PMRC SAGS CULTURE / DENSITY STUDY:

AGE 6 ANALYSIS

Plantation Management Research Cooperative
Daniel B. Warnell School of Forest Resources
University of Georgia

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Compiled by: B.D. Shiver and W.M. Harrison

EXECUTIVE 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 culture plots also received 600 lbs. Of 10-10-10 after the second growing season plus micronutrients plus 117 lbs. Of NH_4NO_3. At the beginning of the 4th growing season they received another 117 lbs of NH_4NO_3, and at the beginning of the 6th growing season they received 300 lbs of NH_4NO_3. The intensive cultural treatment plots received additional herbicide treatments to keep them as completely free of competing vegetation as possible throughout their rotation.

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

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. There was a larger gain in average dbh for 300 trees per acre for intensive management than for the higher initial densities.

Both the management intensity and the initial density had a significant effect on pine average height, but there was no interaction of these factors. There was a gain of 4-5 ft as a result of intensive management rather than operational management and there was a trend toward shorter average heights as density increased above 900 trees per acre for both operational and intensively managed plots. Average dominant height, defined as the average height of trees with above average dbh values, followed the same trends as average height of all trees.

There were no significant differences in survival due to management intensity, initial density, nor their interaction. Initial density was a significant factor for cronartium infection levels and there was a significant density x management interaction. For an initial density of 300 trees per acre the infection rate was the highest of all density-management combinations for intensively managed and the lowest of all combinations for operationally managed stands. Discounting the 300 trees per acre initial density there was a trend for infection rates to decrease as initial density increased for both intensive and operational managed plots.

Management intensity and initial density were significant factors for basal area, total volume per acre and total green weight per acre. Basal area per acre increased as initial density increased. Intensively managed plots had 25-30 ft^2/ac more basal area than operationally managed plots. Total stem volume outside bark also increased with increasing density and intensively managed plots had 500-600 ft^3/ac more wood at age eight than operationally managed plots. Total stem green weight outside bark increased with increasing density with intensively managed plots having 12-15 tons/ac more wood at age eight than operationally managed plots on average.

Stand density index (SDI) was calculated for each plot and averaged. Initial density and management were significant factors for the average stand density index value. The maximum value for loblolly pine is considered 450. As density increased the SDI increased for both intensive and operationally managed plots. The intensively managed plots were uniformly 50-75 units higher than the operationally managed plots on average. The intensively managed plots had values of about 300-350 for 1200 or more trees per acre.

For the other limiting density value calculated, density, management intensity, and the interaction of management intensity and density were significant variables for relative spacing. Relative spacing (RS), the average distance between trees assuming square spacing divided by the dominant height, normally decreases as stands develop and for loblolly pine approaches a lower asymptote of about 0.12. As density increases the relative spacing decreases for both operational and intensive management with operational RS always being larger for a given density. The interaction comes from a decreasing difference between RS values for the two management intensities as the density increases.

Stand development has been accelerated for both of these management intensities compared to the average management of the last 15-20 years. For intensively managed plots, the average across all installations for 1200 trees per acre and higher is about 120 ft^2/ac at age six. By comparison the operational with 600 trees per acre is only at 55 ft^2/ac and that is still almost 10 ft^2/ac/yr and would be considered excellent growth. Though these stands are only six years old they are quickly getting to a level of stand development where they can provide answers to planting density x management intensity questions that are key to improved plantation management as we change silviculture.

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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. The intensive culture plots also received 600 lbs. Of 10-10-10 after the second growing season plus micronutrients plus 117 lbs. of NH_4NO_3. At the beginning of the 4th growing season they received another 117 lbs of NH_4NO_3, and at the beginning of the 6th growing season they received 300 lbs of NH_4NO_3. Any tillage treatments were applied across both management intensities. 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.

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 (dbh) and total heights (ft) on every other tree were measured. Total heights of unmeasured trees were estimated using regression. 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):

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

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

where TVOB = total stem volume outside bark (o.b.) in ft^3,
GWWB = total stem green weight (o.b.) in lbs,
DBH = diameter at breast height (in), and
HT = total tree height (ft).

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, average dominant height, percent survival, percent cornartium infection, per-acre basal area, per-acre total volume, per-acre green weight, stand density index, and relative spacing. All tests of significance were made at the a = 0.05 level. 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 six.

Management	Plant Density	Avg. Dbh (in)	Avg. Height (ft)	Avg. Dom. Height (ft)	% Surv	% Cron	Basal Area/ac (ft^2/ac)	Total Vol/ac (ft^3/ac)	Total Wt/ac (tons/ac)
Intensive	300	6.4	28.1	29.2	94.7	6.2	67.2	925	23
	600	5.2	28.3	29.5	96.4	3.6	88.9	1300	31
	900	4.6	28.0	29.4	94.5	3.5	102.4	1508	36
	1200	4.3	27.8	29.2	92.9	2.0	115.7	1703	40
	1500	3.9	27.3	28.8	93.1	2.6	122.1	1797	42
	1800	3.7	26.9	28.4	91.6	2.1	126.7	1871	43
Operational	300	4.8	24.3	25.6	97.0	2.2	38.4	494	12
	600	4.2	24.0	25.4	93.1	3.5	56.1	731	17
	900	3.9	24.7	26.0	95.2	3.0	73.7	998	23
	1200	3.6	23.9	25.6	93.2	2.7	85.3	1129	26
	1500	3.3	23.7	25.3	93.1	2.2	89.6	1201	27
	1800	3.2	23.6	25.2	93.2	2.8	96.5	1301	29

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 as was density and there was also a significant management x density interaction. 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 six.

Source	Type III F	Pr > F
Management	101.26	<0.0001*
Density	349.00	<0.0001*
Management x Density	20.19	<0.0001*

*Significant at a = 0.05.

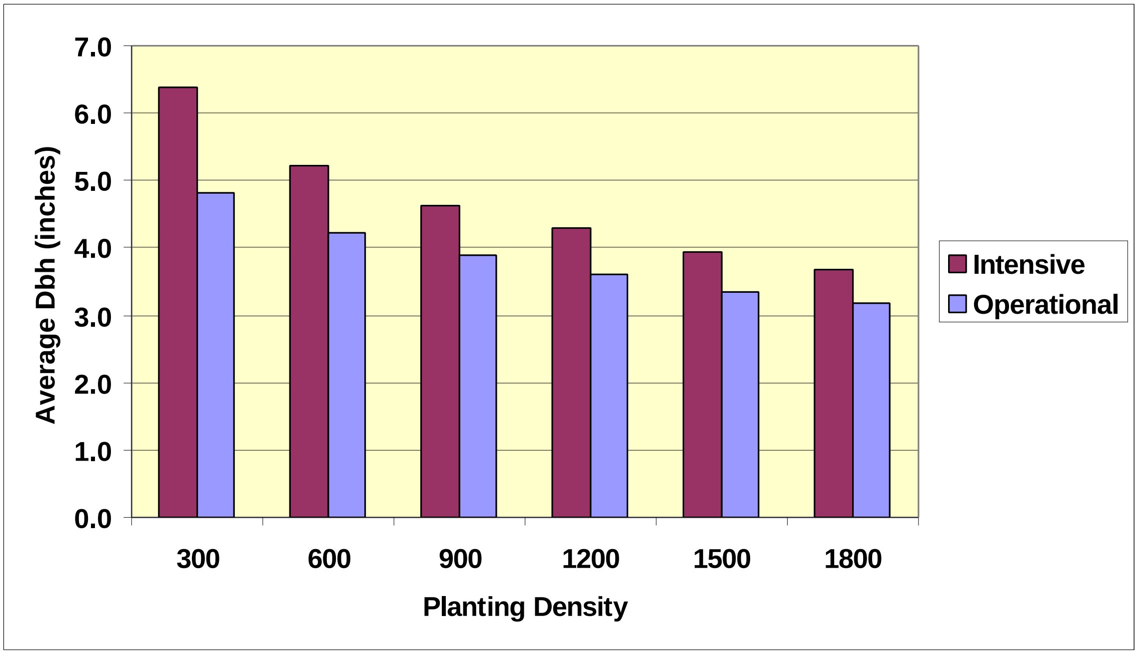

Figure 1. Average dbh by planting density and management intensity for loblolly pine at age six.

There is a consistent trend toward lower average dbh values as density increases for both intensive and operational management. At any density, the intensively managed plots had larger average dbh's than the operational plots. This interaction is probably caused by the increased level of stand development on the intensively managed plots resulting in a larger decrease in average dbh as density increases. While the same general trend is present on the operational plots, the differences in average dbh across the range of densities are much smaller. Also, the level of development means that the operational plots shade out competition at an early age at the higher densities and therefore grow more like the intensively managed plots. 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 a = 0.05 level with the intensive culture treatment heights averaging three to four feet taller across the different densities. The density factor was also significant, but there was no management intensity x density interaction. The density if significant due to consistently lower average heights at higher densities, but from a practical point of view it is only about a foot. Figure 2 shows the average heights by management intensity and initial density. Average dominant height was estimated by averaging the heights of all trees with dbh values greater than the average dbh on a plot. The analysis of variance also indicates that management intensity and density are significant at the 5% level of significance. Figure 3 shows the trends for average dominant height at age 6 by management intensity and density. Note that the trend of average dominant height is the same across densities for the operational and the intensive management plots.

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

Source	Type III F	Pr > F
Management	62.45	<0.0001*
Density	4.22	0.0013
Management x Density	0.91	0.4765

*Significant at a = 0.05.

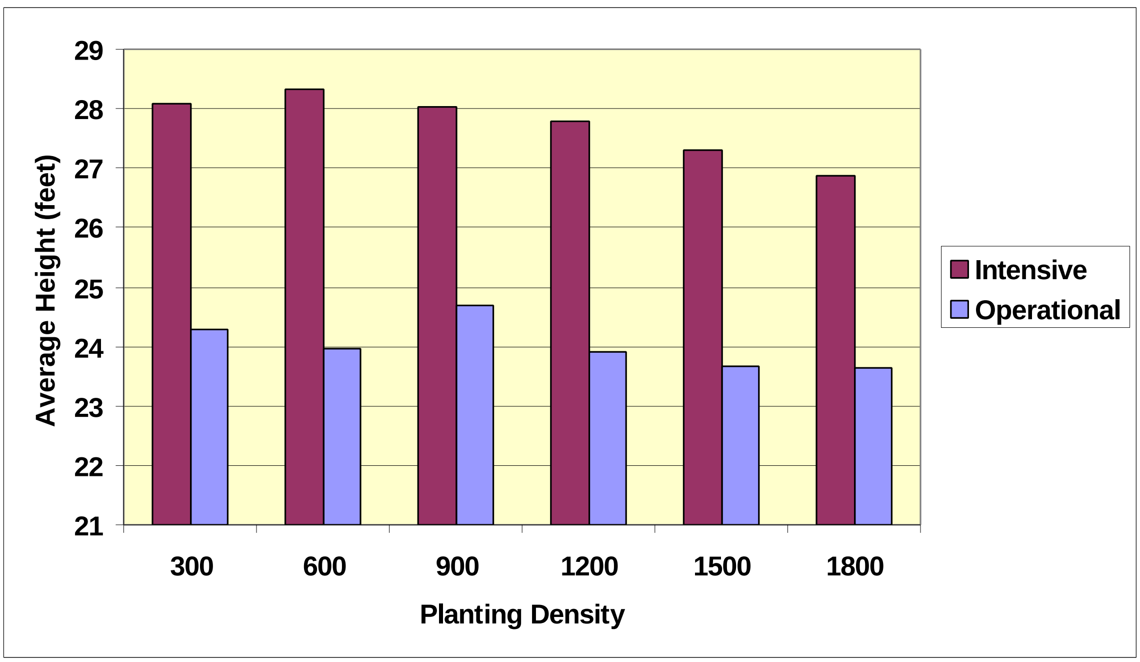

Figure 2. Average height by planting density and management intensity for loblolly pine at age six.

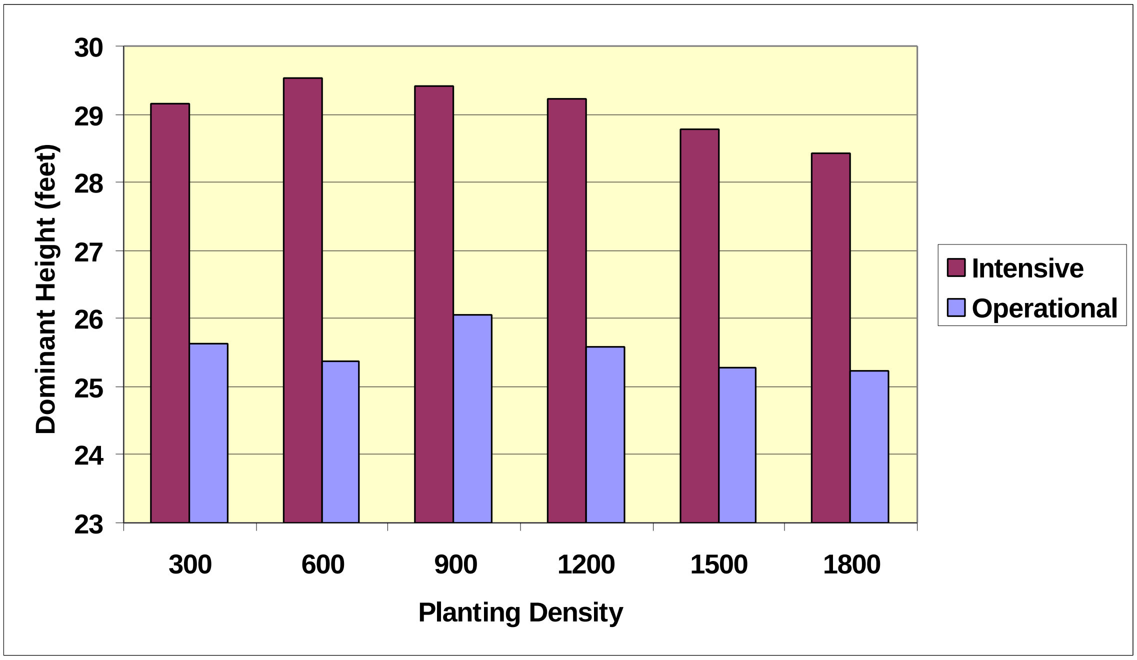

Figure 3. Average dominant height by planting density and management intensity for loblolly pine at age six.

3.3 Percent Survival

Table 7 shows the results of the analysis of variance for average percent survival. Survival percentages were computed using the observed number of trees per acre at age six and the specified planting density that was imposed after the first growing season. The lowest average survival, on the intensively managed 1800 trees per acre density, was over 91%. 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 six.

Source	Type III F	Pr > F
Management	0.04	0.8452
Density	1.60	0.1636
Management x Density	0.83	0.5317

*Significant at a = 0.05.

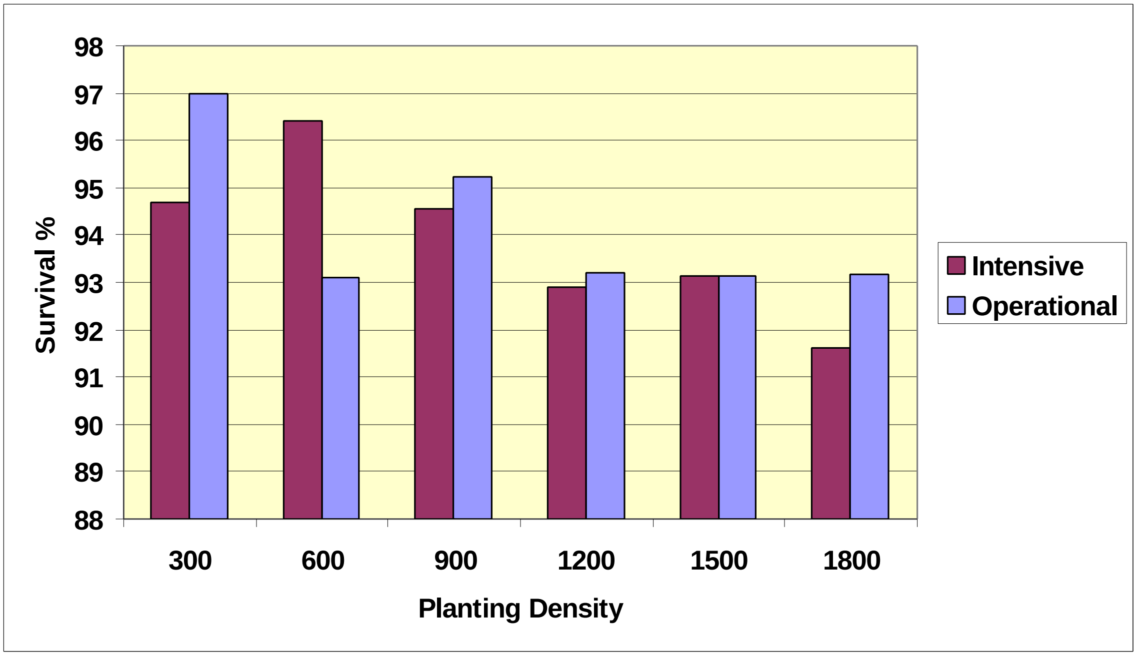

Figure 4. Percent survival by planting density and management intensity for loblolly pine at age six.

3.4 Percent Cronartium Infection

Table 8 shows the results of the analysis of variance for average percent cronartium infection. Average infection rates were very low, ranging from approximately 2.1 to 6.2% 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. There is a clear tendency for infection rate to decrease as density increases. As shown in Figure 5, the intensive management treatment at initial densities of 300 trees/acre had the highest average infection rates and the 300 density also had the largest difference between intensive and operational management. 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 six.

Source	Type III F	Pr > F
Management	0.92	0.3529
Density	3.62	0.0039*
Management x Density	4.97	0.0003*

*Significant at a = 0.05.

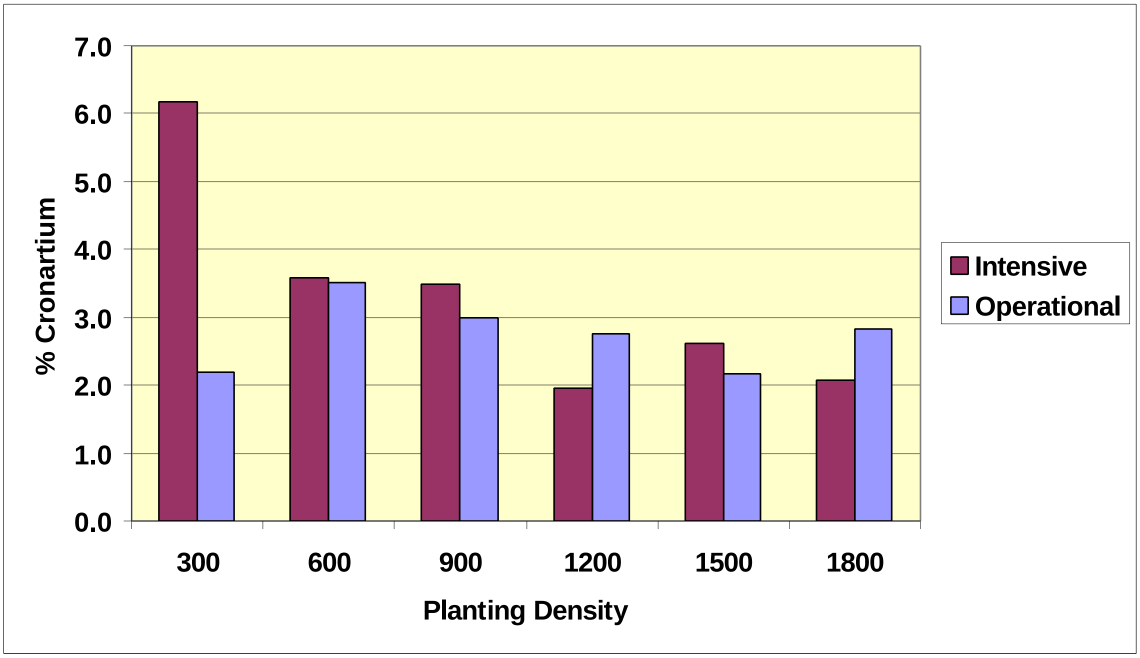

Figure 5. Average percent cronartium infection by planting density and management intensity for loblolly pine at age six.

3.5 Per-Acre Basal Area

Table 9 shows the results of the analysis of variance for per-acre basal area. Management intensity and density were significant factors for per-acre basal area. Basal area increased with increasing density and the gain for intensive management compared to operational management was very consistent across densities (Figure 6). The densities of 1200 to 1800 trees per acre have 115 to 125 ft^2/ac basal area on the intensively managed plots. Gains for intensive management above operational average about 30 ft^2/ac.

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

Source	Type III F	Pr > F
Management	102.88	<0.0001*
Density	155.06	<0.0001*
Management x Density	0.24	0.9449*

*Significant at a = 0.05.

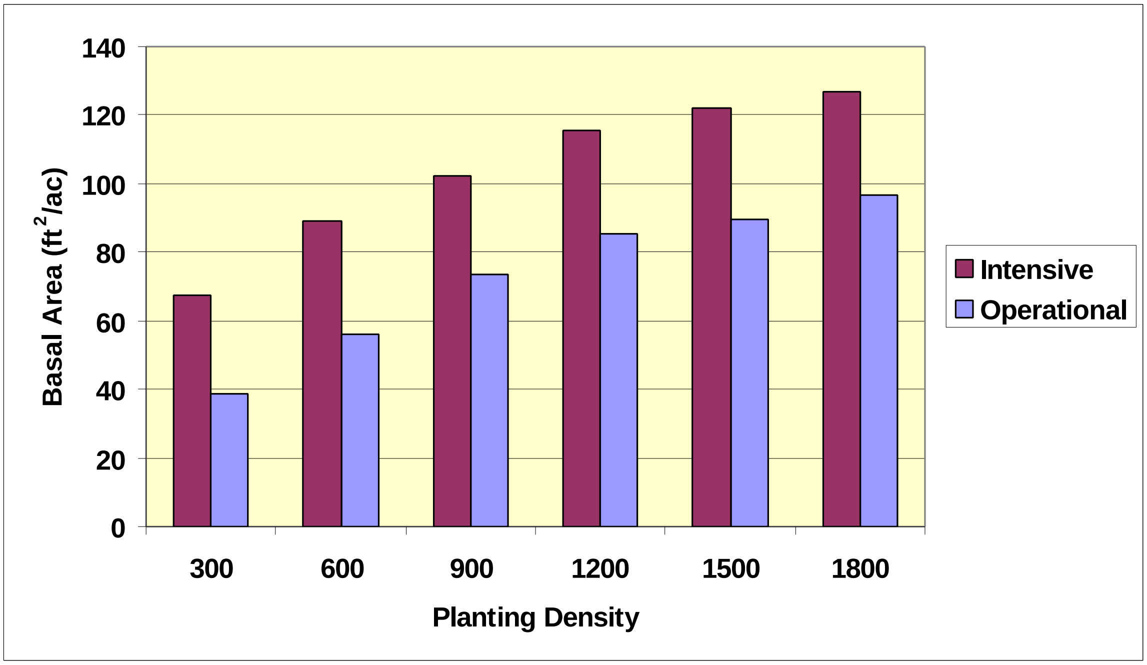

Figure 6. Average per-acre basal area by planting density and management intensity for loblolly pine at age six.

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 and density significantly affected per-acre volume (Figure 7). Total volume increased with increasing planting density. The intensive management treatments resulted in an average per-acre total volume of 400 to 600 ft^3/ac more than that of the operational treatment. Average volumes on the intensively managed plots on initial densities of 1200 to 1800 averaged 1750 to 1850 ft^3/ac. Depending on the conversion factor this is about 3.5 to 4 cords/ac/yr.

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

Source	Type III F	Pr > F
Management	78.79	<0.0001*
Density	120.23	<0.0001*
Management x Density	1.02	0.4080

*Significant at a = 0.05.

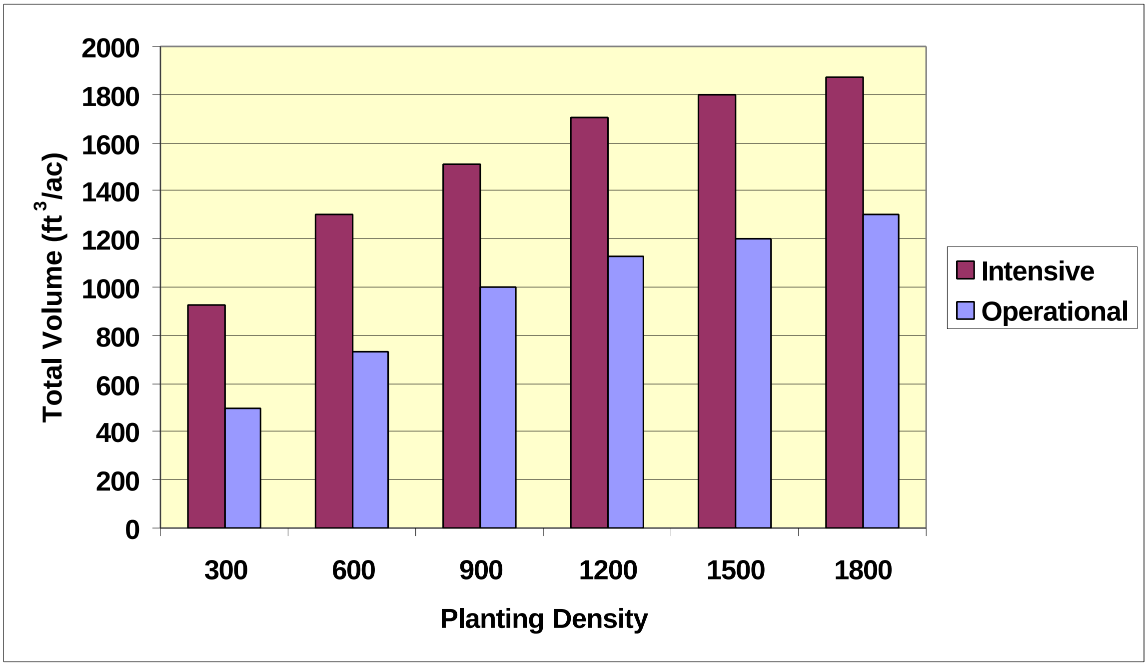

Figure 7. Average per-acre o.b. volume by planting density and management intensity for loblolly pine at age six.

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 total volume and basal area. Management and density significantly affected per-acre green weight (Figure 8). Total green weight per acre increased with increasing density for both operational and intensive management. The gain from intensive management over operational management was consistently 12-14 tons/ac over all initial densities. The 1200 to 1800 intensive management plots averaged 40-43 tons/ac at age six.

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

Source	Type III F	Pr > F
Management	74.61	<0.0001*
Density	89.59	<0.0001*
Management x Density	0.67	0.6501

*Significant at a = 0.05.

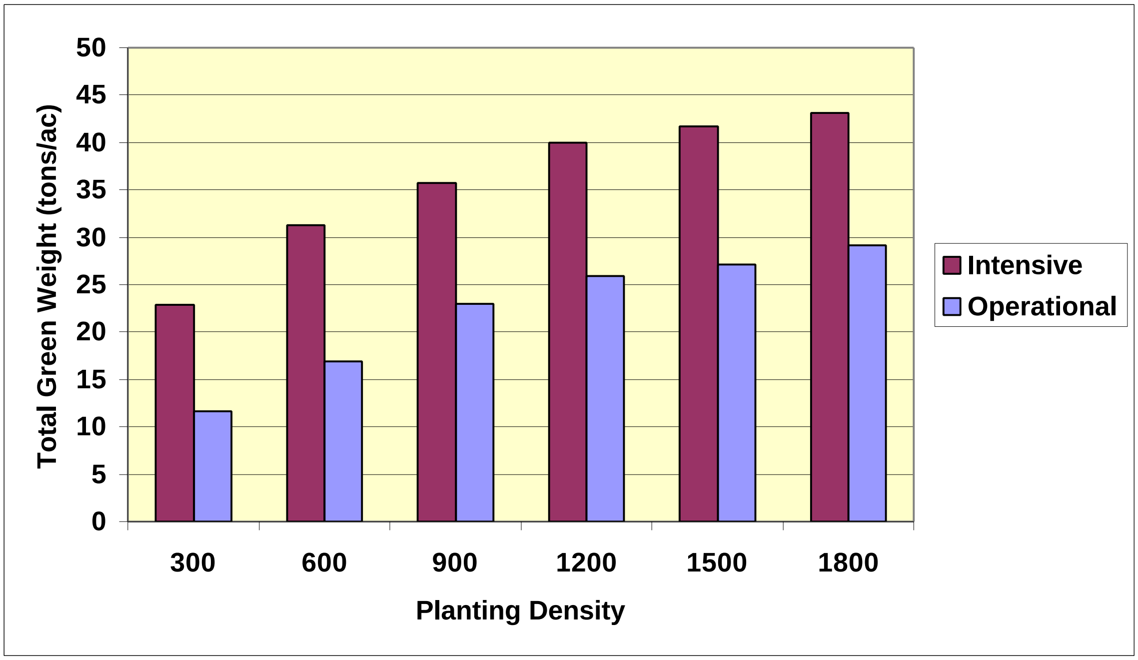

Figure 8. Average per-acre o.b. green weight by planting density and management intensity for loblolly pine at age six.

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 and density were significant factors for SDI (Figure 9). 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 60-75 SDI unit increase across density.

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

Source	Type III F	Pr > F
Management	103.88	<0.0001*
Density	311.92	<0.0001*
Management x Density	0.72	0.6123

*Significant at a = 0.05.

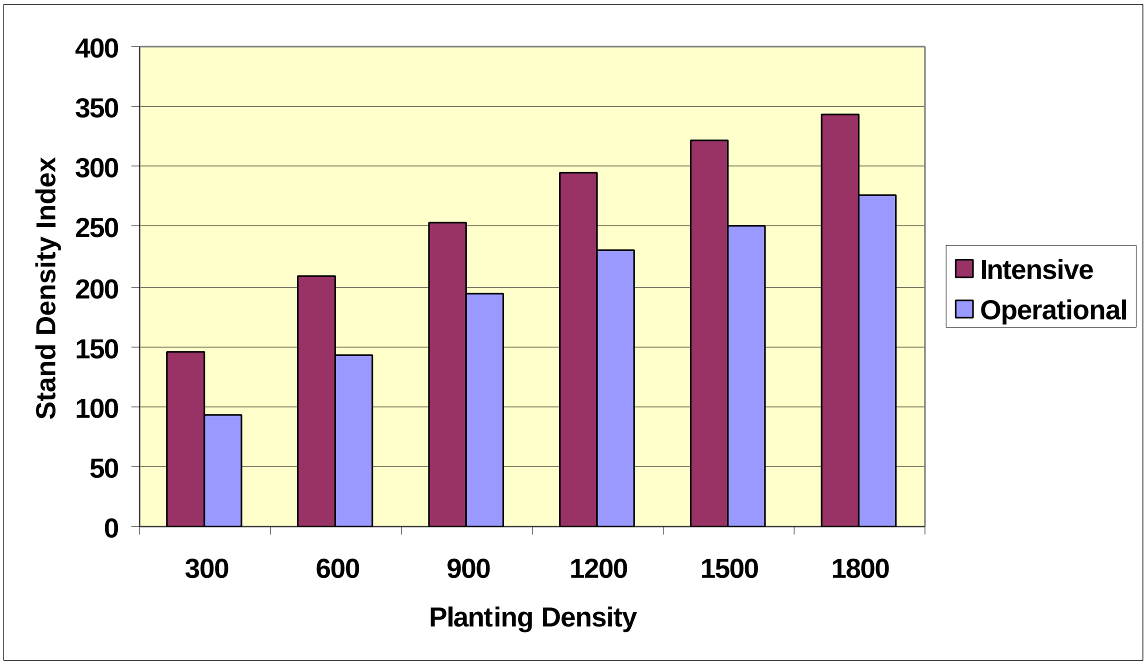

Figure 9. Average stand density index by planting density and management intensity for loblolly pine at age six.

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, management intensity, and their interaction were significant factors for RS. A plot of RS across initial densities and management intensities shows that RS decreases as initial density increases, that intensively managed stands have lower RS than operational stands for the same initial density, and that there is less difference between operational and intensively managed stands at high densities than at lower densities (Figure 9). Even so, none of the plots is at age six approaching the lower asymptote.

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

Source	Type III F	Pr > F
Management	39.59	<0.0001*
Density	522.28	<0.0001*
Management x Density	3.55	0.0046*

*Significant at a = 0.05.

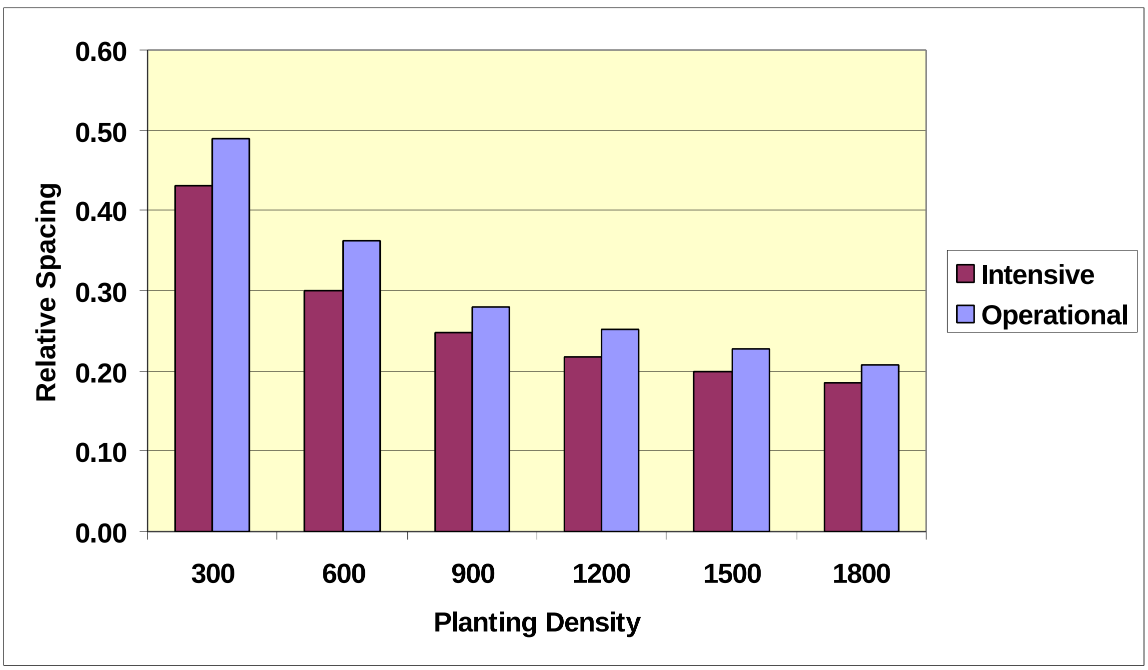

Figure 10. Average relative spacing by planting density and management intensity for loblolly pine at age six.

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4 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, 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 are larger differences between average dbh between intensive and operational treatments at lower initial densities than at higher densities.

More intensive management has significantly increased height growth at all spacing treatment levels. There is a relationship between initial density and both average height and dominant height with average heights being lower for higher initial densities beginning at about 1200 trees per acre.

On the negative side, more intensive management increased the cronartium infection rate over the operational treatment on the 300 trees per acre initial density. The relationship between increased growth and increased cronartium infection has been well documented so does not come as a surprise in this study. Perhaps more of a surprise is the trend of lower infection rates at higher initial densities. 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 added about 30 ft^2 more basal area per acre, between 400 and 600 ft^3/ac more total volume, and between 12 and 14 tons/ac more green weight than the operational treatment.

Stand density index was affected by density and management intensity. None of the treatments is yet approaching the maximum value expected for loblolly pine, but the values for age 6 stands are very high for the combination of intensive management and high initial density.

Relative spacing was also calculated and there is a significant management intensity and initial density interaction. Differences in relative spacing between management intensities are higher at lower initial densities than at higher densities. No treatment is near the expected asymptote for loblolly pine at age six.

These plots cover a range of soils and the analysis for the next measurement will include soil group as a factor.

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