PMRC SAGS CULTURE / DENSITY STUDY:

AGE 4 ANALYSIS

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SUMMARY

The SAGS Intensive Culture / Density study was established in 1997/98 to examine the effects of intensive silviculture and current operational practices on the growth and yield of loblolly pine across a wide range of densities. The study was stratified across seven broad soil classes, four in the Piedmont and three in the upper coastal plain. Twenty-four installations were established in the Piedmont and upper coastal plain regions of Georgia and Alabama. Both the operational and intensive treatments included a chemical site preparation treatment. Any tillage treatments included in site preparation were carried out on all treatment plots. 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.

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. The arrangement of cultural treatments and planting densities results in a split plot design. The main plots 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 and green weight.

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. Only the management intensity factor had a significant effect on pine average height. There were no significant differences in survival due to any of the factors or interactions. Cronartium infection levels increased with management intensity and with decreasing density. The density factor and the density x management interaction significantly affected the cronartium infection rate. The trends for per-acre basal area, per-acre total stem volume and per-acre green weight were similar. The management intensity factor, the density factor and their interaction had significant effects on these per-acre values.

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1 INTRODUCTION

Industrial forest landowners in the Southeastern U.S. have experienced increasing pressure to maximize volume production from 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 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 SAGS Intensive Culture / Density Study in 1997/98. 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 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

Twenty-four installations were established in the Piedmont and upper coastal plain regions of Georgia and Alabama. The study was stratified over seven broad soil classes, four in the Piedmont and three in the upper coastal plain. Tables 1 and 2 show the soil characteristics used to classify the soils.

Table 1. Soil groups used in the SAGS Culture / Density Study plots in the Piedmont.

Subsoil Parent Material	Topsoil Depth
Montmorillonite / Mixed Clay	< 3 inches
Montmorillonite / Mixed Clay	> 3 inches
Kaolinite	< 3 inches
Kaolinite	> 3 inches

Table 2. Soil groups used in the SAGS Culture / Density Study plots in the upper coastal plain.

Drainage Class	Argillic Horizon Depth
Moderately well to well drained	< 20 inches
Moderately well to well drained	20-40 inches
Moderately well to well drained	> 40 inches

Site preparation and subsequent silvicultural treatments represent two levels of management intensity; operational and intensive culture. Both the operational and intensive plots received a chemical site preparation treatment. At planting, 500 lbs. of 10-10-10 fertilizer was applied. Any tillage treatments were also applied to all plots. During the early spring of the first growing season, the operational plots were sprayed with 4 oz./acre Oust in bands equal to ½ the row width to control herbaceous weeds. Directed spraying with non-soil active herbicides was permitted to control hardwoods on the operational plots.

The intensive cultural treatment plots received a broadcast application of 4 oz./acre Oust and directed spraying of Roundup and Garlon as needed to control all competing vegetation. In the fall of 1998, 12 oz./acre Arsenal was applied. The application of 500 lbs. of 10-10-10 fertilizer was repeated at age three on the intensive culture plots.

Within each site preparation treatment, six subplots with densities of 300, 600, 900, 1200, 1500 and 1800 trees per acre (tpa) were planted. To ensure adequate first-year survival, trees were double-planted and reduced to a single surviving seedling after the first growing season. Table 3 shows the spacings and plot sizes for the density subplots.

Table 3. 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 cultural treatments and planting densities results in a split plot design. The main plots are cultural treatments and densities are 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). All factors containing installation were considered random and were listed in the RANDOM statement in SAS PROC MIXED (Littell et.al., 1996).

3 LOBLOLLY PINE RESULTS

After the fourth growing season, diameters of all trees and heights on every other tree were measured. Each tree was also inspected for cronartium infection and tip moth damage. Individual tree, outside bark cubic foot volumes and green weights with bark were calculated using the following equations from Pienaar, et al. (1987):

$$TVOB = 0.00401246\,DBH^{1.829011}\,HT^{0.969142}$$

$$GWWB = 0.110069\,DBH^{1.935455}\,HT^{1.080621}$$

No attempt was made to estimate merchantable volumes and weights at this early age.

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

Table 4. Loblolly pine means by management intensity and initial density at age four.

Management	Plant Density	Avg. DBH	Avg. Height	% Surv	% Cron	Basal Area/ac	Total Vol/ac	Total Wt/ac
Intensive	300	3.78	18.0	95.1	4.16	23.33	235	5
	600	3.39	17.9	96.6	2.72	38.47	395	9
	900	3.05	17.5	94.6	2.97	45.41	464	10
	1200	2.95	17.7	93.3	1.59	55.28	568	12
	1500	2.75	17.4	93.7	1.89	61.00	627	13
	1800	2.60	17.3	92.4	1.47	64.96	673	14
Operational	300	2.49	14.5	96.7	1.68	10.77	97	2
	600	2.29	14.4	92.9	2.10	17.60	162	3
	900	2.26	14.9	94.7	1.80	25.70	242	5
	1200	2.07	14.4	93.1	1.53	28.77	269	6
	1500	2.00	14.6	93.2	1.26	33.40	317	6
	1800	1.94	14.5	93.3	1.77	37.64	354	7

3.1 Average DBH

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

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

Source	df	Type III F	Pr > F
Management	1	120.01	0.0001*
Density	5	70.02	0.0001*
Management x Density	5	9.70	0.0001*

*Significant at α = 0.05.

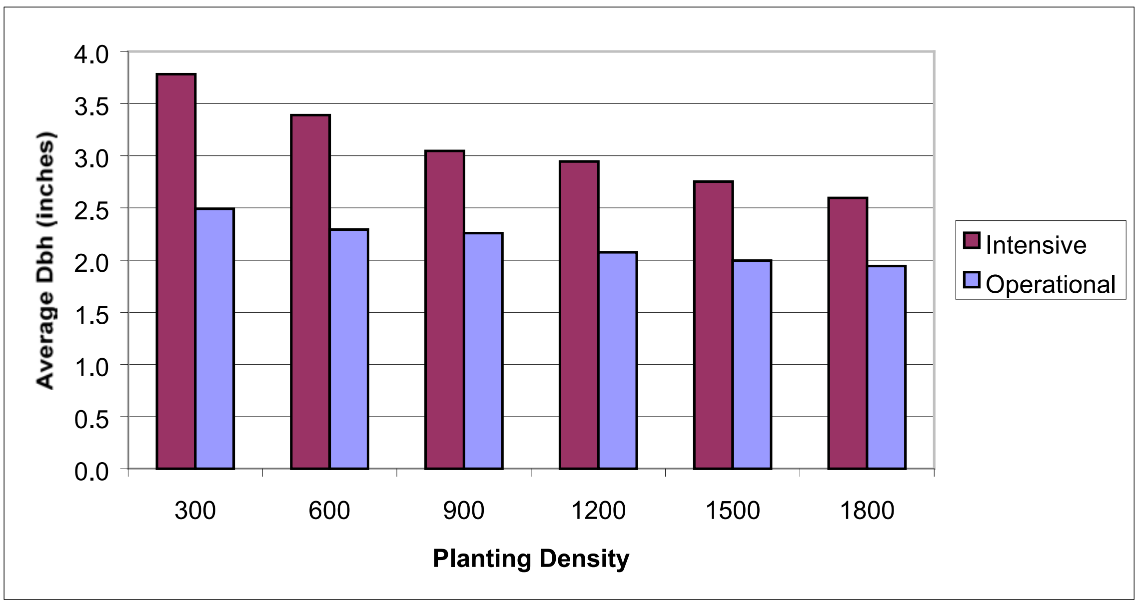

Figure 1. Average DBH by planting density and management intensity for loblolly pine at age four.

The analysis indicates that even as young as age four, 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. Also, the level of development means that the operational plots shade out competition at an ealy age at the higher densities. At low densities, this does not occur and the competition effect is shown in lower DBH values for 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 α = 0.05 level with the intensive culture treatment heights averaging three to four feet taller across the different densities. The density factor had no significant effect on average height, and there was no management intensity x density interaction. 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 four.

Source	df	Type III F	Pr > F
Management	1	57.70	0.0001*
Density	5	0.76	0.5794
Management x Density	5	1.47	0.2025

*Significant at α = 0.05.

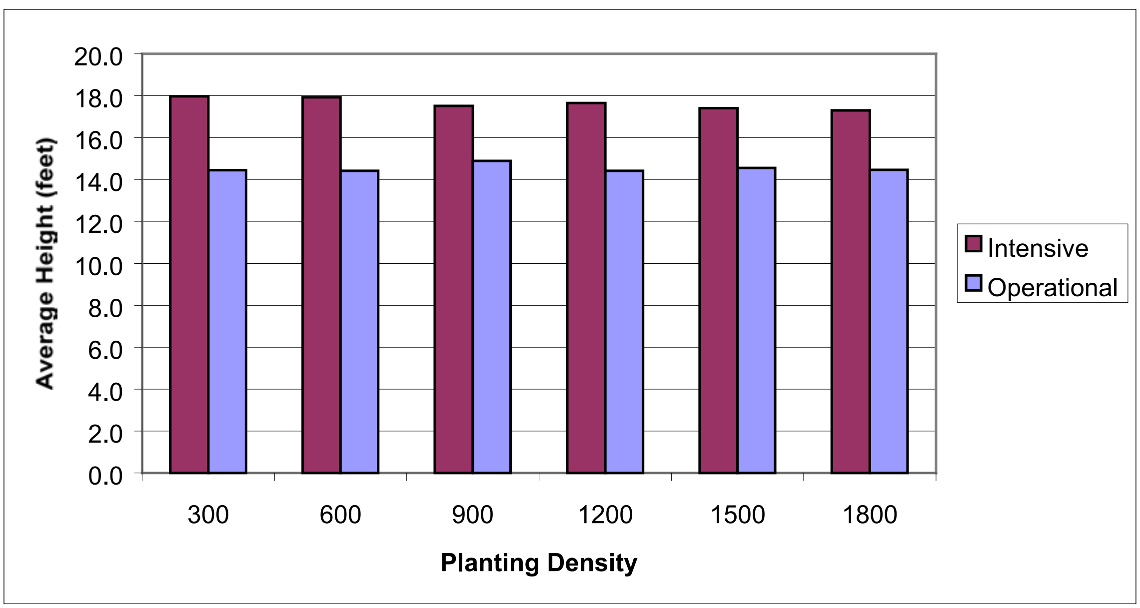

Figure 2. Average height by planting density and management intensity for loblolly pine at age four.

3.3 Percent Survival

Table 7 shows the results of the analysis of variance for average percent survival. Survival percentages were computed using the observed number of trees per acre at age four and the specified planting density that was imposed after the first growing season. Average survival by treatment was in excess of 94%. 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 four.

Source	df	Type III F	Pr > F
Management	1	0.06	0.8066
Density	5	1.19	0.3148
Management x Density	5	0.75	0.5859

*Significant at α = 0.05.

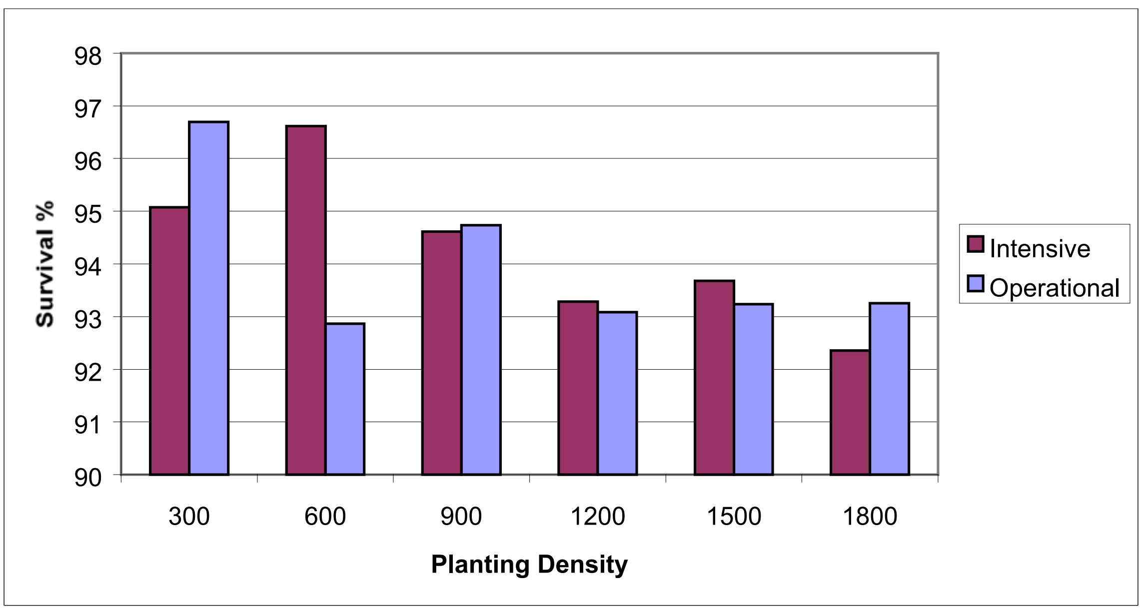

Figure 3. Percent survival by planting density and management intensity for loblolly pine at age four.

3.4 Percent Cronartium Infection

Table 8 shows the results of the analysis of variance for average percent cronartium infection. Average infection rates were very low, ranging from approximately 1.3 to 4.2% for all densities and management regimes. Management intensity was not significant but density and the management x density interaction significantly affected the cronartium infection rate. As shown in Figure 4, the intensive management treatment at initial densities of 300 and 900 trees/acre had the highest average infection rates. As indicated in previous studies of loblolly pine, treatments that tend to accelerate height and diameter growth also tend to increase the cronartium infection rate (Zutter *et al.,* 1987; Shiver and Harrison, 2000).

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

Source	df	Type III F	Pr > F
Management	1	3.46	0.0815
Density	5	3.88	0.0024*
Management x Density	5	2.83	0.0176*

*Significant at α = 0.05.

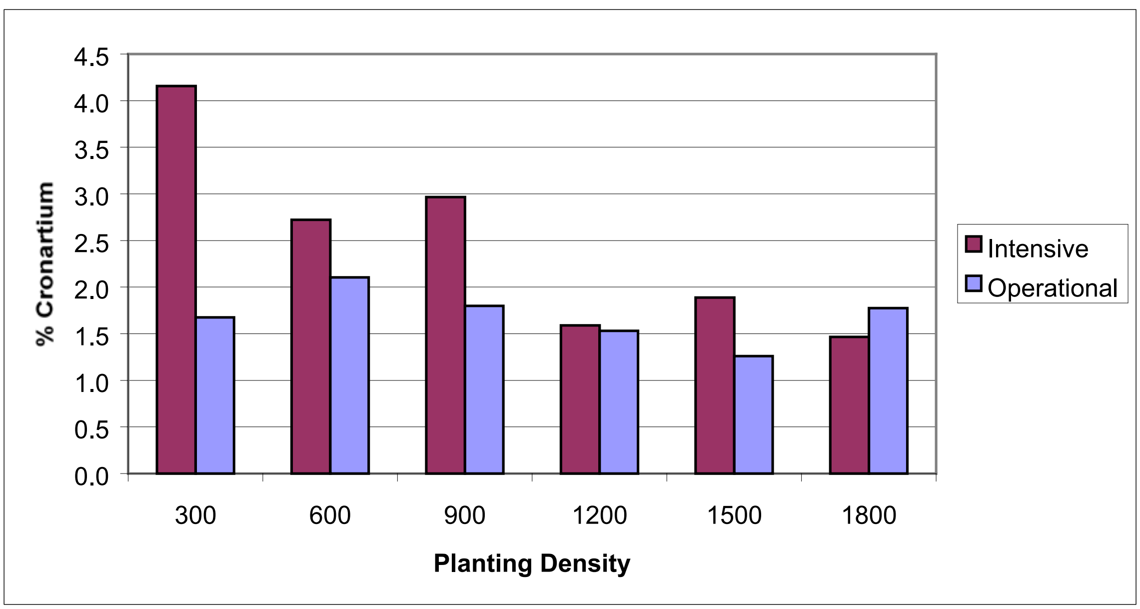

Figure 4. Average percent cronartium infection by planting density and management intensity for loblolly pine at age four.

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 of more (Figure 5).

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

Source	df	Type III F	Pr > F
Management	1	98.09	0.0001*
Density	5	142.05	0.0001*
Management x Density	5	7.62	0.0001*

*Significant at α = 0.05.

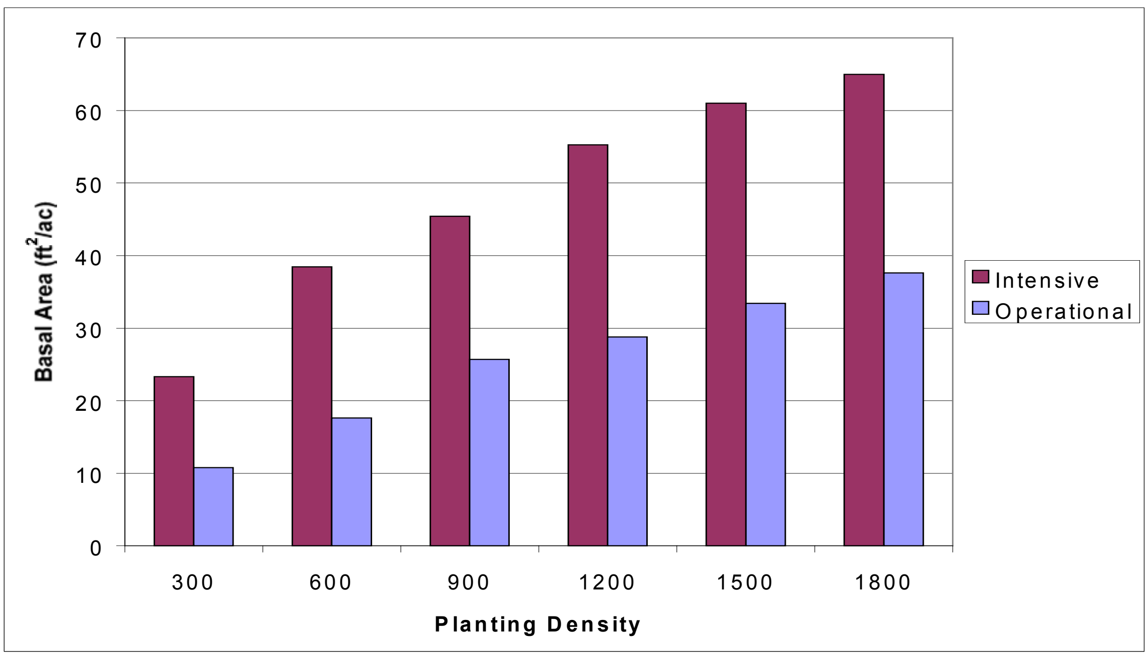

Figure 5. Average per-acre basal area by planting density and management intensity for loblolly pine at age four.

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 6). The intensive management treatments resulted in an average per-acre total volume more than twice that of the operational treatment. Total volume increased with increasing planting density.

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

Source	df	Type III F	Pr > F
Management	1	64.31	0.0001*
Density	5	92.13	0.0001*
Management x Density	5	6.71	0.0001*

*Significant at α = 0.05.

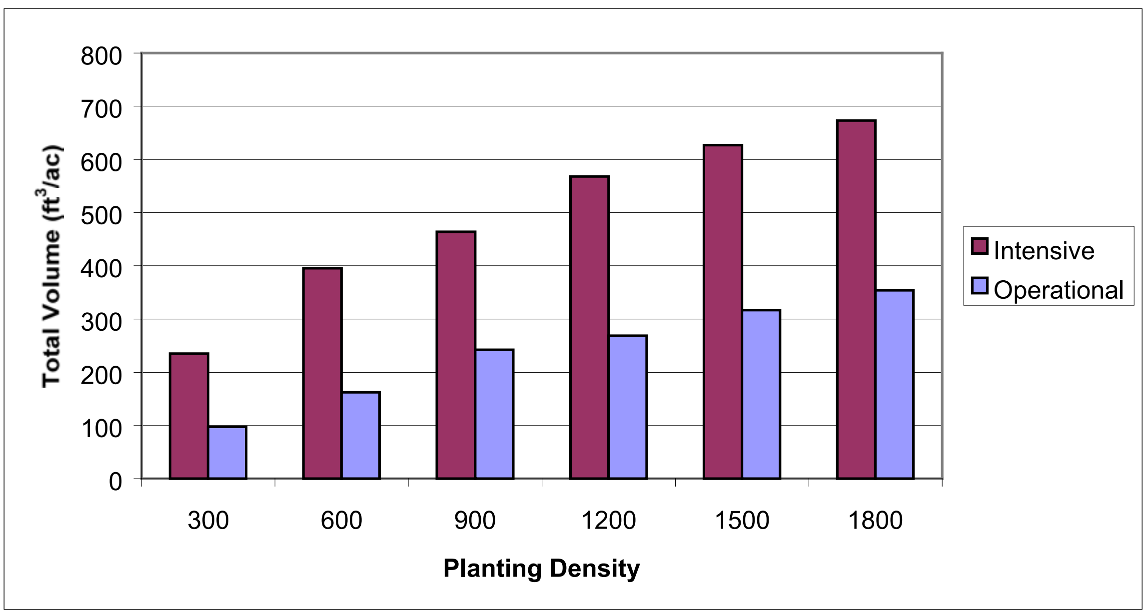

Figure 6. Average per-acre o.b. volume by planting density and management intensity for loblolly pine at age four.

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 total volume and basal area. Management, density and their interaction significantly affected per-acre green weight (Figure 7).

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

Source	df	Type III F	Pr > F
Management	1	59.41	0.0001*
Density	5	79.75	0.0001*
Management x Density	5	6.37	0.0001*

*Significant at $\alpha = 0.05$.

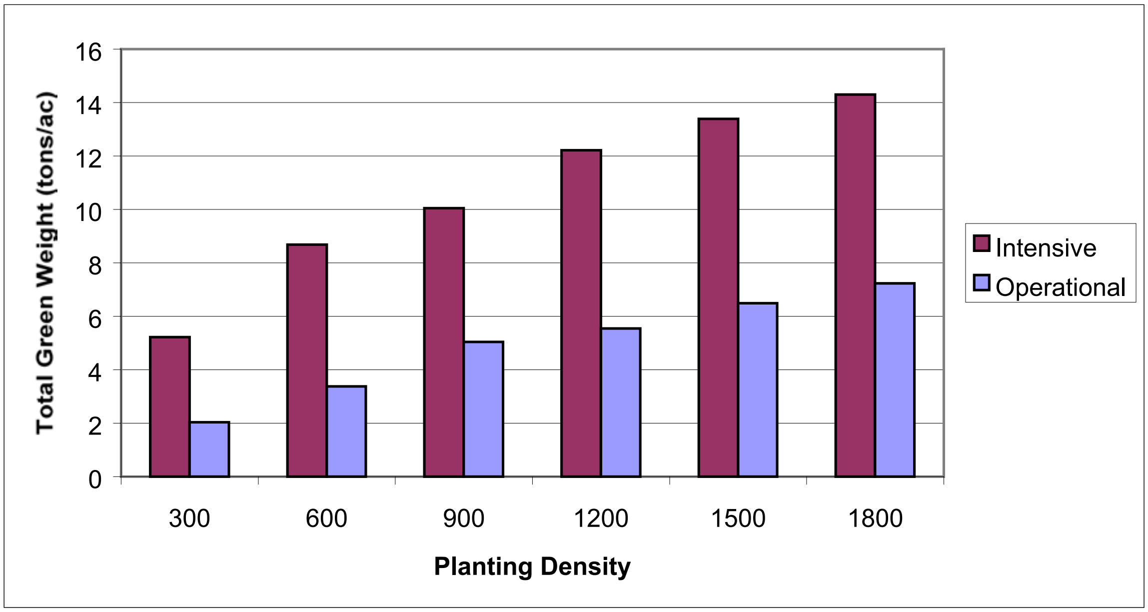

Figure 7. Average per-acre o.b. green weight by planting density and management intensity for loblolly pine at age four.

4 DISCUSSION

The data reported on here are from 4-year-old plantations. Accelerated growth for both the operational and more intensive treatments has allowed the calculation of realistic per-acre basal areas, green weights 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 and planting density.

As with numerous studies reported in the literature, more intensive management has resulted in larger average DBH's for all spacing treatments. 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. There is a hint of the relationship between average DBH and initial density on the operational treatment plots, but the relationship is already prominent under the more intensive regime.

More intensive management has significantly increased height growth at all spacing treatment levels. 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. Overall, infection rates were low.

Trends for per-acre basal area, green weight and total volume were nearly identical. All three quantities increased with increasing initial density. The more intensive management regime produced between 72 and 119 percent more basal area per acre, between 90 and 144 percent more total volume, and between 98 and 157 percent more green weight than the operational treatment.

5 LITERATURE CITED

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