PMRC COASTAL PLAIN CULTURE / DENSITY STUDY:

AGE 6 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 received additional fertilization treatments and 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 NH_4NO_3 was added in the spring of the fourth 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 and per-acre, outside bark total volume 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. Management intensity and planting density had significant effects on loblolly pine average height. 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 soil type x density interaction. 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.

For slash pine, management intensity, density and their interaction significantly impacted average DBH. There was also a significant soil type x density interaction. Only the management factor was significant for average slash pine height. There were no significant factors affecting slash pine survival. The management, density and soil factors significantly affected the cronartium infection rate. Slash pine plots on the B2 soil type had nearly double the infection rate than the soil type with the next highest rate. For per-acre basal area, per-acre green weight and total stem volume, management and planting density had significant effects.

The average DBH, average height, survival, cronartium infection level, basal area, weight and volume 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 3-6 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 mainly 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. On the intensively managed plots, loblolly had more basal area on the lower density (300, 900 tpa) plots and slash pine had more basal area on the 1500 tpa plots. Loblolly pine had more total, per-acre stem volume than slash pine for all planting densities on the intensively managed plots. Volumes were nearly equal on all planting densities on the operational plots. Loblolly pine had more, per-acre green weight than slash pine on all treatment combinations.

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1 INTRODUCTION

Industrial forest landowners in the Southeastern U.S. have experienced increasing pressure to maximize 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. To address this issue, 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, merchantable green and dry weight production and product class distributions.
- Describe and compare the development of stand leaf area index (LAI) produced by the various combinations of cultural intensity and stand density.

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 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. 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 NH_4NO_3 was added in the spring of the fourth 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 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 ranged from 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.

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, 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 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		20
DENSITY*INST(SOIL)	[error (b)]	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 sixth growing season, diameters of all trees and heights on every other tree were measured. 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):

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

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

Analysis of variance as described above was carried out for average DBH, average height, percent survival, percent cornartium infection, per-acre basal area and per-acre total volume. 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 six.

CRIFF Soil Type A

Management	Plant Density	Avg. DBH	Avg. Height	% Surv	% Cron	Basal Area/ac	Total Vol/ac	Total Wt/ac
Intensive	300	6.51	27.9	85.4	22.6	62.9	748	26
	600	5.83	32.3	92.1	28.9	104.4	1453	47
	900	5.02	31.1	90.6	23.7	115.0	1591	51
	1200	4.69	31.9	94.4	14.3	139.6	2000	64
	1500	4.34	30.8	70.8	19.5	111.5	1554	49
	1800	4.02	31.3	94.2	12.9	152.8	2192	69
Operational	300	4.36	23.0	91.3	21.3	30.5	313	11
	600	3.79	22.8	85.8	22.4	46.1	506	17
	900	4.01	25.2	94.4	16.9	77.1	852	28
	1200	3.70	24.3	93.6	12.0	88.1	967	32
	1500	3.30	23.6	89.8	17.2	86.0	938	31
	1800	3.23	23.2	85.9	9.0	95.4	1037	34

CRIFF Soil Type B1

Management	Plant Density	Avg. DBH	Avg. Height	% Surv	% Cron	Basal Area/ac	Total Vol/ac	Total Wt/ac
Intensive	300	6.85	33.2	98.3	18.6	76.4	1064	35
	600	5.55	33.1	98.3	9.8	101.1	1470	47
	900	4.82	32.5	97.2	10.0	113.5	1651	52
	1200	4.43	31.7	96.7	4.1	128.2	1848	58
	1500	4.04	31.1	96.5	3.2	133.2	1917	60
	1800	3.92	30.8	95.3	3.8	149.2	2146	67
Operational	300	5.16	27.5	97.5	12.1	43.7	516	17
	600	4.40	26.6	91.7	9.6	59.9	707	23
	900	3.94	26.2	90.3	7.6	72.6	869	28
	1200	3.55	25.1	91.1	7.4	79.0	901	29
	1500	3.47	26.2	93.5	6.9	97.2	1172	38
	1800	3.13	25.1	92.4	7.3	94.6	1113	36

CRIFF Soil Type B2

Management	Plant Density	Avg. DBH	Avg. Height	% Surv	% Cron	Basal Area/ac	Total Vol/ac	Total Wt/ac
Intensive	300	6.23	30.7	93.3	28.5	60.4	778	26
	600	5.18	31.3	90.4	26.7	81.1	1106	36
	900	4.69	31.3	87.5	23.9	97.7	1370	44
	1200	4.40	31.3	91.4	12.9	119.1	1682	53
	1500	4.08	31.0	87.9	9.5	124.6	1784	56
	1800	3.70	29.8	90.6	8.6	127.0	1747	55
Operational	300	4.19	23.7	92.9	25.0	28.0	293	10
	600	3.85	25.7	94.2	17.2	47.8	553	18
	900	3.69	26.7	94.4	7.0	65.6	802	26
	1200	3.11	24.1	87.8	10.9	58.5	652	21
	1500	3.10	25.5	93.5	10.4	76.9	914	29
	1800	2.90	24.8	93.8	6.9	80.6	933	30

CRIFF Soil Type C

Management	Plant Density	Avg. DBH	Avg. Height	% Surv	% Cron	Basal Area/ac	Total Vol/ac	Total Wt/ac
Intensive	300	6.29	30.8	96.0	18.5	63.3	823	27
	600	5.30	32.7	96.3	11.7	91.1	1324	43
	900	4.57	31.5	96.3	7.6	102.4	1470	47
	1200	4.13	30.6	96.7	4.6	113.7	1632	51
	1500	3.84	30.2	96.9	6.7	123.5	1757	55
	1800	3.52	29.5	96.7	6.4	124.0	1744	54
Operational	300	4.52	26.2	95.8	11.1	33.6	391	13
	600	4.33	28.6	94.3	9.9	60.3	785	25
	900	3.79	28.3	98.5	7.7	73.3	971	31
	1200	3.28	26.0	99.3	5.7	74.8	934	30
	1500	3.18	27.0	97.4	4.8	85.1	1083	34
	1800	3.05	27.3	97.9	4.9	95.3	1247	39

CRIFF Soil Type D

Management	Plant Density	Avg. DBH	Avg. Height	% Surv	% Cron	Basal Area/ac	Total Vol/ac	Total Wt/ac
Intensive	300	6.51	32.4	92.5	8.4	65.0	888	29
	600	5.45	33.9	94.4	3.9	93.4	1393	45
	900	5.05	35.4	90.6	5.2	116.3	1852	58
	1200	4.28	32.7	91.7	3.6	113.0	1693	53
	1500	3.91	31.5	93.4	4.1	120.8	1781	55
	1800	3.65	31.7	94.0	4.0	128.8	1945	60
Operational	300	4.25	25.5	89.4	6.9	27.2	303	10
	600	3.71	24.9	92.5	6.1	43.6	497	16
	900	3.37	24.2	86.5	5.4	50.2	554	18
	1200	2.93	23.4	92.5	7.0	56.1	622	20
	1500	2.76	23.0	95.6	1.6	63.1	688	22
	1800	2.68	22.8	85.9	3.8	69.6	819	26

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 $\alpha = 0.05$ level but there was no 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 and initial density.

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

Source	df	Type III F	Pr > F
Soil	4	1.15	0.3857
Management	1	243.91	0.0001*
Soil x Management	4	2.16	0.1409
Density	5	287.47	0.0001*
Soil x Density	20	1.59	0.0645
Management x Density	5	25.05	0.0001*

*Significant at $\alpha = 0.05$.

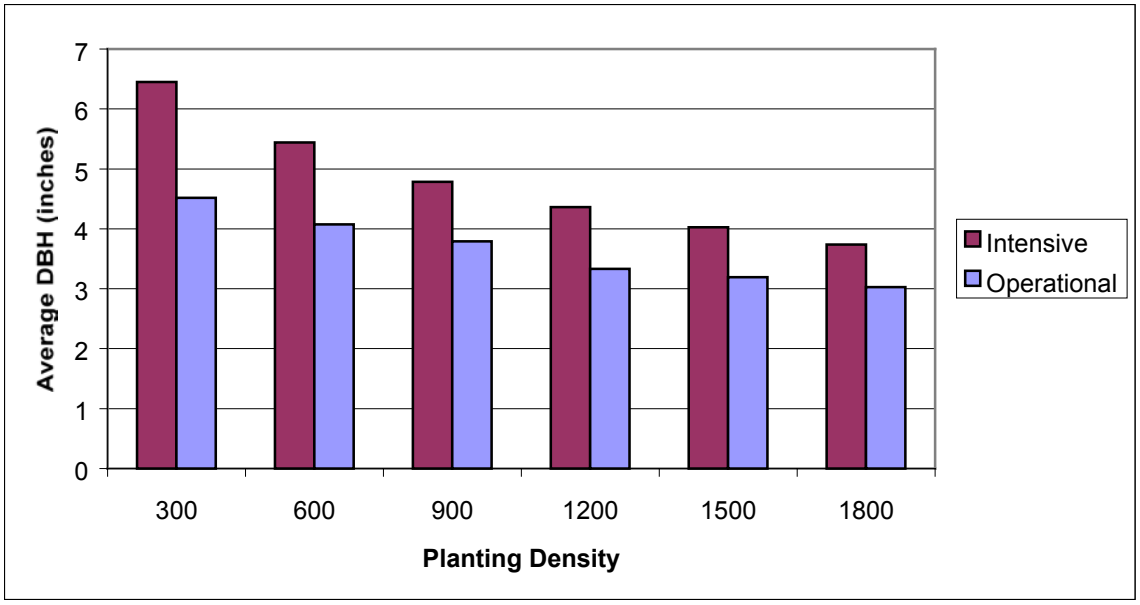

Figure 1. Average DBH by planting density and management intensity for loblolly pine at age six.

The analysis indicates that the effects of more intensive management are significant and that there is a management intensity x density interaction. This interaction is probably caused by the increased level of stand development on the intensive culture plots. As a result, there is a marked effect on DBH as density increases. While the same trends are present on the operational plots, the differences are much smaller. The level of development indicates that the operational plots shade themselves at an early age at high densities. This effect is much less prevalent at low densities as evidenced by the lower DBH values on the operational plots.

3.2 Average 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 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.

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

Source	df	Type III F	Pr > F
Soil	4	0.48	0.7507
Management	1	111.75	0.0001*
Soil x Management	4	2.34	0.1190
Density	5	4.80	0.0005*
Soil x Density	20	1.20	0.2636
Management x Density	5	0.91	0.4741

*Significant at α = 0.05.

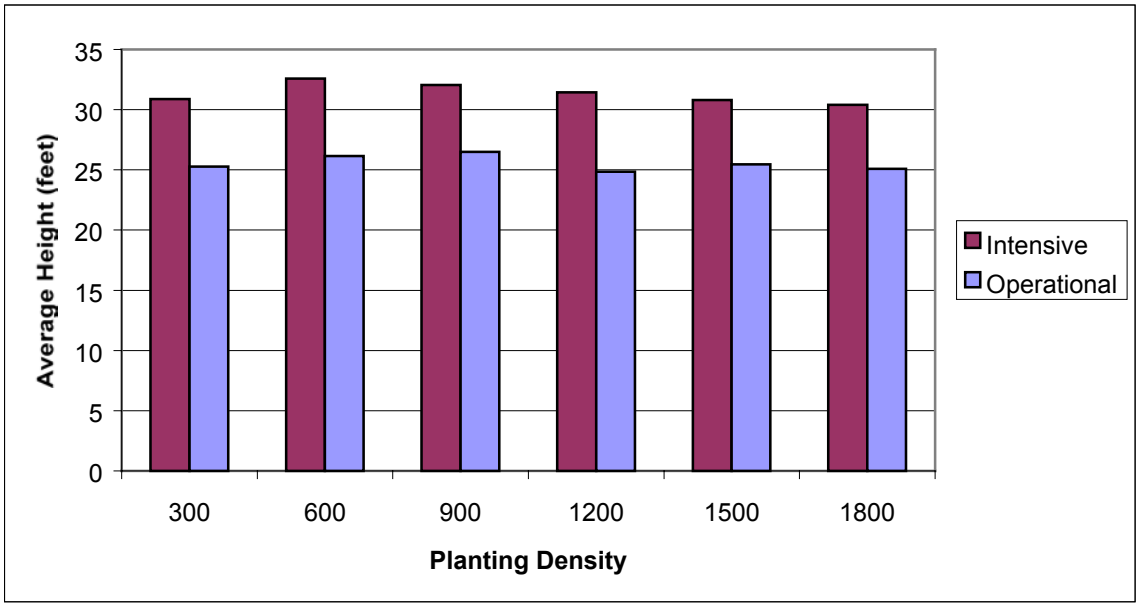

Figure 2. Average height by planting density and management intensity for loblolly pine at age six.

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. There were no significant differences in survival rates due to any factor included in the analysis of variance. Figure 3 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 six.

Source	df	Type III F	Pr > F
Soil	4	1.57	0.2512
Management	1	0.04	0.8416
Soil x Management	4	1.38	0.3037
Density	5	0.49	0.7815
Soil x Density	20	1.57	0.0697
Management x Density	5	1.88	0.1013

*Significant at α = 0.05.

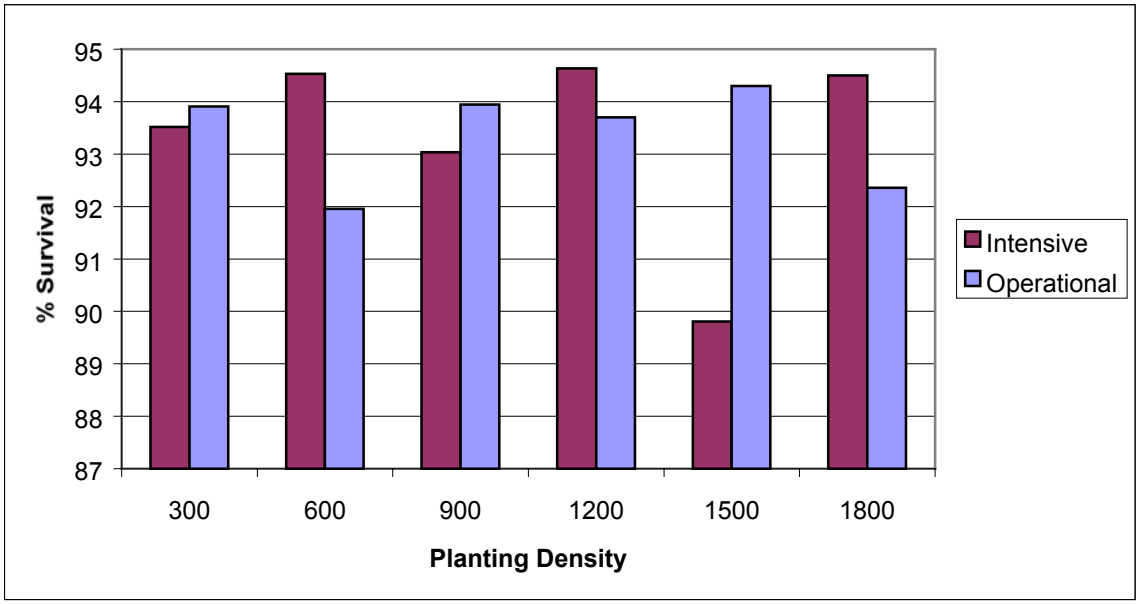

Figure 3. Percent survival by planting density and management intensity for loblolly pine at age six.

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 6 to 20% for all densities and management regimes. Average infection rates increased by nearly 100% between the ages of four and six years. Density and the soil group x density interaction significantly affected the cronartium infection rate. As shown in Figure 4, the intensive management treatment at initial densities of 300 and 600 trees/acre had the highest average infection rates. Figure 5 shows the average infection rates by CRIFF soil group and planting density. The highest average infection rates were observed in soil groups A and B2 at low planting densities.

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

Source	Df	Type III F	Pr > F
Soil	4	2.65	0.0904
Management	1	2.82	0.1215
Soil x Management	4	0.73	0.5910
Density	5	18.81	0.0001*
Soil x Density	20	1.66	0.0488*
Management x Density	5	1.59	0.1687

*Significant at α = 0.05.

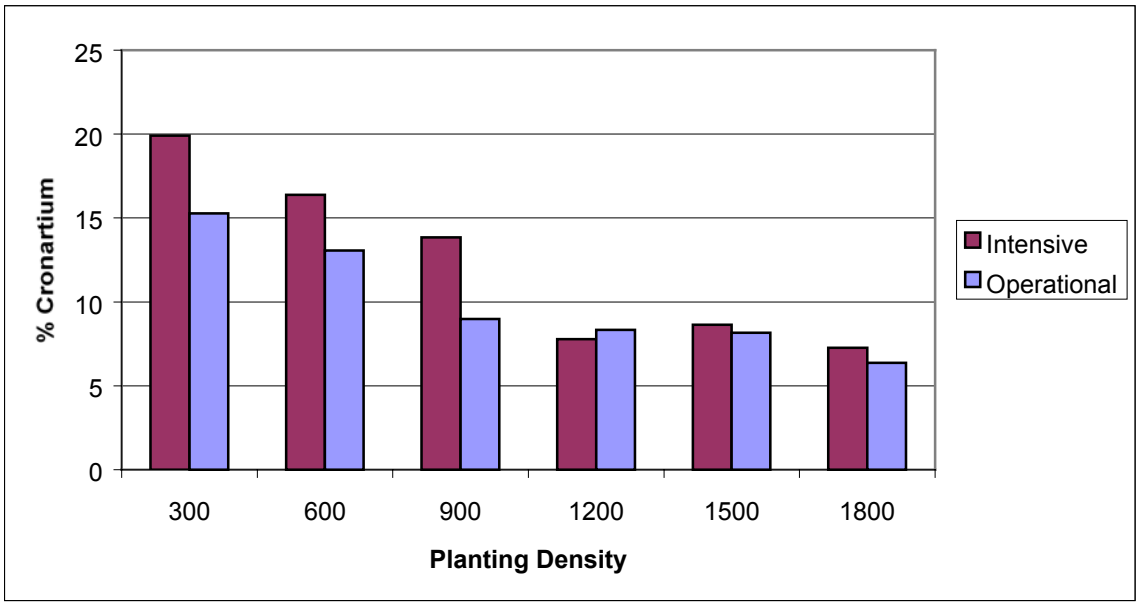

Figure 4. Average percent cronartium infection by planting density and management intensity for loblolly pine at age six.

3.5 Per-Acre Basal Area

Table 9 shows the results of the analysis of variance for per-acre basal area. Management intensity, density and their interaction were significant factors for per-acre basal area. Basal area increased with increasing density and at a much greater rate with the most intensive silvicultural regime at densities of 1200 trees/acre or more (Figure 6).

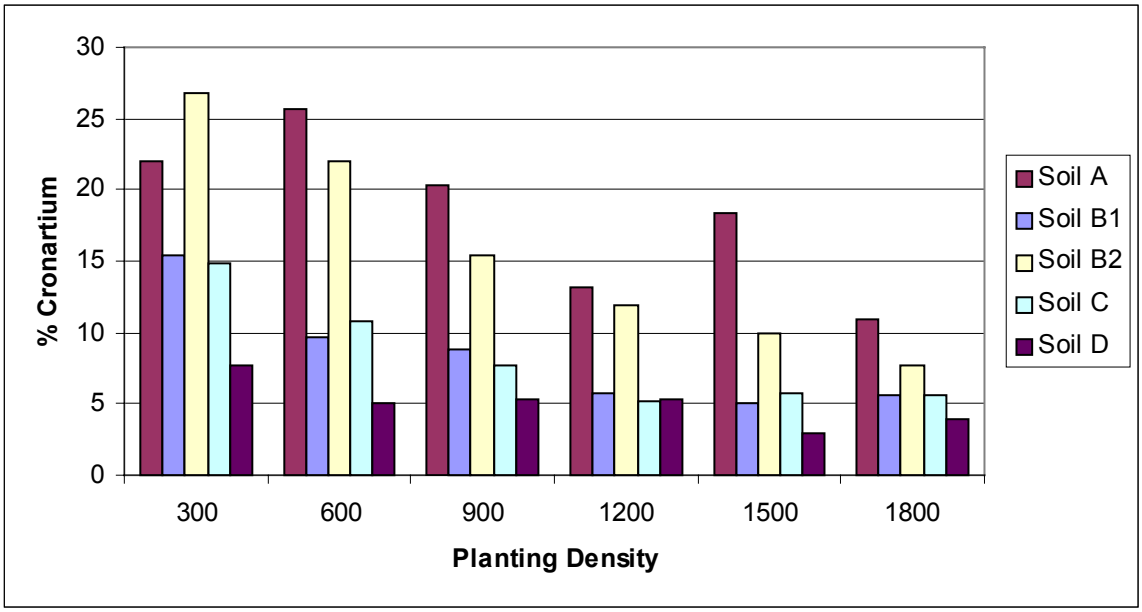

Figure 5. Average percent cronartium infection by planting density and CRIFF soil group for loblolly pine at age six.

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

Source	df	Type III F	Pr > F
Soil	4	0.98	0.4559
Management	1	174.18	0.0001*
Soil x Management	4	1.20	0.3648
Density	5	131.17	0.0001*
Soil x Density	20	1.34	0.1668
Management x Density	5	2.54	0.0313*

*Significant at $\alpha = 0.05$.

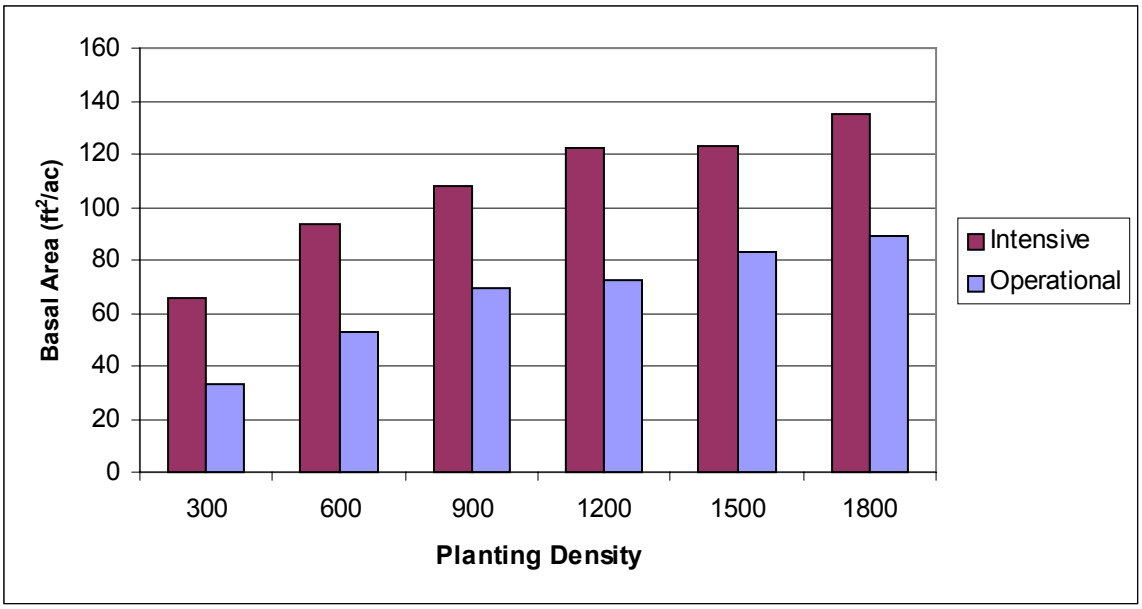

Figure 6. Average per-acre basal area by planting density and management intensity for loblolly pine at age six.

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 nearly identical trends as seen for per-acre basal area. Management, density and their interaction significantly affected per-acre volume (Figure 7).

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

Source	df	Type III F	Pr > F
Soil	4	0.51	0.7283
Management	1	137.78	0.0001*
Soil x Management	4	1.28	0.3357
Density	5	94.97	0.0001*
Soil x Density	20	1.04	0.4195
Management x Density	5	4.82	0.0004*

*Significant at α = 0.05.

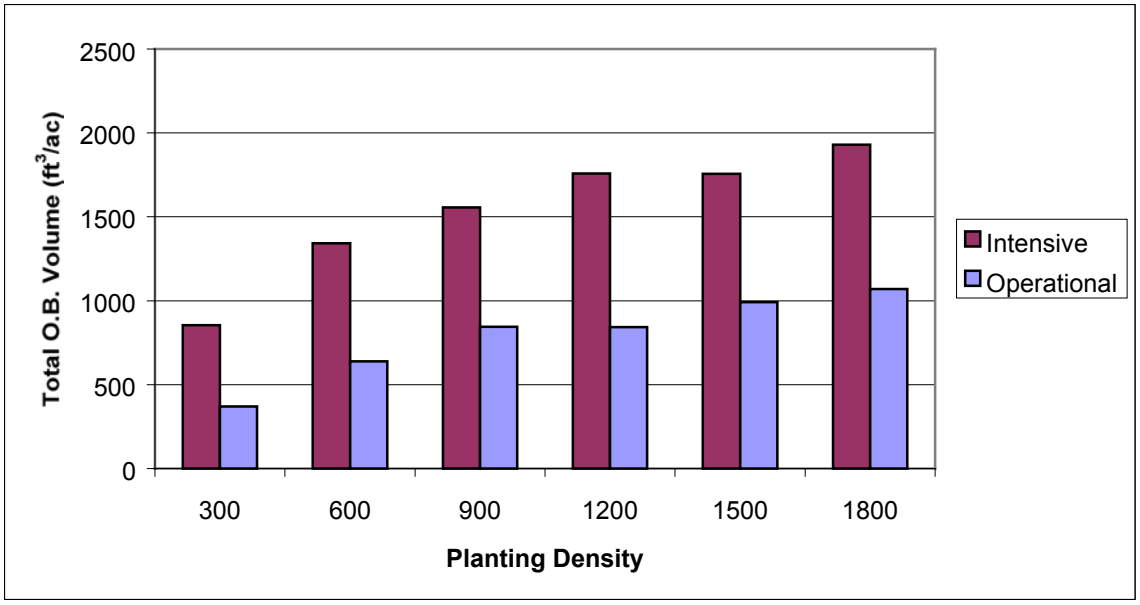

Figure 7. Average per-acre o.b. volume by planting density and management intensity for loblolly pine at age six.

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 volume (Figure 8).

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

Source	Df	Type III F	Pr > F
Soil	4	0.50	0.7374
Management	1	136.11	0.0001*
Soil x Management	4	1.25	0.3469
Density	5	77.92	0.0001*
Soil x Density	20	1.03	0.4274
Management x Density	5	4.43	0.0009*

*Significant at α = 0.05.

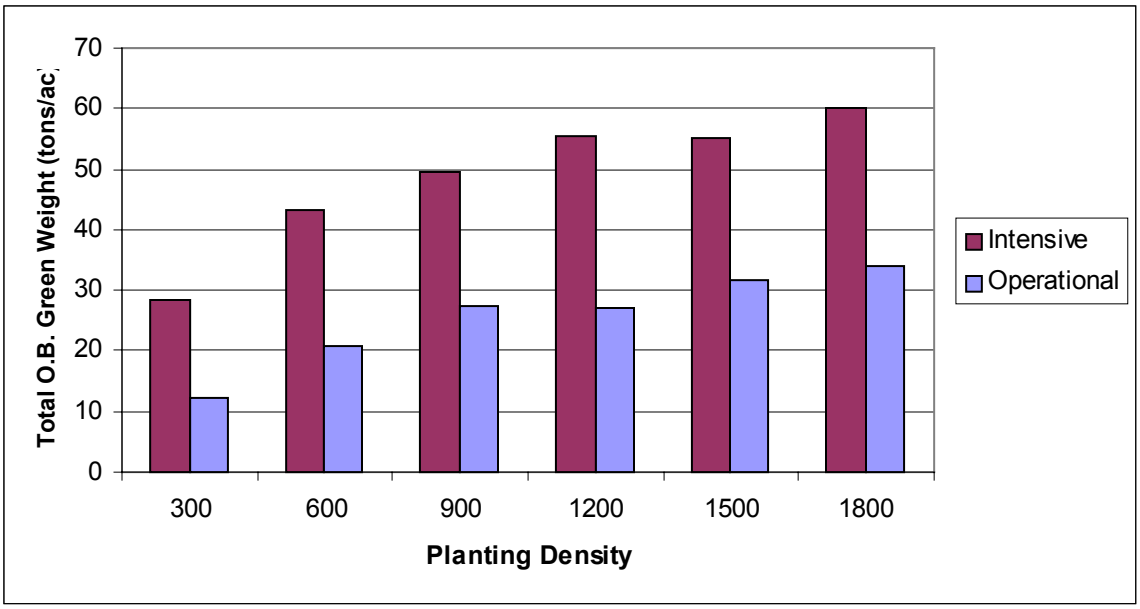

Figure 8. Average per-acre o.b. green weight by planting density and management intensity for loblolly pine at age six.

4 SLASH PINE RESULTS

Individual tree, outside bark cubic foot volumes and green weights for slash pine were calculated using the following equation from Pienaar, et al. (1996):

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

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

Analysis of variance as described above was carried out for average DBH, average height, percent survival, percent cornartium infection, per-acre basal area and per-acre total volume. Table 12 shows the slash pine means by soil type, management intensity and initial density.

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

CRIFF Soil Type B1

Management	Plant Density	Avg. DBH	Avg. Height	% Surv	% Cron	Basal Area/ac	Total Vol/ac	Total Wt/ac
Intensive	300	6.42	27.1	99.2	28.1	68.2	966	26
	900	4.87	27.1	92.4	19.4	110.4	1549	43
	1500	4.13	25.3	95.6	12.0	137.4	1798	50
Operational	300	4.97	23.5	89.2	13.2	36.4	452	12
	900	3.96	22.7	86.5	16.6	68.0	813	23
	1500	3.48	21.6	88.5	9.9	92.5	1079	30

CRIFF Soil Type B2

Management	Plant Density	Avg. DBH	Avg. Height	% Surv	% Cron	Basal Area/ac	Total Vol/ac	Total Wt/ac
Intensive	300	6.12	23.9	71.9	41.0	45.8	594	16
	900	4.67	22.9	72.4	41.4	80.2	979	27
	1500	4.37	24.4	77.8	22.3	125.1	1599	44
Operational	300	4.33	21.5	86.3	26.1	27.0	309	8
	900	3.83	22.8	90.6	18.0	66.3	786	22
	1500	3.16	20.9	89.4	24.0	77.1	870	24

CRIFF Soil Type C

Management	Plant Density	Avg. DBH	Avg. Height	% Surv	% Cron	Basal Area/ac	Total Vol/ac	Total Wt/ac
Intensive	300	6.02	23.9	89.6	19.3	54.1	689	18
	900	4.67	24.9	91.0	8.8	100.0	1303	36
	1500	4.02	24.5	93.1	7.7	126.9	1610	45
Operational	300	4.58	23.3	95.8	5.1	33.4	410	11
	900	3.86	23.1	93.4	9.0	70.4	855	24
	1500	3.54	23.8	95.6	2.4	100.8	1248	35

CRIFF Soil Type D

Management	Plant Density	Avg. DBH	Avg. Height	% Surv	% Cron	Basal Area/ac	Total Vol/ac	Total Wt/ac
Intensive	300	6.46	27.6	95.0	17.1	65.9	943	26
	900	4.76	27.3	95.8	12.0	109.1	1516	42
	1500	4.01	27.3	93.8	14.7	127.2	1759	50
Operational	300	4.73	23.5	92.5	20.3	34.2	420	11
	900	3.97	24.3	95.8	5.4	74.8	927	26
	1500	3.41	22.7	98.8	2.5	95.7	1123	32

4.1 Average DBH

Table 13 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 9, average DBH decreased with increasing density and the differences were more dramatic under the more intensive management scenario. The CRIFF soil group x density interaction also significantly affected average DBH. Figure 10 shows that the average DBH's for the 300 trees per acre plots were higher on the B1 and D soil groups.

Table 13. Analysis of variance results for slash pine average DBH at age six.

Source	df	Type III F	Pr > F
Soil	3	0.32	0.8143
Management	1	214.41	0.0001*
Soil x Management	3	1.46	0.3302
Density	2	449.04	0.0001*
Soil x Density	6	2.50	0.0478*
Management x Density	2	38.11	0.0001*

*Significant at $\alpha = 0.05$.

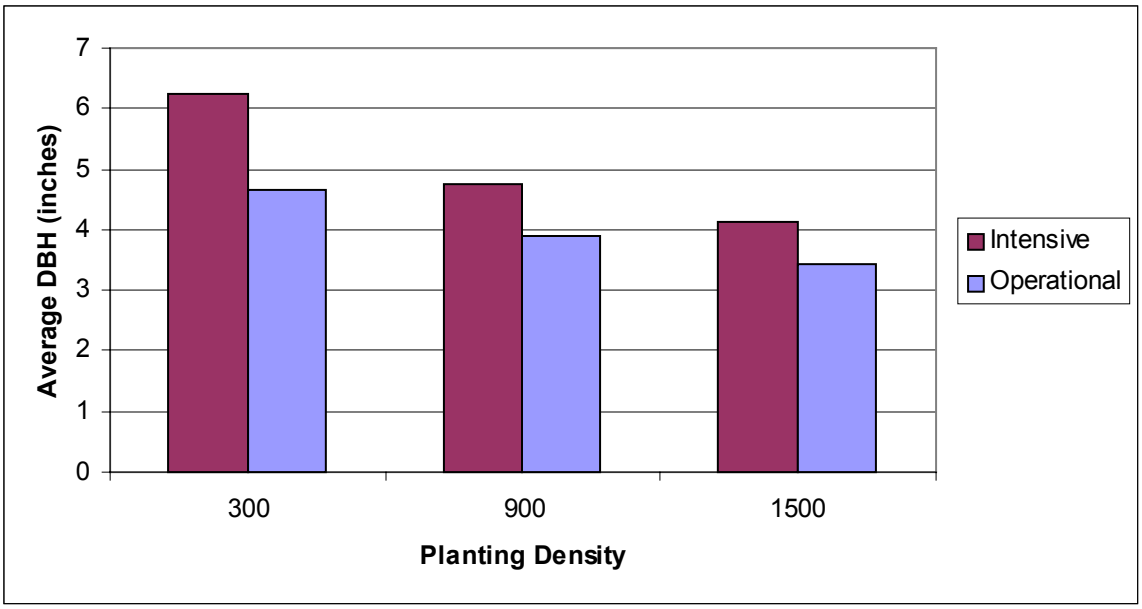

Figure 9. Average DBH by planting density and management intensity for slash pine at age six.

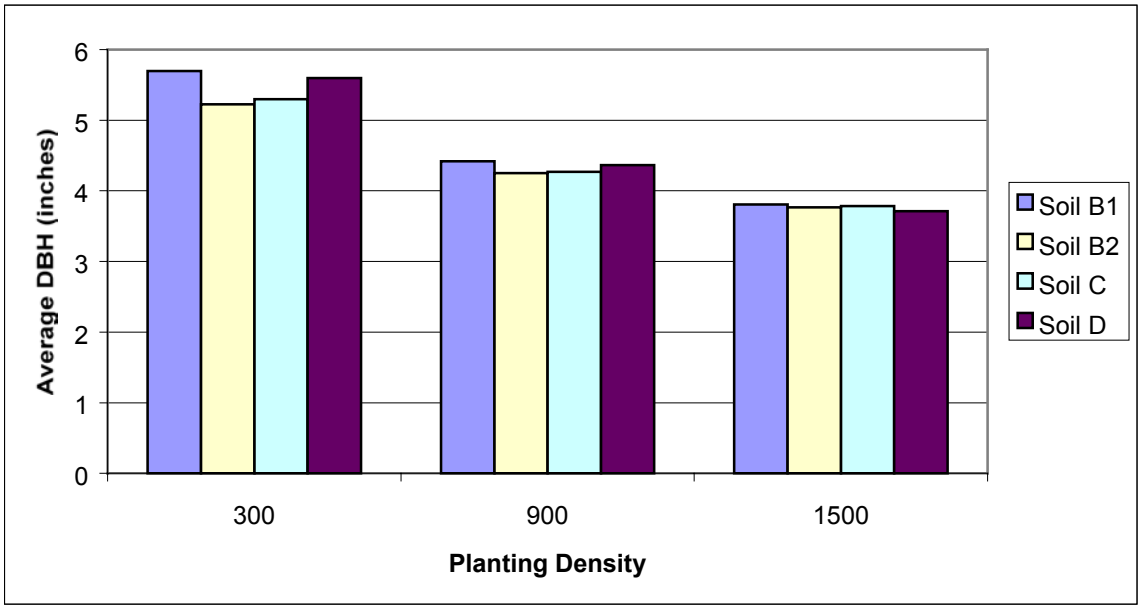

Figure 10. Average DBH by planting density and CRIFF soil group for slash pine at age six.

4.2 Average Height

Table 14 shows the results of the analysis of variance for slash pine average height. Management intensity was the only significant factor affecting average height. Figure 11 shows the average heights by initial density and management intensity. Average heights were two to three feet higher on the more intensively managed plots.

Table 14. Analysis of variance results for slash pine average height at age six.

Source	df	Type III F	Pr > F
Soil	3	0.94	0.4873
Management	1	16.10	0.0102*
Soil x Management	3	1.42	0.3414
Density	2	1.23	0.3100
Soil x Density	6	1.54	0.2050
Management x Density	2	0.17	0.8460

*Significant at α = 0.05.

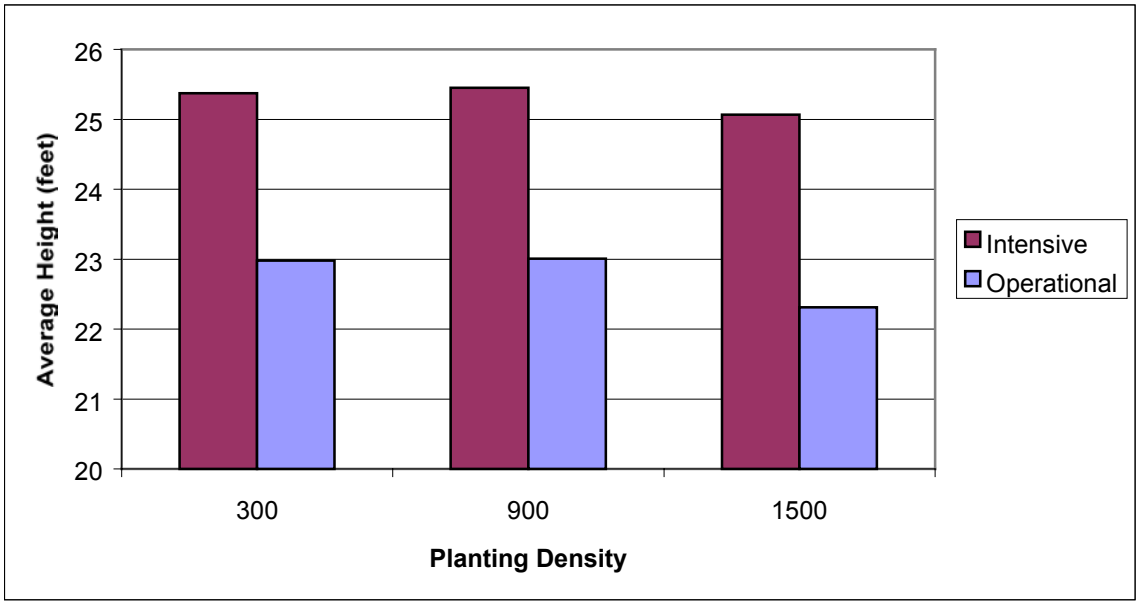

Figure 11. Average height by planting density and management intensity for slash pine at age six.

4.3 Percent Survival

Table 15 shows the results of the analysis of variance for slash pine average percent survival. The slash pine plots had good survival, averaging from 79% to 96% for all densities and management regimes. There were no significant differences in survival rates due to any factor included in the analysis of variance. Average survival rates by initial density and management intensity are shown in Figure 12.

Table 15. Analysis of variance results for slash pine average percent survival at age six.

Source	df	Type III F	Pr > F
Soil	3	4.85	0.0609
Management	1	1.06	0.3511
Soil x Management	3	3.47	0.1070
Density	2	0.59	0.5611
Soil x Density	6	0.59	0.7325
Management x Density	2	0.09	0.9112

*Significant at α = 0.05.

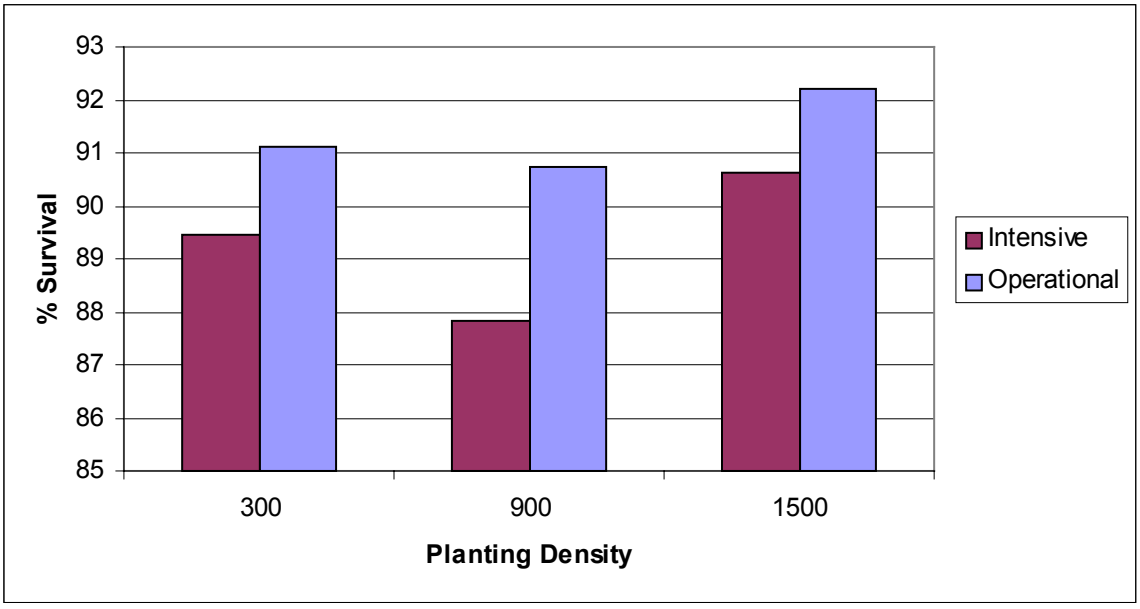

Figure 12. Average percent survival by planting density and management intensity for slash pine at age six.

4.4 Percent Cronartium Infection

Table 16 shows the results of the analysis of variance for slash pine average percent cronartium infection. All of the main factors, soil, management regime and density significantly affected the cronartium infection rate for slash pine. Figure 13 shows that more intensive management increased the infection level and the rates were higher at the 300 and 600 trees/acre planting densities. Figure 14 shows that the cronartium infection rate was much greater on the B2 soil type.

Table 16. Analysis of variance results for slash pine average percent cronartium infection at age six.

Source	df	Type III F	Pr > F
Soil	3	8.49	0.0209*
Management	1	11.52	0.0194*
Soil x Management	3	0.50	0.6976
Density	2	5.82	0.0081*
Soil x Density	6	0.21	0.9708
Management x Density	2	1.78	0.1883

*Significant at α = 0.05.

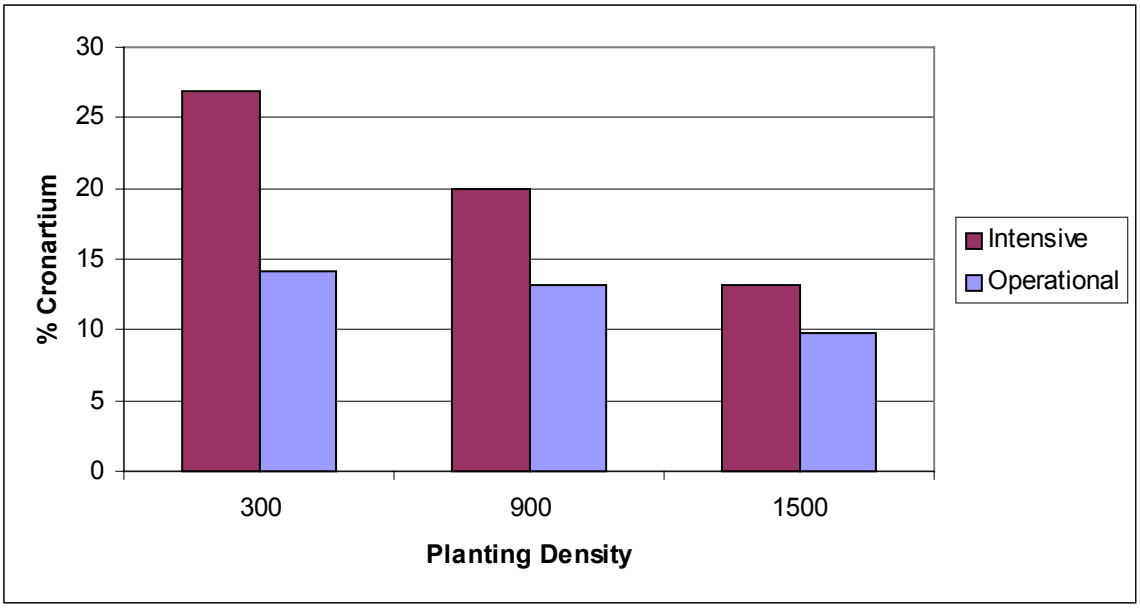

Figure 13. Average percent cronartium infection by planting density and management intensity for slash pine at age six.

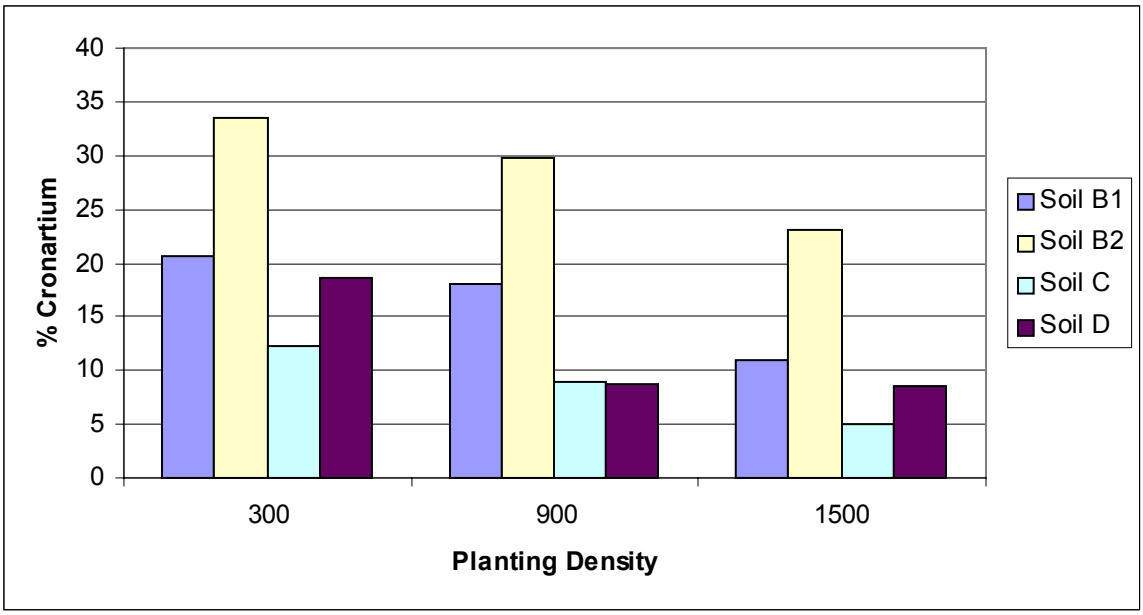

Figure 14. Average percent cronartium infection by CRIFF soil group and planting density for slash pine at age six.

4.5 Per-Acre Basal Area

Table 17 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 management intensity. The differences between intensive and operational treatments were fairly consistent among the planting density treatments. Figure 15 illustrates these trends.

Table 17. Analysis of variance results for slash pine average per-acre basal area at age six.

Source	df	Type III F	Pr > F
Soil	3	0.86	0.5189
Management	1	58.99	0.0006*
Soil x Management	3	0.96	0.4790
Density	2	221.58	0.0001*
Soil x Density	6	0.35	0.9022
Management x Density	2	2.55	0.0977

*Significant at α = 0.05.

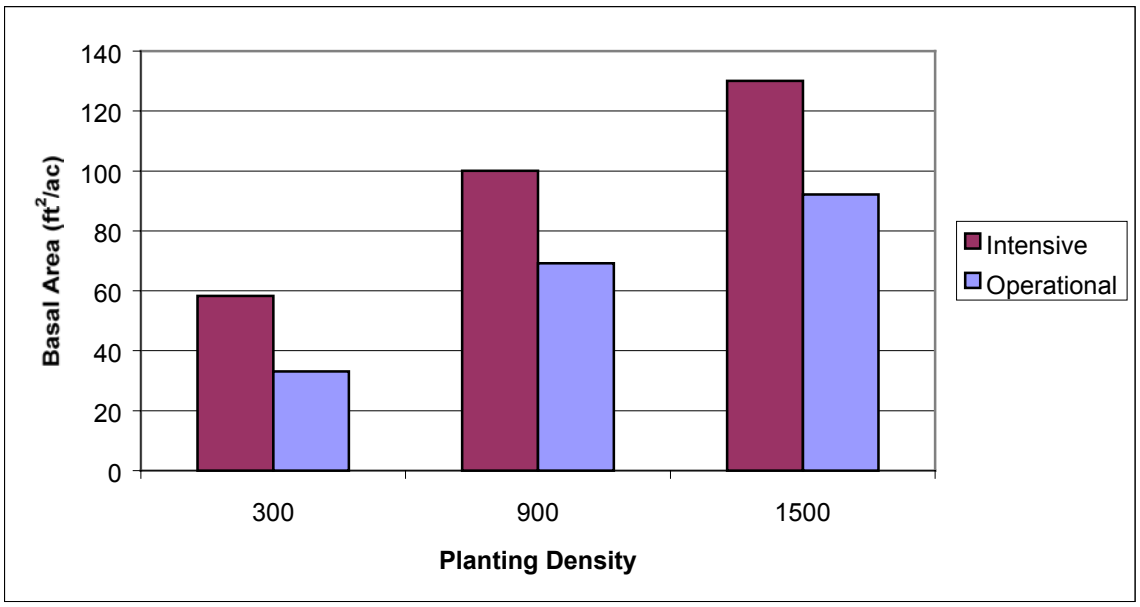

Figure 15. Average per-acre basal area by planting density and management intensity for slash pine at age six.

4.6 Per-Acre O.B. Volume

Table 18 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 16 shows a nearly identical trend for volume as for basal area.

Table 18. Analysis of variance results for slash pine average per-acre, total volume at age six.

Source	df	Type III F	Pr > F
Soil	3	0.91	0.4986
Management	1	38.93	0.0015*
Soil x Management	3	1.37	0.3534
Density	2	134.97	0.0001*
Soil x Density	6	0.42	0.8585
Management x Density	2	3.10	0.0621

*Significant at α = 0.05.

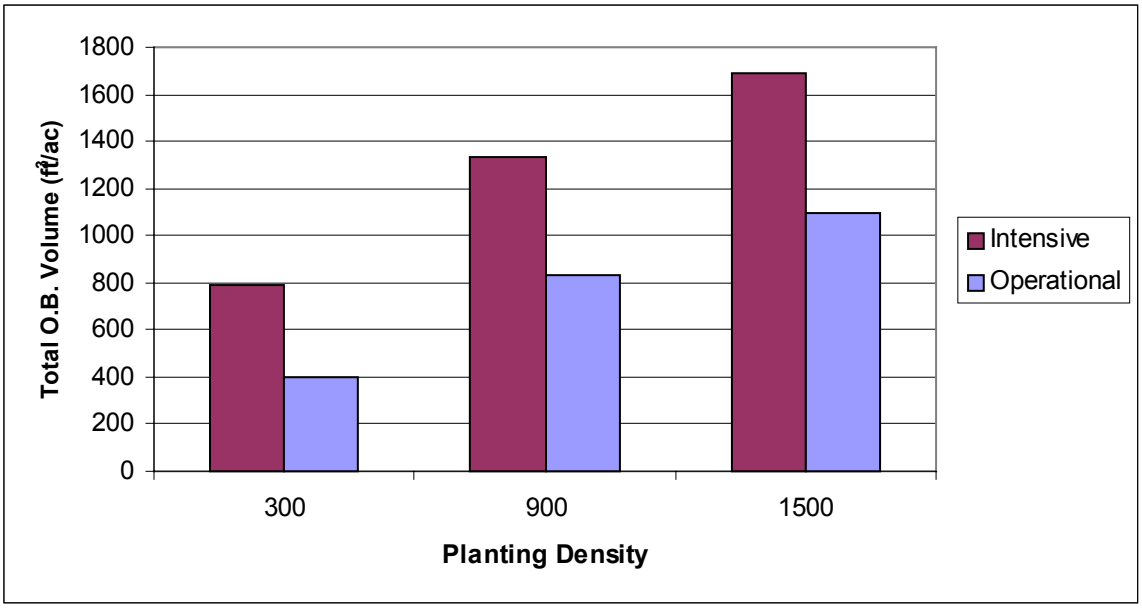

Figure 16. Average per-acre o.b. volume by planting density and management intensity for slash pine at age six.

4.7 Per-Acre O.B. Green Weight

Table 19 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 17 shows the per-acre green weights by density and management treatment.

Table 19. Analysis of variance results for slash pine average per-acre, total green weight at age six.

Source	Df	Type III F	Pr > F
Soil	3	0.88	0.5129
Management	1	40.42	0.0014*
Soil x Management	3	1.40	0.3449
Density	2	113.50	0.0001*
Soil x Density	6	0.43	0.8500
Management x Density	2	2.80	0.0789

*Significant at $\alpha = 0.05$.

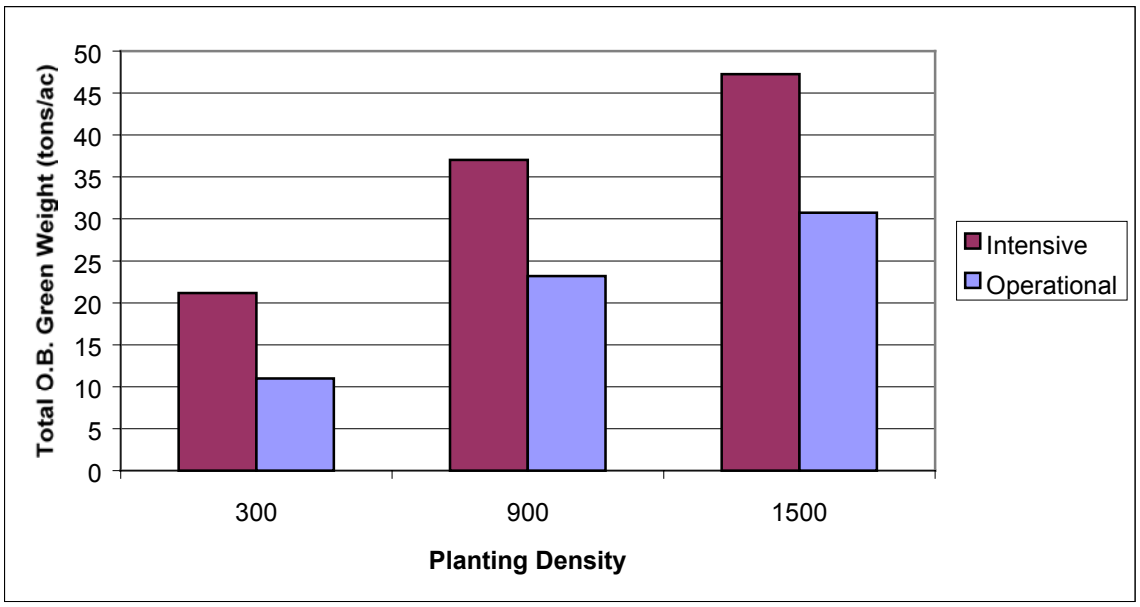

Figure 17. Average per-acre o.b. green weight by planting density and management intensity for slash pine at age six.

5 SPECIES COMPARISON

A graphical comparison was carried out to assess differences in tree and stand characteristics of slash and loblolly pine. Figures 18-24 show the average DBH, height, survival percentage, cronartium infection percentage, per-acre basal area, per-acre total volume and per-acre total green weight by species, initial density and management intensity level for all soil groups.

For operational treatments, slash pine had a greater average DBH than loblolly at all spacings. On the intensive treatments, slash pine had a smaller DBH at the 300 trees/acre density, nearly equal at the 900 density and had a slightly greater DBH than loblolly at the 1500 trees/acre treatment (Figure 18).

The intensively managed loblolly pine plots had consistently greater average heights (6-8 feet) than any other treatments. The operational loblolly plots were nearly equal to slash intensive at all spacings. The intensive slash pine plots had average heights only 2-2.5 feet taller than the operational slash pine plots (Figure 19).

In all cases, operational treatment plots had better survival than the more intensively managed plots. Loblolly pine survived better than slash pine by about 4% on the average (Figure 20).

As has been reported in many previous studies, treatments that accelerated pine growth also tended to increase the cronartium infection rate. Slash pine had higher infection rates, overall. Infection rates for both species also tended to increase with decreasing planting density (Figure 21).

For all treatments and species, per-acre basal area increased with increasing initial density. Within each treatment group, the basal areas for slash and loblolly pine were nearly equal for each spacing level (Figure 22). Slash pine had slightly higher basal areas than loblolly at the highest density.

The trends for per-acre, outside bark volume were nearly identical to those seen for per-acre basal area. Volume increased with increasing management intensity and initial density. Slash pine had slightly more volume at all spacings for the operational treatments. Loblolly pine had slightly greater volumes on the intensive treatments at all spacings (Figure 23). This result seems peculiar in light of the fact that loblolly pine survived slightly better and was nearly five feet taller, on the average, than slash pine. Two points may provide some explanation. First, the equations used to calculate individual tree volumes were not developed from trees of this young age and relatively small size. Second, volumes computed using the slash pine equation are up to 1/3 more than the loblolly pine equation for the same sized tree. For example, a 3.5-inch DBH, 17-foot tall slash pine has 0.6095 ft^3 while the same sized loblolly pine has 0.4571 ft^3. Using the overall average dimensions for slash and loblolly pines, a 4.52-inch DBH, 24.0-foot tall slash pine has 1.3714 ft^3 of stem volume, while a 4.46-inch DBH, 28.5-foot tall loblolly pine has 1.3373 ft^3, a 3% advantage in favor of slash pine.

The trends for total green weight were similar to the trends for total volume. As shown in Figure 24, however, the advantage for loblolly pine in terms of green weight was greater than the advantage in terms of volume.

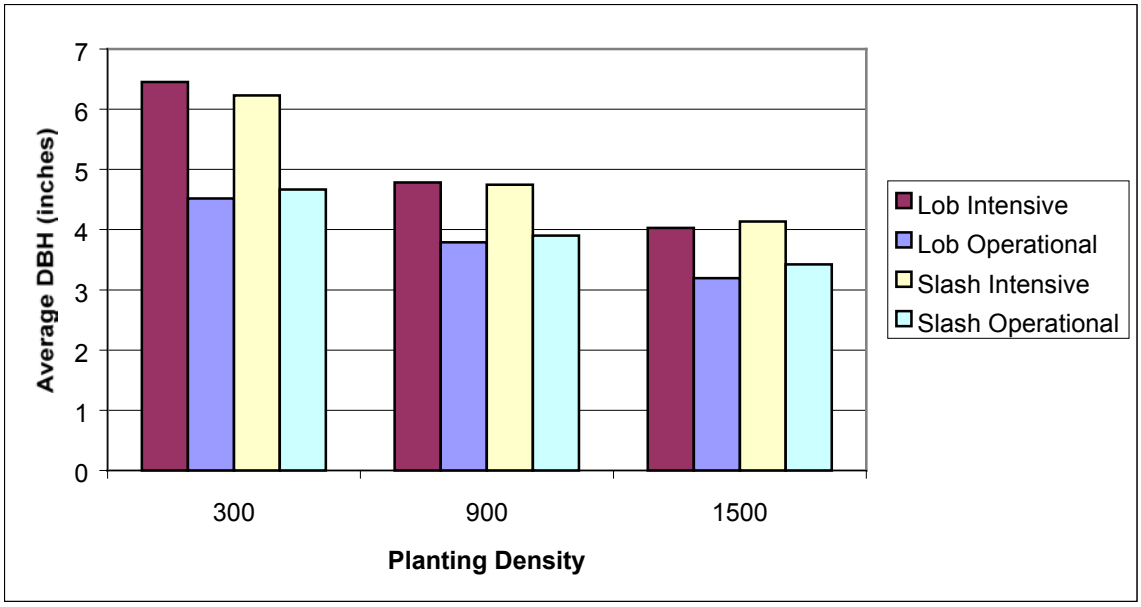

Figure 18. Average DBH by species, management intensity and density at age six.

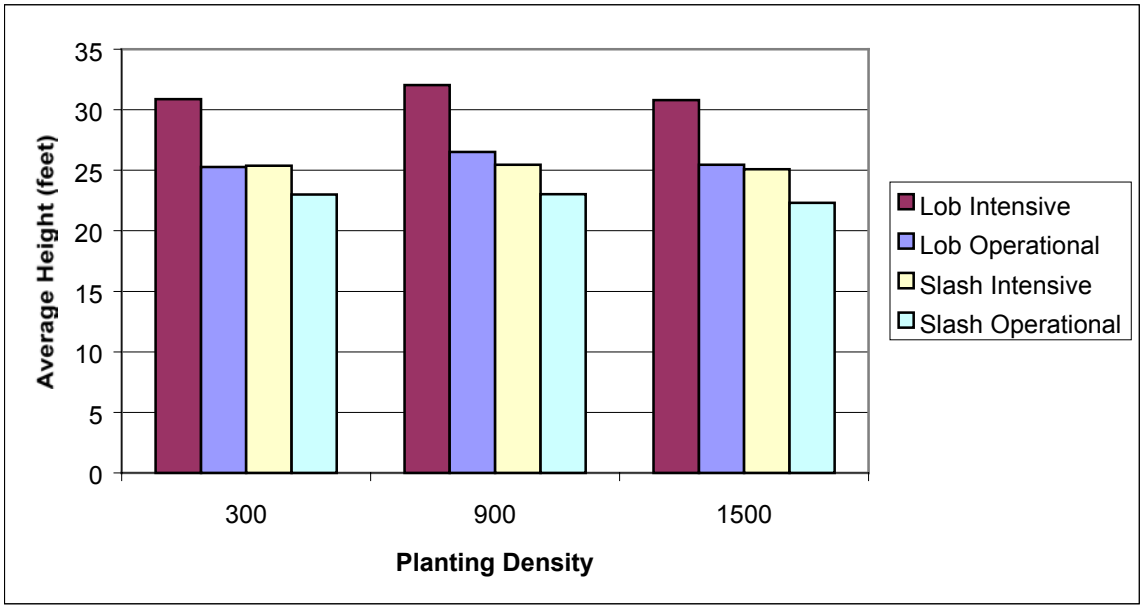

Figure 19. Average height by species, management intensity and density at age four.

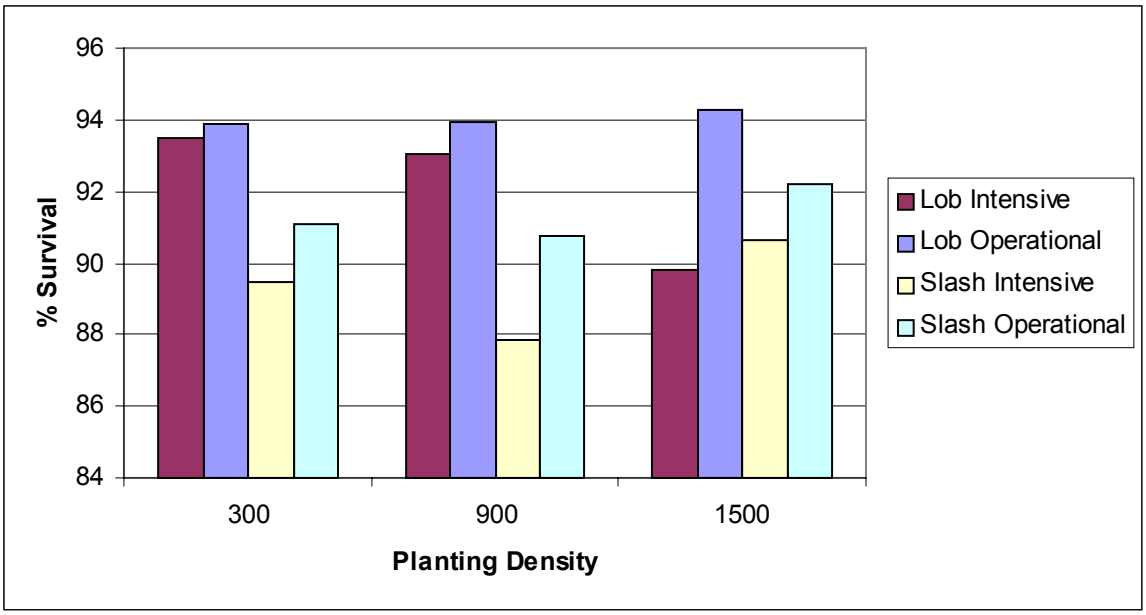

Figure 20. Average percent survival by species, management intensity and density at age four.

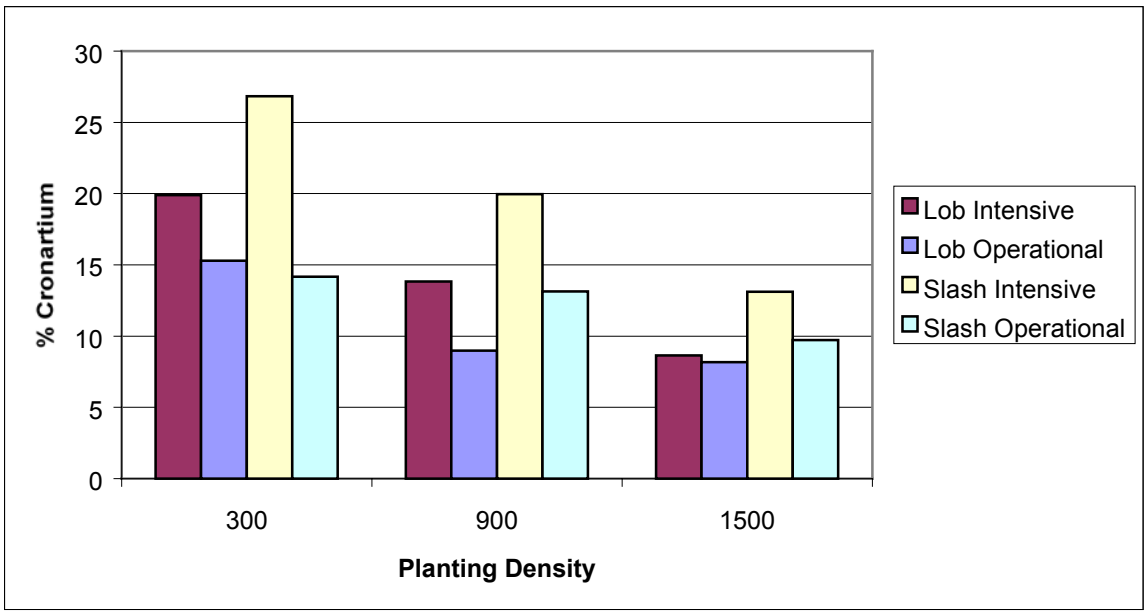

Figure 21. Average percent cronartium infection by species, management intensity and density at age four.

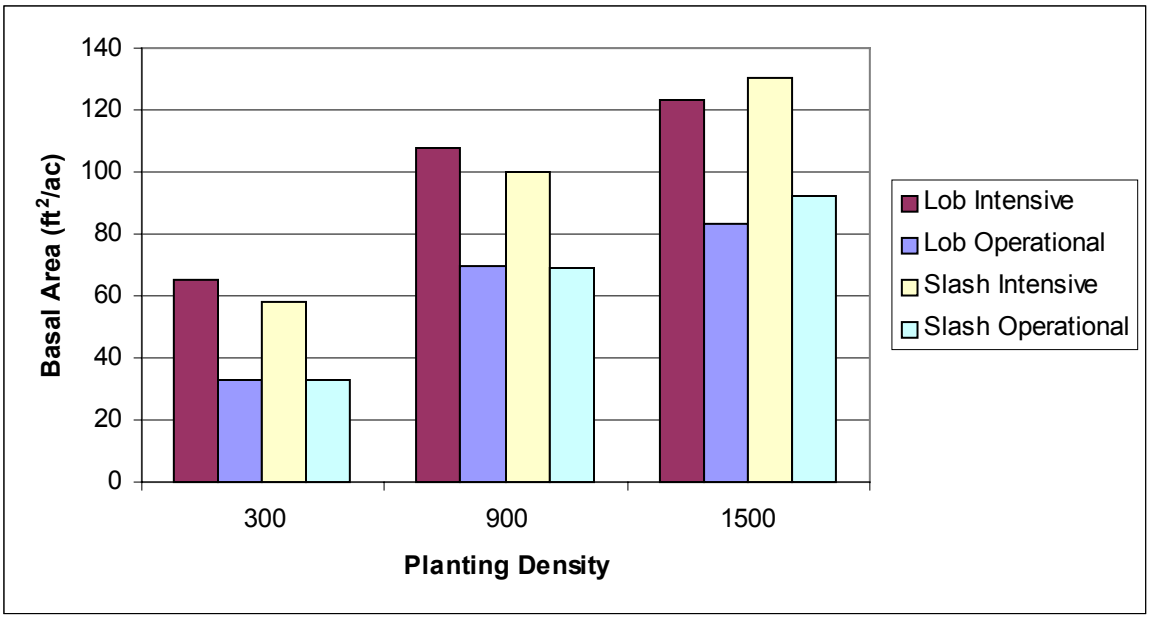

Figure 22. Average per-acre basal area by species, management intensity and density at age four.

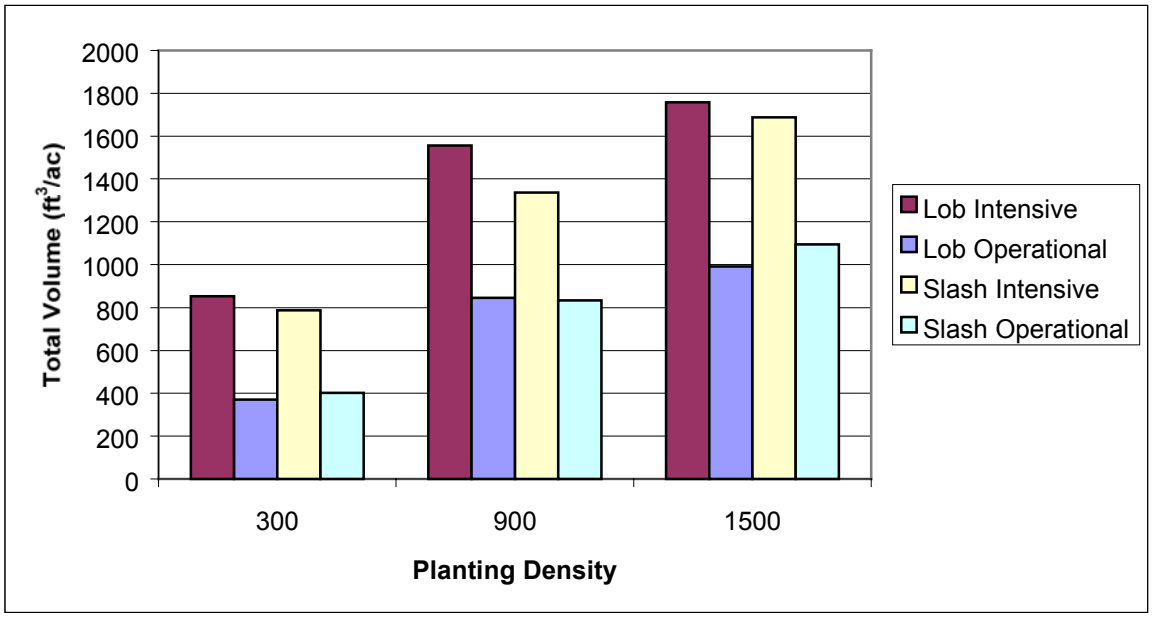

Figure 23. Average per-acre o.b. volume by species, management intensity and density at age four.

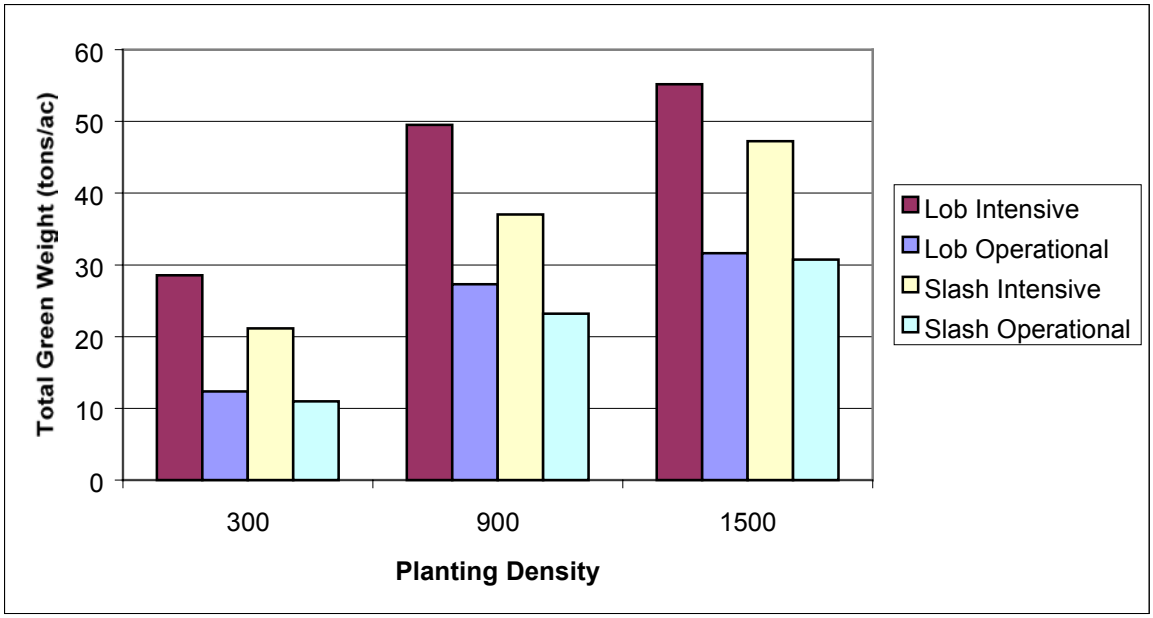

Figure 24. Average per-acre o.b. green weight by species, management intensity and density at age six.

Differences between slash and loblolly pine tree and stand characteristics for the culture density study can be clarified, somewhat, by an analysis of the differences on a soil group basis. Figures 25-31 show the average DBH, average height, survival percentage, cronartium infection percentage, per-acre basal area, per-acre volume and per-acre green weight by CRIFF soil group, species, management treatment and initial density.

On all soil groups, the intensively managed slash pine plots had greater average DBH's than the intensive loblolly plots at the 1500 trees/acre initial density. On soil class D, slash pine had greater average DBH's than loblolly pine for both management schemes and all spacings (Figure 25). Loblolly pine had a greater average DBH in all other cases.

Loblolly pine had consistently taller average heights than slash pine for all soil and treatment groups. Soil group seemed to have little effect on loblolly pine average height. Slash pines were taller on the B1 and D compared to other soil groups. On all but the D soils, the operational loblolly pine plots were taller than the intensively managed slash pine plots at all densities (Figure 26).

There were no obvious trends in average survival. In general, loblolly pine survived better than slash pine. Slash pine survival was particularly poor on the CRIFF B2 soil type (Figure 27).

With only a couple of exceptions, the intensive treatments had higher cronartium infection rates than the operational plots for both species. Slash pine had higher infection rates, overall. Slash pine infection rates were particularly high on the intensively managed plots found on the CRIFF B2 soil type (Figure 28). This may be contributing to the higher mortality rate mentioned earlier.

Slash pine had more per-acre basal area on the intensive, 1500 trees per acre density treatments on all soil types. Slash pine had consistently more per-acre basal area for both management treatments on the D soil group. The species differences on soil group D were much greater on the operational plots (Figure 29).

Loblolly pine had more volume in nearly all cases. Slash pine had more total volume on the operational plots on the D soil group (Figure 30). The trends for total green weight are nearly identical, but the differences seem to be more pronounced than for volume (Figure 31).

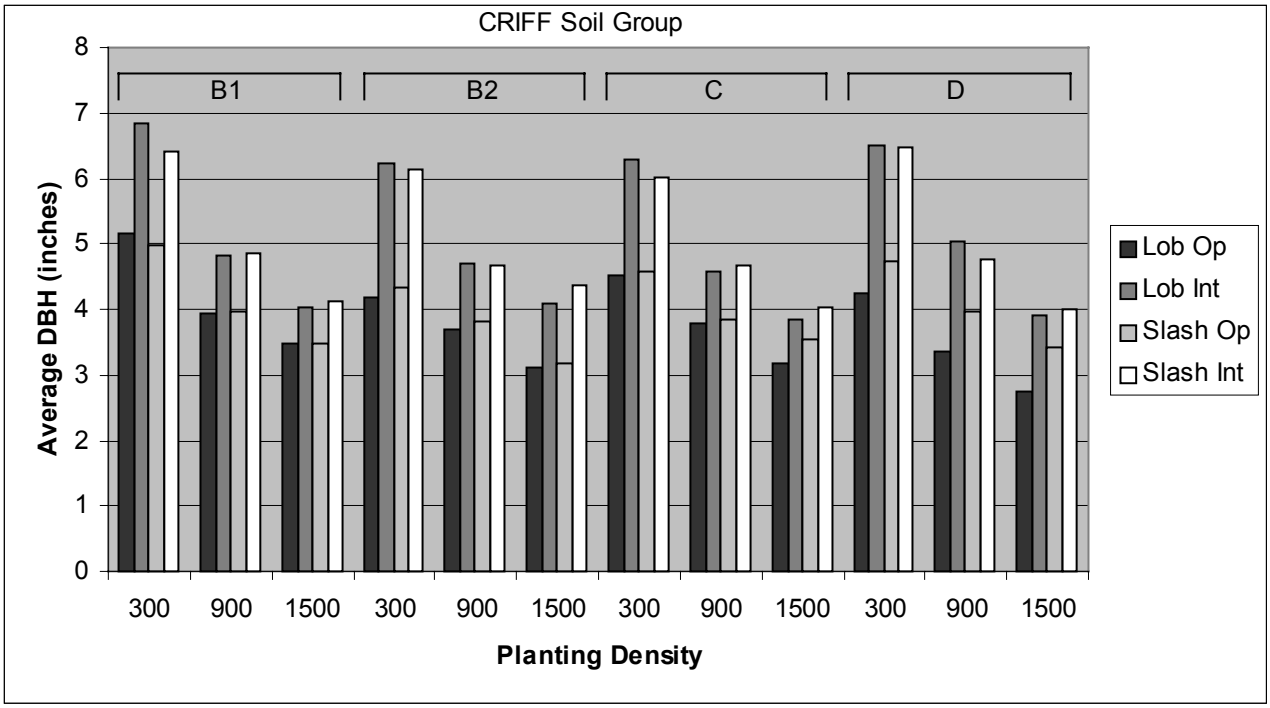

Figure 25. Average DBH by CRIFF soil group, species, management intensity and density at age six.

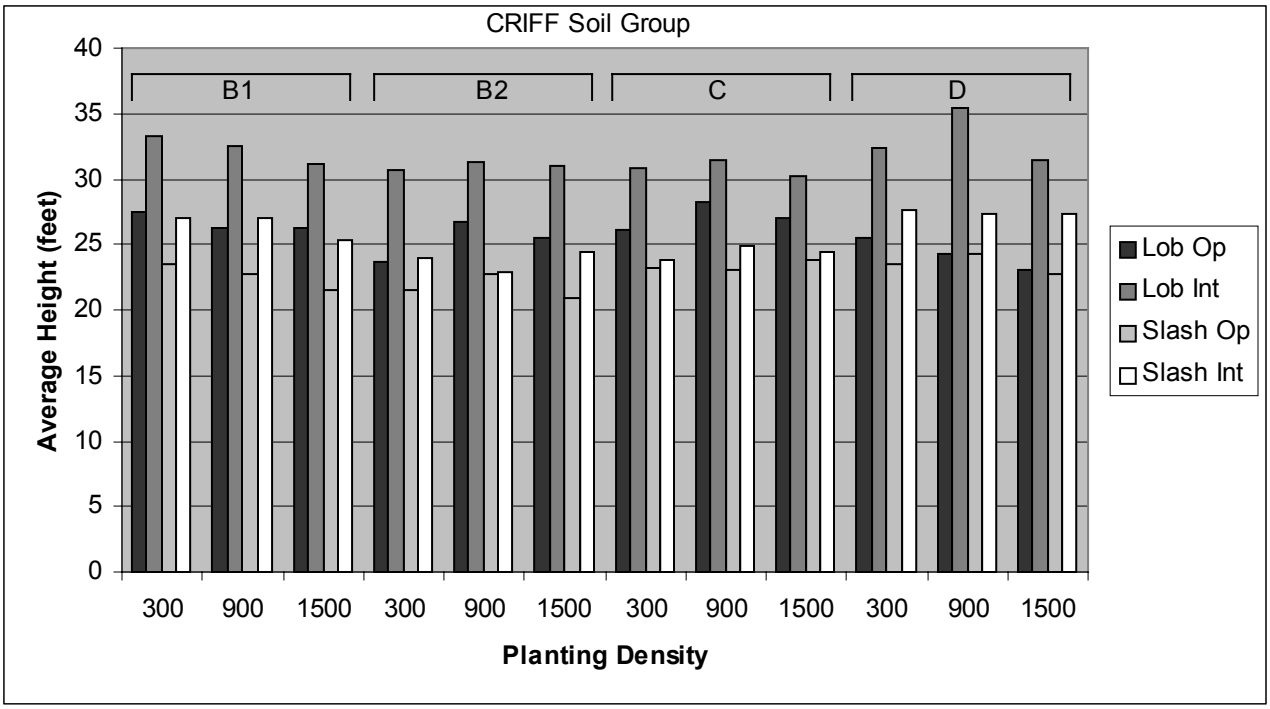

Figure 26. Average height by CRIFF soil group, species, management intensity and density at age six.

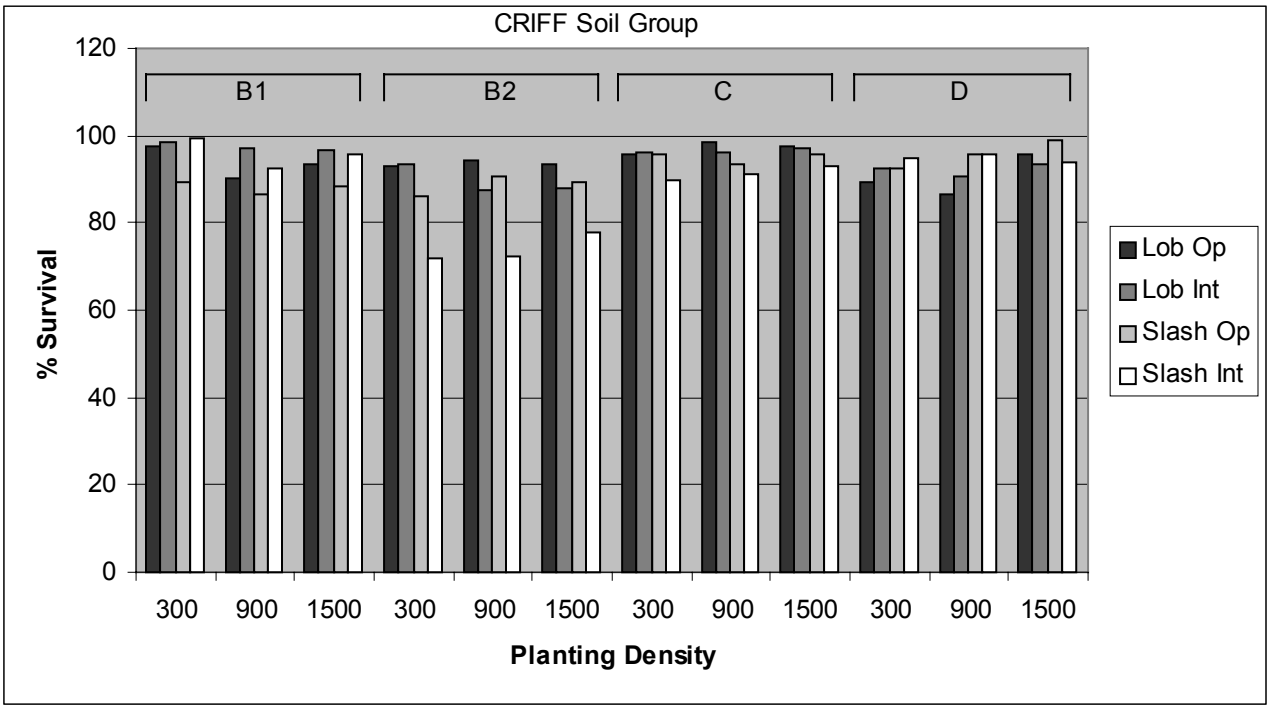

Figure 27. Average percent survival by CRIFF soil group, species, management intensity and density at age six.

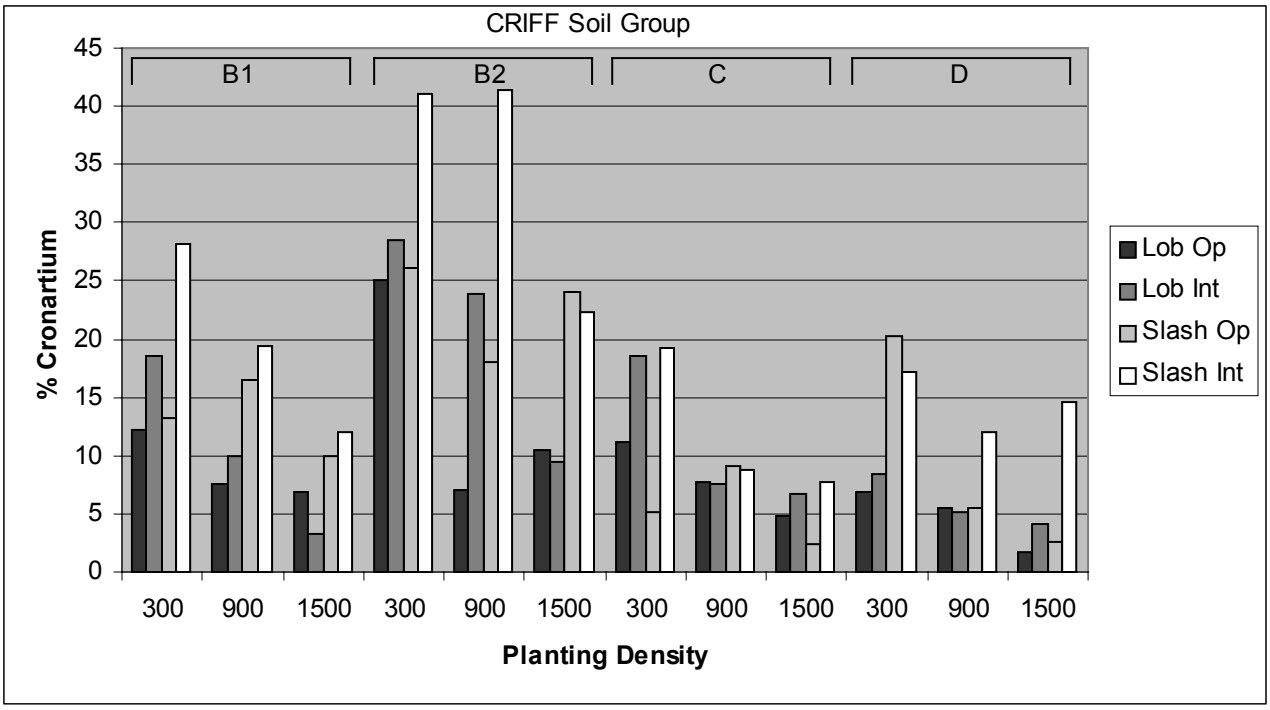

Figure 28. Average percent cronartium by CRIFF soil group, species, management intensity and density at age six.

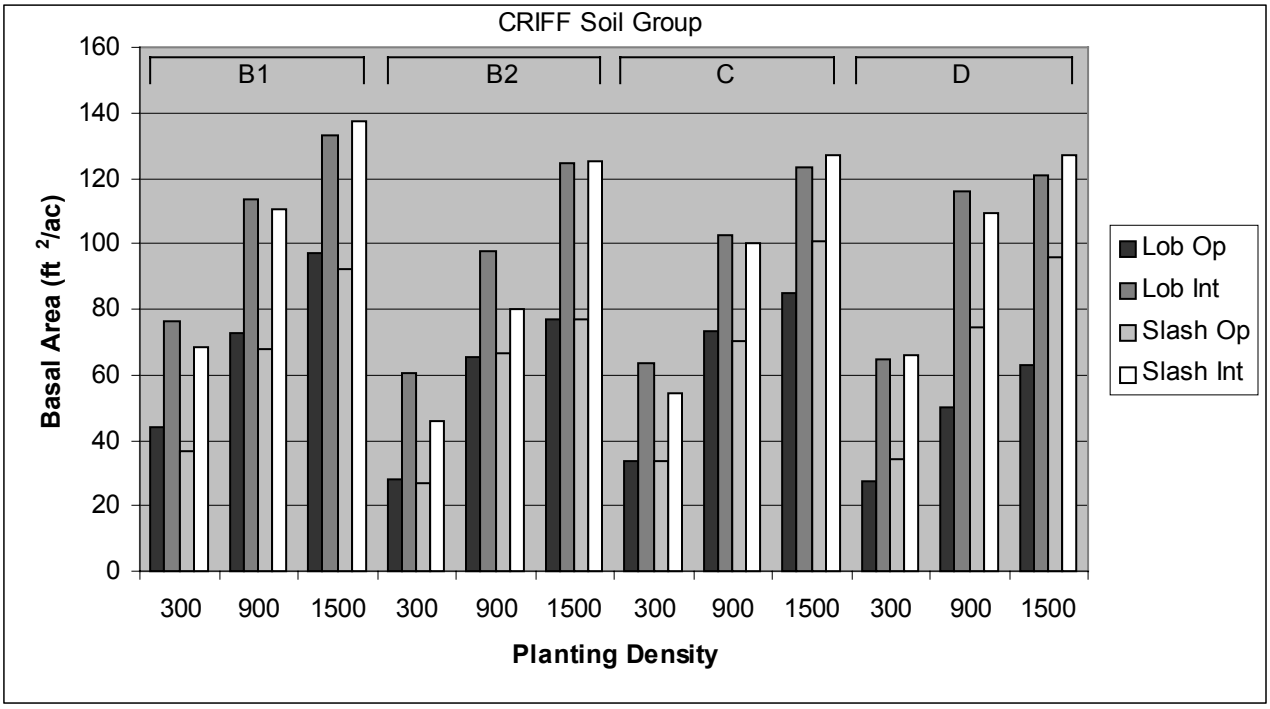

Figure 29. Per-acre basal area by CRIFF soil group, species, management intensity and density at age six.

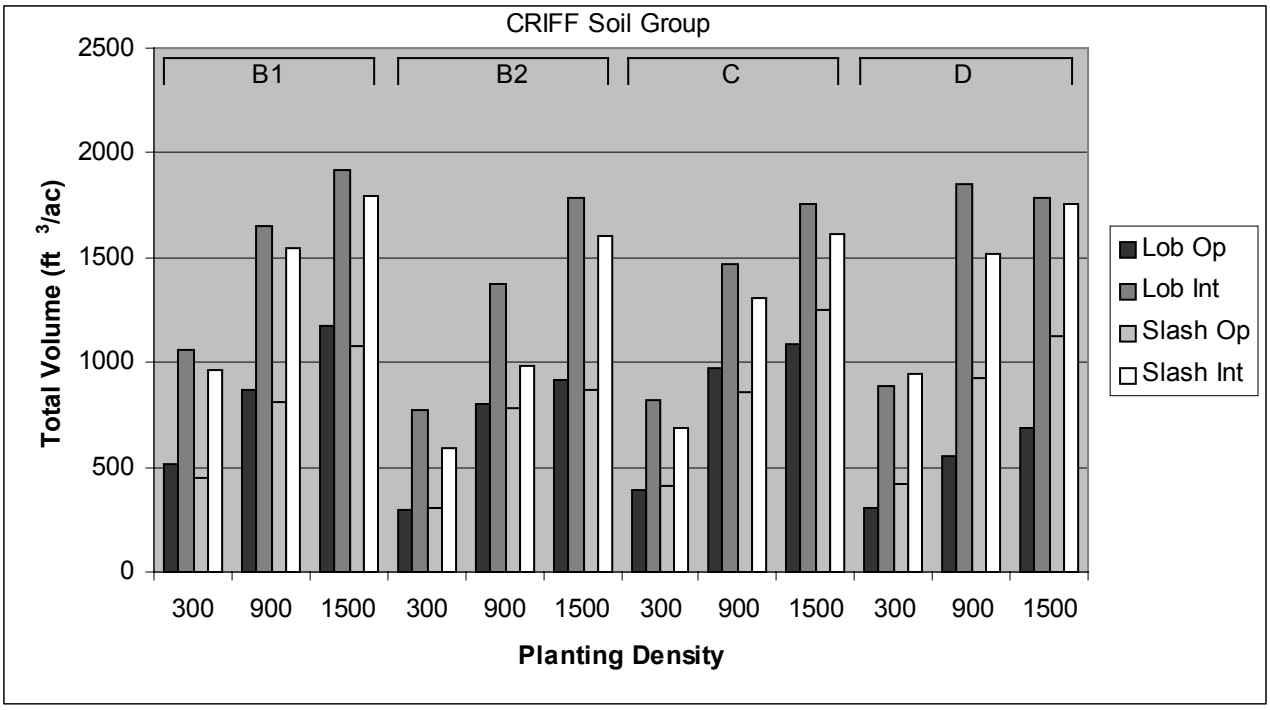

Figure 30. Per-acre o.b. volume by CRIFF soil group, species, management intensity and density at age six.

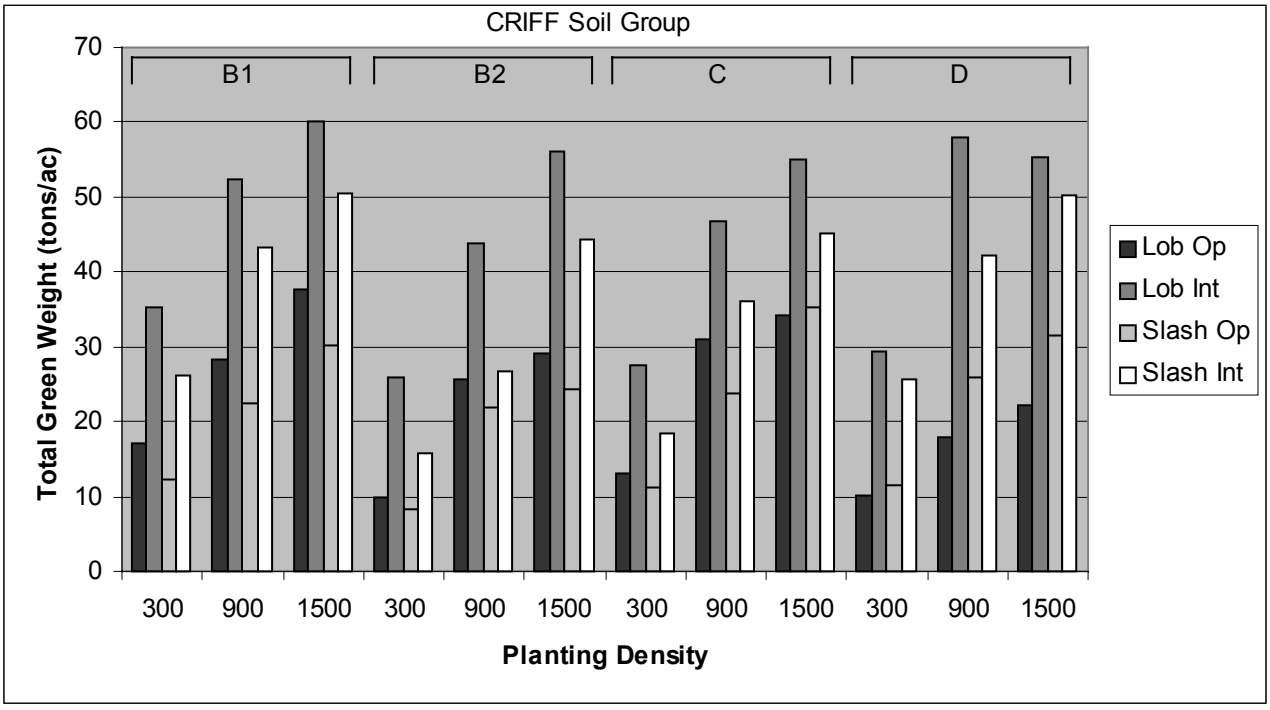

Figure 31. Per-acre o.b. green weight by CRIFF soil group, species, management intensity and density at age six.

6 DISCUSSION

The data reported on here are from 6-year-old plantations. Accelerated growth for both the operational and more intensive treatments has allowed the calculation of realistic per-acre basal areas and total volumes. 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 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 differences in average height between the operational and more intensive treatments are much more pronounced in slash pine. There is no discernable relationship between initial density and average height for either species.

On the negative side, more intensive management has increased mortality and the cronartium infection rate over the operational treatment. Increased mortality may be due to overspray of herbicide onto pine trees or increased inter-species competition due to accelerated growth. The relationship between increased growth and increased cronartium infection has been well documented so 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 slash pine also 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 nearly identical for slash and loblolly pine. Both quantities increased with increasing initial density. The more intensive management regime produced between 76 and 234 percent more basal area per acre and between 105 and 354 percent more total volume than the operational treatment. Slash pine outgrew loblolly pine in terms of per-acre basal area and total volume on the higher initial densities. Also, slash pine grew better for all treatments on the D soil group.

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