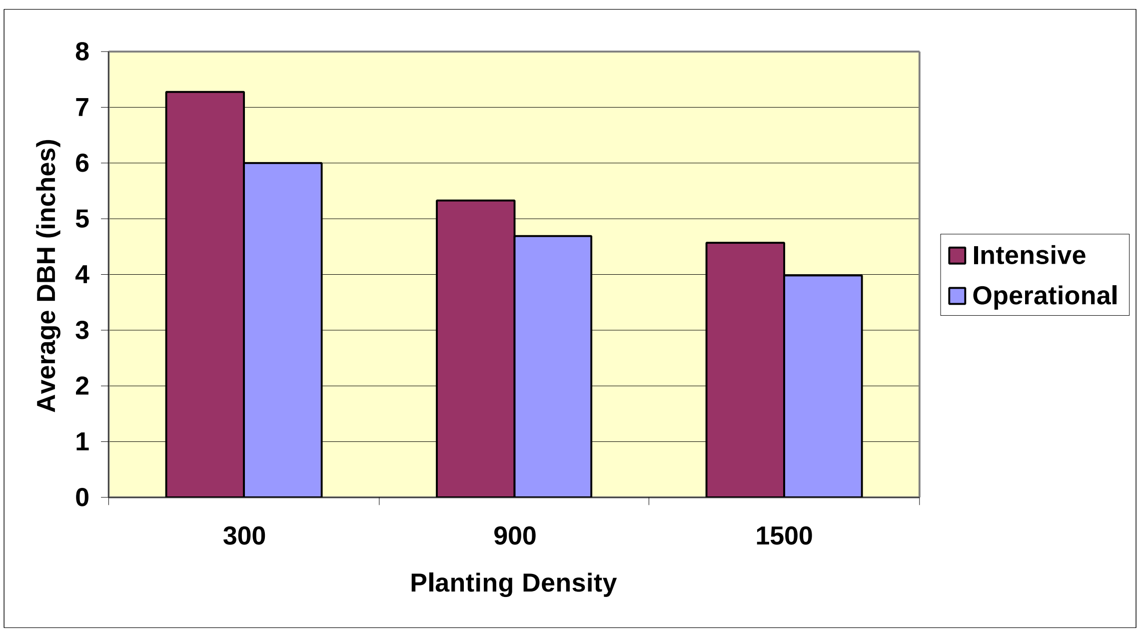

Figure 13. Average dbh by planting density and management intensity for slash pine at age eight.

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 14 shows the average heights by initial density and management intensity. Average heights were two to three 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 decrease averaged a little less than a foot for intensively managed plots and more than a foot and an half for the operational plots.

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

Source	Type III F	Pr > F
Soil	0.88	0.5110
Management	21.24	0.0058*
Soil x Management	1.25	0.3862
Density	4.55	0.0202*
Soil x Density	1.12	0.3767
Management x Density	0.75	0.4816

*Significant at a = 0.05.

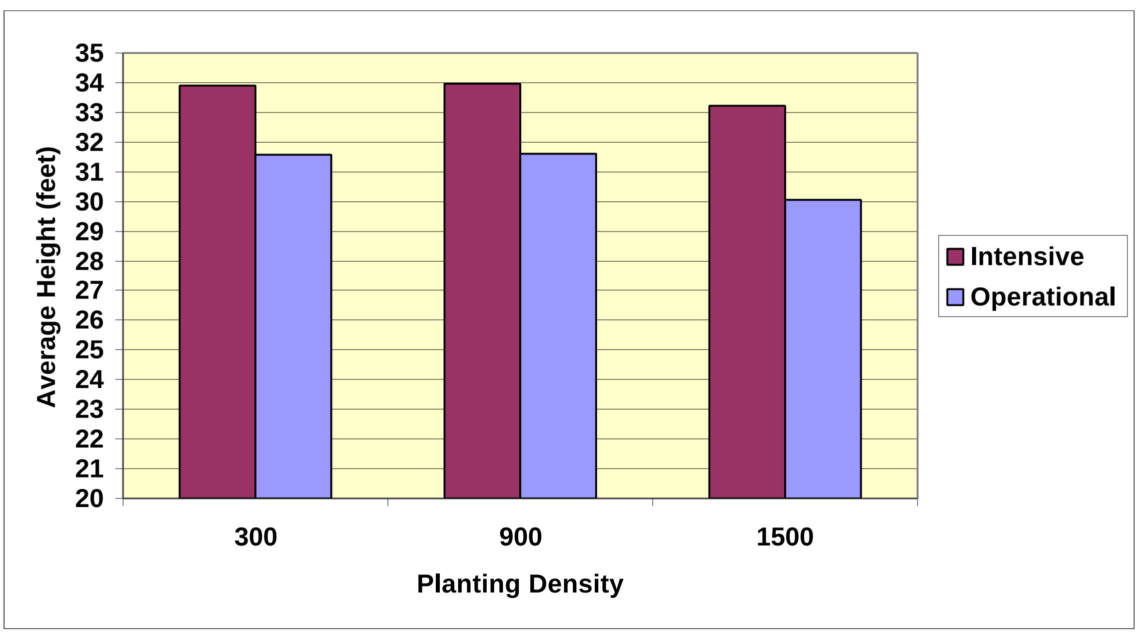

Figure 14. Average height by planting density and management intensity for slash pine at age eight.

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 was still a significant factor at the 5% level, but density was not significant. It was, however, significant at the 10% level of significance. As shown in Figure 15, the differences in average dominant height across density, regardless of management, are less than a foot.

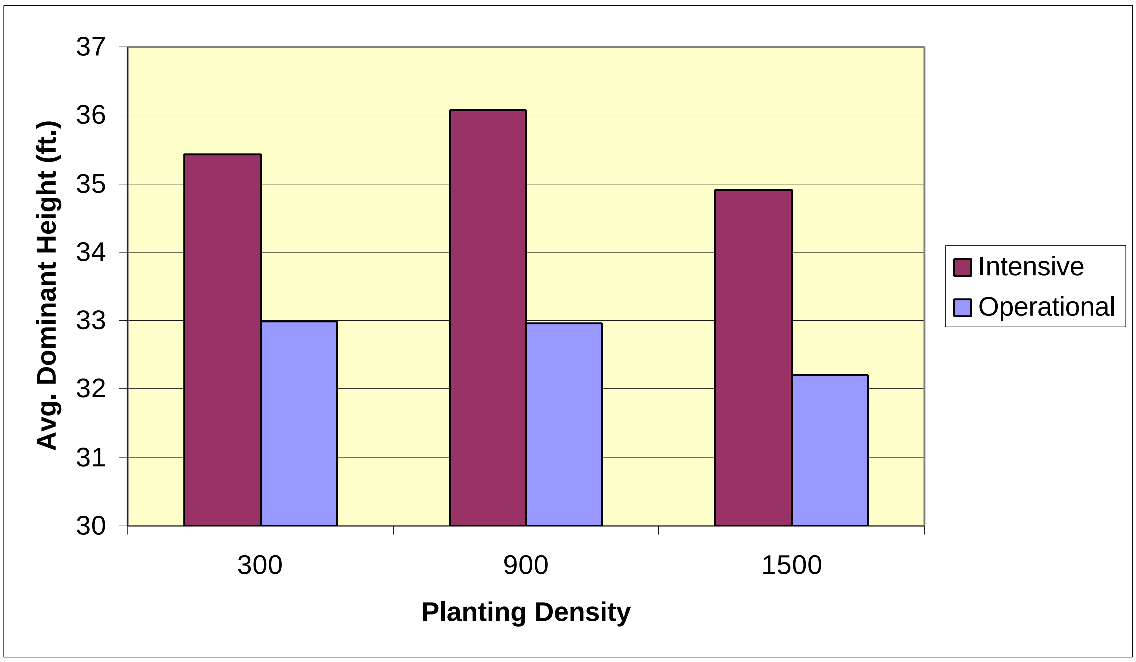

Figure 15.	Average dominant height by planting density and management intensity for slash pine at age eight.

4.3 Percent Survival

Table 17 shows the results of the analysis of variance for slash pine average percent survival. The only significant factor for slash pine survival from age 1 to age 8 was soil type. . Average survival rates by CRIFF soil type are shown in Figure 16. The B2 soil type has, by far, the lowest survival of the four CRIFF soil types represented in the study. The low percent survival values were evident on both management intensities and across all planting densities.

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

Source	Type III F	Pr > F
Soil	6.91	0.0315*
Management	1.48	0.2783
Soil x Management	3.94	0.0871
Density	0.62	0.5445
Soil x Density	0.62	0.7133
Management x Density	0.23	0.7928

*Significant at a = 0.05.

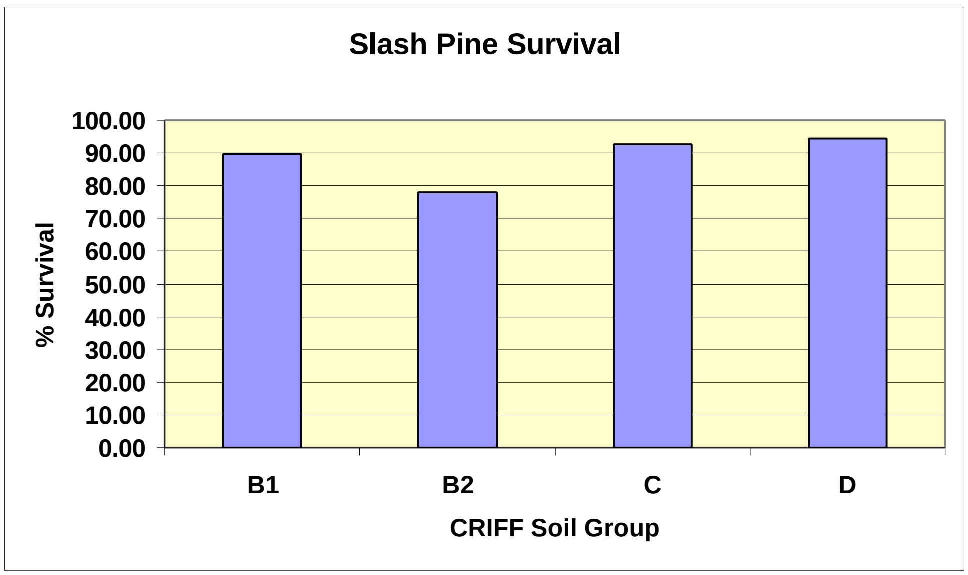

Figure 16. Average percent survival by CRIFF soil group for slash pine at age eight.

4.4 Percent Cronartium Infection

Table 18 shows the results of the analysis of variance for slash pine average percent cronartium infection. Soil and density significantly affected the cronartium infection rate for slash pine. Figure 17 shows that there is a definite trend toward lower infection rates at higher densities, and even though there was not a management x density interaction at age eight, there was a larger effect of management at 300 trees per acre than at 900 or 1500 trees per acre.

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

Source	df	Type III F	Pr > F
Soil	3	8.84	0.0192*
Management	1	3.93	0.1044
Soil x Management	3	0.02	0.9949
Density	2	5.54	0.0099*
Soil x Density	6	0.23	0.9613
Management x Density	2	2.05	0.1484

*Significant at a = 0.05.

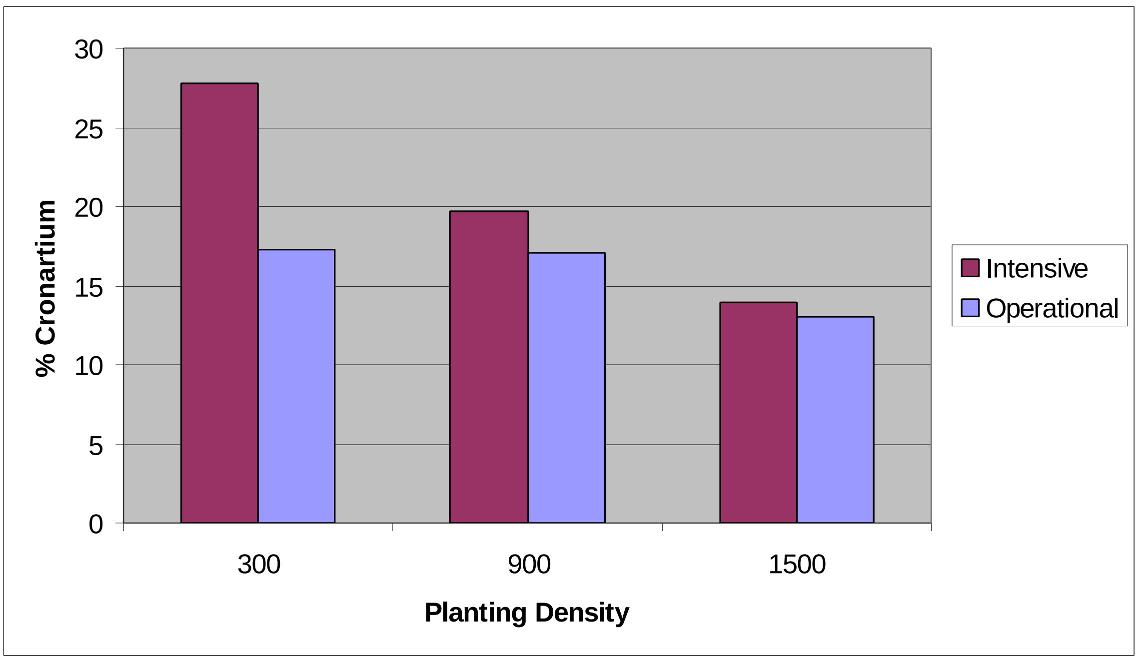

Figure 17. Average percent cronartium infection by planting density and management intensity for slash pine at age eight.

Figure 18 indicates that the B2 soil type has the highest infection rates across all densities. For most of the soil types, intensive management increases 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 result 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 operational managed stands for infection rates to decrease as density increases from 300 to 900 to 1500.

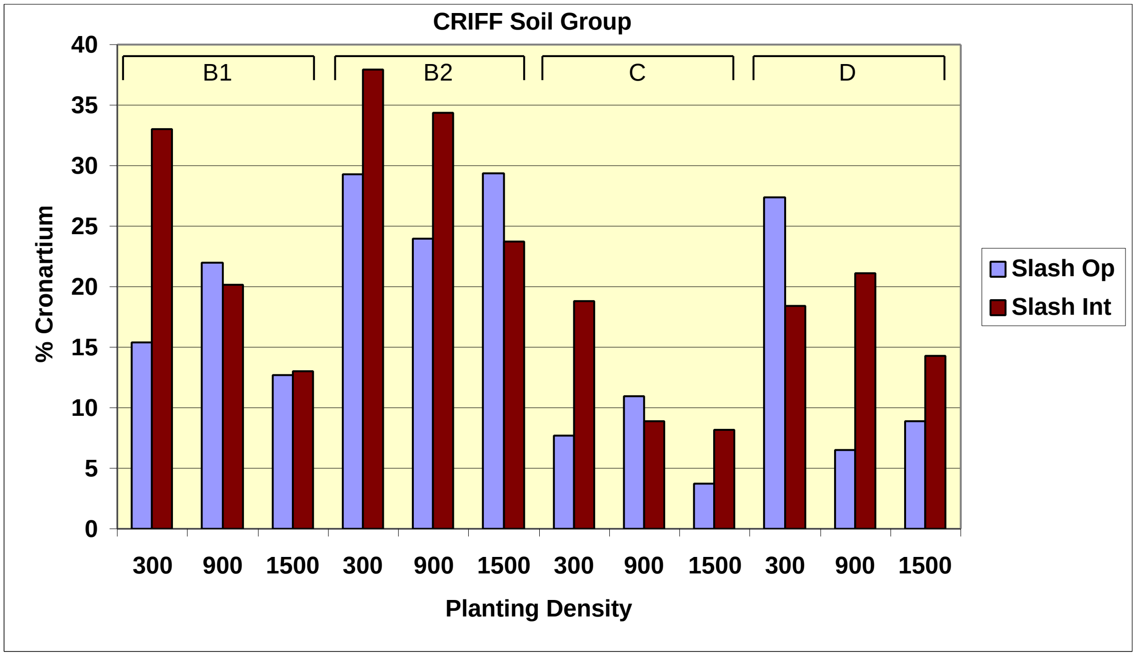

Figure 18. Average percent cronartium infection by CRIFF soil group and planting density by management intensity for slash pine at age eight.

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 were fairly consistent among the planting density treatments with intensive management adding about 25 or so ft^2/ac. Increasing initial density from 300 to 900 to 1500 increased basal area per acre substantially for both intensive and operational management. Figure 19 illustrates these trends.

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

Source	Type III F	Pr > F
Soil	1.49	0.3248
Management	83.36	0.0003*
Soil x Management	1.34	0.3612
Density	238.60	<0.0001*
Soil x Density	0.47	0.8208
Management x Density	1.48	0.2455

*Significant at a = 0.05.

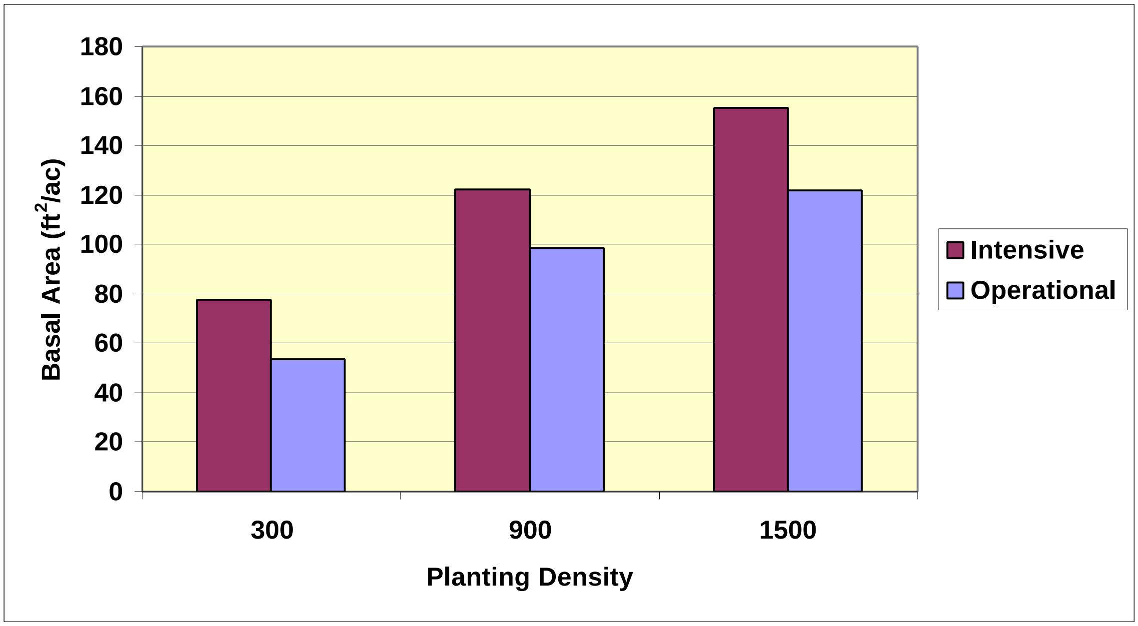

Figure 19. Average per-acre basal area (ft^2/ac) by planting density and management intensity for slash pine at age eight.

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 20 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 500 to 700 ft^3/ac at age eight. Likewise, an increase in density from 300 to 1500 increased total stem volume per acre from about 800 to nearly 2000 ft3/ac on operational managed stands. On intensively managed stands an increase in planted trees per acre from 300 to 1500 increased volume per acre at age eight from about 1250 ft^3/ac to about 2700 ft^3/ac.

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

Source	Type III F	Pr > F
Soil	1.17	0.4089
Management	75.54	0.0003*
Soil x Management	1.78	0.2677
Density	127.44	<0.0001*
Soil x Density	0.61	0.7203
Management x Density	1.46	0.2502

*Significant at a = 0.05.

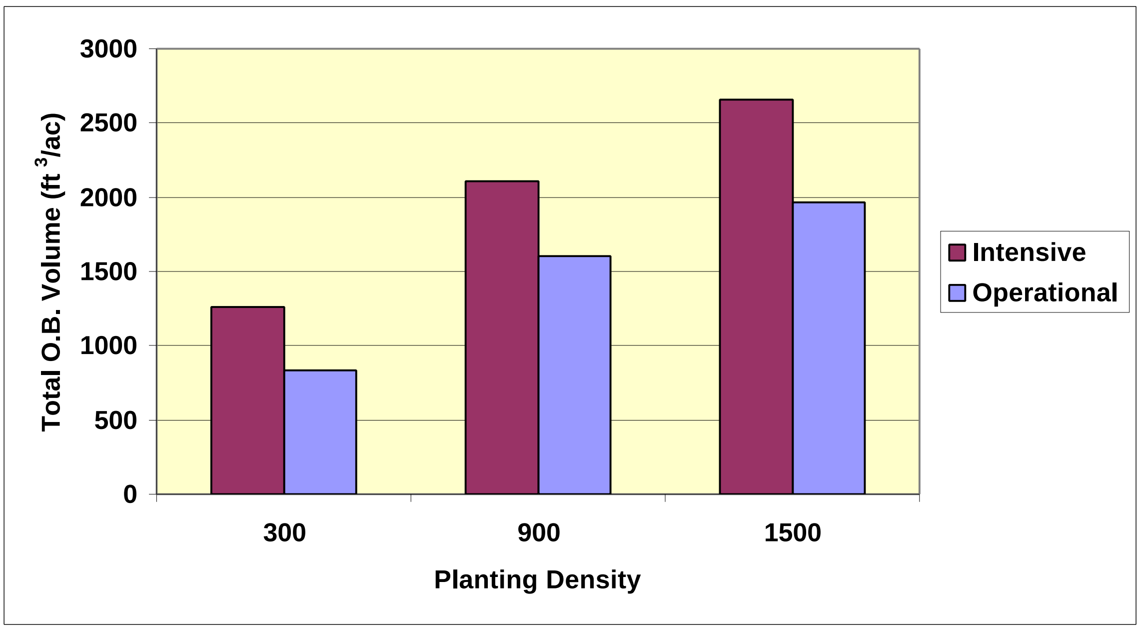

Figure 20. Average total per-acre outside bark. Volume (ft^3/ac) by planting density and management intensity for slash pine at age eight.

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 21 shows the per-acre green weights by density and management treatment. Green weight per acre increases as initial density increases from 300 to 1500 with weights going from about 20 tons for 300 trees per acre to about 46 tons for 1500 with operational management. Intensive management increased green weight about 11 to 15 tons per acre. The values there for 300 trees per acre were about 31 tons per acre on average and increased to about 63 tons per acre on average for 1500 trees per acre.

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

Source	Type III F	Pr > F
Soil	1.20	0.4003
Management	66.55	0.0004*
Soil x Management	1.86	0.2539
Density	133.90	<0.0001*
Soil x Density	0.59	0.7375
Management x Density	1.78	0.1888

*Significant at a = 0.05.

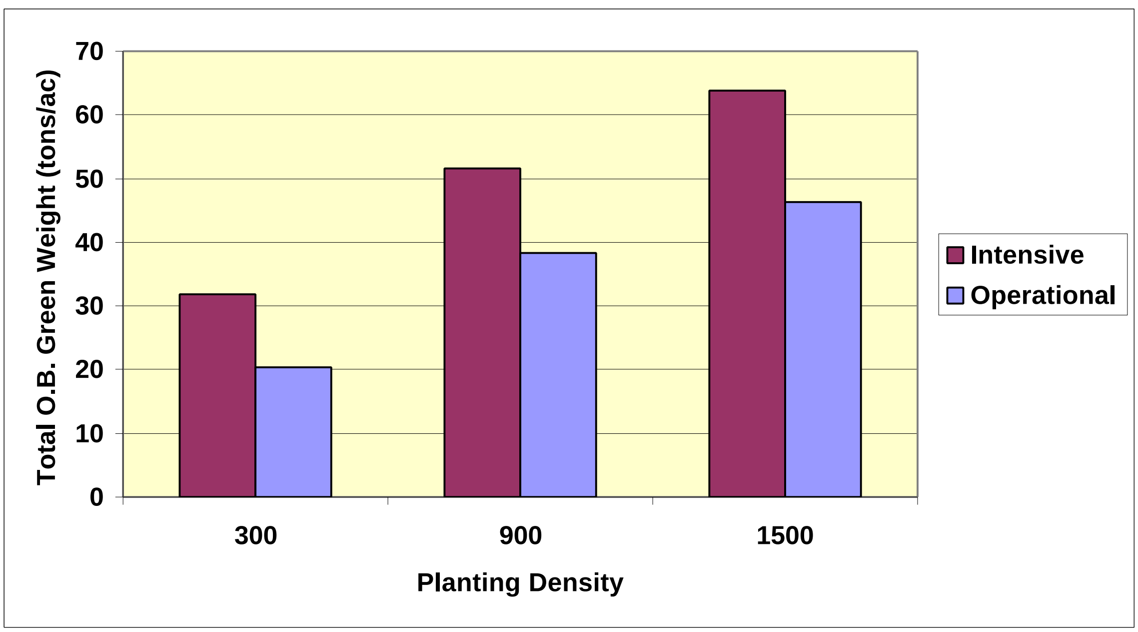

Figure 21. Average total per-acre outside bark green weight (tons/ac) by planting density and management intensity for slash pine at age eight.

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 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 density had significant effects on SDI. Figure 22 shows the per-acre 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 eight the combination of 1500 trees per acre initial density and intensive management results in an average SDI that is approaching the published maximum value for slash pine. Figure 23 has the % 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.

Table 22. Analysis of variance results for slash pine average stand density index at age eight.

Source	Type III F	Pr > F
Soil	2.11	0.2176
Management	53.46	0.0007*
Soil x Management	1.58	0.3047
Density	426.82	<0.0001*
Soil x Density	0.41	0.8645
Management x Density	2.19	0.1317

*Significant at a = 0.05.

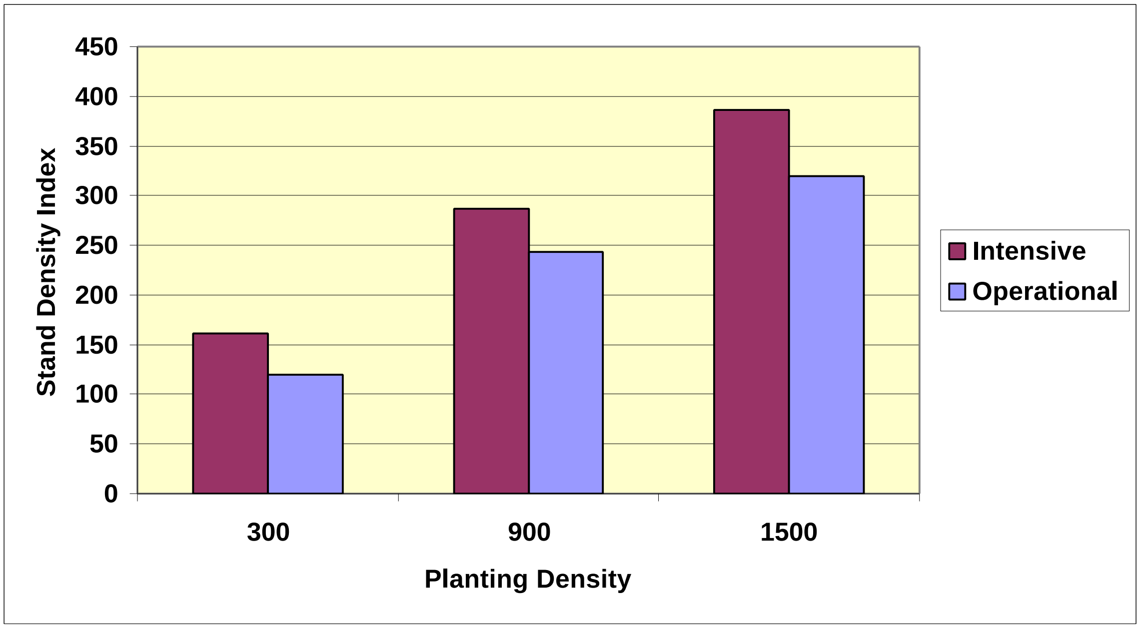

Figure 22. Average stand density index by planting density and management intensity for slash pine at age eight.

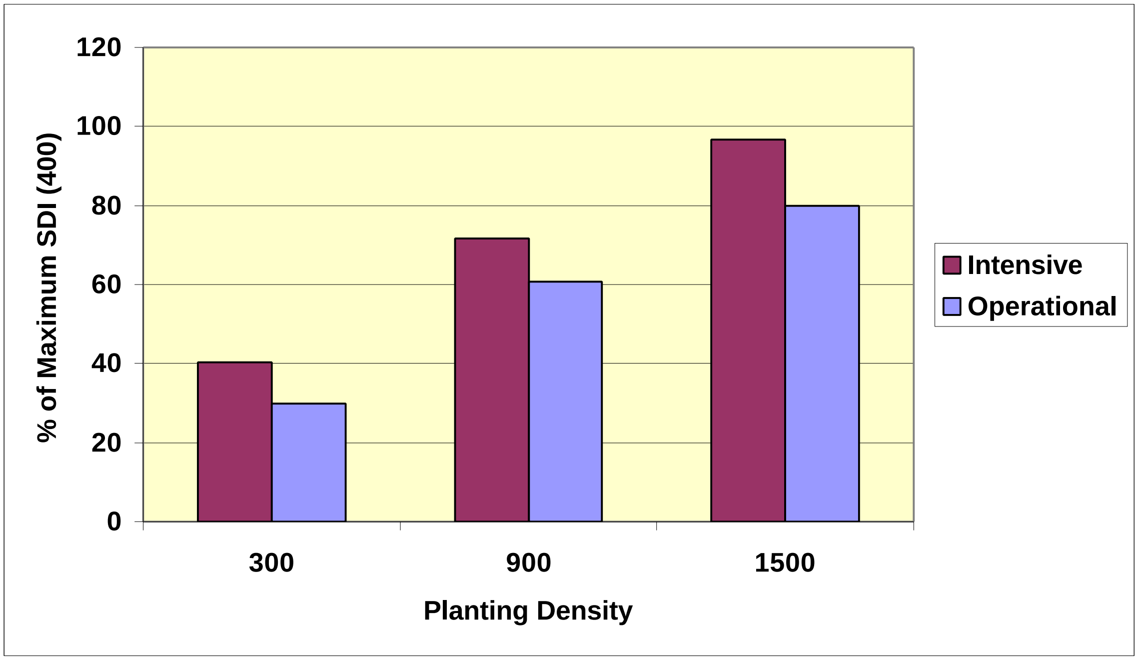

Figure 23. Average percentage of maximum stand density index by planting density and management intensity for slash pine at age eight.

4.9 Relative Spacing

The other measure of limiting density calculated for these plots is 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 pine. 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. There was a significant soil x density interaction. Examination of Figure 24 leads to the conclusion that relative spacing across soil classes for the same initial densities are

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

Source	Type III F	Pr > F
Soil	4.20	0.0782
Management	2.58	0.1689
Soil x Management	2.45	0.1789
Density	672.71	<0.0001*
Soil x Density	3.41	0.0128
Management x Density	0.25	0.7828

*Significant at a = 0.05.

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 .15 for the 1500 density, but are not as low as loblolly pine at the same age. This is due in part to the taller heights for loblolly.

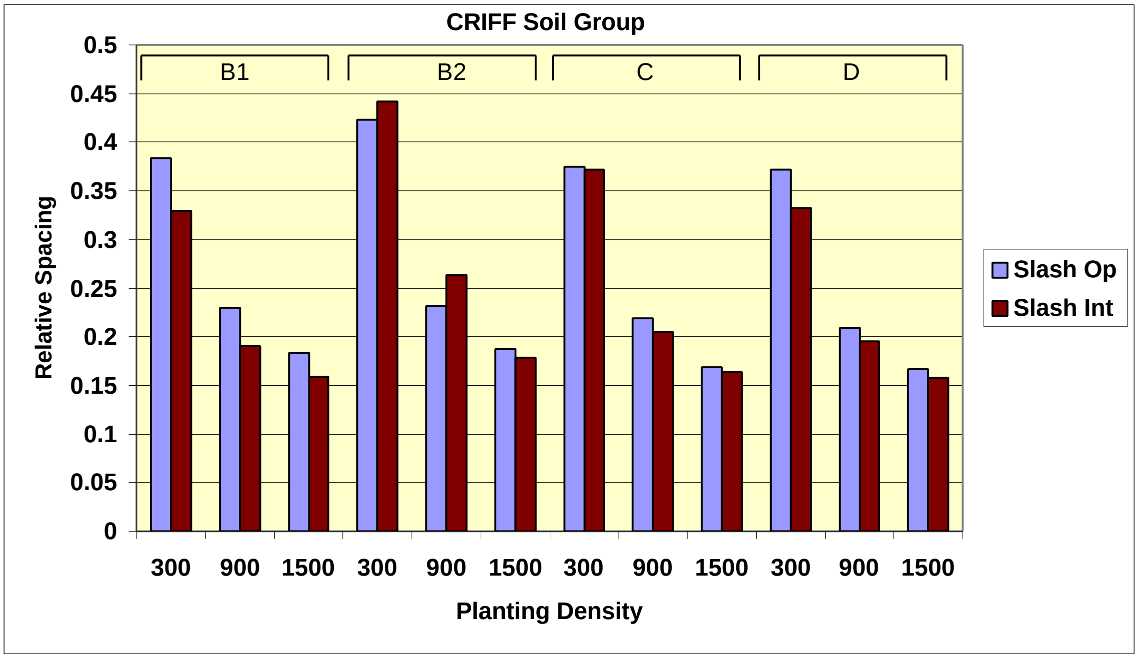

Figure 24. Average relative spacing by management intensity and density within CRIFF soil group at age eight.

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 25-34 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 for all 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 0.4 in, to loblolly at the 300 density with intensive management. For all other pairs the largest difference was about 0.1 in (Figure 25).

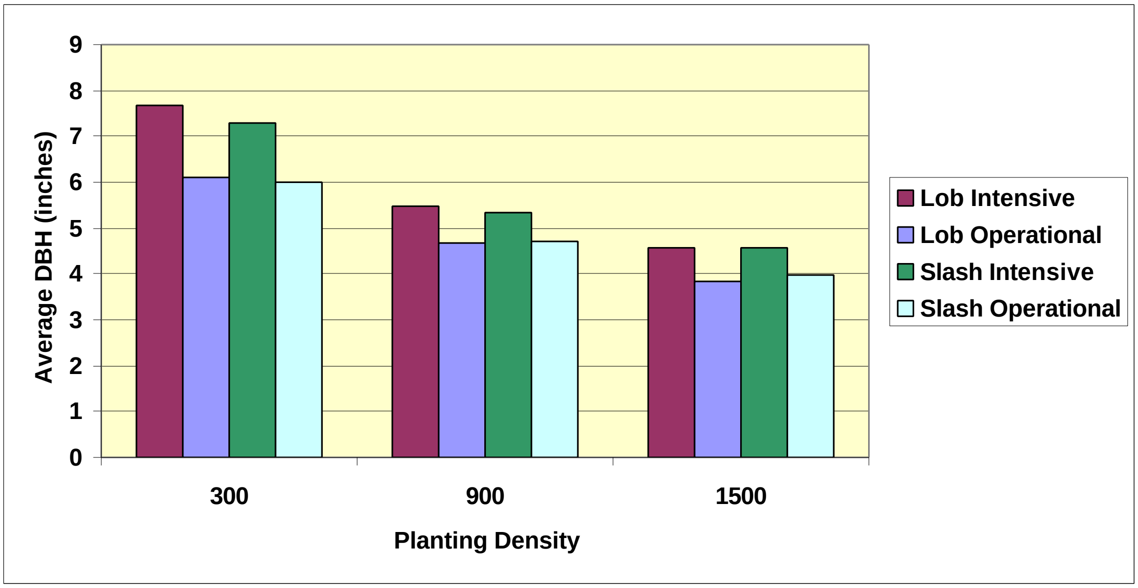

Figure 25. Average dbh by species, management intensity and density at age eight.

The intensively managed loblolly pine plots had consistently greater average heights (6-10 feet) than all other treatments (Figure 26). The intensively managed loblolly stands had average heights about 6 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.

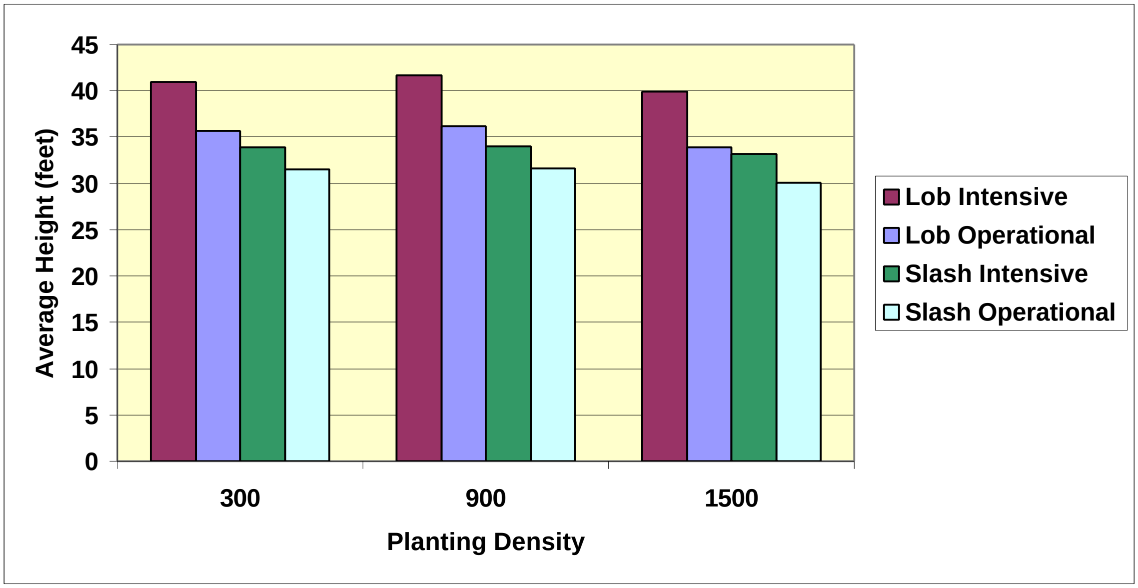

Figure 26. Average height by species, management intensity and density at age eight.

The same trends that are evident for average height are also evident when only the average height of dominants is evaluated (Figure 27).

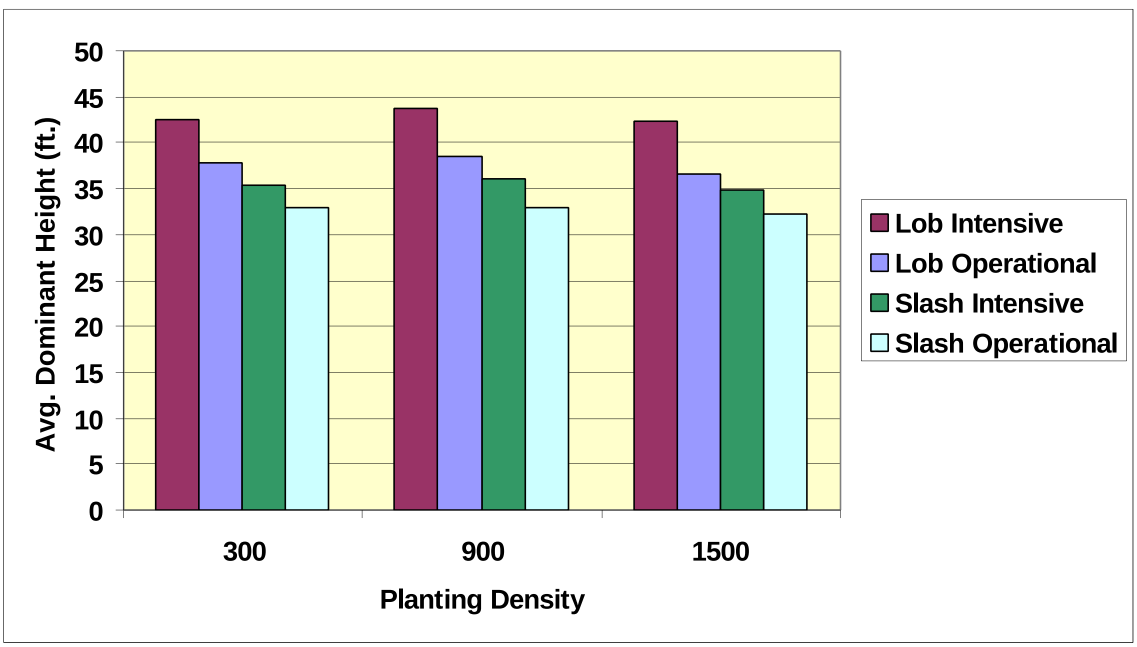

Figure 27. Average dominant height by species, management intensity and density at age eight.

In all cases, operational treatment plots had better survival than the more intensively managed plots (Figure 28). Loblolly pine survived better than slash pine in most comparisons by about 4-5 % on the average, but intensive slash had slightly better survival than intensive loblolly at the

1500 initial density. The higher cronartium infection levels associated with slash pine for both operational and intensively managed stands discussed next may be responsible for the slightly lower survival of slash pine compared to loblolly.

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 29). It is also noteworthy that the slash pine plots typically had higher cronartium infection levels than loblolly. In fact, for the 900 and 1500 densities, 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.

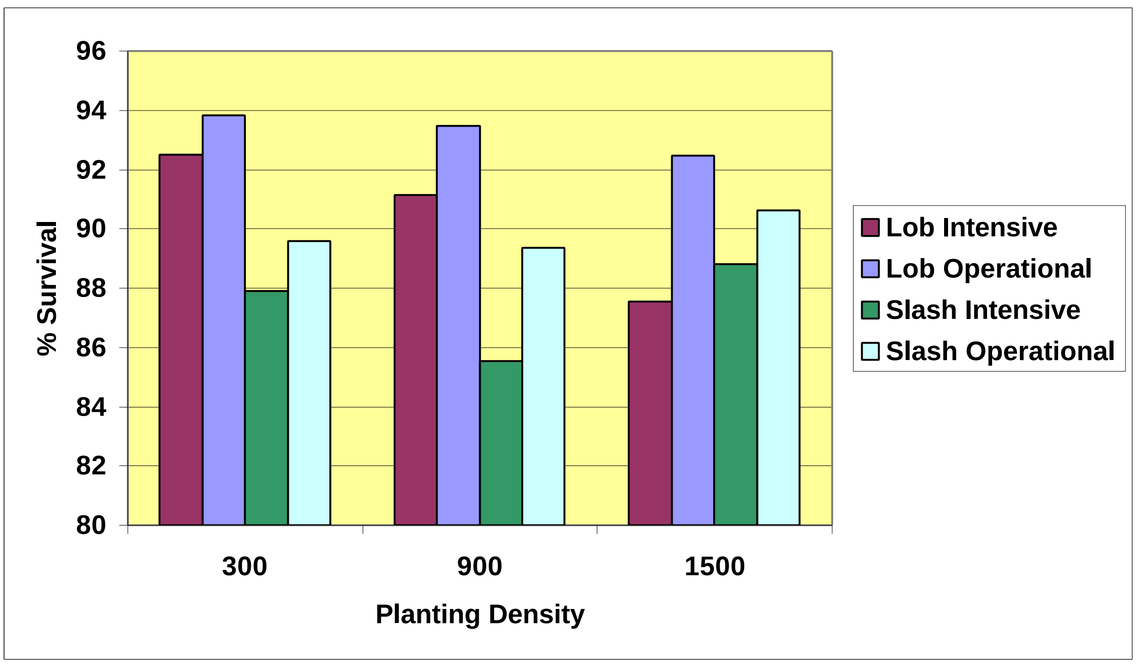

Figure 28. Average percent survival by species, management intensity and density at age eight.

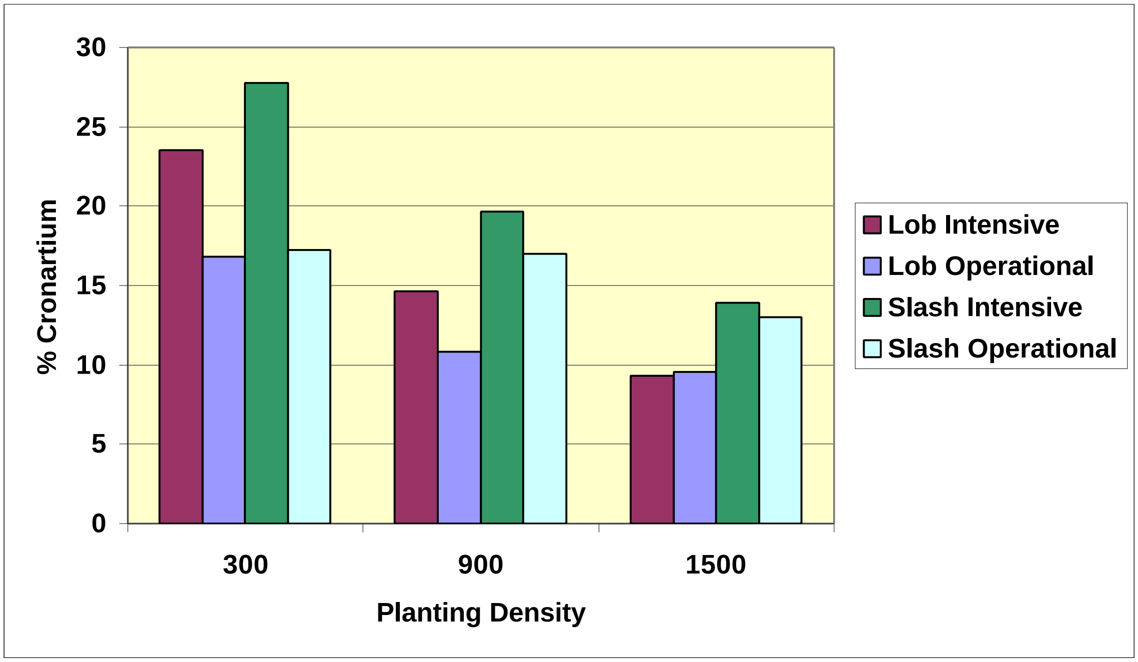

Figure 29. Average percent cronartium infection by species, management intensity and density at age eight.

For all treatments and species, per-acre basal area increased with increasing initial density (Figure 30). At the 300 and 900 trees per acre initial densities, there was slightly more basal area per acre (3-5 ft^2/ac) on operational loblolly than on operational slash pine plots. Loblolly pine had more basal area per acre by about 15 ft^2/ac than slash pine on intensively managed plots for the two lower initial densities. Slash pine had slightly higher basal area per acre than loblolly at the highest density for operational plots and virtually the same basal area per acre for intensively managed stands.

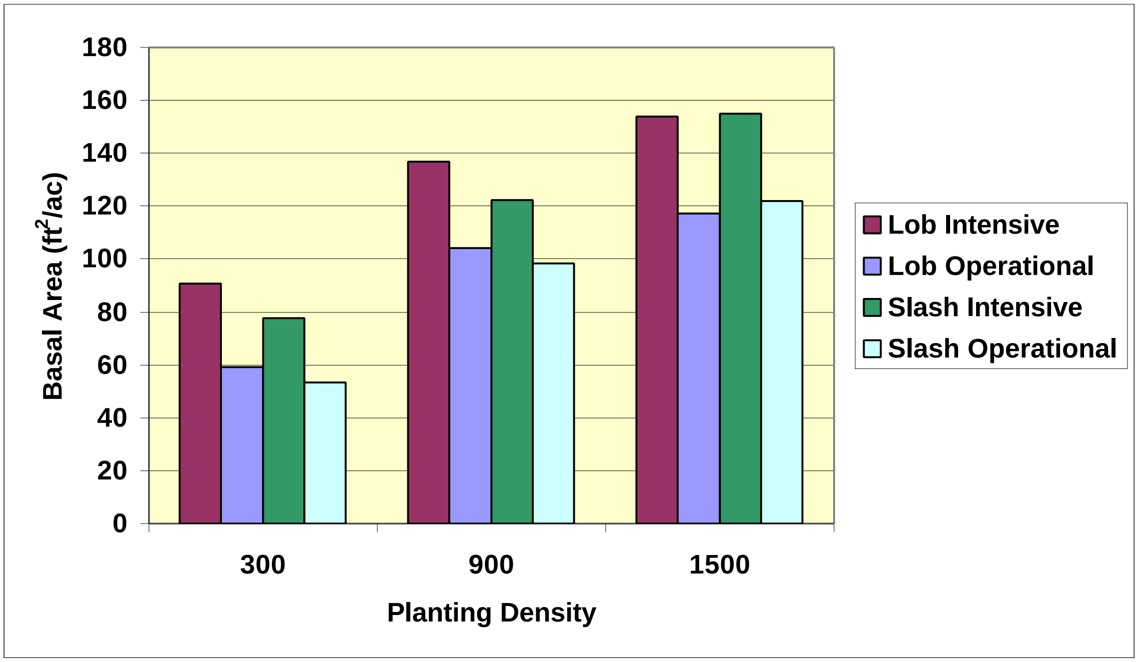

Figure 30. Average per-acre basal area by species, management intensity and density at age eight.

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 31). Volume increased with increasing management intensity and initial density. Loblolly pine had more volume by 200-400 ft^3/ac at all spacings for the operational treatments. Loblolly pine had greater volumes than slash pine by 500 to 700 ft^3/ac on the intensive treatments at all spacings.

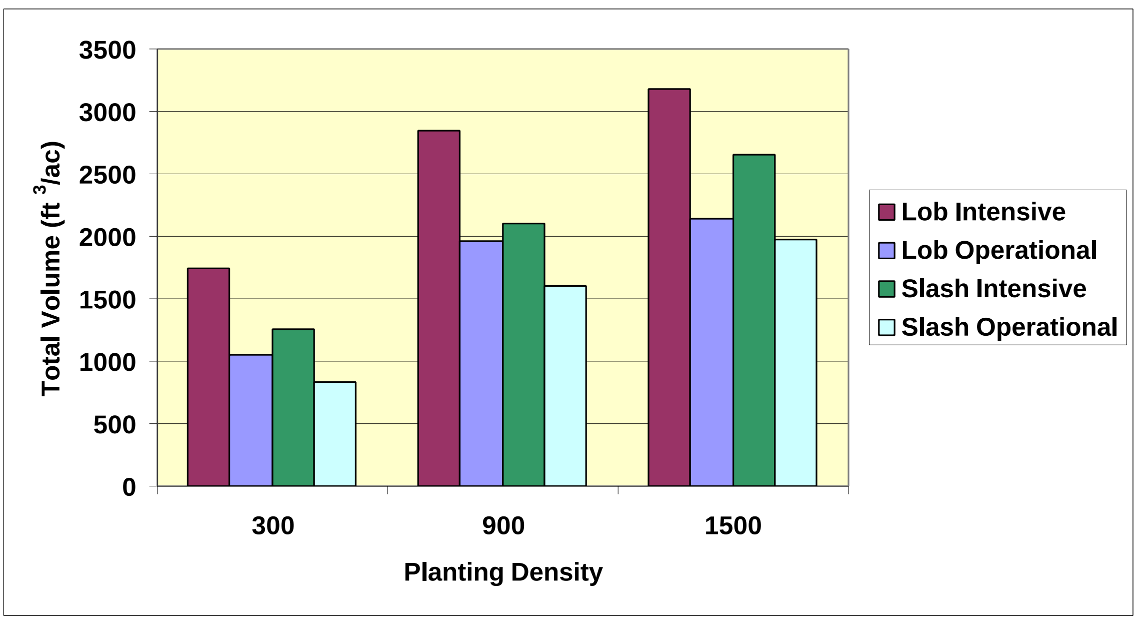

Figure 31. Average total per-acre outside bark volume (ft^3/ac) by species, management intensity and density at age eight.

The trends for total green weight were similar to the trends for total volume (Figure 32). The advantage for loblolly pine in terms of green weight was 13-20 tons/ac for intensively managed stands and was 3-10 tons/ac for operational stands depending on the initial density.

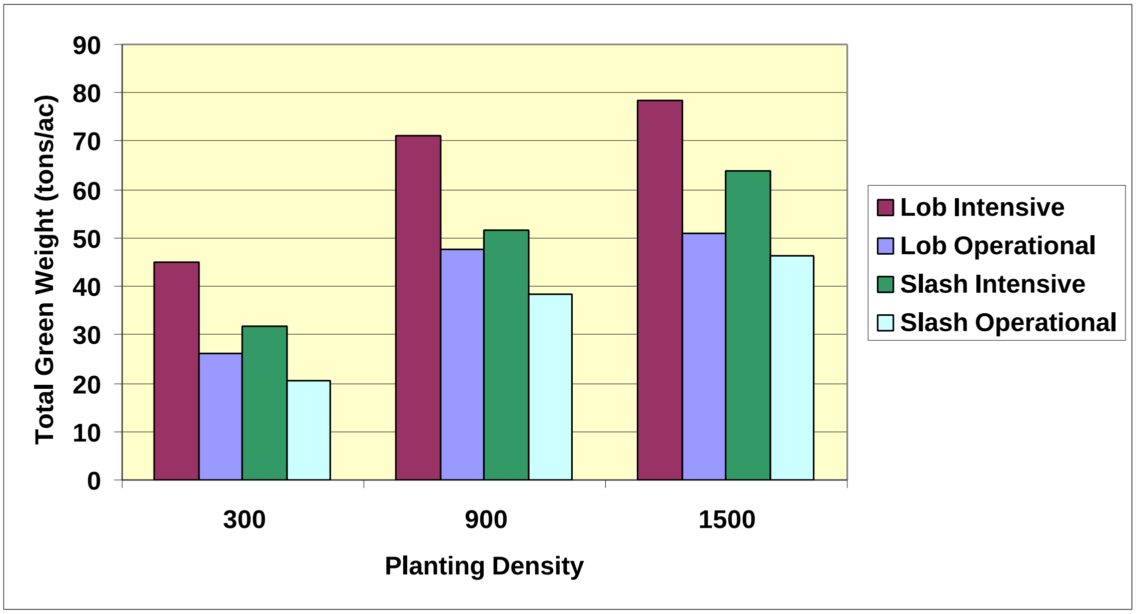

Figure 32. Average total per-acre outside bark green weight (tons/ac) by species, management intensity and density at age eight.

The comparison of the stand density index for the two species looks very similar to the comparison of basal area per acre (Figure 33). Loblolly has a higher stand density index than slash when compared on a management intensity and initial density basis. The differences, however, are not large.

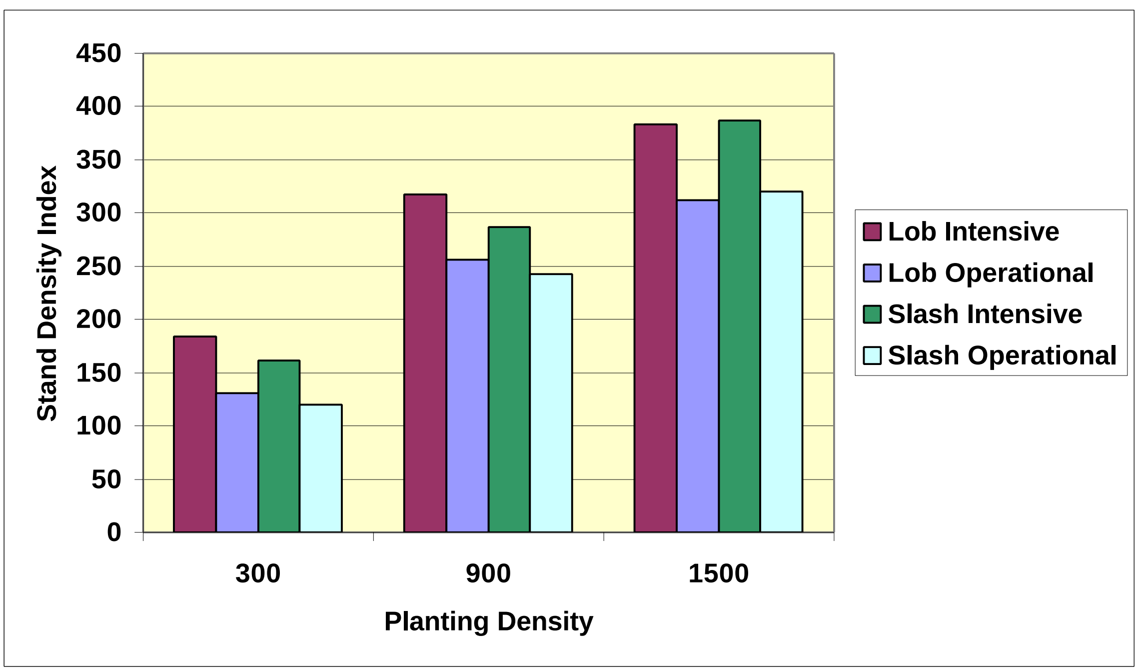

Figure 33. Average stand density index by species, management intensity and density at age eight.

Average relative spacing is lower for loblolly than for slash pine at age eight (Figure 34). 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.

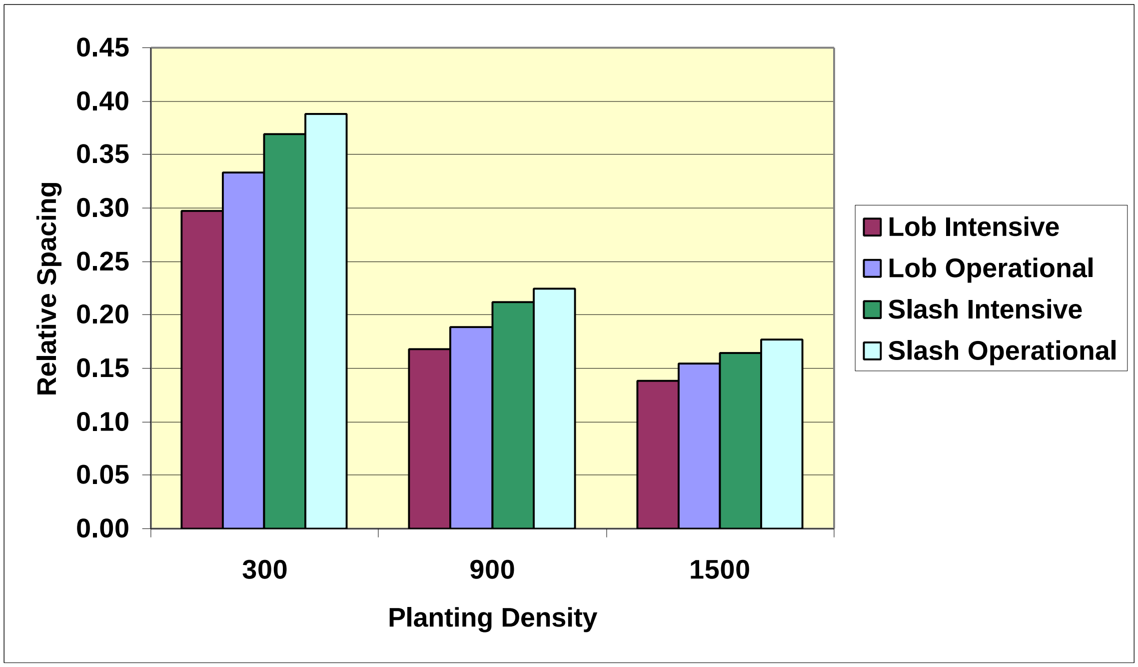

Figure 34. Average relative spacing by species, management intensity and density at age eight.

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.

Figures 35 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. On more operationally managed plots, there was very little difference in average dbh by species for B1, B2, and C groups 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 all soil groups and management intensities, slash tended to compare better with loblolly for average dbh as initial density increased.

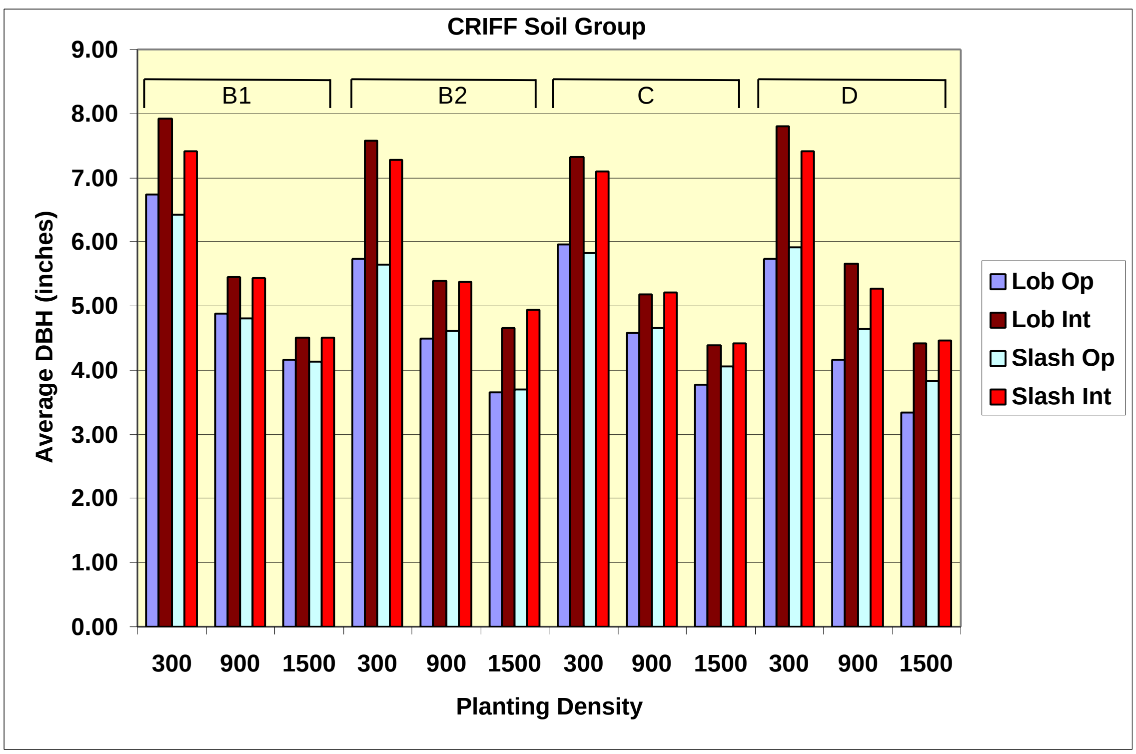

Figure 35. Average dbh (in) by CRIFF soil group, species, management intensity and density at age eight.

Loblolly pine had consistently taller average heights than slash pine for all soil and treatment groups (Figure 36). For intensively managed plots this difference was from 6 to 9 feet taller for loblolly. Soil group seemed to have little effect on average heights for either species, though operationally managed plots were more variable than intensively managed plots. On all but the D soils, the operational loblolly pine plots were 3-5 feet taller than operationally managed slash pine plots at all densities. On D group soils operational loblolly plots averaged about the same or slightly taller heights than operational slash. On B1 and C group soils, those soils with an argillic horizon relatively near the surface, the operational loblolly plots were typically taller than the slash pine intensively managed plots by three to five feet. On the B2 and D group soils, those soils without a shallow argillic, there was only a slight advantage to loblolly (B2 soils) or there tended to be a slight advantage to slash pine (D group soils).

The same general trends hold for average dominant height as for average height (Figure 37). The only soil group where intensively managed slash pine has average dominant heights that or equal to or slightly taller than operationally managed loblolly pine is on the D group soils at densities that are 900 to 1500 per acre.

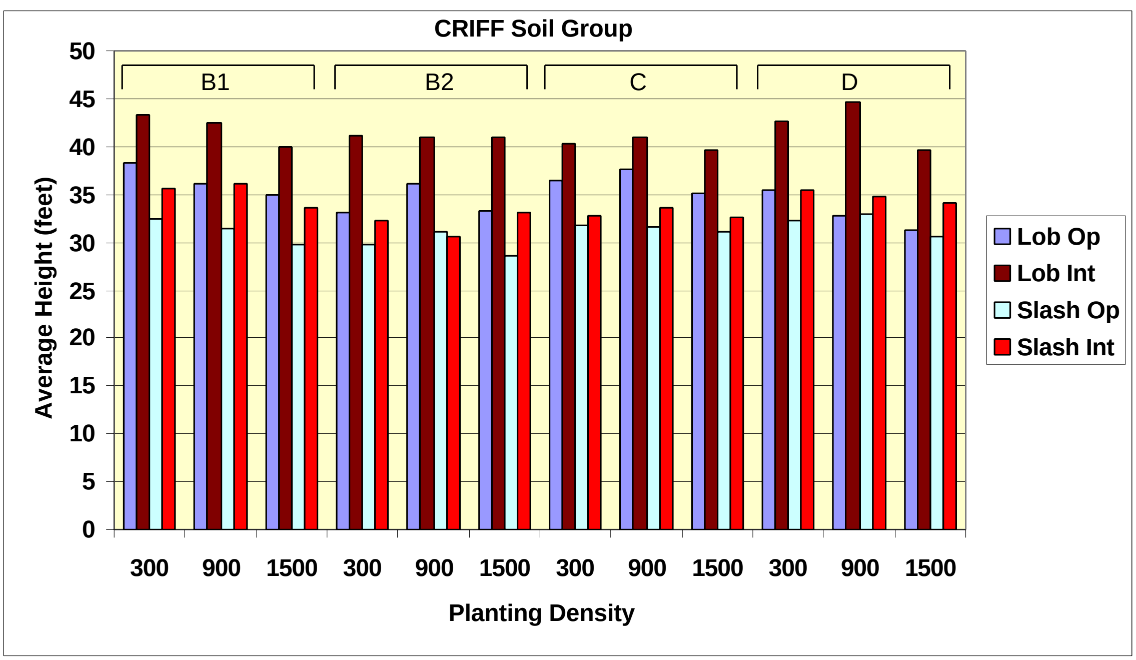

Figure 36. Average height (ft) by CRIFF soil group, species, management intensity and density at age eight.

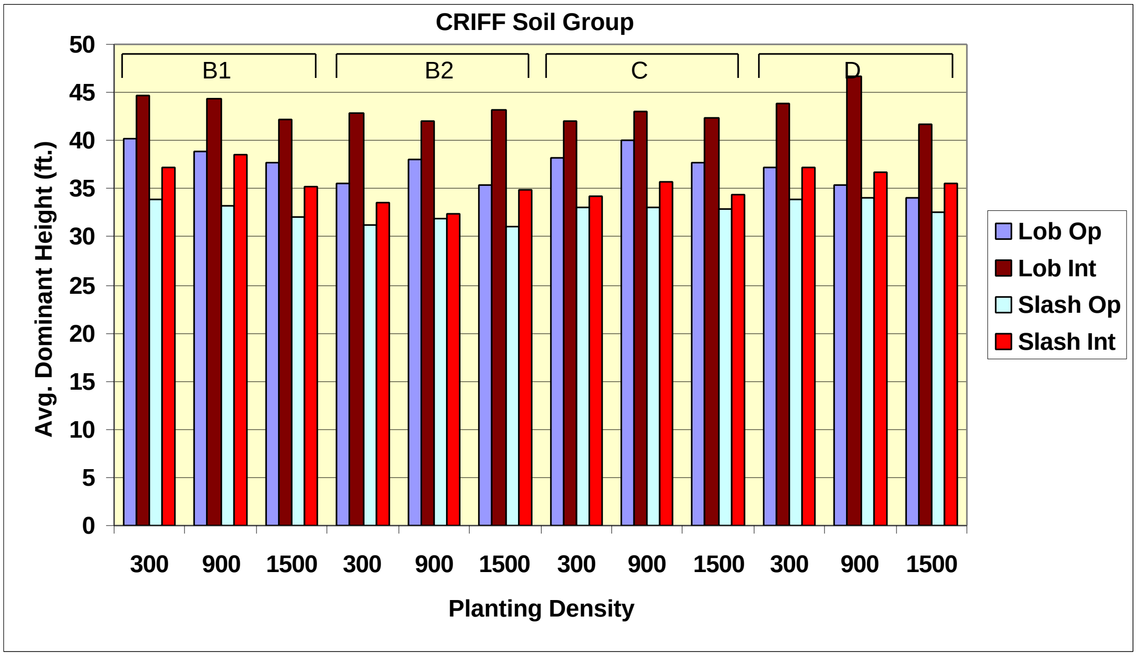

Figure 37. Average dominant height (ft) by CRIFF soil group, species, management intensity and density at age eight.

Survival trends for the two species by CRIFF soil group, management intensity, and density are shown in Figure 38. Survival for both species was uniformly good on the spodosols, CRIFF groups C and D. On B1 soils, survival was 90+% for both species on intensively managed plots across all densities. For operational plots, slash pine had lower survival than loblolly on B1 soils. On B2 soils intensively managed slash pine had very poor survival. Intensively managed loblolly pine had low survival for 900 and 1500 initial densities, but still much better than for intensively managed slash pine.

Cronartium infection rates were lower on the spodosols, CRIFF groups C and D, than on the nonspodosol soils (Figure 39). The trend of lower infection levels as density increased is evident on all soil groups, though for slash pine and 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 25-38% may be contributing 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.

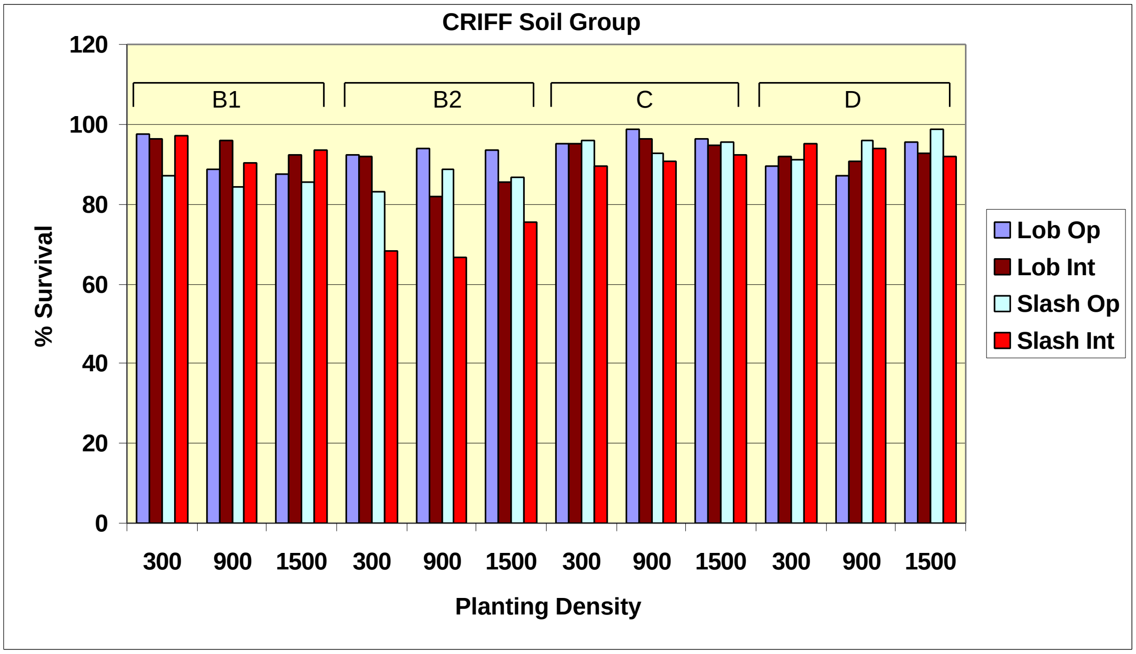

Figure 38. Average percent survival by CRIFF soil group, species, management intensity and density at age eight.

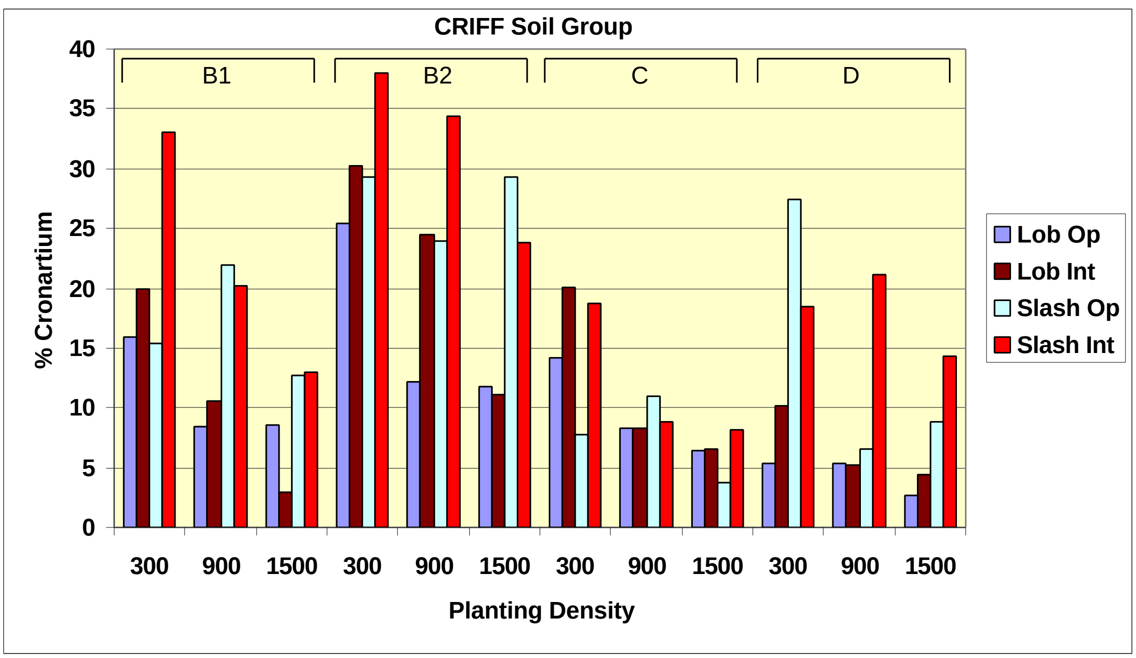

Figure 39. Average percent cronartium by CRIFF soil group, species, management intensity and density at age eight.

Across soil classes, slash pine had comparable per-acre basal area to loblolly with intensive management and 1500 trees per acre initial density treatments (Figure 40). On other soil groups and lower densities, intensively managed loblolly resulted in 10-30 ft^2 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 1500 initial density on the C group. Loblolly had higher basal area for all other soil groups and initial densities.

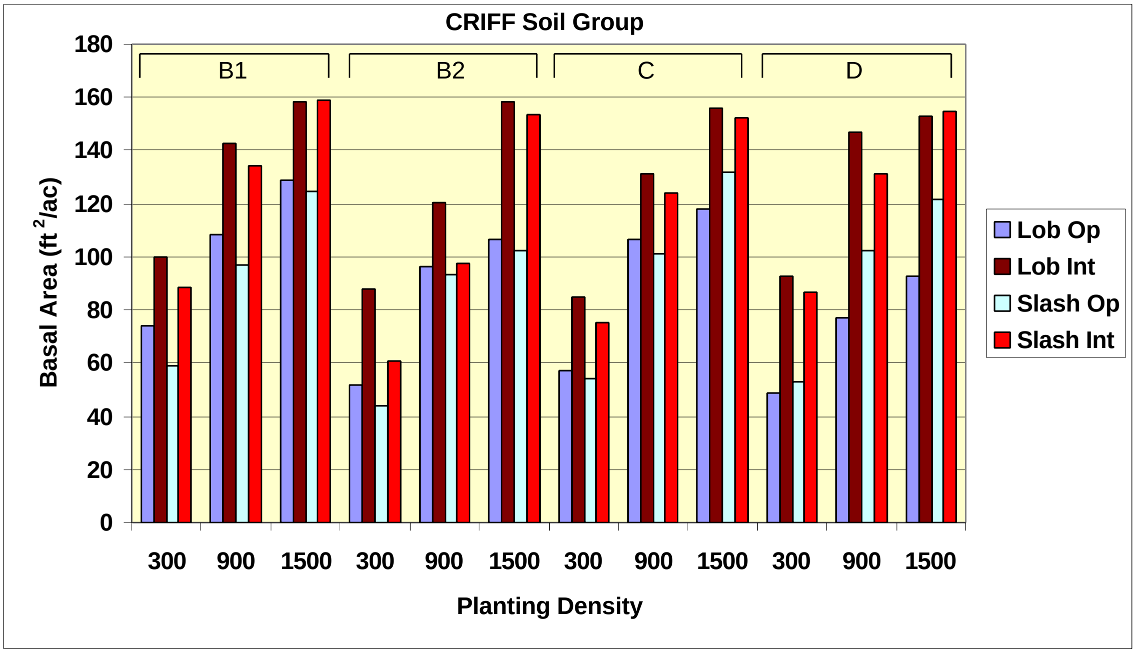

Figure 40. Per-acre basal area (ft^2/ac) by CRIFF soil group, species, management intensity and density at age eight.

Loblolly pine with intensive management had more volume than slash pine with intensive management in every soil group and density class (Figure 41). This was even true on the spodosols where slash had a slight advantage on some density classes for basal area per acre. The extra height and better survival of the loblolly more than makes up for the slight basal area deficit. The loblolly advantage ranged from about 500 ft^3/ac to about a 1000 ft^3/ac. Slash pine had more total volume on the operational plots on the D soil group with 900 and 1500 initial trees per acre. Loblolly had the same or more volume on all other initial densities and across all other soil groups. The difference ranged from very slight to about 450 ft^3/ac.

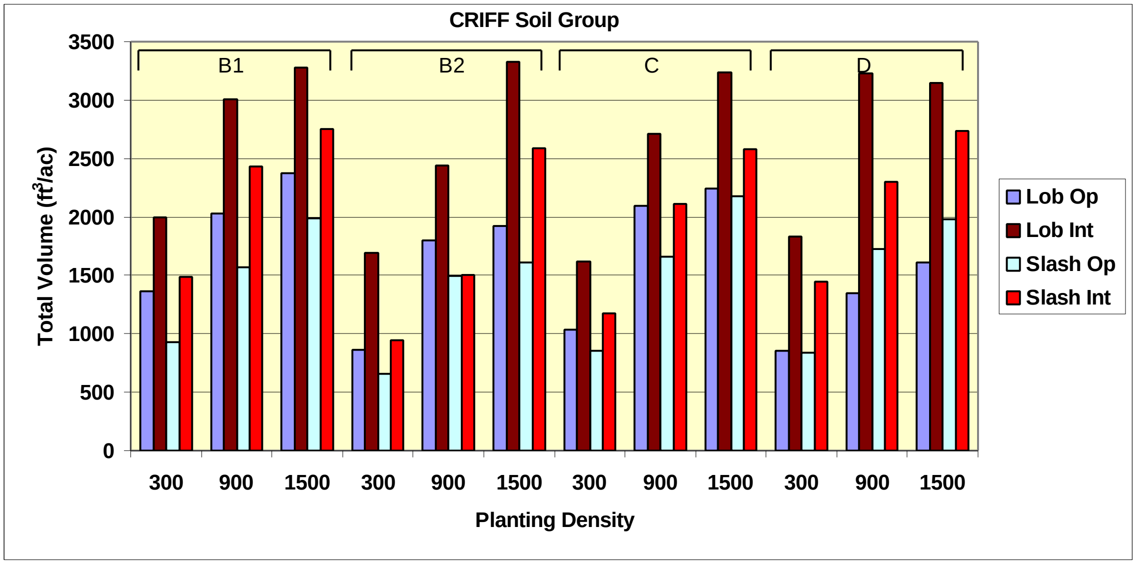

Figure 41. Per-acre total outside bark volume (ft^3/ac) by CRIFF soil group, species, management intensity and density at age eight.

The trends for total green weight are nearly identical (Figure 42). The advantage for using intensively managed loblolly rather than intensively managed slash ranges from about 8-25 tons/ac at age eight. The advantages of loblolly on the operational managed plots, with the exception of the D group soils, ranges from about 3 to over 12 tons/ac. On D group soils the slash advantage is about 8 tons/ac on the 900 and 1500 initial densities.

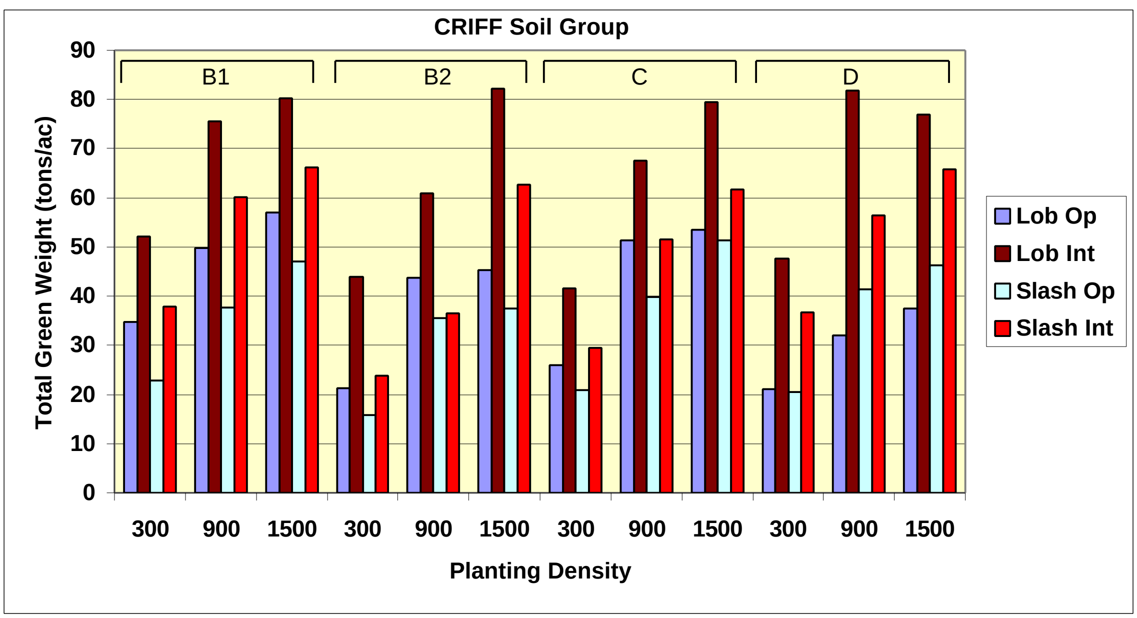

Figure 42. Per-acre total outside bark green weight (tons/ac) by CRIFF soil group, species, management intensity and density at age eight.

The stand density index (SDI) comparison for species across soil groups, management intensities, and initial densities at age eight follows a pattern almost identical to total green weight and total green volume. Loblolly has higher SDI values than slash pine for all soil groups and all initial densities for intensively managed plots. Slash pine approaches loblolly pine SDI for intensively managed plots with 1500 initial trees per acre. The SDI values for the two species are closer for operationally managed plots, but loblolly is higher except for high density C group soils and all densities on the D group soils.

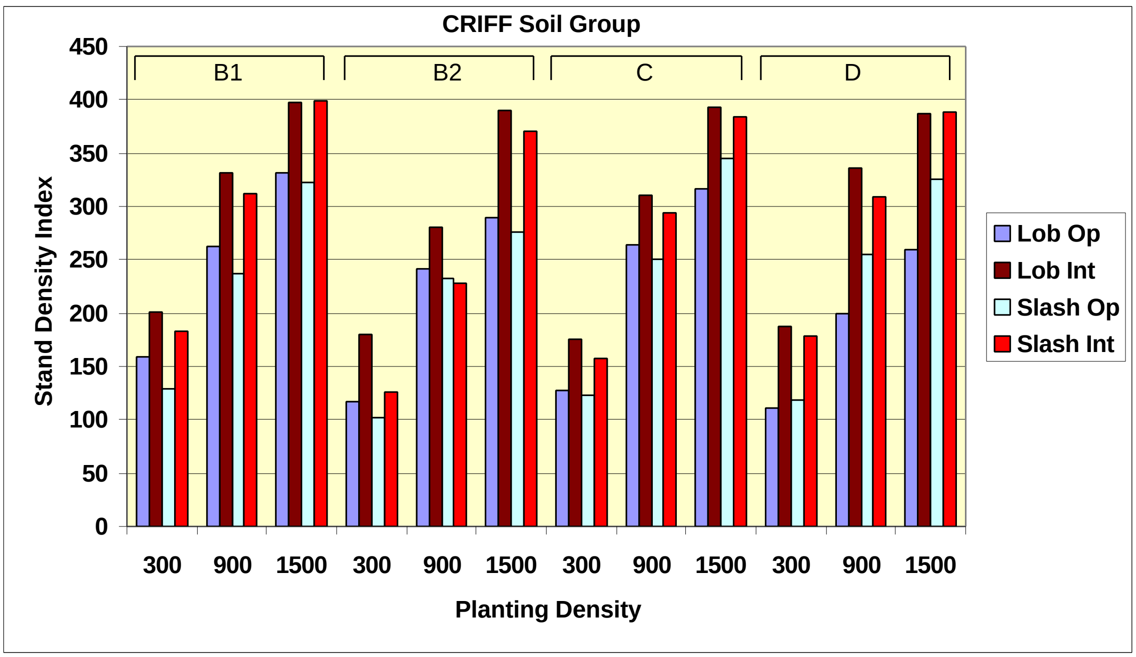

Figure 42. Stand Density Index by CRIFF soil group, species, management intensity and density at age eight.

Because it has a lower maximum SDI value (400) than loblolly (450), the average percentage of maximum SDI values are often higher for slash pine than for loblolly (Figure 43). Most of the 1500 initial density slash pine plots with intensive management are at or near their maximum density at age eight. This means that by the next measurement there will either be dbh stagnation, mortality, or a new definition of the maximum possible density for slash pine will be established. Intensively managed loblolly plots are also approaching their maximum values and this means the next measurement will be very interesting in terms of the stand development for these two species.

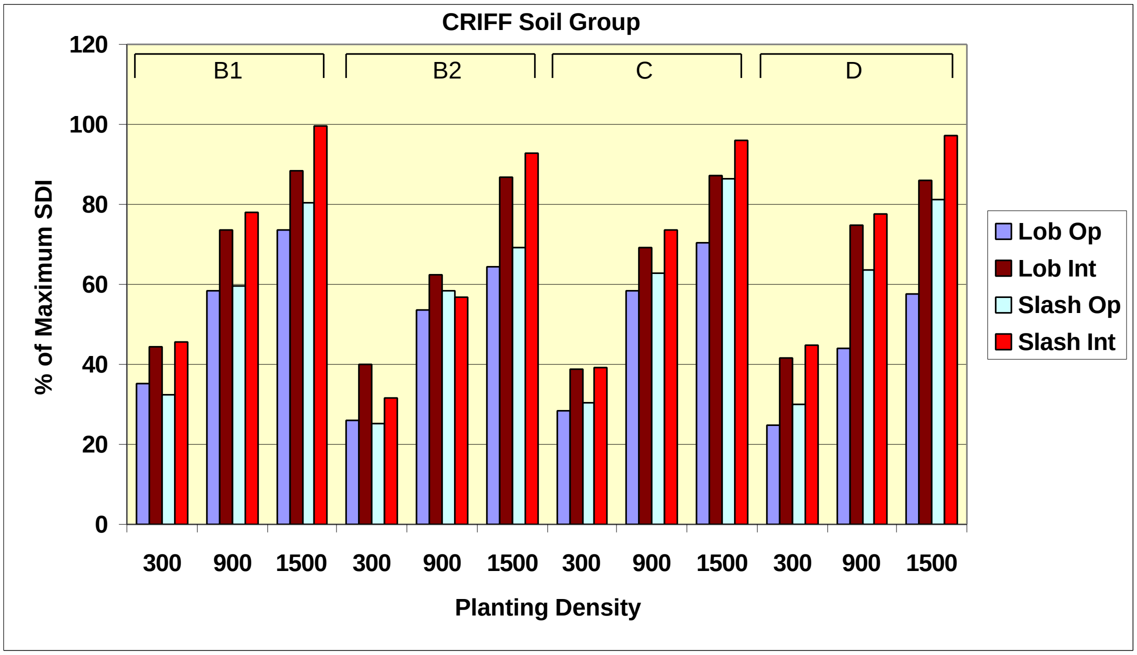

Figure 43. Percentage of Maximum Stand Density Index by CRIFF soil group, species, management intensity and density at age eight.

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.

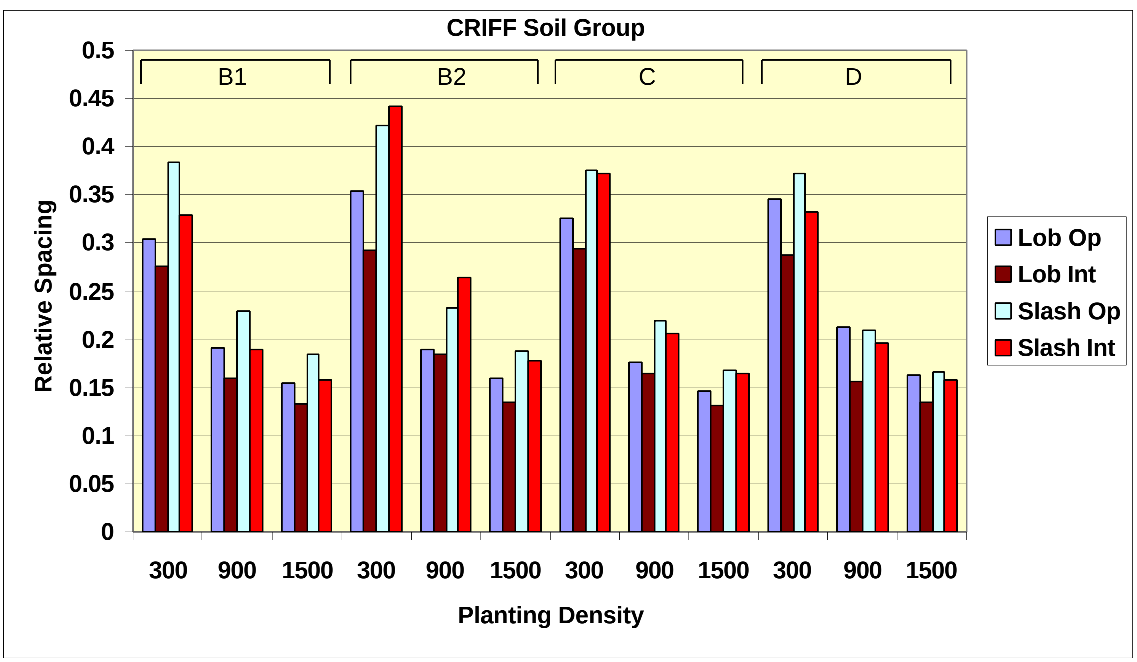

Figure 44. Average relative spacing by CRIFF soil group, species, management intensity and density at age eight.

6 DISCUSSION

The data reported on here are from 8-year-old plantations. Accelerated growth for both the operational and more intensive treatments has allowed the calculation of per-acre basal areas, total volumes, and total green weights normally seen in much older stands. These stand characteristics account for 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 up to 7 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 affects average height and average dominant height for loblolly pine. The lowest densities and the densities of 1200 trees per acre and higher had significantly shorter heights.

On the negative side, more intensive management has increased mortality and the cronartium infection rate compared to the operational treatment. Increased mortality may be due to overspray of herbicide onto pine trees or, more likely, 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 slash pine averaging 155 ft^2/ac basal area with 1500 initial trees per acre at age eight.

In comparing slash and loblolly pine, it appears that the D groups 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 eight.

Many of the plots in this study are now approaching their historical 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 sever mortality in these plots perhaps as early as the next planned remeasurement in two years.

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