IMPACT OF CULTURAL TREATMENTS AND PLANTING DENSITY ON BRANCH CHARACTERISTICS OF LOBLOLLY PINE AT SEVEN AND EIGHT YEARS OF AGE

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EXECUTIVE SUMMARY

The effect of planting density and management intensity factors on loblolly pine branch development at different heights along the stem was examined at thirteen installations of the Plantation Management Research Cooperative's Lower Coastal Plain and Upper Coastal Plain Piedmont culture x density studies. Six 8-year-old installations in the Lower Coastal Plain of Georgia and Florida and seven 7-year-old installations in the Piedmont and Upper Coastal Plain of Georgia and Alabama were evaluated.

Site preparation and subsequent silvicultural treatment regimes were designed to represent two levels of management intensity; current operational practices and intensive culture. The operational treatment consisted of bedding in the spring followed by a fall herbicide treatment applied in 5-foot bands over the rows. At planting, 500 lbs. of 10-10-10 fertilizer were applied and 200 lbs of elemental N and 25 lbs of elemental P were applied in the spring of the eighth growing season. The intensive cultural treatment consisted of bedding in the spring followed by a broadcast herbicide application in the fall. The intensive cultural treatment plots received additional herbicide treatments to keep them as completely free of competing vegetation as possible throughout their rotation. Insecticides designed to control tip moths were applied as often as necessary to maintain tip moth control through the first two growing seasons. 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 NH4NO3. An additional 117 lbs/ac NH4NO3 was applied in the spring of the fourth growing season, 300 lbs/ac NH4NO3 was added in the spring of the sixth growing season, and 200 lbs of elemental N and 25 lbs of elemental P were applied in the spring of the eighth growing season.

Within both the intensive and operational treatments, six loblolly pine subplots with densities of 300, 600, 900, 1200, 1500 and 1800 trees per acre (tpa) were randomly located and established. The arrangement of cultural treatments and planting densities results in a split plot experimental design. The main plots are cultural treatments while planting densities are the 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.

Branch characteristics were measured on four to five randomly selected trees on each plot of the 12 management – planting density combinations per installation. For each tree, branches in the lower 24 feet of stem were characterized. The lower third of the sampled section was defined as from ground level to 8 feet, the mid-third was from 8.1 to 16 feet, and the upper third was from 16.1 to 24 feet. The analysis was carried out for average diameter at the base of branches, average branch basal area per tree, average branch length, average branch angle to the stem, total number of branches per tree, total number of dead branches per tree, and total

number of live branches per tree. ANOVAs were conducted for the previous variables for the different sections of the stem. Within each section, all the treatment combinations means were compared using Tukey's studentized multiple comparison tests.

The density factor had a statistically significant effect on average diameter at the base of branches in all sections of the stem. There was a consistent trend toward smaller branch diameter values as densities increased for both intensive and operational management. The branch diameter for the lower 24 ft of the stem decreased on average 6.1 mm when the planting density increased from 300 tpa to 1800 tpa. The management factor had a significant effect on average branch diameter on the lower and mid sections of the stem. The branch diameter for intensive management was on average 2 mm more than for operational management. There was also a significant interaction between management and density for branch diameter in the lower section of the stem. There were no significant differences in branch diameter among the three higher planting densities (1200, 1500, and 1800 tpa) within, and between, management regimes. The average branch diameter increased toward the upper sections of the stem for both management regimes.

Average branch basal area per section of the tree followed the same trends as average branch diameter. The density factor had a statistically significant effect on average branch basal area across all sections of the stem. There was a consistent trend toward lower branch basal area values as densities increased for both intensive and operational management. The branch basal area for the lower 24 ft of the stem decreased on average 250 cm^2 when the planting density increased from 300 tpa to 1800 tpa. The management factor had a significant effect on average branch basal area on the lower and mid sections of the stem. The branch basal area per tree on the intensive management was on average 49 cm^2 more than on the operational management. There was also a significant interaction between management and density for branch basal area on the lower and mid sections of the stem. There were no significant differences in branch basal area among the three higher planting densities (1200, 1500, and 1800 tpa) within and between management regimes. The average branch basal area increased toward the upper sections of the stem for both management regimes.

Both the planting density and the management intensity had a significant effect on branch length, but there was no interaction of these factors for the lower 24 ft of the stem. There was a consistent trend toward shorter branches as densities increased for both intensive and operational management. The branch length for the lower 24 ft of the stem decreased on average 1.12 ft when the planting density increased from 300 tpa to 1800 tpa. The management factor had a significant effect on average branch length on all sections of the stem. The branch length on the intensive management was on average 0.74 ft larger than on the operational management. There were no significant differences in branch length among the four higher planting densities (900, 1200, 1500, and 1800 tpa) within, and between,

management regimes. The average branch length increased toward the upper sections of the stem for both management regimes.

The angle of branches from vertical on the lower 24 ft of the stem became more acute with increasing stockings. Across all crown positions, there was a consistent trend toward smaller angles as density increased for both intensive and operational management. The branch angle decreased on average 6º when the planting density increased from 300 tpa to 1800 tpa. The management intensity factor had no significant effect on the branch angle. The average angle of branches decreased toward the upper sections of the stem for both management regimes.

There were no significant differences in the total number of branches per tree due to management intensity, initial density, nor their interaction for all sections of the stem. The total number of branches increased towards the upper two sections of the stem.

The initial planting density factor had a significant effect on the average number of live branches per tree in the lower 24 ft of the stem. There was a decline in the number of live branches as densities increased for both intensive and operational management. The number of live branches for the lower 24 ft of the stem decreased on average 14 units when the planting density increased from 300 tpa to 1800 tpa. The management factor had a significant effect on the number of live branches only in the Lower Coastal Plain. The operationally managed plots had on average 10 live branches more per tree than the intensively managed ones. The average number of live branches per tree increased toward the upper sections of the stem for both management regimes.

The number of dead branches per tree in the lower 24 ft of the stem was significantly affected by planting density. As planting density increased from 300 to 1800 tpa, the average number of dead branches per tree increased by 11 units. The management factor had a significant effect on the number of dead branches only in the Piedmont/Upper Coastal Plain. The intensively managed plots had on average 5 dead branches more per tree than the operationally managed ones. The average number of dead branches per tree decreased toward the upper sections of the stem for both management regimes.

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1. INTRODUCTION

Over the past 30 years intensive pine plantation management has been studied and developed in the southeastern U.S. Intensive management makes use of genetically improved planting stock and cultural treatments such as chemical-mechanical site preparation, herbaceous weed control, fertilization, tip moth control and possibly other activities to increase productivity on both industry and non-industry owned timberlands. A great deal of knowledge has been accumulated concerning the efficient use of these cultural treatments for increasing productivity on a wide range of sites (Pienaar and Shiver 1993; Borders and Bailey, 2001; Shiver and Martin, 2002; Borders et al., 2004; Martin and Jokela, 2004; Jokela et al., 2004). However, the impact that these treatments have on the quality of logs and wood within logs has been only recently being studied (Faust et al., 1999; Mora, 2003; Clark et al., 2004; Trincado, G., 2006; Will et al., 2006).

Branch growth is critical to both quality and quantity of timber produced from plantations (Clark and Saucier, 1989). The size and vitality status (live or dead) of branches influence the development and persistence of knots and knot-related defects, which are an important cause of timber degrade in plantations (Alcorn et al., 2007). Reducing the number and size of knots is crucial for the production of high value timber. The angle at which branches are attached to the stem has a major influence on crown form as well as wood quality (Kantola and Mäkelä, 2004). Branch angle impacts the size of the knots projected on boards. Acute angled branches may be associated with the combined effects of reduced wood and foliage mass, reduced branch size, delayed branch ejection processes, and greater competition for light (Medhurst and Beadle, 2001).

Branches can be regarded as a population of individuals sharing a common environment subject to competition for resources (Umeki, 1995). Light availability is one of the resources differentially limited at different planting densities. Branches growing at lower stockings capture more light than those growing at higher stockings, allowing them to attain greater sizes and to provide extra resources for stem growth. Stand density can be an easily controllable silvicultural factor that regulates crown and branch characteristics (Mäkinen and Colin, 1998).

Most silvicultural treatments that have been found to be successful for increasing growth rates of southern pines are associated with increased crown and branch size as well as increased foliage biomass (Baldwin et al., 2000). As a consequence, there are a greater number of relatively large live branches on a tree grown under intensive management than on a tree grown under more extensive management. In addition, for loblolly pine the large live branches often do not prune at the tree stem once they die. Instead they leave branch stubs around which large loose knots form that greatly reduce lumber grade. Smaller branch diameters prune better and produce smaller knots. The ability to predict the impact of silvicultural practices on branch size and distribution and ultimately lumber quality

would be a valuable addition to our knowledge of how to better manage loblolly pine plantations for solid wood products.

Detailed studies of branch responses in loblolly pine to silvicultural treatments are lacking across a range of site conditions in the Southeast US.

In this study we quantify the impact that silvicultural activities and initial planting density have on crown and branch size distributions in two region-wide intensively managed loblolly pine study established by the Plantation Management Research Cooperative (PMRC) of the Warnell School of Forestry and Natural Resources.

The objectives of this report are to:

- Summarize branch measurement data to meaningful metrics per stem section and per tree (average branch diameter, average branch basal area per tree, average branch angle to the stem; average branch length; total number of branches; total number of dead and live branches).

- Evaluate all branch metrics by level of silvicultural activity, initial planting density and silvicultural intensity and planting density combinations.

2. METHODS

The data used in this study come from the PMRC Culture/Density plots. Six locations in the Lower Coastal Plain of Georgia and Florida, and seven locations in the Piedmont and Upper Coastal Plain regions of Georgia and Alabama were randomly selected, visited and measured for branch characteristics. Loblolly pine was 8 years old at the time of measurement in the Lower Coastal Plain and 7 years old in the Piedmont/Upper Coastal Plain.

This study has two levels of silvicultural management: operational (appropriate mechanical site preparation for each location, limited plantation establishment weed control application and appropriate operationally defined fertilization) and high-end intensive management (complete competition control, tip moth control and multiple fertilizations). Detailed descriptions of the study sites and silvicultural management treatments are reported by Harrison and Kane (2008) for the Lower Coastal Plain study and by Zhao et al. (2008) for the Piedmont Upper Coastal Plain study. The operational treatment in the Lower Coastal Plain consisted of bedding in the spring followed by a fall herbicide treatment. The herbicide treatment consisted of 12 oz. Arsenal (imazapyr) plus 1 qt. Garlon 4 (tryclopyr) per acre if competition was waxy-leafed species such as gallberry (*Ilex glabra*) or palmetto (*Serenoa repens*), or 12 oz. Arsenal plus 1 qt. Accord (glyphosate) 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 in the Lower Coastal Plain 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 were 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. Beginning in the spring of the first growing season, the plots were sprayed with 4 oz. Oust (sulfometuron methyl) per acre along with directed sprays of Accord to keep the plots as completely free of competing vegetation as possible. These plots also were sprayed for tip moth control during the first two growing seasons. Insecticides (usually Pounce (permethrin) designed to control tip moths were applied as often as necessary to maintain tip moth control. In the spring of the third growing season, the plots received 600 lbs/ac 10-10-10 plus micronutrients and 117 lbs/ac NH4NO3. An additional 117 lbs/ac NH4NO3 was applied in the spring of the fourth growing season, 300 lbs/ac NH4NO3 was added in the spring of the sixth growing season, and 200 lbs of elemental N and 25 lbs of elemental P were applied in the spring of the eighth growing season. The silvicultural regimes implemented on installations in the Upper Coastal Plain and Piedmont were similar to those identified above except that mechanical site preparation was prescribed on installation basis, the operational regime had a broadcast rather than banded pre-plant herbicide application, and for both regimes Garlon use was more limited.

Open pollinated, bare-root stock of the family 7-56 was planted at all installations in the Lower Coastal Plain. Each Cooperator selected genetic stock of high quality for use in installations in the Upper Coastal Plain and Piedmont.

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. Bed widths were 6 feet for the 1200-1800 tpa treatments, 8 feet for the 600 and 900 tpa plots and 12 feet for the 300 tpa treatment. To ensure the targeted initial density, each planting spot was double-planted and reduced to a single surviving seedling after the first growing season.

At each selected location all branches from the ground level up to 24 feet were measured on each of 4 or 5 randomly selected trees at age 8 in the Lower Coastal Plain and age 7 in the Upper Coastal Plain and Piedmont. Trees were measured for dbh (in), total tree height (ft.), height to base of live crown (ft.), diameter at the base of live crown (in.), number of branch whorls and height to each branch whorl (ft.), number of living and dead branches in each whorl, basal diameter of branches (in), length of branches (ft), and branch angle as its deviation from the stem. Branches were classified as being in one of three sections of the stem; the lower section from ground level to 8 feet, the mid-section from 8.1 to 16 feet, and the upper section from 16.1 to 24 feet. Field personnel used climbing ladders to take direct measurement of all branches. For each sample tree, branch basal area per tree was calculated as the sum of the individual branch basal areas for the stem height classes of interest.

At each location there was a random allocation of management intensity to one side of the site. Within management intensity the density subplots were randomly assigned. The arrangement of management intensity treatments and planting densities at each region results in a split-plot design. The main plots are management intensity treatments and densities are subplots. The installations (replications) were considered as a random sample of all possible locations, thus this factor was treated as random. This results in a mixed model. The mixed model, split plot design results in the analysis of variance (ANOVA) setup shown in Table 1 and Table 2. The linear model corresponding to the mixed, split plot design at each region is shown below:

$$y_{ijkh} = \mu + \tau_i + \beta_j + (\tau\beta)_{ij} + \gamma_k + (\tau\gamma)_{ik} + (\beta\gamma)_{jk} + (\tau\beta\gamma)_{ijk} + \varepsilon_{ijkh}$$

where:

Y_{ijkh}: represents the observed measurement of interest in the h^{th} plot, in the k^{th} installation, receiving the j^{th} silvicultural management level, and i^{th} planting density treatment.

μ: overall mean.

τ_i: effect of installation. Random factor assumed to be independent and identically

distributed normal random variables with mean zero and variance σ^2_{τ}.

β_j: effect of the j^{th} silvicultural management factor.

$(\tau\beta)_{ij}$: effect of interaction installation* silvicultural management. Random factor assumed to be independent and identically distributed normal random variables with mean zero and variance $\sigma^2_{\tau\beta}$.

γ_k: effect of planting density (tpa). Fixed term, representing the subplot treatment effect

$(\tau\gamma)_{ik}$: effect of interaction Density*Installation. Random factor, assumed to be independent and identically-distributed normal random variables with mean zero and variance $\sigma^2_{\tau\gamma}$.

$(\beta\gamma)_{ik}$: effect of interaction silvicultural management*density. Fixed effect factor.

$(\tau\beta\gamma)_{iik}$: effect of interaction installation*silvicultural management*density. Represents the split-plot error. Random factor assumed to be independent and identically-distributed random variables with mean zero and variance $\sigma^2_{\tau\beta\gamma}$.

ε_{ijkh}: residual error term, assumed to be independent and identically-distributed random variables with mean zero and variance σ^2.

Table 1. Analysis of variance and expected mean squares for the mixed model, split plot experiment (Lower Coastal Plain Region) [a].

Source of Variation	d.f.	E (MS)
Whole plot		
Installation (A)	5	$\sigma^2 + 12 \cdot \sigma^2_{\tau}$
Management (B)	1	$\sigma^2 + 6 \cdot \sigma^2_{\tau\beta} + 36 \cdot \sum \beta^2_j$
A*B (whole plot error)	5	$\sigma^2 + 6 \cdot \sigma^2_{\tau\beta}$
Subplot		
Density (C)	5	$\sigma^2 + 2 \cdot \sigma^2_{\tau\gamma} + \frac{12 \cdot \sum \gamma^2_k}{5}$
A*C	25	$\sigma^2 + 2 \cdot \sigma^2_{\tau\gamma}$
B*C	5	$\sigma^2 + \sigma^2_{\tau\gamma} + \frac{6 \cdot \sum (\beta\gamma)^2_{jk}}{5}$
A*B*C (subplot error)	25	$\sigma^2 + \sigma^2_{\tau\beta\gamma}$
TOTAL	71	

[a] The study in the Coastal Plain region has two levels of silvicultural management (operational and intensive), six planting densities and six installations. All plots are 8 years old at time of measurement.

Table 2. Analysis of variance and expected mean squares for the mixed model, split plot experiment (Piedmont/ Upper Coastal Plain Region) [a].

Source of Variation	d.f.	E (MS)
Whole plot		
Installation (A)	6	$\sigma^2 + 12 \cdot \sigma^2_{\tau}$
Management (B)	1	$\sigma^2 + 6 \cdot \sigma^2_{\tau\beta} + 42 \cdot \sum \beta^2_j$
A*B (whole plot error)	6	$\sigma^2 + 6 \cdot \sigma^2_{\tau\beta}$
Subplot		
Density (C)	5	$\sigma^2 + 2 \cdot \sigma^2_{\tau\gamma} + \frac{14 \cdot \sum \gamma^2_k}{5}$
A*C	30	$\sigma^2 + 2 \cdot \sigma^2_{\tau\gamma}$
B*C	6	$\sigma^2 + \sigma^2_{\tau\beta\gamma} + \frac{7 \cdot \sum \sum (\beta\gamma)^2_{jk}}{5}$
A*B*C (subplot error)	30	$\sigma^2 + \sigma^2_{\tau\beta\gamma}$
TOTAL	84	

[a] The study in the Piedmont/ Upper Coastal Plain region has two levels of silvicultural management, six planting densities and seven installations. All plots are 7 years old at time of measurement.

Analyses were conducted separately by region because of differences in sample sizes between regions. A full model with main effects and interactions was used to test each response variable within a region. Separate analyses of variance were conducted for average diameter at the base of branches, average branch basal area per tree, average branch length, average branch angle to the stem, total number of branches/tree, total number of dead branches/tree, and total number of live branches/tree. ANOVAs were conducted for the previous variables in different sections of the stem. Within each region, all the treatment combinations means were compared using the Tukey's studentized multiple comparison tests. Significance was defined as $P<0.05$.

3 RESULTS

A total of 66,426 branches was measured in this study, 26,623 branches from 333 sample trees from the six Lower Coastal Plain locations and 39,803 branches from 517 sample trees from the seven locations in the Piedmont/Upper Coastal Plain. Table 3 shows tree level means (average dbh, total height, height to live crown, branch diameter, and number sampled trees) by management intensity and initial density for each region.

Table 3. Means at tree level by region, management regime, and planting density.

Lower Coastal Plain (8 years)

Management	Plant Density	Number of Sampled Trees	Avg. DBH (in)	Avg. Height (ft)	Avg. Height to Live Crown (ft)	Avg. Branch Basal Diameter (mm)
Intensive	300	25	8.2	44.4	15.1	20.3
	600	31	7.0	45.6	20.2	16.7
	900	26	6.5	44.6	20.4	15.7
	1200	31	6.0	44.9	21.3	14.3
	1500	26	6.0	43.8	22.3	13.9
	1800	30	5.9	45.1	23.5	13.3
Operational	300	28	7.2	39.2	10.5	16
	600	25	6.1	38.2	13.7	14.3
	900	29	5.9	38.8	15.5	13.8
	1200	26	5.4	38.7	16.3	12.8
	1500	28	5.2	38.7	17.8	12.3
	1800	28	5.1	39.8	19.7	11.8

Table 3. - Continuation

Piedmont/ Upper Coastal Plain (7 years)

Management	Plant Density	Number of Sampled Trees	Avg. DBH (in)	Avg. Height (ft)	Avg. Height to Live Crown (ft)	Avg. Branch Basal Diameter (mm)
Intensive	300	43	7.2	32.9	6.2	10.9
	600	43	6.2	33.2	9.3	9.6
	900	44	5.8	33.8	10.9	6.9
	1200	43	5.5	33.3	11.9	7.8
	1500	43	5.3	33.0	11.7	7.3
	1800	43	4.9	32.8	13.6	6.6
Operational	300	43	6.2	30.2	6.1	4.9
	600	43	5.7	31.6	8.7	5.7
	900	43	5.4	32.4	10.2	7.6
	1200	43	5.2	31.7	10.5	6.8
	1500	43	4.7	30.8	11.9	6.1
	1800	43	4.5	31.5	11.9	5.1

3.1. Average Branch Diameter

Average branch diameter across regions, logs, planting densities, and management regimes is summarized in Figure 1 and Figure 2.

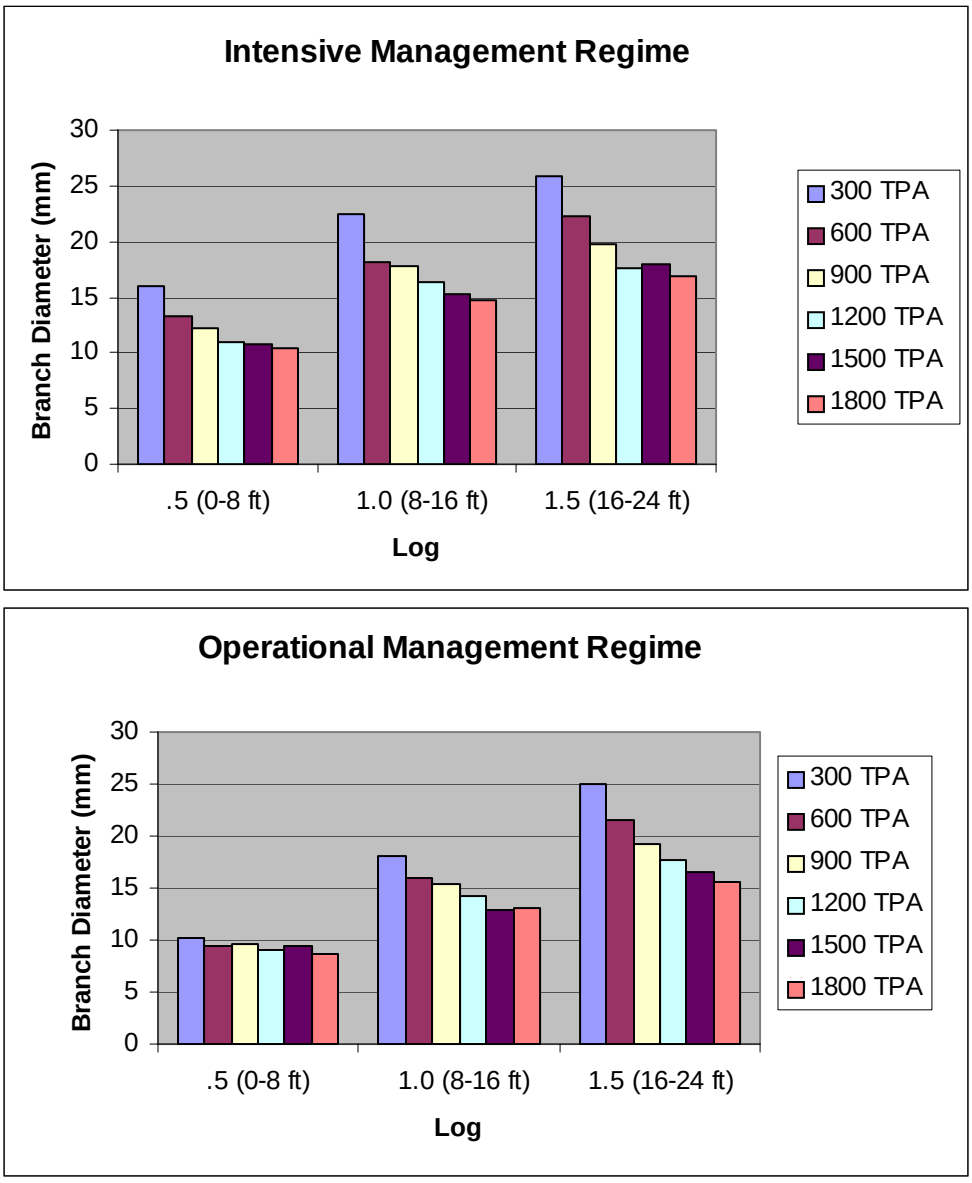


Figure 1. Average branch diameter (mm) by half-log, management regime, and planting density in the Lower Coastal Plain.

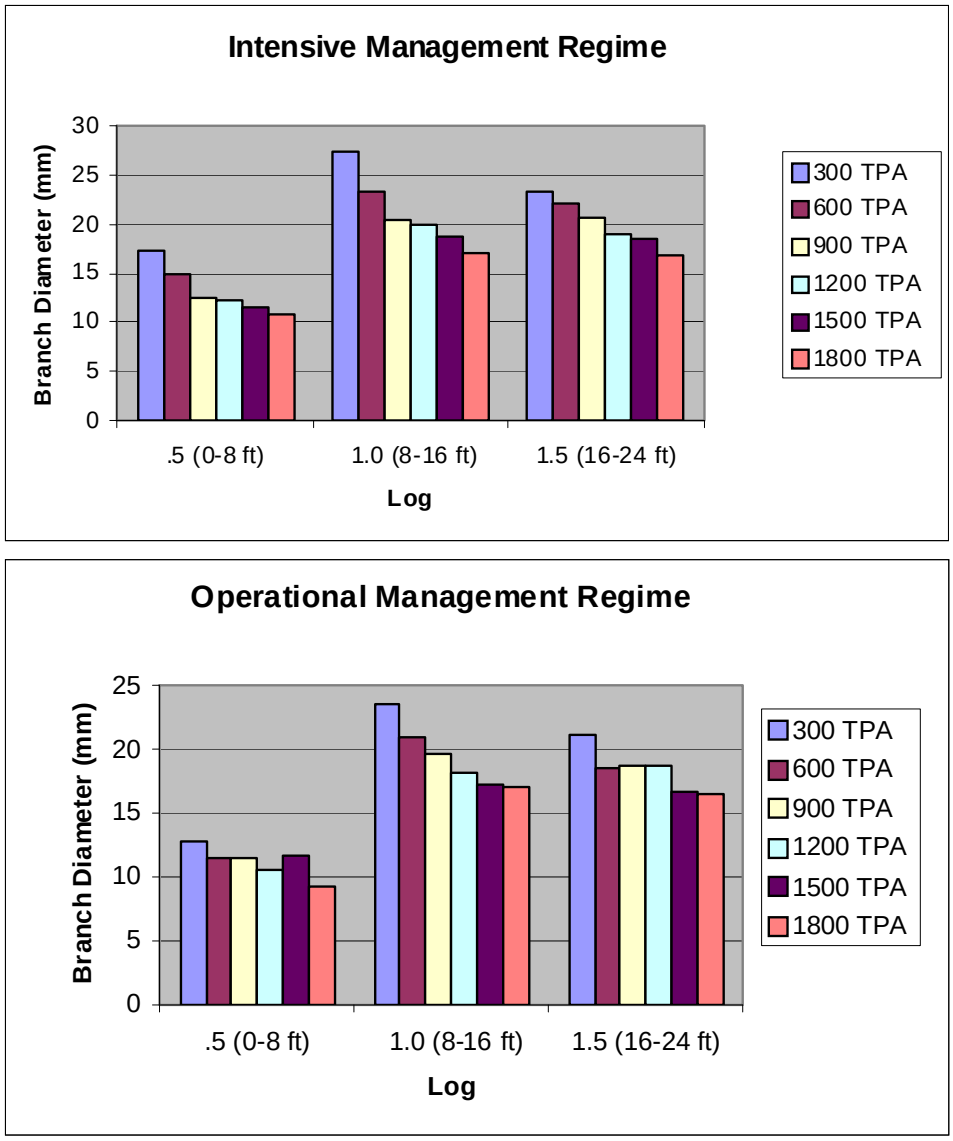


Figure 2. Average branch diameter (mm) by half-log, management regime, and planting density in the Piedmont/Upper Coastal Plain.

3.1.1. Average branch diameter for 0-24 ft stem height

For average branch diameter management intensity and density effects were significant in both regions while the management by density interaction was significant in the Piedmont/Upper Coastal Plain and was close to significant in the Lower Coastal Plain (Table 4).

Table 4. Analysis of variance results for average branch diameter in the lower 24 ft of the stem by region.

	Lower Coastal Plain		**Piedmont/Upper Coastal Plain**	
Source	Type III F	Pr > F	Type III F	Pr > F
Management	29.94	0.0028 *	58.31	0.0003 *
Density	47.72	< 0.0001 *	68.80	<0.0001 *
Management*Density	2.44	0.0620	3.66	0.0105 *

* Significant at $\alpha = 5\%$

In the Lower Coastal Plain the management regime effect was 2.2 mm (i.e. the branch diameter on the intensive management was on average 2.2 mm more than on the operational management (Figure 3). In the Piedmont/Upper Coastal Plain the management regime effect was 1.9 mm. Considering planting density, the 300 tpa treatment yielded mean branch diameters that were significantly larger from those of all other densities (Figure 4). There were no significant differences between the two higher densities (1500 and 1800 tpa) in either region. As planting density increased, average branch diameter decreased from 18.1 mm for 300 tpa to 12.5 mm for 1800 tpa in the Lower Coastal Plain, and from 19.7 mm for 300 tpa to 13.5 mm for 1800 tpa in the Piedmont/Upper Coastal Plain.

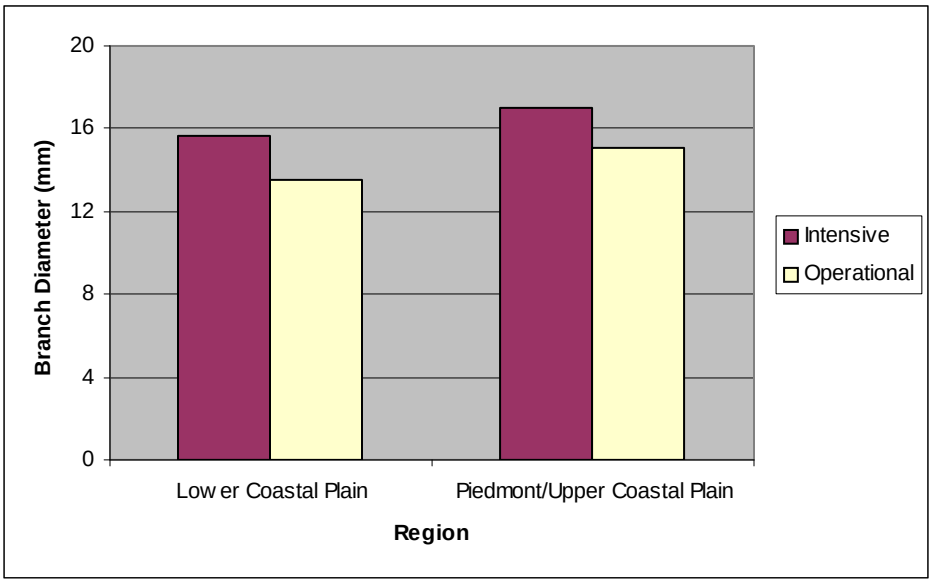


Figure 3. Average branch diameter (mm) in the lower 24 ft of the stem by management regime and region.

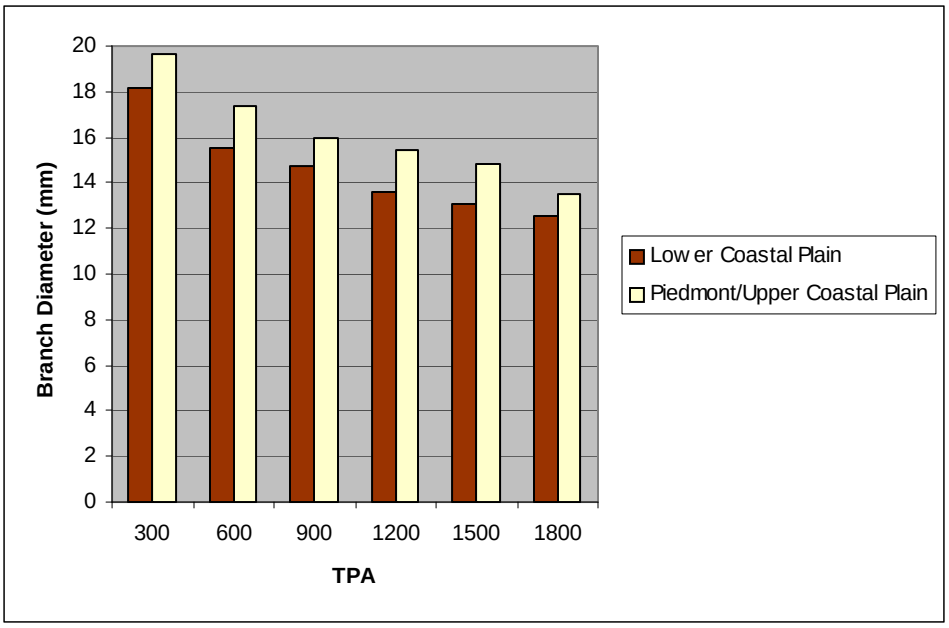


Figure 4. Average branch diameter (mm) in the lower 24 ft of the stem by planting density and region.

There was a consistent trend toward lower average branch diameter values as density increased for both intensive and operational management. At each density, the intensively managed plots had larger average branch diameters than the operational plots, but the difference tended to decrease as the density increased (Figure 5).

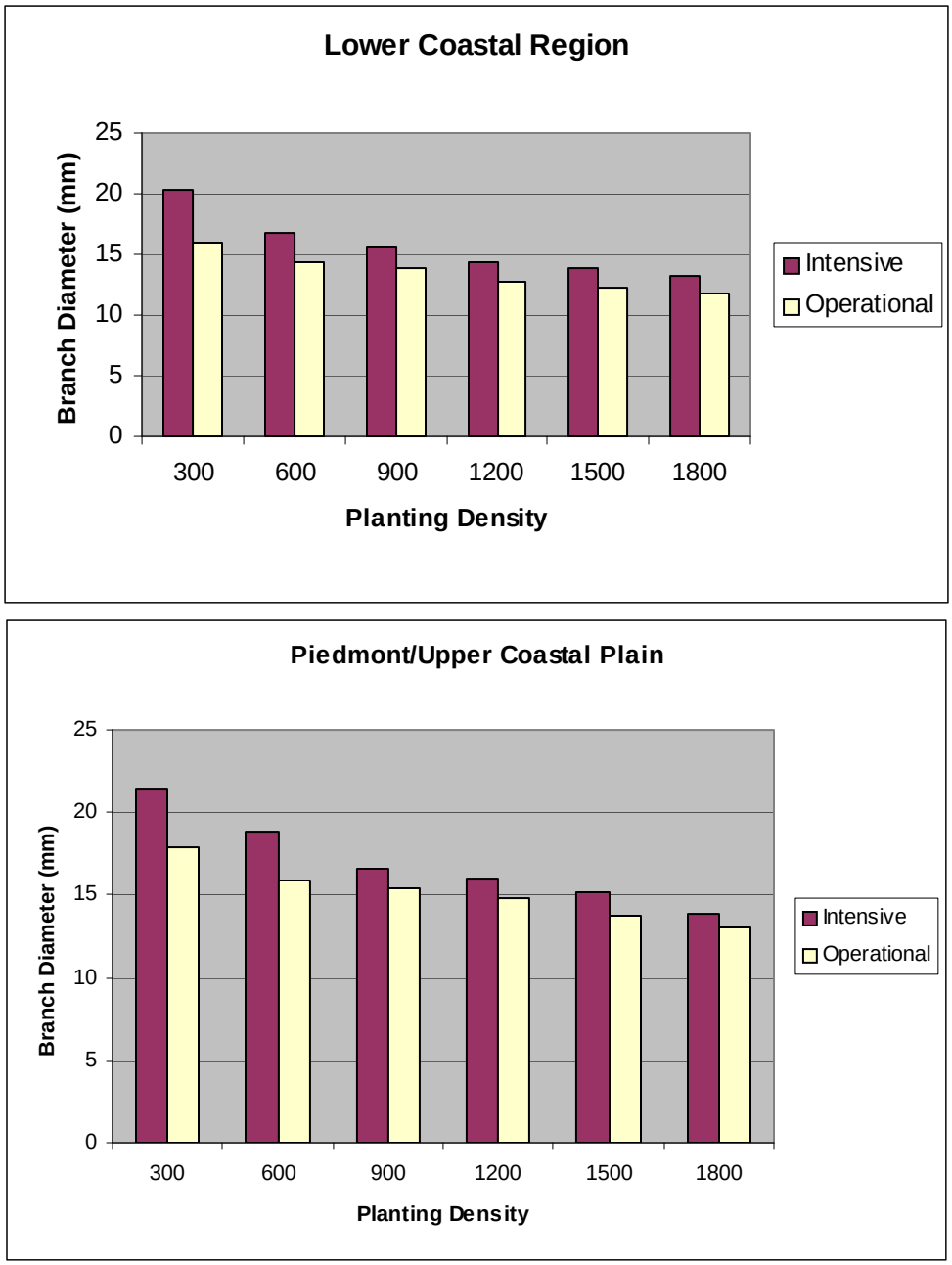


Figure 5. Average branch diameter (mm) in the lower 24 ft of the stem by planting density, management regime and region.

Pairwise multiple comparisons were carried out for the Piedmont/Upper Coastal Plain given the statistically significant interaction between the planting density and management regime (Table 5).

Table 5. P-values of Tukey's studentized multiple comparison tests of the differences among the average branch diameter (mm) in the lower 24 ft of the stem, across management regime and planting density treatment combinations for the Piedmont/Upper Coastal Plain.

Piedmont/Upper Coastal Region											
	IN600	**IN900**	**IN1200**	**IN1500**	**IN1800**	**OP300**	**OP600**	**OP900**	**OP1200**	**OP1500**	**OP1800**
IN300	**0.004**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**
IN600		**0.019**	**0.001**	**<.0001**	**<.0001**	0.916	**0.001**	**0.000**	**<.0001**	**<.0001**	**<.0001**
IN900			0.996	0.499	**0.004**	0.442	0.990	0.744	0.165	**0.002**	**<.0001**
IN1200				0.974	**0.046**	0.069	1.000	0.999	0.707	**0.021**	**0.001**
IN1500					0.512	**0.003**	0.988	1.000	1.000	0.321	**0.024**
IN1800						**<.0001**	0.062	0.291	0.897	1.000	0.910
OP300							0.052	**0.008**	**0.000**	**<.0001**	**<.0001**
OP600								1.000	0.781	**0.029**	**0.001**
OP900									0.994	0.161	**0.009**
OP1200										0.737	0.115
OP1500											0.981

References: first two letters refer to the management regime intensity treatment (IN: intensive, OP: operational Intensive). The last three digits refer to the planting density (300, 600, 900, 1200, 1500, 1800 TPA). Significance differences are in bold and defined as P-values <0.05.

The intensive management regime at 300 tpa (IN300) yielded the largest average branch diameter, and it was significantly different from those of all other treatment combinations. IN600 was also significantly different from all other treatment combinations with the exception of OP300. Considering the intensively managed plots, there were no significant differences in branch diameter between the two higher densities (1500 and 1800 tpa). For the operationally managed plots, there were no significant differences among the three highest densities (1200, 1500, and 1800 tpa).

There were significant linear trends of average branch diameters across densities for the regions and management regimes under study (Table 6). Considering the Lower Coastal Plain, the operational management regime yielded average branch diameters that decreased linearly from 16.0 mm when the planting density was 300 tpa to 11.4 mm when the density was 1,800 tpa. For the intensive management regime, the average branch diameter decreased linearly from 20.3 mm at 300 tpa to 13.3 mm at 1,800 tpa. For the Piedmont/Upper Coastal Plain, the operational management regime yielded average branch diameters that decreased linearly from 17.9 mm when the planting density was 300 tpa to 13.0 mm when the density was 1,800 tpa. For the intensive management regime, the average branch diameter decreased linearly from 21.4 mm at 300 tpa to 13.9 mm at 1,800 tpa

(Figure 5).

Table 6. Linear contrasts: average branch diameter (mm) by planting density in each region in the lower 24 ft of the stem.

	Lower Coastal Plain		**Piedmont/Upper Coastal Plain**	
Contrast	Type III F	Pr > F	Type III SS	Pr > F
Linear Trend across Density (both Management Regimes)	216.1	<0 .0001 *	326.24	<0.0001*
Linear Trend across Density at Intensive Regime	122.85	< 0.0001 *	207.40	<0.0001 *
Linear Trend across Density at Operational Regime	49.001	< 0.0001 *	86.44	<0.0001 *

* Significant at $\alpha = 5\%$

3.1.2. Average branch diameter for 0-16 ft stem heights

Management intensity, density, and the management by density interaction were significant effects on average diameter at the base of branches in the lower 16 ft of the stem in both regions (Table 7).

Table 7. Analysis of variance results for average branch diameter in each region in the lower 16 ft of the stem.

	Lower Coastal Plain		**Piedmont/Upper Coastal Plain**	
Source	Type III F	Pr > F	Type III SS	Pr > F
Management	59.51	0.0006 *	55.35	0.0003 *
Density	38.98	< 0.0001 *	54.80	<0.0001 *
Management*Density	4.32	0.0057 *	4.09	0.0060 *

* Significant at $\alpha = 5\%$

In the Lower Coastal Plain the branch diameter for intensive management was on average 2.6 mm more than for operational management, with the average on the intensive being 14.3 mm, and the average on the operational being 11.7 mm (Figure 6). In the Piedmont/Upper Coastal Plain the branch diameter on the intensive management was on average 2 mm more than on the operational management, with the average on the intensive being 15.9 mm, and the average on the operational being 13.9 mm. For the planting density factor, the 300 tpa treatment yielded mean branch diameters that were significantly different from those of all other densities. There were no significant differences between the three

higher densities (1200, 1500, and 1800 tpa) in either region. As the planting density increased, the average branch diameter decreased from 15.9 mm at 300 tpa to 11.3 mm at 1800 tpa in the Lower Coastal Plain, and from 18.8 mm at 300 tpa to 12.4 mm at 1800 tpa in the Piedmont/Upper Coastal Plain (Figure 7).

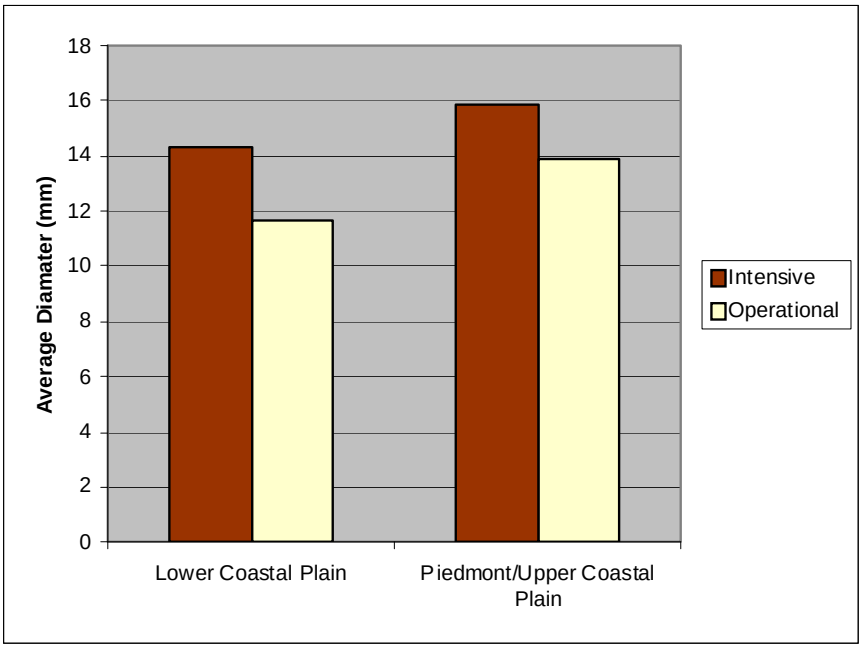


Figure 6. Average branch diameter (mm) in the lower 16 ft of the stem by management regime and region.

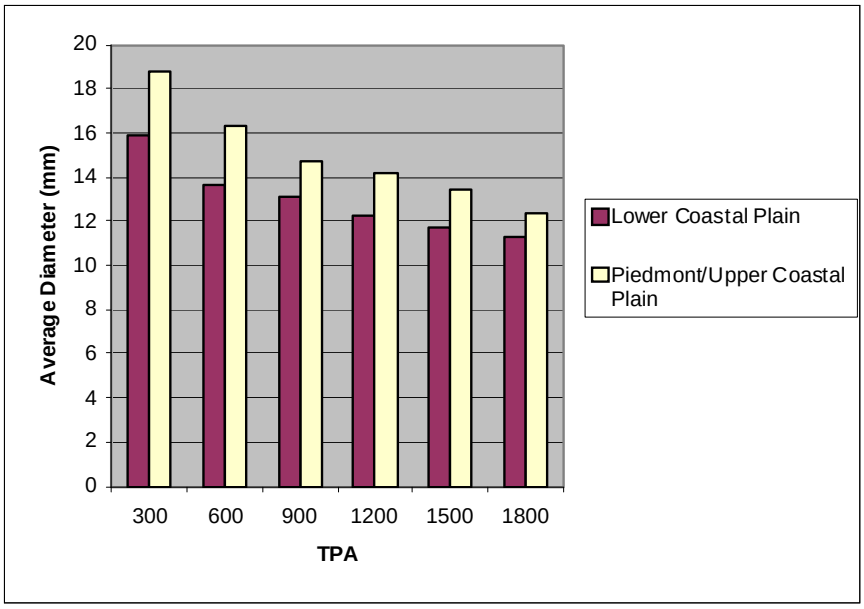


Figure 7. Average branch diameter (mm) in the lower 16 ft of the stem by planting density and region.

There was a consistent trend toward lower average branch diameter values as density increased for both intensive and operational management regimes. At each density, the intensively managed plots had larger average branch diameters than the operational plots, but the difference tended to decrease as the density increased (Figure **8**).

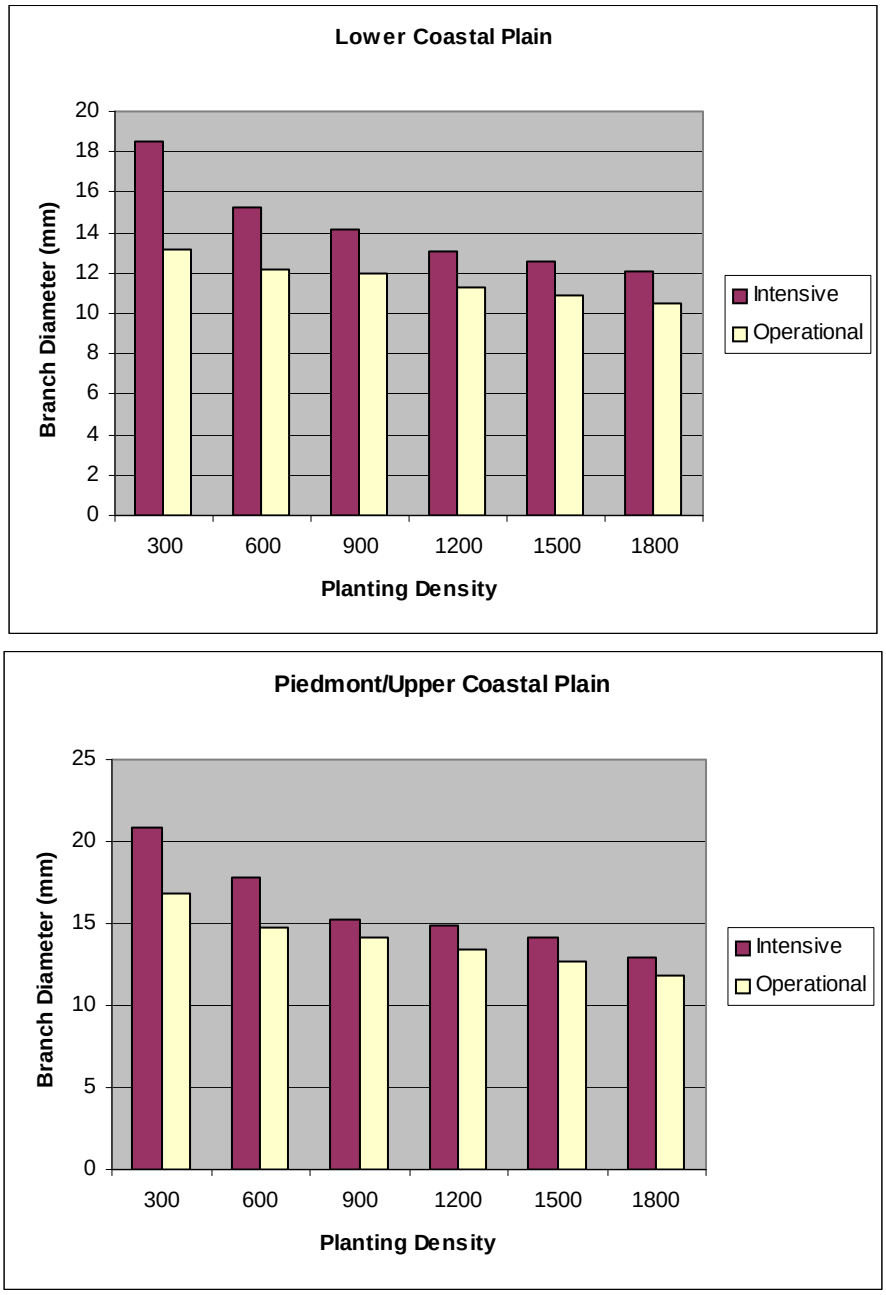


Figure 8. Average branch diameter (mm) in the lower 16 ft of the stem by planting density, management regime and region.

Results from pairwise multiple comparisons are presented in Table 8. For both regions, the intensive management regime at 300 tpa (IN300) yielded the largest average branch diameter, and it was significantly different from those of all other treatment combinations. Observe that there were no significant differences among the three higher planting densities (1200, 1500, and 1800 tpa) within a management regime.

Table 8. P-values of Tukey's studentized multiple comparison tests of the differences among the average branch diameter (mm) in the lower 16 ft of the stem across all management regime and planting density treatment combinations.

Lower Coastal Region											
	IN600	**IN900**	**IN1200**	**IN1500**	**IN1800**	**OP300**	**OP600**	**OP900**	**OP1200**	**OP1500**	**OP1800**
IN300	**0.002**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**
IN600		0.962	0.174	**0.034**	**0.008**	0.233	**0.011**	**0.005**	**<.0001**	**<.0001**	**<.0001**
IN900			0.884	0.433	0.156	0.938	0.203	0.109	**0.010**	**0.003**	**0.001**
IN1200				1.000	0.950	1.000	0.976	0.895	0.295	0.126	**0.033**
IN1500					1.000	0.998	1.000	0.999	0.758	0.466	0.172
IN1800						0.902	1.000	1.000	0.977	0.836	0.464
OP300							0.945	0.824	0.224	0.090	**0.023**
OP600								1.000	0.952	0.760	0.380
OP900									0.993	0.910	0.578
OP1200										1.000	0.992
OP1500											1.000

Piedmont/Upper Coastal Region											
	IN600	**IN900**	**IN1200**	**IN1500**	**IN1800**	**OP300**	**OP600**	**OP900**	**OP1200**	**OP1500**	**OP1800**
IN300	**0.001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**
IN600		**0.010**	**0.002**	**<.0001**	**<.0001**	0.890	**0.002**	**0.001**	**<.0001**	**<.0001**	**<.0001**
IN900			1.000	0.808	**0.036**	0.328	1.000	0.873	0.207	**0.014**	**0.001**
IN1200				0.979	0.119	0.122	1.000	0.991	0.486	**0.050**	**0.001**
IN1500					0.761	**0.006**	0.992	1.000	0.994	0.512	**0.031**
IN1800						**<.0001**	0.160	0.678	0.999	1.000	0.771
OP300							0.090	**0.009**	**0.001**	**<.0001**	**<.0001**
OP600								0.997	0.579	0.070	**0.002**
OP900									0.985	0.427	**0.022**
OP1200										0.983	0.281
OP1500											0.938

References: first two letters refer to the management regime intensity treatment (IN: intensive, OP: operational Intensive). The last three digits refer to the planting density (300, 600, 900, 1200, 1500, 1800 TPA). Significance differences are in bold and are defined as P-values <0.05.

There were significant linear trends for average branch diameters across densities for the regions and management regimes under study (Table 9). For the Lower Coastal Plain, operational management yielded average branch diameters that decreased linearly from 13.2 mm when the planting density was 300 tpa to 10.5 mm when the density was 1,800 tpa. For intensive management, the average branch diameter decreased linearly from 18.5 mm at 300 tpa to 12.1 mm at 1,800 tpa. In the Piedmont/Upper Coastal Plain, operational management yielded average branch diameters that decreased linearly from 16.8 mm when the planting density was 300 tpa to 11.8 mm when the density was 1,800 tpa. For intensive management, the average branch diameter decreased linearly from 20.8 mm at 300 tpa to 13.0 mm at

1,800 tpa (Figure **8**).

Table 9. Linear contrasts: average branch diameter (mm) in the lower 16 ft of the stem by planting density in each region.

	Lower Coastal Plain		**Piedmont/Upper Coastal Plain**	
Contrast	Type III F	Pr > F	Type III SS	Pr > F
Linear Trend across Density (both Management Regimes)	175.69	< 0.0001 *	253.39	<0.0001*
Linear Trend across Density at Intensive Regime	101.49	< 0.0001 *	197.20	<0.0001 *
Linear Trend across Density at Operational Regime	19.92	0.0001 *	77.33	<0.0001 *

* Significant at $\alpha = 5\%$

3.1.3. Average branch diameter for 0-8 ft stem heights

Management intensity, planting density, and the management by density interaction were significant for average diameter at the base of branches in the lower 8 feet of the stem in both regions (Table 10).

Table 10. Analysis of variance results for average branch diameter in each region in the lower 8 ft of the stem.

	Lower Coastal Plain		**Piedmont/Upper Coastal Plain**	
Source	Type III F	Pr > F	Type III SS	Pr > F
Management	49.15	0.0009 *	111.98	<0.0001 *
Density	19.05	<0.0001 *	35.23	<0.0001 *
Management*Density	6.28	0.0007 *	3.68	0.0102 *

* Significant at $\alpha = 5\%$

In the Lower Coastal Plain the branch diameter for intensive management was on average 2.8 mm more than for operational management, with the average on the intensive being 12.2 mm, and the average on the operational being 9.4 mm Figure 9). In the Piedmont/Upper Coastal Plain the branch diameter for intensive management was on average 2.3 mm more than for operational management, with the average on the intensive being 13.2 mm, and the average on the operational being 10.9 mm). Considering the planting density factor, the 300 tpa treatment yielded mean branch diameters significantly greater than those of other densities (

Figure 10). There were no significant differences between the three higher densities (1200, 1500, and 1800 tpa) in either region. As the planting density increased, the average branch diameter decreased from 12.9 mm at 300 tpa to 9.5 mm at 1800 tpa in the Lower Coastal Plain, and from 15.0 mm at 300 tpa to 10.0 mm at 1800 tpa in the Piedmont/Upper Coastal Plain

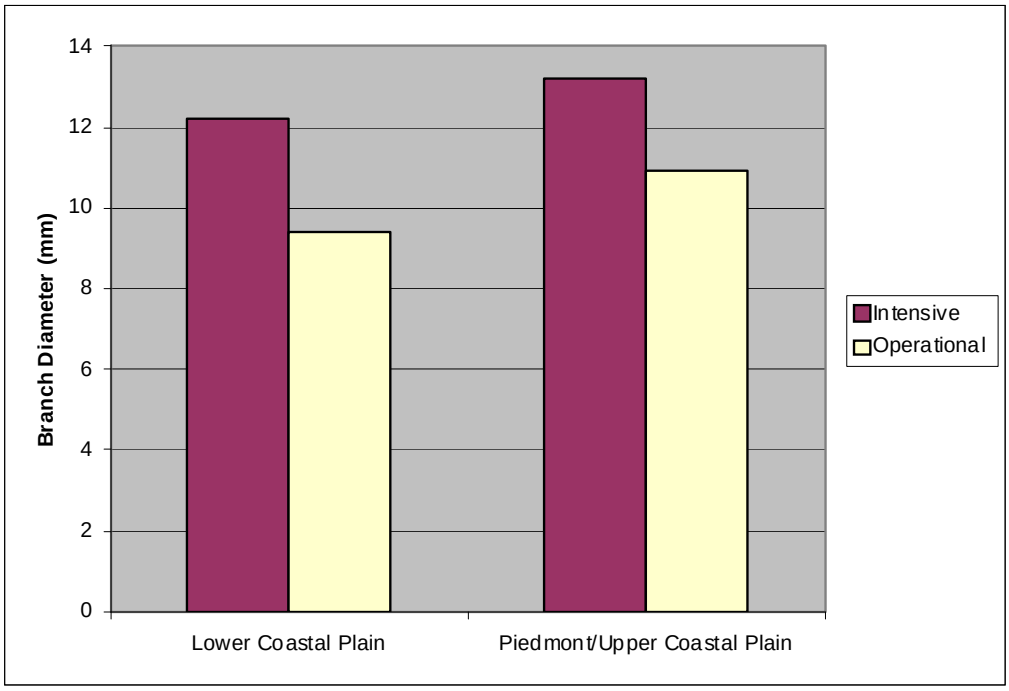


Figure 9. Average branch diameter (mm) in the lower 8 ft of the stem by management regime and region.

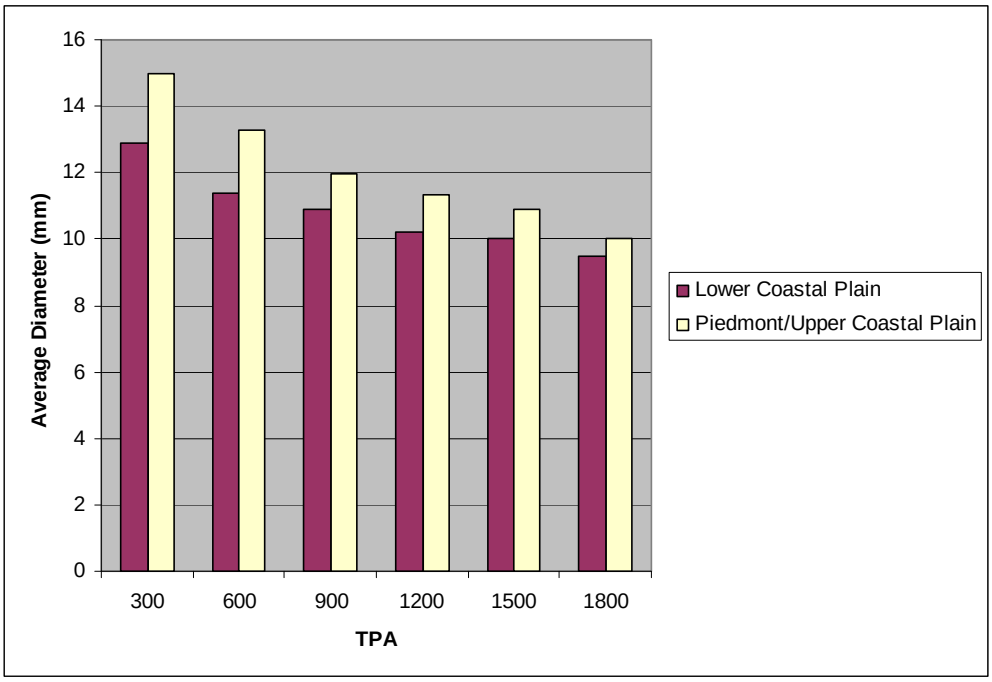


Figure 10. Average branch diameter (mm) in the lower 8 ft of the stem by planting density and region.

There was a consistent trend toward lower average branch diameter values as density increased for both intensive and operational management. At each density, the intensively managed plots had larger average branch diameters than the operational plots (Figure 11).

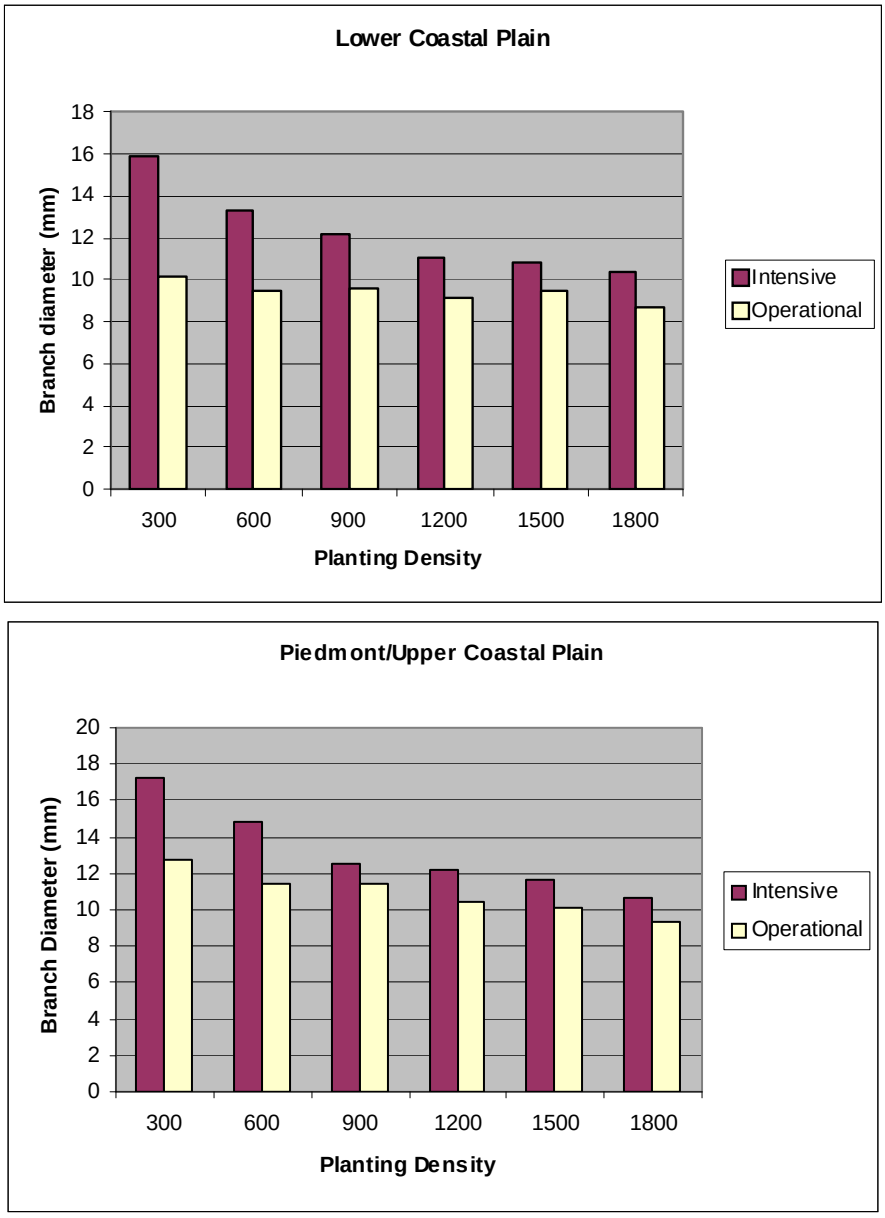


Figure 11. Average branch diameter (mm) in the lower 8 ft of the stem by planting density, management regime and region.

Results from pairwise multiple comparisons are presented in Table 11. In both regions, the intensive management regime at 300 tpa (IN300) yielded the largest average branch diameter, and it was significantly different from those of all other treatment combinations (Table 11). Observe that there were no significant differences among the higher planting densities (900, 1200, 1500, and 1800 tpa) within a management regime, and between management regimes.

Table 11. P-values of Tukey's studentized multiple comparison tests of the differences among the average branch diameter (mm) in the lower 8 ft of the stem across all management regime and planting density treatment combinations.

Lower Coastal Region											
	IN600	**IN900**	**IN1200**	**IN1500**	**IN1800**	**OP300**	**OP600**	**OP900**	**OP1200**	**OP1500**	**OP1800**
IN300	**0.034**	**0.001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**
IN600		0.881	0.064	**0.044**	**0.010**	**0.003**	**<.0001**	**0.001**	**0.001**	**<.0001**	**<.0001**
IN900			0.781	0.678	0.293	0.122	**0.020**	**0.025**	**0.006**	**0.023**	**0.001**
IN1200				1.000	0.999	0.968	0.596	0.653	0.286	0.625	0.083
IN1500					1.000	0.989	0.706	0.758	0.376	0.733	0.118
IN1800						1.000	0.969	0.981	0.773	0.976	0.372
OP300							0.999	1.000	0.959	1.000	0.668
OP600								1.000	1.000	1.000	0.984
OP900									1.000	1.000	0.972
OP1200										1.000	1.000
OP1500											0.978

Piedmont/Upper Coastal Region											
	IN600	**IN900**	**IN1200**	**IN1500**	**IN1800**	**OP300**	**OP600**	**OP900**	**OP1200**	**OP1500**	**OP1800**
IN300	**0.062**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**
IN600		0.082	**0.033**	**0.004**	**<.0001**	0.157	**0.002**	**0.001**	**<.0001**	**<.0001**	**<.0001**
IN900			1.000	0.980	0.303	1.000	0.914	0.873	0.158	0.059	**0.003**
IN1200				0.999	0.536	1.000	0.989	0.979	0.323	0.138	**0.009**
IN1500					0.957	0.910	1.000	1.000	0.831	0.551	0.070
IN1800						0.174	0.993	0.997	1.000	0.999	0.691
OP300							0.773	0.710	0.083	**0.028**	**0.001**
OP600								1.000	0.943	0.740	0.132
OP900									0.966	0.800	0.164
OP1200										1.000	0.881
OP1500											0.988

References: first two letters refer to the management regime intensity treatment (IN: intensive, OP: operational Intensive). The last three digits refer to the planting density (300, 600, 900, 1200, 1500, 1800 TPA). Significance differences are in bold and are defined as P-values <0.05.

There were significant linear trends of average branch diameters for the 0 to 8 ft stem height across densities for the regions under study (Table 12). In the Lower Coastal Plain, operational management yielded a non-significant linear trend across planting densities (p-value=0.0836) while the linear trend was significant for intensive management where the average branch diameter decreased linearly from 15.9 mm at 300 tpa to 10.4 mm at 1,800 tpa (Figure 11). In the Piedmont/Upper Coastal Plain operational management yielded average branch diameters that decreased linearly from 12.7 mm when the planting density was 300 tpa to 9.3 mm when the density was 1,800 tpa. For the intensive management regime, the average branch diameter decreased linearly from 17.2 mm at 300 tpa to 10.7 mm at 1,800 tpa.

Table 12. Linear contrasts: average branch diameter (mm) in the lower 8 ft of the stem by planting density in each region.

	Lower Coastal Plain		Piedmont/Upper Coastal Plain	
Contrast	Type III F	Pr > F	Type III SS	Pr > F
Linear Trend across Density (both Management Regimes)	83.88	< 0.0001*	165.41	<0.0001*
Linear Trend across Density at Intensive Regime	80.75	< 0.0001*	106.61	<0.0001*
Linear Trend across Density at Operational Regime	3.25	0.0836	28.96	<0.0001*

* Significant at $\alpha = 5\%$

3.1.4. Average branch diameter for 8-16 ft stem height

Management intensity factor and planting density significantly affected average diameter at the base of branches in whorls at 8-16 ft stem heights in both regions (Table 13). The management by density interaction was not significant in either region.

Table 13. Analysis of variance results for average branch diameter at heights 8-16 ft of the stem in each region.

	Lower Coastal Plain		Piedmont/Upper Coastal Plain	
Source	Type III F	Pr > F	Type III SS	Pr > F
Management	12.90	0.0157 *	18.10	0.0054 *
Density	27.30	<0.0001 *	51.51	<0.0001 *
Management*Density	1.12	0.3771	1.95	0.1161

* Significant at $\alpha = 5\%$

In the Lower Coastal Plain the branch diameter for intensive management was on average 2.5 mm more than for operational management, with the average on the intensive being 17.4 mm and the average on the operational being 14.9 mm (Figure 12). In the Piedmont/Upper Coastal Plain the branch diameter on the intensive management was on average 1.9 mm more than on the operational management, with the average on the intensive being 21.2 mm and the average on the operational being 19.3 mm. For the planting density factor, the 300 tpa treatment yielded mean branch diameters that were significantly greater than those of other densities (Figure 13). There were no significant differences between the three higher densities (1200, 1500, and 1800 tpa) in either region. As the planting

density increased, the average branch diameter decreased from 20.1 mm at 300 tpa to 14.0 mm at 1800 tpa in the Lower Coastal Plain, and from 25.5 mm at 300 tpa to 16.7 mm at 1800 tpa in the Piedmont/Upper Coastal Plain.

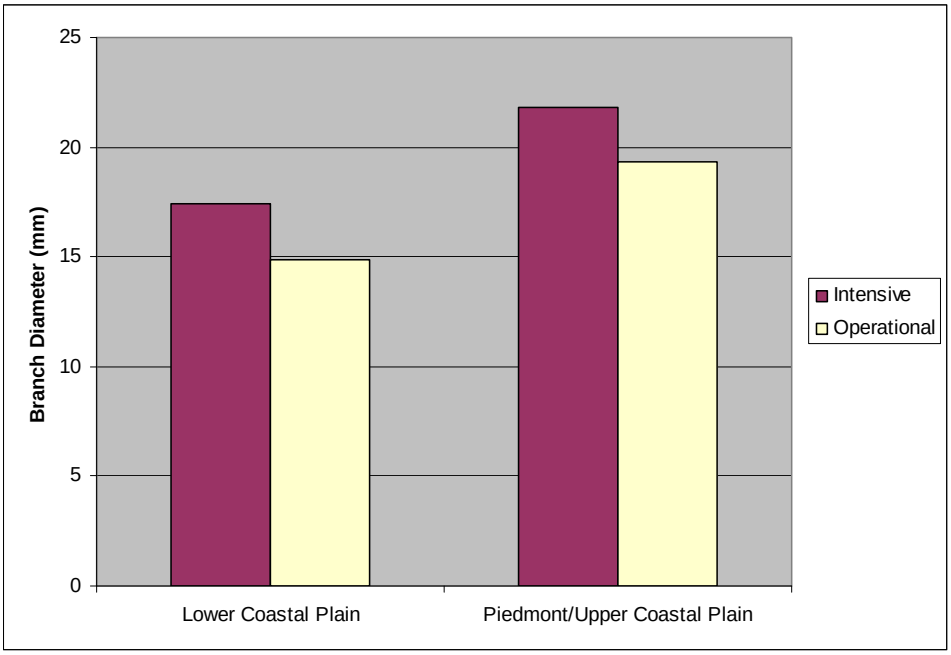


Figure 12. Average branch diameter (mm) at heights 8-16 ft of the stem by management regime and region.

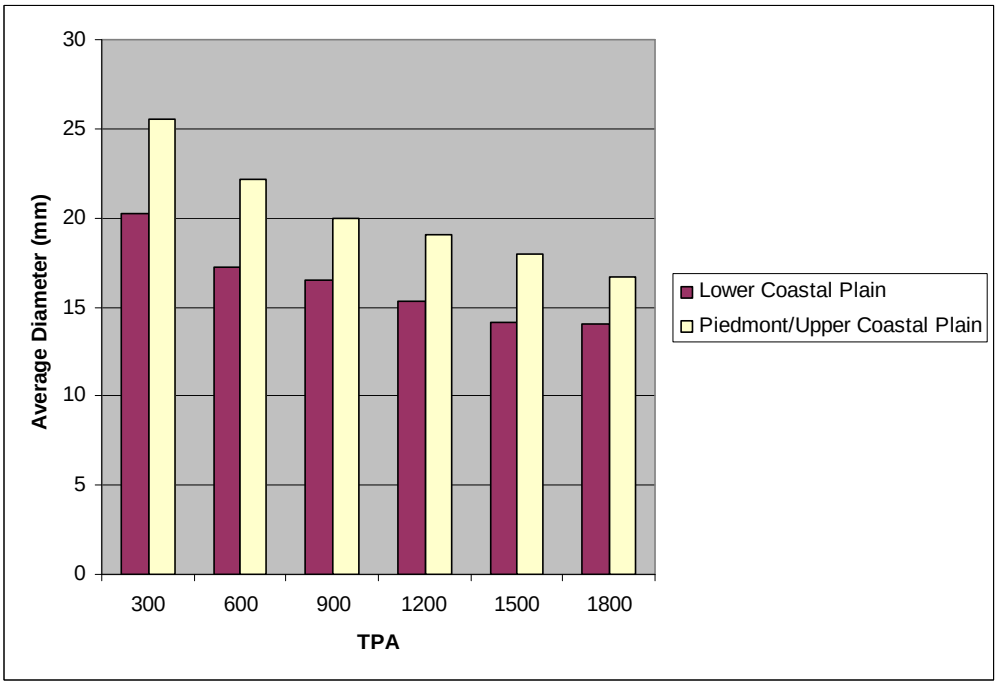


Figure 13. Average branch diameter (mm) at heights 8-16 ft of the stem by planting density and region.

There was a consistent trend toward lower average branch diameter values as density increased for both intensive and operational management. At each density, the intensively managed plots had larger average branch diameters than the operational plots (Figure 14). As there were no significant planting density by management regime interactions in either region, pairwise multiple comparisons were not warranted.

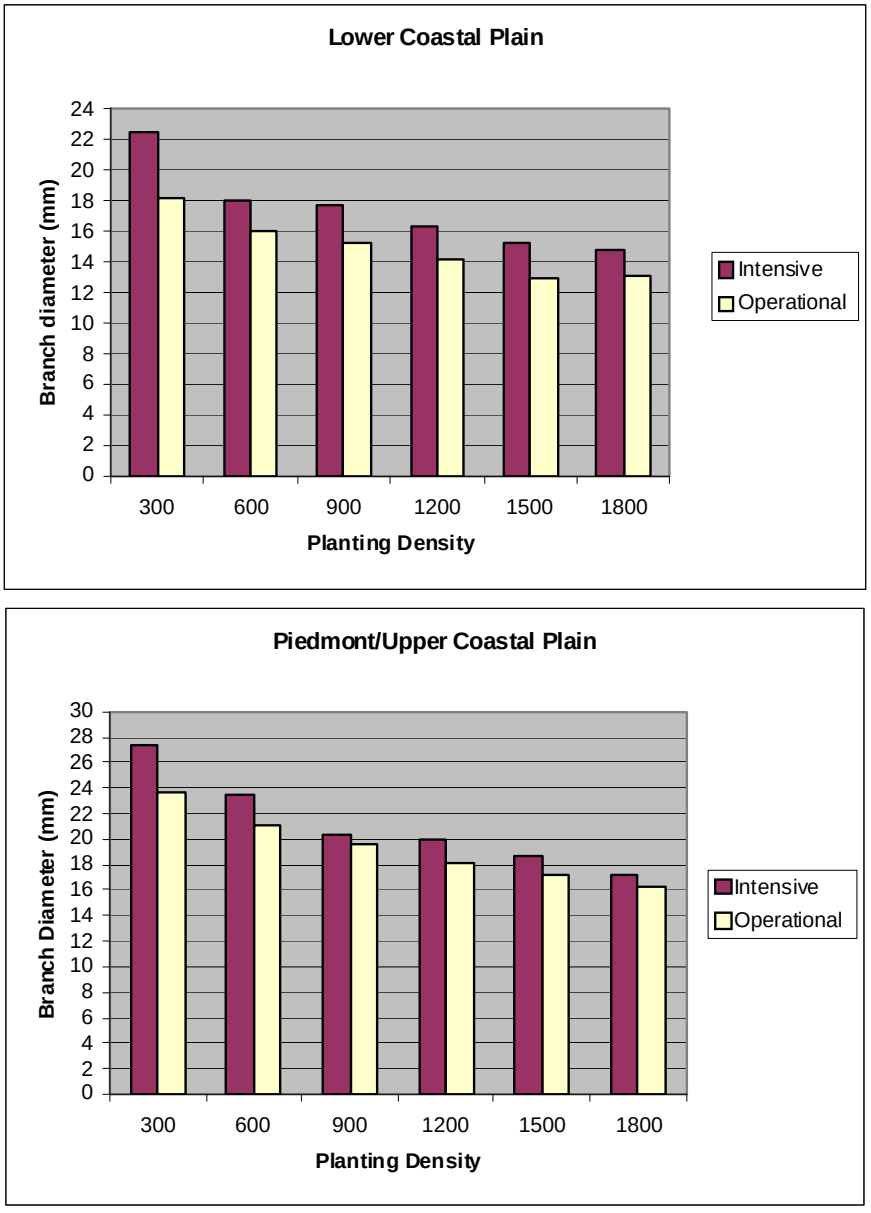


Figure 14. Average branch diameter (mm) at heights 8-16 ft of the stem by planting density, management regime and region.

There were significant linear trends of average branch diameters at heights 8-16 ft of the stem across densities for the regions under study (Table 14). In the Lower Coastal Plain, operational management yielded average branch diameters that decreased linearly from 18.1 mm when the planting density was 300 tpa to 12.9 mm when the density was 1,800 tpa. For intensive management, the average branch diameter decreased linearly from 22.5 mm at 300 tpa to 14.8 mm at 1,800 tpa. Considering the Piedmont/Upper Coastal Plain, operational management yielded average branch diameters that decreased linearly from 23.6 mm when the planting density was 300 tpa to 16.4 mm when the density was 1,800 tpa. For intensive management, the average branch diameter decreased linearly from 27.4 mm at 300 tpa to 17.1 mm at 1,800 tpa.

Table 14. Linear contrasts: average branch diameter (mm) at heights 8-16 ft of the stem by planting density in each region.

	Lower Coastal Plain		**Piedmont/Upper Coastal Plain**	
Contrast	Type III F	Pr > F	Type III SS	Pr > F
Linear Trend across Density (both Management Regimes)	121.14	<0 .0001 *	240.2	<0.0001*
Linear Trend across Density at Intensive Regime	80.01	< 0.0001 *	187.9	<0.0001 *
Linear Trend across Density at Operational Regime	42.95	< 0.0001 *	105.1	<0.0001 *

* Significant at $\alpha = 5\%$

3.1.5. Average branch diameter for 16-24 ft stem height

For average diameter at the base of branches in whorls at 16-24 ft stem heights, the density factor was significant in both regions, the management factor was significant only in the Piedmont/Upper Coastal Plain, and the management by density interaction was not significant in either region (Table 15).

Table 15. Analysis of variance results for average branch diameter at heights 16-24 ft of the stem in each region.

	Lower Coastal Plain		**Piedmont/Upper Coastal Plain**	
Source	Type III F	Pr > F	Type III SS	Pr > F
Management	0.97	0.3688	6.75	0.0408 *
Density	38.07	<.0001 *	15.11	<0.0001 *
Management*Density	0.61	0.6956	1.29	0.2946

* Significant at $\alpha = 5\%$

In the Piedmont/Upper Coastal Plain, the branch diameter on the intensive management was on average 1.7 mm more than on the operational management, with the average on the intensive being 20.1 mm, and the average on the operational being 18.4 m (Figure 15). In the Lower Coastal Plain, the management regime effect was 0.6 mm, the difference between regimes not significant. For planting density the 300 tpa treatment yielded mean branch diameters that were significantly greater than those of other densities. There were no significant differences between the three higher densities (1200, 1500, and 1800 tpa) in either region. As the planting density increased, the average branch diameter decreased from 25.4 mm at 300 tpa to 16.3 mm at 1800 tpa for the Lower Coastal Plain, and from 22.3 mm at 300 tpa to 16.7 mm at 1800 tpa for the Piedmont/Upper Coastal Plain (Figure 16).

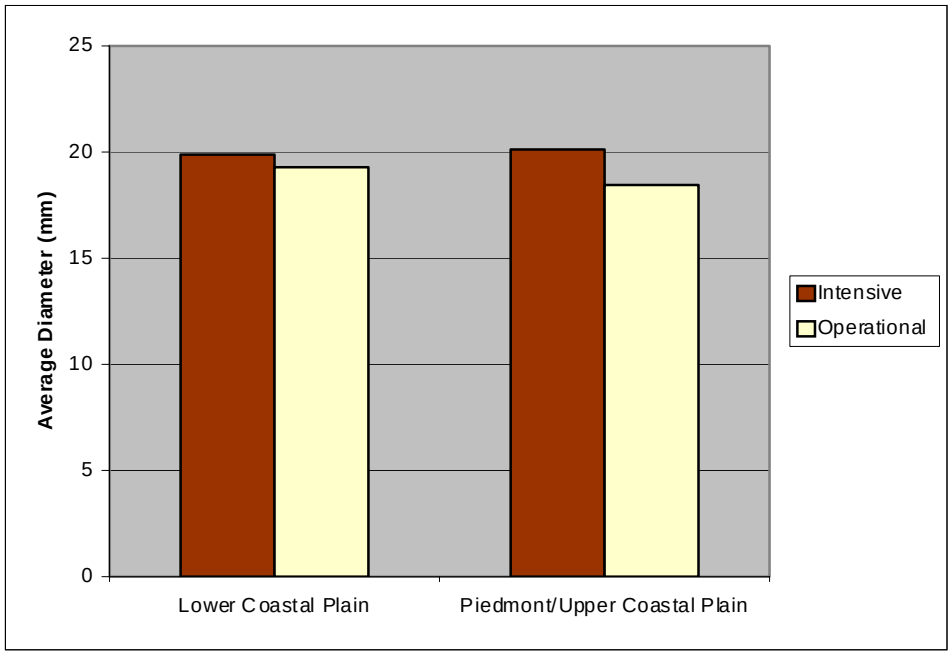


Figure 15. Average branch diameter (mm) at heights 16-24 ft of the stem by management regime and region.

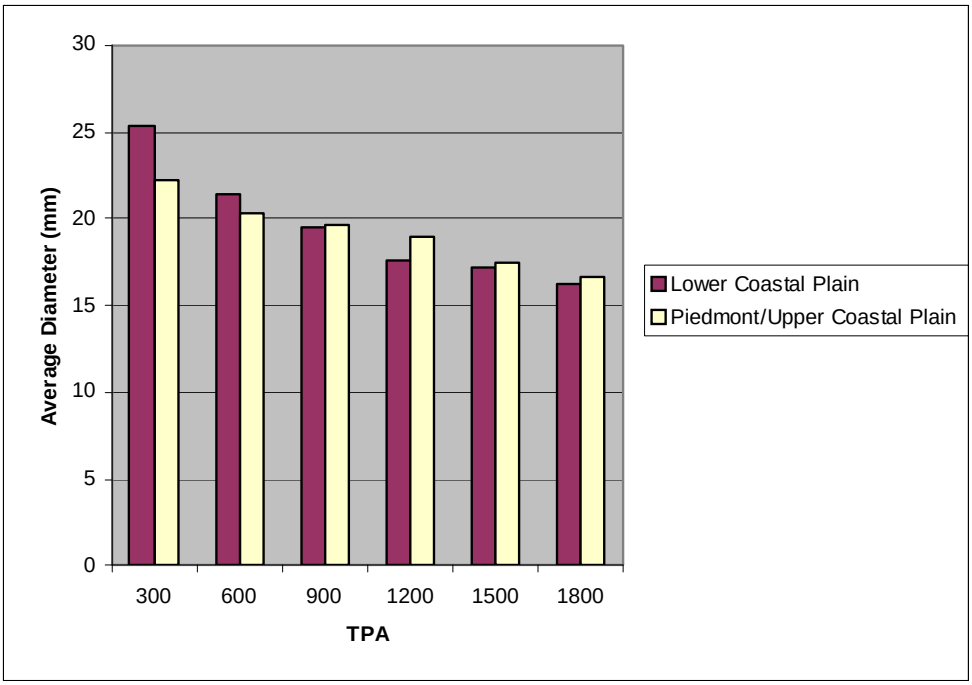


Figure 16. Average branch diameter (mm) at heights 16-24 ft of the stem by planting density and region.

There was a consistent trend toward lower average branch diameter values as density increased for both intensive and operational management (Figure 17). The intensively managed plots tended to have larger average branch diameters than the operational plots.

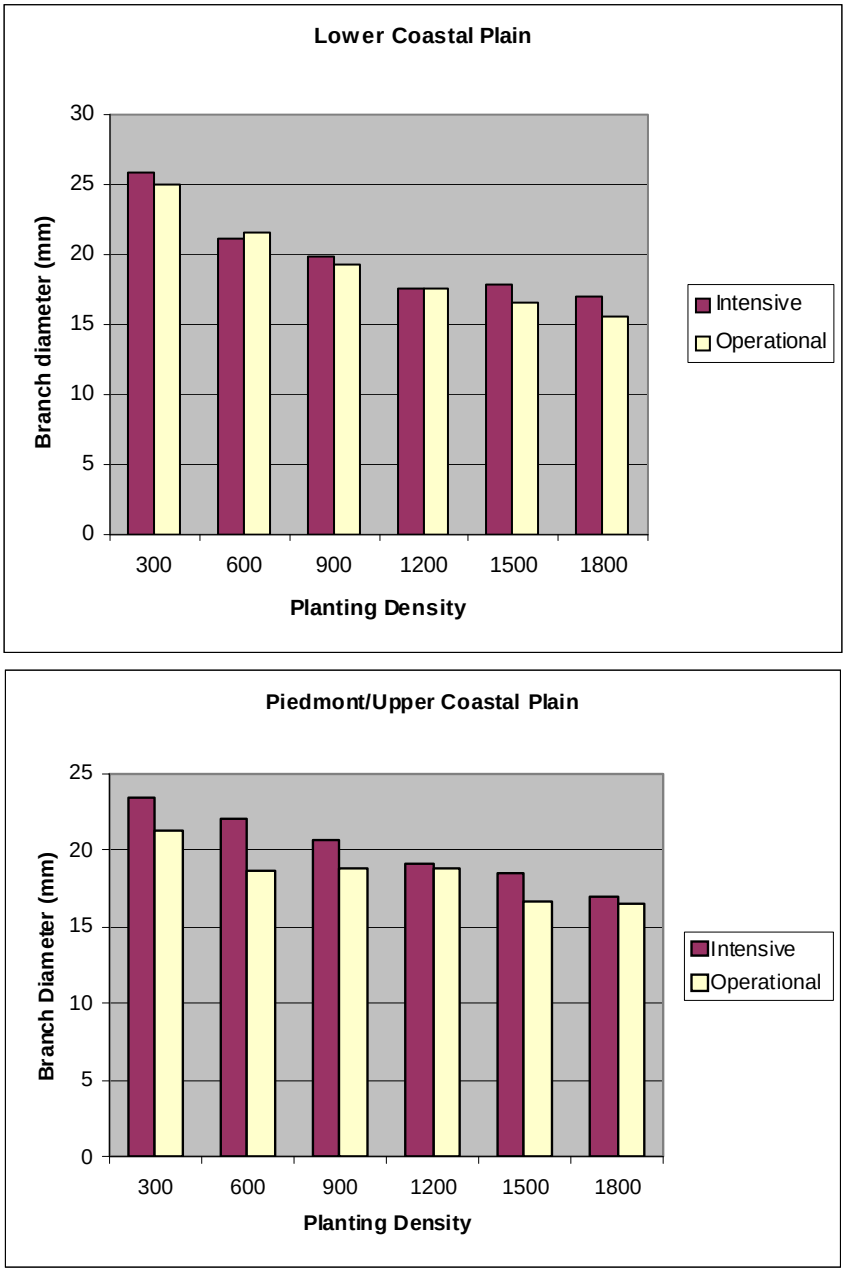


Figure 17. Average branch diameter (mm) at heights 16-24 ft of the stem by planting density, management regime and region.

There were significant linear trends of average branch diameters in the range 16-24 ft stem height across densities for the regions under study (Table 16). In the Lower Coastal Plain, operational management yielded average branch diameters that decreased linearly from 25.0 mm when the planting density was 300 tpa to 15.9 mm when the density was 1,800 tpa (Figure 17). For intensive management, the average branch diameter decreased linearly from 25.9 mm at 300 tpa to 16.9 mm at 1,800 tpa. In the Piedmont/Upper Coastal Plain, operational management yielded average branch diameters that decreased linearly from 21.2 mm when the planting density was 300 tpa to 16.4 mm when the density was 1,800 tpa. For intensive management, the average branch diameter decreased linearly from 23.3 mm at 300 tpa to 16.9 mm at 1,800 tpa.

Table 16. Linear contrasts: average branch diameter (mm) at heights 16-24 ft of the stem by planting density in each region.

	Lower Coastal Plain		**Piedmont/Upper Coastal Plain**	
Contrast	Type III F	Pr > F	Type III SS	Pr > F
Linear Trend across Density (both Management Regimes)	170.36	<0 .0001 *	73.47	<0.0001*
Linear Trend across Density at Intensive Regime	277.59	< 0.0001 *	56.90	<0.0001 *
Linear Trend across Density at Operational Regime	346.09	< 0.0001 *	26.08	<0.0001 *

* Significant at $\alpha = 5\%$

3.2. Average Branch Basal Area per Tree

Average branch basal area per tree is summarized across regions, logs, planting densities, and management regimes in Figure 18 and Figure 19.

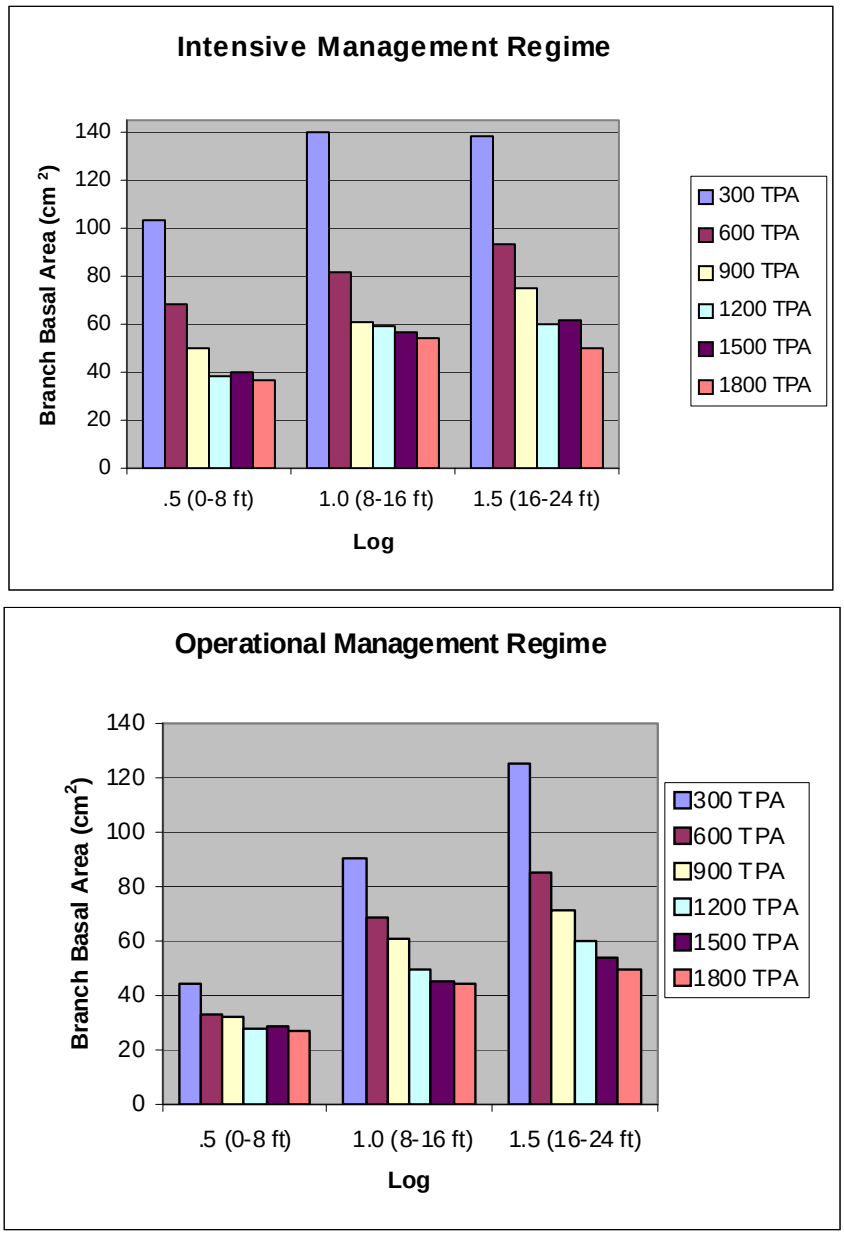


Figure 18. Average branch basal area (cm^2) per tree by half-log, management regime, and planting density in the Lower Coastal Plain.

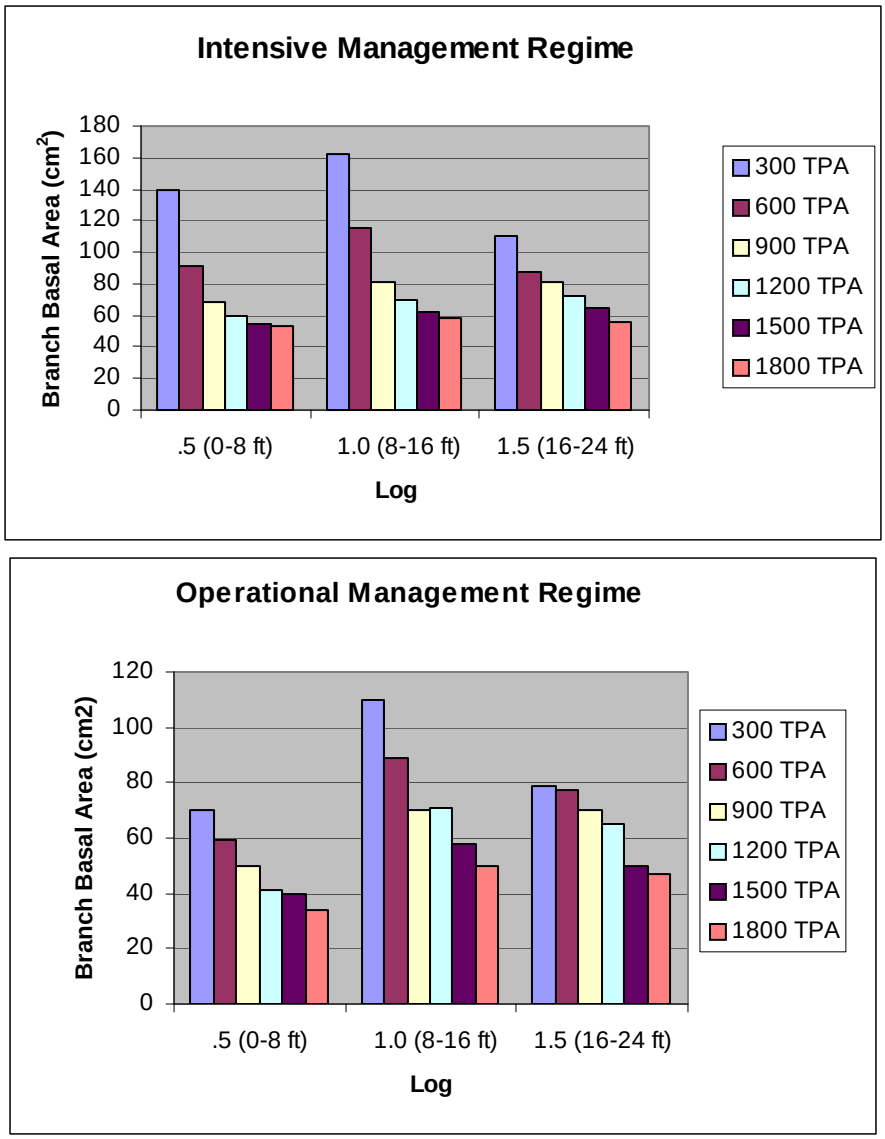


Figure 19. Average total branch basal area per tree (cm^2) by half-log, management regime, and planting density in the Piedmont/ Upper Coastal Plain.

3.2.1. Average branch basal area per tree for 0-24 ft stem height

Management intensity, density, and the management by density interaction were significant effects for average branch basal area per tree in the lower 24 feet of the stem in both regions (Table 17).

In the Lower Coastal Plain management regime the branch basal area per tree for intensive management was on average 42 cm^2 more than for operational management, with the average on the intensive being 209 cm^2/tree, and the average on the operational being 167 cm^2/tree (Figure 20). In the Piedmont/Upper Coastal Plain the branch basal area/tree on the intensive management was on average 56 cm^2/tree more than on the operational management, with the average on the intensive being 245 cm^2/tree, and the average on the operational being 189 cm^2/tree (Figure 20).

Table 17. Analysis of variance results for average branch basal area per tree in the lower 24 ft of the stem in each region.

	Lower Coastal Plain		**Piedmont/Upper Coastal Plain**	
Source	Type III F	Pr > F	Type III F	Pr > F
Management	33.76	0.0021*	40.89	0.0007*
Density	109.76	< 0.0001*	109.93	<0.0001 *
Management*Density	5.40	0.0017*	15.06	<0.0001 *

* Significant at $\alpha = 5\%$

For the planting density factor, the 300 tpa treatment yielded mean branch basal area per tree values that were significantly greater than those of other densities (Figure 21). There were no significant differences between the two higher densities (1500, and 1800 tpa) in either region. As planting density increased, average branch basal area/tree decreased from 377 cm^2 at 300 tpa to 137 cm^2 at 1800 tpa in the Lower Coastal Plain, and from 415 cm^2 at 300 tpa to 158 cm^2 at 1800 tpa in the Piedmont/Upper Coastal Plain.

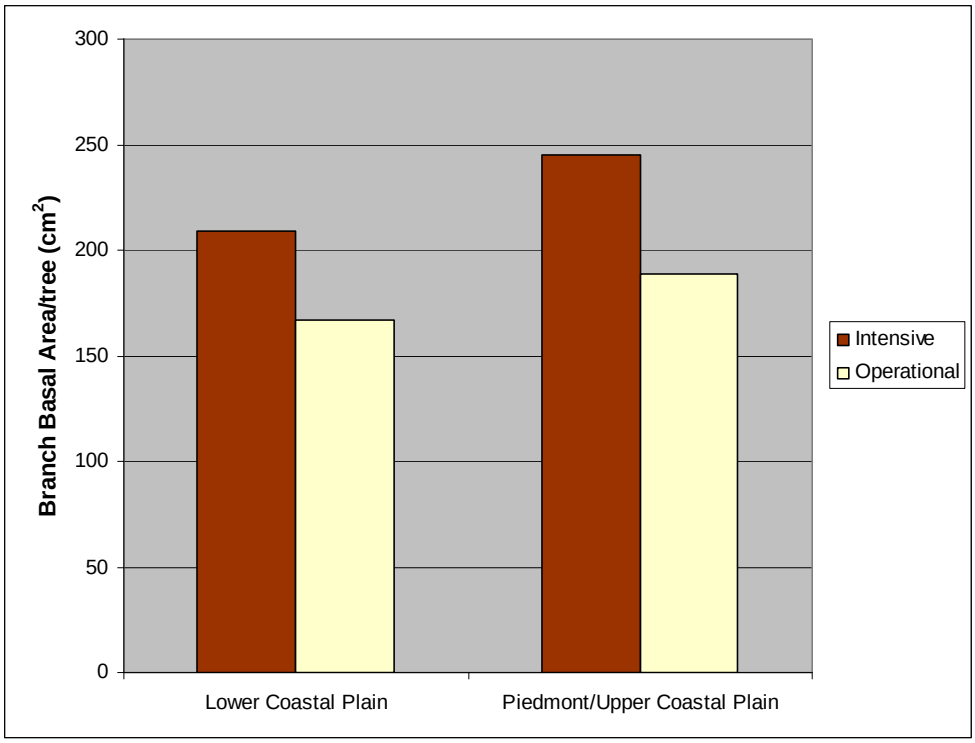


Figure 20. Average branch basal area per tree (cm^2) in the lower 24 ft of the stem by management regime and region.

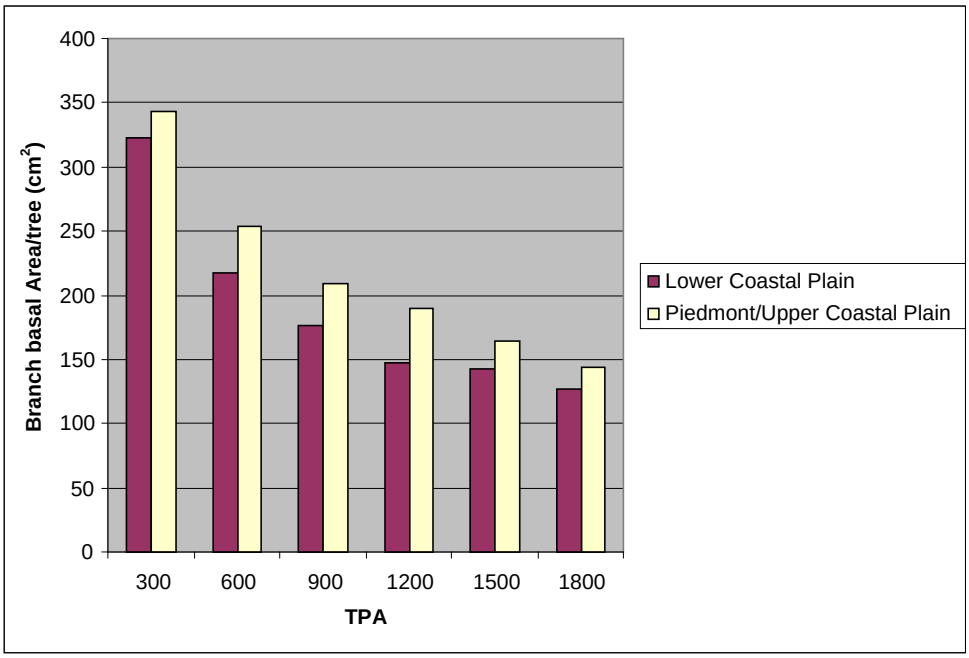


Figure 21. Average branch basal area per tree (cm^2) in the lower 24 ft of the stem by planting density and region.

There was a consistent trend toward lower average branch basal area/tree values as density increased for both intensive and operational management (Figure 22). At each density, the intensively managed plots had larger average branch basal area/tree than the operational plots, but the difference tended to decrease as the density increased.

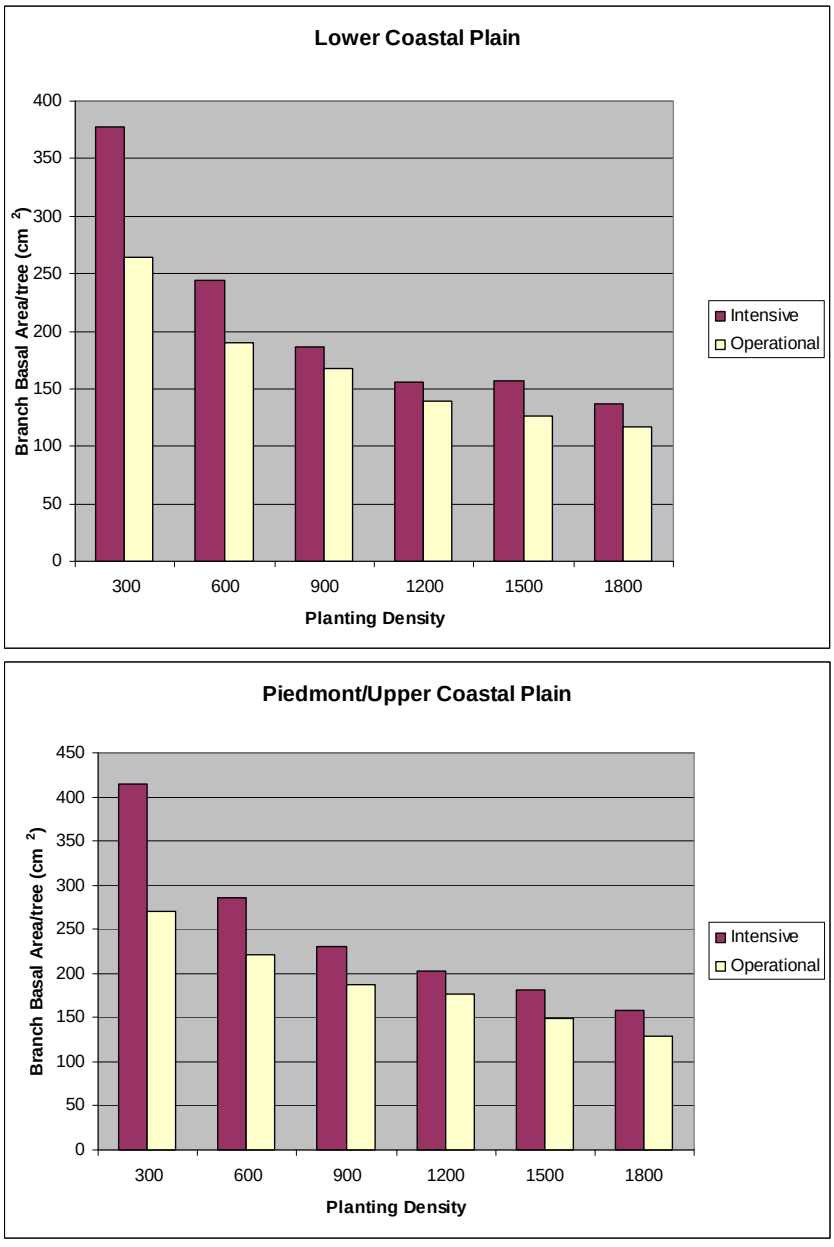


Figure 22. Average branch basal area per tree (cm^2) in the lower 24 ft of the stem by planting density, management regime and region.

Results from pairwise multiple comparisons are presented in Table 18 The intensive management regime at 300 tpa (IN300) yielded the largest average branch basal area/tree, and it was significantly different from those of other treatment combinations. IN600 (intensive at 600 tpa) was significantly different from all treatment combinations with the exception of OP300. There were no significant differences among the three highest planting densities (1200, 1500, and 1800 tpa) within a management regime in the Lower Coastal Plain.

Table 18. P-values of Tukey's studentized multiple comparison tests of the differences among the average branch basal area per tree (cm^2), in the lower 24 ft of the stem, across all management regime and planting density treatment combinations.

Lower Coastal Region											
	IN600	**IN900**	**IN1200**	**IN1500**	**IN1800**	**OP300**	**OP600**	**OP900**	**OP1200**	**OP1500**	**OP1800**
IN300	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**
IN600		**0.029**	**<.0001**	**<.0001**	**<.0001**	0.713	**0.003**	**<.0001**	**<.0001**	**<.0001**	**<.0001**
IN900			**0.044**	**0.023**	**0.003**	**0.013**	0.334	**0.046**	**0.002**	**<.0001**	**<.0001**
IN1200				0.759	0.272	**<.0001**	0.266	0.980	0.180	**0.037**	**0.010**
IN1500					0.424	**<.0001**	0.160	0.740	0.296	0.071	**0.021**
IN1800						**<.0001**	**0.033**	0.262	0.801	0.292	0.111
OP300							**0.001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**
OP600								0.277	**0.019**	**0.003**	**0.001**
OP900									0.173	**0.035**	**0.010**
OP1200										0.419	0.175
OP1500											0.570

Piedmont/Upper Coastal Region											
	IN600	**IN900**	**IN1200**	**IN1500**	**IN1800**	**OP300**	**OP600**	**OP900**	**OP1200**	**OP1500**	**OP1800**
IN300	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**
IN600		**0.005**	**<.0001**	**<.0001**	**<.0001**	0.974	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**
IN900			0.354	**0.009**	**<.0001**	0.106	0.984	**0.015**	**0.003**	**<.0001**	**<.0001**
IN1200				0.854	**0.019**	**<.0001**	0.968	0.932	0.576	**0.003**	**<.0001**
IN1500					0.532	**<.0001**	0.149	1.000	1.000	0.156	**0.004**
IN1800						**<.0001**	**0.001**	0.402	0.821	1.000	0.480
OP300							**0.006**	**<.0001**	**<.0001**	**<.0001**	**<.0001**
OP600								0.222	0.054	**<.0001**	**<.0001**
OP900									1.000	0.102	**0.002**
OP1200										0.361	**0.013**
OP1500											0.907

References: first two letters refer to the management regime intensity treatment (IN: intensive, OP: operational Intensive). The last three digits refer to the planting density (300, 600, 900, 1200, 1500, 1800 TPA). Significance differences are in bold and are defined as P-values <0.05.

There were significant linear trends of average branch basal area per tree across densities for the regions under study (Table 19). In the Lower Coastal Plain, operational management yielded average branch basal area/tree that decreased linearly from 264 cm^2 when the planting density was 300 tpa to 117 cm^2 when the density was 1,800 tpa (Figure 22). For intensive management, the average branch basal area/tree decreased linearly from 377 cm^2 at 300 tpa to 136 cm^2 at 1,800 tpa. In the Piedmont/Upper Coastal Plain, operational management yielded average branch basal area/tree that decreased linearly from 271 cm^2 when the planting density was 300 tpa to 129 cm^2 when the density was 1,800 tpa. For intensive

management, the average branch basal area/tree decreased linearly from 415 cm^2 at 300 tpa to 158 cm^2 at 1,800 tpa.

Table 19. Linear contrasts: average branch basal area per tree (cm^2) in the lower 24 ft of the stem by planting density for each region.

	Lower Coastal Plain		**Piedmont/Upper Coastal Plain**	
Contrast	Type III F	Pr > F	Type III SS	Pr > F
Linear Trend across Density (both Management Regimes)	447.60	<0 .0001 *	488.26	<0.0001*
Linear Trend across Density at Intensive Regime	286.40	< 0.0001 *	552.12	<0.0001 *
Linear Trend across Density at Operational Regime	109.67	< 0.0001 *	177.64	<0.0001 *

* Significant at $\alpha = 5\%$

3.2.2. Branch basal area per tree for 0-16 ft stem heights

Management intensity, density and the management by density interaction for average branch basal area per tree in the lower 16 feet of the stem were significant in both regions (Table 20).

Table 20. Analysis of variance results for average branch basal area per tree in the lower 16 ft of the stem in each region.

	Lower Coastal Plain		**Piedmont/Upper Coastal Plain**	
Source	Type III F	Pr > F	Type III F	Pr > F
Management	84.09	0.0003*	24.71	0.0025*
Density	107.13	< 0.0001*	71.70	<0.0001 *
Management*Density	11.00	<0.0001*	15.11	<0.0001 *

* Significant at $\alpha = 5\%$

In the Lower Coastal Plain the branch basal area per tree for the intensive management was on average 37 cm^2 more than for operational management, with the average for intensive being 130 cm^2/tree, and the average for operational being 93 cm^2/tree (Figure 23). In the Piedmont/Upper Coastal Plain, the branch basal area/tree for intensive management was on average 43 cm^2/tree more than for operational management, with the average on the intensive being 167 cm^2/tree, and

the average on the operational being 124 cm^2/tree. See for a graphical comparison of the silvicultural treatment effect on the branch basal area per tree among regions.

For planting density factor, the 300 tpa treatment yielded branch basal area values significantly greater than those of other densities (Figure 24). There were no significant differences between the three higher densities (1200, 1500, and 1800 tpa) in either region. As planting density increased, average branch basal area/tree decreased from 192 cm^2 at 300 tpa to 77 cm^2 at 1800 tpa in the Lower Coastal Plain, and from 248 cm^2 at 300 tpa to 93 cm^2 at 1800 tpa in the Piedmont/Upper Coastal Plain.

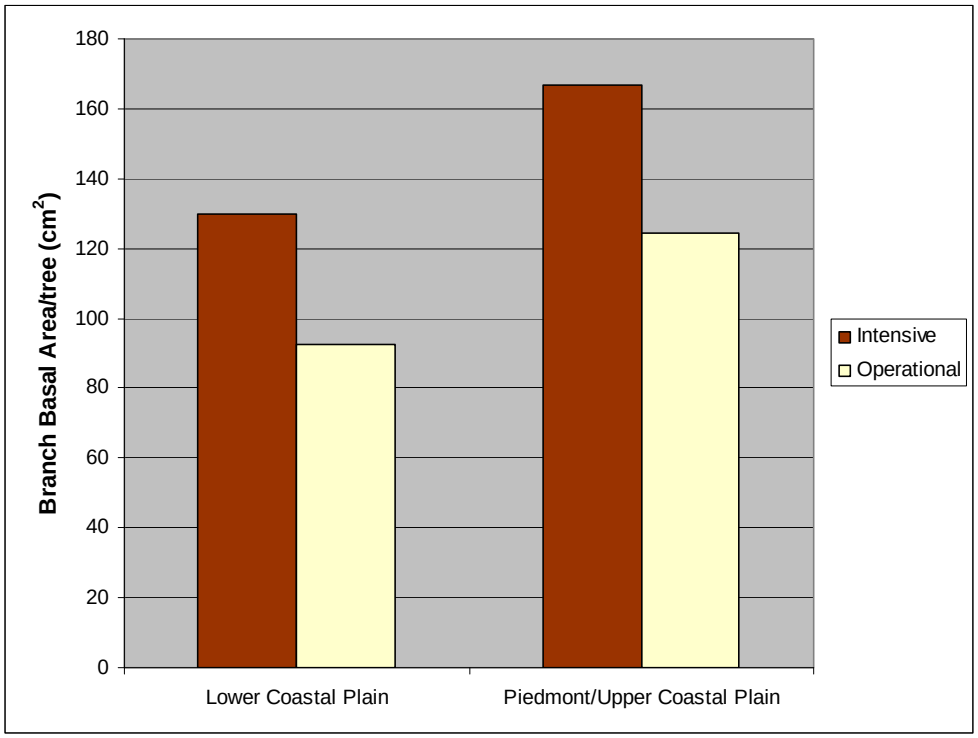


Figure 23. Average branch basal area per tree (cm^2) in the lower 16 ft of the stem by management regime and region.

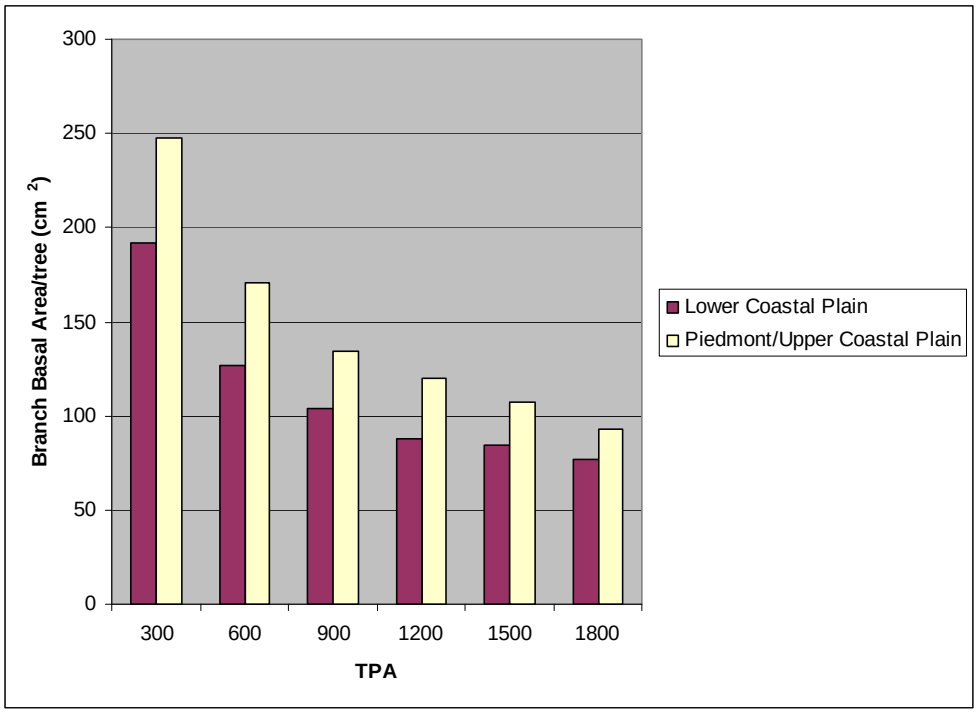


Figure 24. Average branch basal area per tree (cm^2) in the lower 16 ft of the stem by planting density and region.

There was a consistent trend toward lower average branch basal area per tree values as density increased for both intensive and operational management (Figure 25). At each density, intensively managed plots had larger average branch basal area per tree than operational plots, but the difference tended to decrease as the density increased.

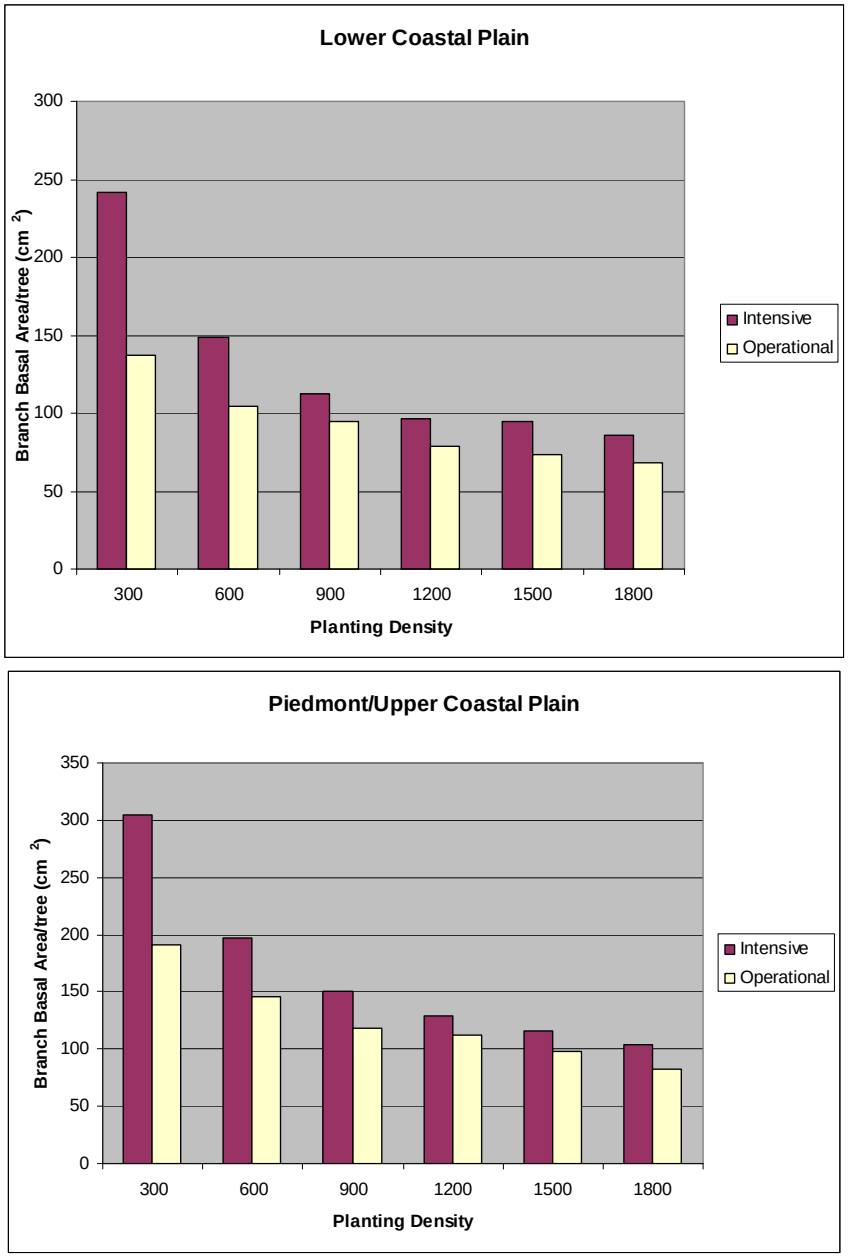


Figure 25. Average branch basal area per tree (cm^2) in the lower 16 ft of the stem by planting density, management regime and region.

Results from pairwise multiple comparisons are presented in Table 21. The intensive management regime at 300 tpa (IN300) yielded significantly greater branch basal area per tree than other treatment combinations (Table 21). IN600 was significantly different from all treatment combinations with the exception of OP300 in both regions. There were no significant differences among the three highest planting densities (1200, 1500, and 1800 tpa) within a management regime, and across management regimes.

Table 21. P-values of Tukey's studentized multiple comparison tests of the differences among the average branch basal area per tree (cm^2), in the lower 16 ft of the stem, across all management regime and planting density treatment combinations.

Lower Coastal Region											
	IN600	IN900	IN1200	IN1500	IN1800	OP300	OP600	OP900	OP1200	OP1500	OP1800
IN300	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**
IN600		0.052	**0.001**	**0.0002**	**<.0001**	0.094	**0.001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**
IN900			0.105	**0.032**	**0.011**	0.763	0.051	**0.016**	**0.001**	**0.0003**	**<.0001**
IN1200				0.566	0.291	0.058	0.715	0.370	0.053	**0.018**	**0.006**
IN1500					0.623	**0.017**	0.834	0.744	0.160	0.062	**0.023**
IN1800						**0.005**	0.484	0.868	0.350	0.157	0.065
OP300							**0.027**	**0.008**	**0.001**	**0.001**	**<.0001**
OP600								0.592	0.109	**0.040**	**0.014**
OP900									0.274	0.116	**0.046**
OP1200										0.616	0.337
OP1500											0.641

Piedmont/Upper Coastal Region											
	IN600	IN900	IN1200	IN1500	IN1800	OP300	OP600	OP900	OP1200	OP1500	OP1800
IN300	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**
IN600		**0.003**	**<.0001**	**<.0001**	**<.0001**	1.000	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**
IN900			0.490	**0.043**	**0.001**	**0.020**	0.996	**0.029**	**0.010**	**<.0001**	**<.0001**
IN1200				0.974	0.248	**<.0001**	0.976	0.941	0.758	0.059	**0.001**
IN1500					0.939	**<.0001**	0.337	1.000	1.000	0.578	**0.025**
IN1800						**<.0001**	**0.015**	0.973	0.999	1.000	0.463
OP300							**0.001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**
OP600								0.257	0.113	**0.002**	**<.0001**
OP900									1.000	0.683	**0.038**
OP1200										0.903	0.099
OP1500											0.878

References: first two letters refer to the management regime intensity treatment (IN: intensive, OP: operational Intensive). The last three digits refer to the planting density (300, 600, 900, 1200, 1500, 1800 TPA). Significance differences are in bold and are defined as P-values <0.05.

There were significant linear trends of average branch basal area per tree in whorls at heights 0-16 ft across densities in the regions under study. In the Lower Coastal Plain, operational management yielded average branch basal area/tree that decreased linearly from 137 cm^2 when the planting density was 300 tpa to 68 cm^2 when the density was 1,800 tpa (Figure 25). For intensive management, average branch basal area/tree decreased linearly from 242 cm^2 at 300 tpa to 86 cm^2 at 1,800 tpa. In the Piedmont/Upper Coastal Plain, operational management yielded average branch basal area/tree that decreased linearly from 191 cm^2 when the planting density was 300 tpa to 82 cm^2 when the density was 1,800 tpa. For intensive management, average branch basal area/tree decreased linearly from 305 cm^2 at 300 tpa to 104 cm^2 at 1,800 tpa.

Table 22. Linear contrasts: average branch basal area per tree (cm^2) in the lower 16 ft of the stem by planting density in each region.

	Lower Coastal Plain		**Piedmont/Upper Coastal Plain**	
Contrast	Type III F	Pr > F	Type III SS	Pr > F
Linear Trend across Density (both Management Regimes)	425.92	<0 .0001 *	300.52	<0.0001*
Linear Trend across Density at Intensive Regime	265.91	< 0.0001 *	499.32	<0.0001 *
Linear Trend across Density at Operational Regime	56.66	< 0.0001 *	145.84	<0.0001 *

* Significant at $\alpha = 5\%$

3.2.3. Branch basal area per tree for 0-8 ft stem heights

Management intensity, density and the management by density interaction for average branch basal area per tree in the lower 8 feet of the stem were significant in both regions (Table 23).

Table 23. Analysis of variance results for average branch basal area per tree in the lower 8 ft of the stem in each region.

	Lower Coastal Plain		**Piedmont/Upper Coastal Plain**	
Source	Type III F	Pr > F	Type III F	Pr > F
Management	247.89	<.0001*	40.91	0.0007*
Density	77.52	<.0001*	49.14	<0.0001*
Management*Density	15.42	<.0001*	10.57	<0.0001*

* Significant at $\alpha = 5\%$

In the Lower Coastal Plain the branch basal area per tree for intensive management was on average 25 cm^2 more than for operational management, with the average on the intensive being 56 cm^2/tree, and the average on the operational being 31 cm^2/tree (Figure 26). In the Piedmont/Upper Coastal Plain the branch basal area/tree for intensive management was on average 27 cm^2/tree more than for operational management, with the average for intensive being 76 cm^2/tree, and the average for operational being 49 cm^2/tree.

For the planting density factor, the 300 tpa treatment yielded mean branch basal area values that were significantly greater than those of other densities (Figure 27). There were no significant differences between the three higher densities (1200, 1500, and 1800 tpa) in both regions. As planting density increased, average branch basal area/tree decreased from 74 cm^2 at 300 tpa to 31 cm^2 at 1800 tpa in the Lower Coastal Plain, and from 106 cm^2 at 300 tpa to 39 cm^2 at 1800 tpa in the Piedmont/Upper Coastal Plain.

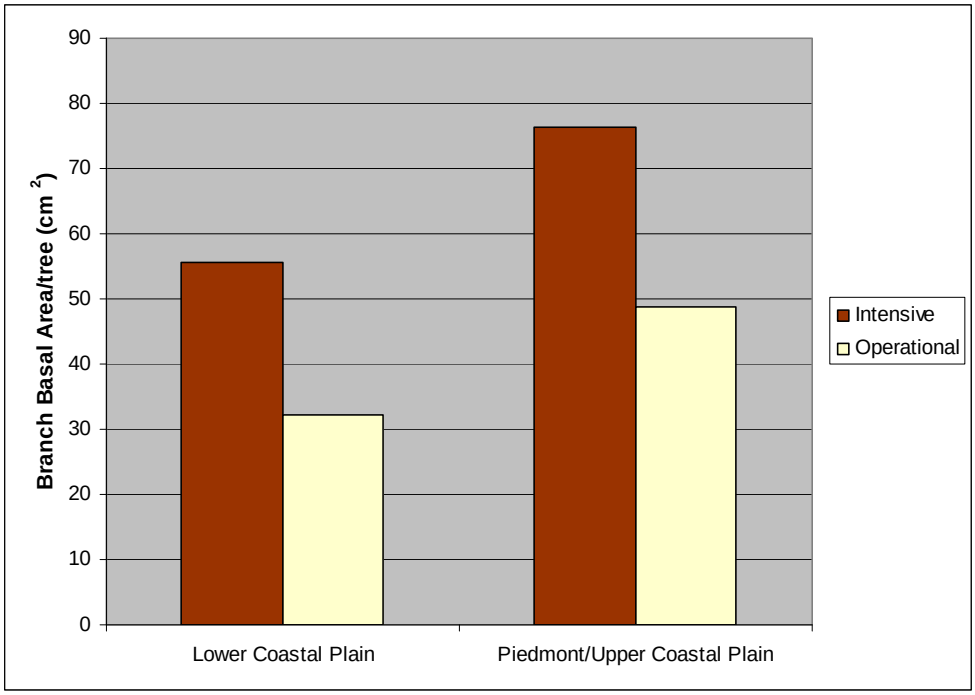


Figure 26. Average branch basal area per tree (cm^2) in the lower 8 ft of the stem by management regime and region.

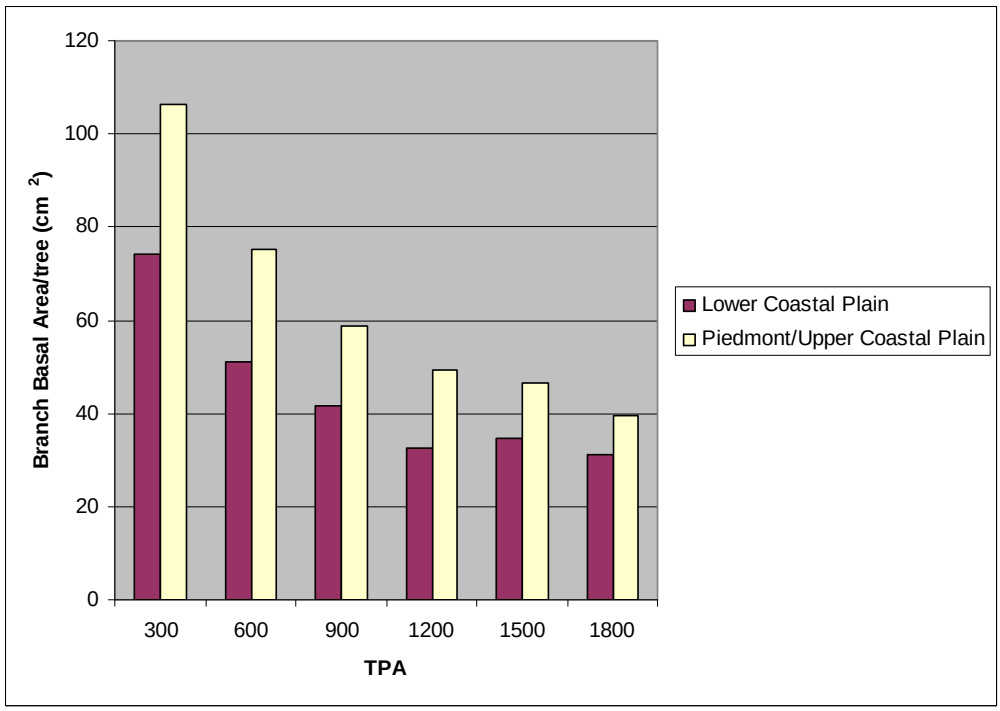


Figure 27. Average branch basal area per tree (cm^2) in the lower 8 ft of the stem by planting density and region.

There was a trend toward lower average branch basal area/tree values as density increased for both intensive and operational management (Figure 28). At each density, the intensively managed plots had larger average branch basal area/tree than the operational plots, but the difference tended to decrease as the density increased.

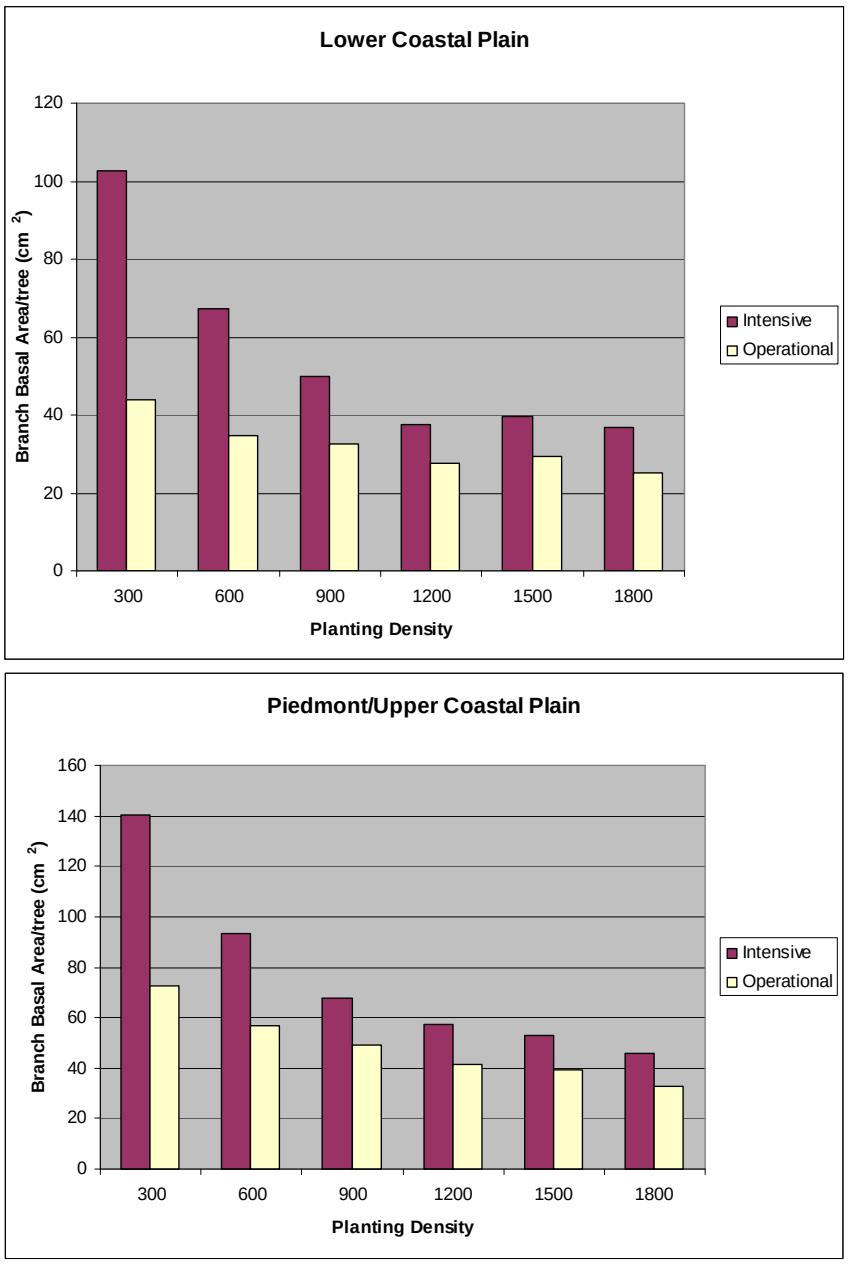


Figure 28. Average branch basal area per tree (cm^2) in the lower 8 ft of the stem by planting density, management regime and region.

Results from pairwise multiple comparisons are presented in Table 24. The intensive management regime at 300 tpa (IN300) yielded an average branch basal area/tree significantly greater than those of all other treatment combinations. IN600 was significantly different from all treatment combinations in the Lower Coastal Plain, and different from all but OP300 in the Piedmont/Upper Coastal Plain. There were no significant differences among the four higher planting densities (900, 1200, 1500, and 1800 tpa) within a management regime, and across management regimes, in the Piedmont/Upper Coastal Plain.

Table 24. P-values of Turkey's studentized multiple comparison tests of the differences among the average branch basal area per tree (cm^2), in the lower 8 ft of the stem, across all management regime and planting density treatment combinations.

Lower Coastal Region											
	IN600	**IN900**	**IN1200**	**IN1500**	**IN1800**	**OP300**	**OP600**	**OP900**	**OP1200**	**OP1500**	**OP1800**
IN300	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**
IN600		**0.028**	**0.0002**	**0.0002**	**<.0001**	**0.0002**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**
IN900			0.055	0.055	**0.027**	0.061	**0.006**	**0.004**	**0.001**	**0.0019**	**0.0002**
IN1200				0.999	0.738	0.957	0.323	0.248	0.074	0.160	**0.024**
IN1500					0.738	0.958	0.324	0.247	0.073	0.161	**0.024**
IN1800						0.699	0.509	0.406	0.140	0.278	**0.050**
OP300							0.298	0.227	0.067	0.146	**0.0216**
OP600								0.862	0.401	0.665	0.177
OP900									0.503	0.795	0.236
OP1200										0.681	0.598
OP1500											0.351

Piedmont/Upper Coastal Region											
	IN600	**IN900**	**IN1200**	**IN1500**	**IN1800**	**OP300**	**OP600**	**OP900**	**OP1200**	**OP1500**	**OP1800**
IN300	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**
IN600		**0.032**	**0.0006**	**0.0001**	**<.0001**	0.107	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**
IN900			0.916	0.587	0.061	1.000	0.764	0.155	**0.010**	**0.0043**	**0.0003**
IN1200				1.000	0.747	0.638	1.000	0.939	0.289	0.166	**0.016**
IN1500					0.975	0.274	1.000	0.999	0.658	0.463	0.068
IN1800						**0.017**	0.905	1.000	1.000	0.994	0.620
OP300							0.428	**0.049**	**0.002**	**0.001**	**<.0001**
OP600								0.990	0.474	0.302	**0.035**
OP900									0.985	0.927	0.349
OP1200										1.000	0.965
OP1500											0.995

References: first two letters refer to the management regime intensity treatment (IN: intensive, OP: operational Intensive). The last three digits refer to the planting density (300, 600, 900, 1200, 1500, 1800 TPA). Significance differences are in bold and are defined as P-values <0.05.

There were significant linear trends of average branch basal area per tree in the lower 8 ft of the stem across densities for the regions under study (Table 25). In the Lower Coastal Plain, operational management yielded average branch basal area/tree that decreased linearly from 44 cm^2 when the planting density was 300 tpa to 25 cm^2 when the density was 1,800 tpa (Figure 28). For intensive management, the average branch basal area/tree decreased linearly from 103 cm^2 at 300 tpa to 37 cm^2 at 1,800 tpa. In the Piedmont/Upper Coastal Plain, operational management yielded average branch basal area/tree that decreased linearly from 73 cm^2 when the planting density was 300 tpa to 33 cm^2 when the density was 1,800 tpa. For intensive management, the average branch basal area/tree decreased linearly from 140 cm^2 at 300 tpa to 46 cm^2 at 1,800 tpa.

Table 25. Linear contrasts: average branch basal area per tree (cm^2) in the lower 8 ft of the stem by planting density in each region.

	Lower Coastal Plain		**Piedmont/Upper Coastal Plain**	
Contrast	Type III F	Pr > F	Type III SS	Pr > F
Linear Trend across Density (both Management Regimes)	305.24	<0 .0001*	209.68	<0.0001*
Linear Trend across Density at Intensive Regime	225.33	< 0.0001*	238.50	<0.0001*
Linear Trend across Density at Operational Regime	14.97	< 0.0001*	44.85	<0.0001*

* Significant at $\alpha = 5\%$

3.2.4. Branch basal area per tree for 8-16 ft stem heights

Management intensity, density and the management by density interaction for average branch basal area per tree at heights 8-16 feet of the stem were significant in both regions (Table 26)

Table 26. Analysis of variance results for average branch basal area at heights 8-16 ft of the stem in each region.

	Lower Coastal Plain		**Piedmont/Upper Coastal Plain**	
Source	Type III F	Pr > F	Type III F	Pr > F
Management	14.32	0.0128*	9.06	0.0235*
Density	65.03	<.0001*	66.37	<0.0001*
Management*Density	4.94	0.0028*	6.66	0.0003 *

* Significant at $\alpha = 5\%$

In the Lower Coastal Plain the branch basal area per tree for intensive management was on average 13 cm^2 more than on the operational management, with the average for intensive being 74 cm^2/tree, and the average for operational being 61 cm^2/tree (Figure 29). In the Piedmont/Upper Coastal Plain the branch basal area/tree for intensive management was on average 15 cm^2/tree more than for operational management, with the average on the intensive being 91 cm^2/tree, and the average on the operational being 76 cm^2/tree.

For the planting density factor, the 300 tpa treatment yielded mean branch basal area values significantly greater than those of all other densities (Figure 30). There were no significant differences between the two higher densities (1500, and 1800 tpa) in either region. As the planting density increased, the average branch basal area/tree decreased from 117 cm^2 at 300 tpa to 46 cm^2 at 1800 tpa in the Lower Coastal Plain, and from 141 cm^2 at 300 tpa to 54 cm^2 at 1800 tpa in the Piedmont/Upper Coastal Plain.

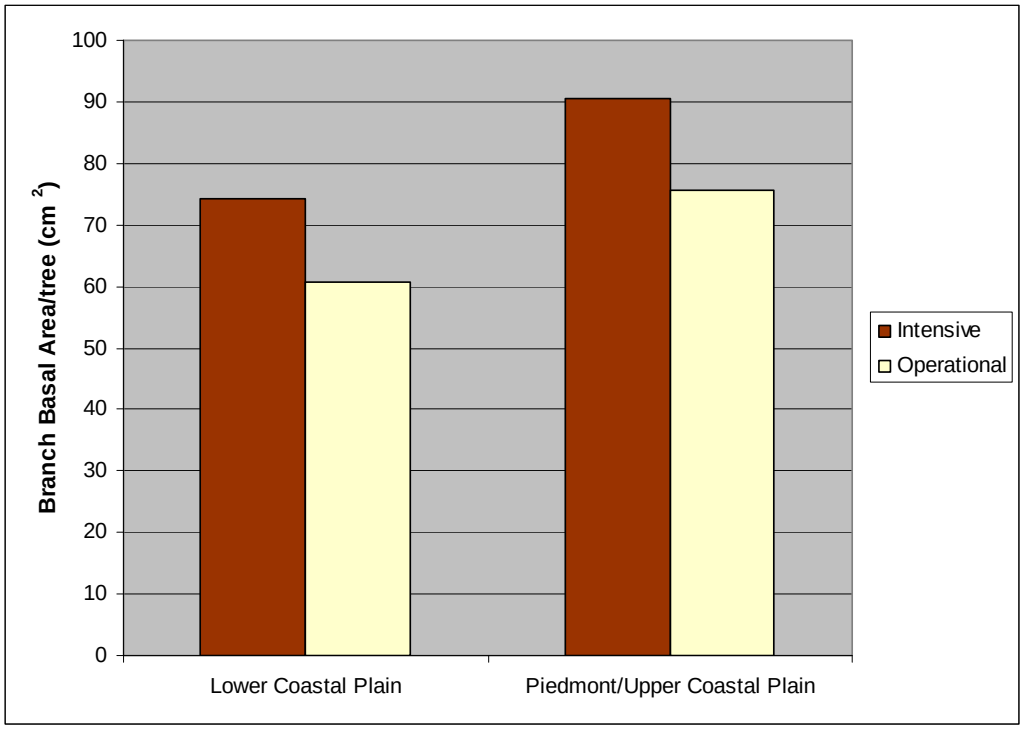


Figure 29. Average branch basal area per tree (cm^2) at heights 8-16 ft of the stem by management regime and region.

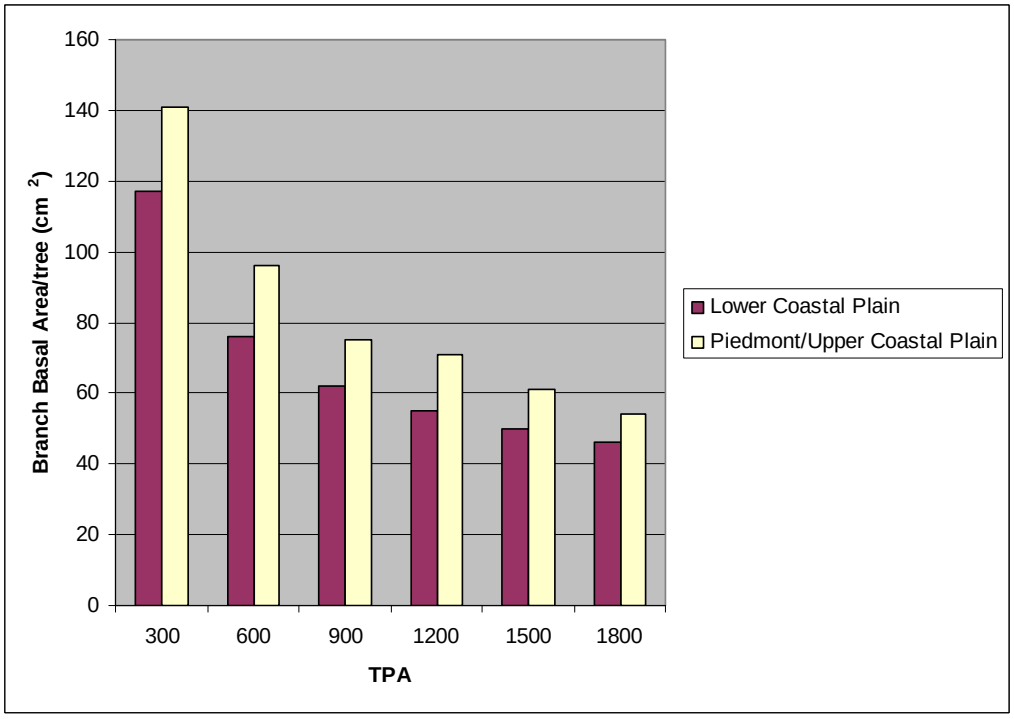


Figure 30. Average branch basal area per tree (cm^2) at heights 8-16 ft of the stem by planting density and region.

There was a trend toward lower average branch basal area/tree values as density increased for both intensive and operational management (Figure 31). At each density, the intensively managed plots had larger average branch basal area/tree than the operational plots, but the difference tended to decrease as the density increased.

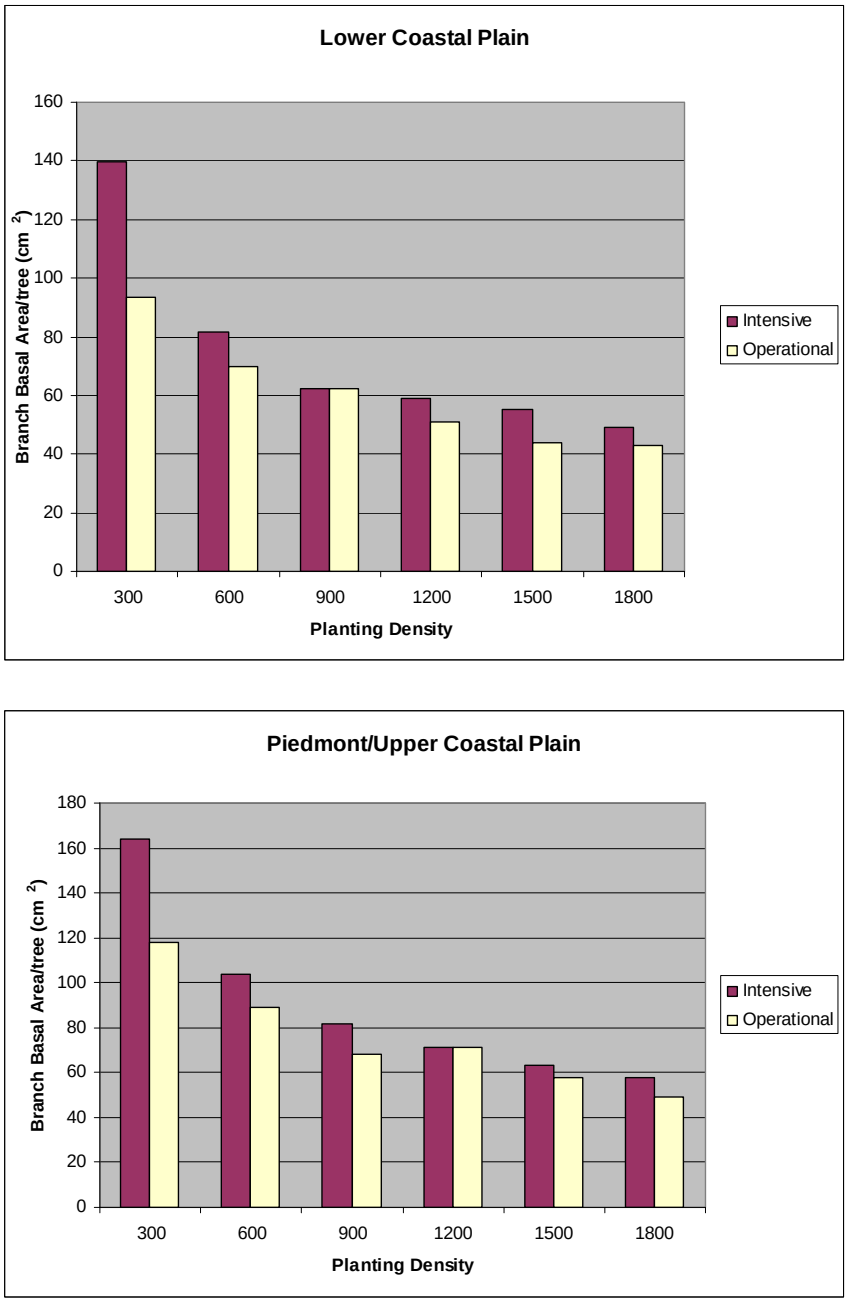


Figure 31. Average branch basal area per tree (cm^2) at heights 8-16 ft of the stem by planting density, management regime and region.

Results from pairwise multiple comparisons are presented in Table 27. The intensive management regime at 300 tpa (IN300) yielded an average branch basal area/tree significantly larger than those of all other treatment combinations. OP300 was significantly different from all treatment combinations, but IN600 in the Piedmont/Upper Coastal Plain, and from all treatment combinations but IN600 and IN900 in the Lower Coastal Plain. There were no significant differences among the three higher planting densities (1200, 1500, and 1800 tpa) within a management regime, and across management regimes in either region (Table 27).

Table 27. P-values of Tukey's studentized multiple comparison tests of the differences among the average branch basal area per tree (cm^2), at heights 8-16 ft of the stem, across all management regime and planting density treatment combinations.

Lower Coastal Region											
	IN600	**IN900**	**IN1200**	**IN1500**	**IN1800**	**OP300**	**OP600**	**OP900**	**OP1200**	**OP1500**	**OP1800**
IN300	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**
IN600		0.279	**0.0149**	**0.002**	**0.001**	0.484	**0.015**	**0.002**	**0.001**	**<.0001**	**<.0001**
IN900			0.1444	**0.028**	**0.009**	0.081	0.143	**0.032**	**0.002**	**<.0001**	**<.0001**
IN1200				0.417	0.198	**0.003**	0.997	0.455	0.073	**0.007**	**0.009**
IN1500					0.623	**0.001**	0.419	0.948	0.306	**0.046**	0.056
IN1800						**<.0001**	0.199	0.578	0.589	0.120	0.143
OP300							**0.003**	**0.001**	**<.0001**	**<.0001**	**<.0001**
OP600								0.457	0.074	**0.007**	0.009
OP900									0.277	**0.040**	0.048
OP1200										0.299	0.344
OP1500											0.924

Piedmont/Upper Coastal Region											
	IN600	**IN900**	**IN1200**	**IN1500**	**IN1800**	**OP300**	**OP600**	**OP900**	**OP1200**	**OP1500**	**OP1800**
IN300	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**
IN600		0.104	**0.001**	**<.0001**	**<.0001**	0.655	0.204	**0.001**	**0.001**	**<.0001**	**<.0001**
IN900			0.763	0.112	**0.014**	**0.001**	1.000	0.338	0.683	**0.015**	**0.001**
IN1200				0.974	0.578	**<.0001**	0.550	1.000	1.000	0.587	**0.048**
IN1500					0.999	**<.0001**	0.053	1.000	0.988	0.999	0.522
IN1800						**<.0001**	**0.006**	0.934	0.663	1.000	0.959
OP300							**0.002**	**<.0001**	**<.0001**	**<.0001**	**<.0001**
OP600								0.187	0.465	**0.006**	**0.001**
OP900									1.000	0.938	0.206
OP1200										0.672	0.065
OP1500											0.956

References: first two letters refer to the management regime intensity treatment (IN: intensive, OP: operational Intensive). The last three digits refer to the planting density (300, 600, 900, 1200, 1500, 1800 TPA). Significance differences are in bold and are defined as P-values <0.05.

There were significant linear trends of average branch basal area per tree at heights 8-16 ft of the stem across densities for the regions under study (Table 28). In the Lower Coastal Plain, operational management yielded average branch basal area/tree that decreased linearly from 74 cm^2 when the planting density was 300 tpa to 42 cm^2 when the density was 1,800 tpa (Figure 31). For intensive management, the average branch basal area/tree decreased linearly from 140 cm^2 at 300 tpa to 49 cm^2 at 1,800 tpa. In the Piedmont/Upper Coastal Plain, operational management yielded average branch basal area/tree that decreased linearly from 118 cm^2 when the planting density was 300 tpa to 49 cm^2 when the density was 1,800 tpa. For intensive management the average branch basal area/tree decreased linearly from 164 cm^2 at 300 tpa to 58 cm^2 at 1,800 tpa.

Table 28. Linear contrasts: average branch basal area per tree (cm^2) at heights 8-16 ft of the stem by planting density in each region.

	Lower Coastal Plain		**Piedmont/Upper Coastal Plain**	
Contrast	Type III F	Pr > F	Type III SS	Pr > F
Linear Trend across Density (both Management Regimes)	258.50	<0 .0001*	274.58	<0.0001*
Linear Trend across Density at Intensive Regime	175.62	< 0.0001*	310.70	<0.0001*
Linear Trend across Density at Operational Regime	68.20	< 0.0001*	124.63	<0.0001*

* Significant at $\alpha = 5\%$

3.2.5. Branch basal area per tree for16-24 ft stem heights

For average branch basal area per tree at heights 16-24 ft of the stem, planting density was significant in both regions, while management intensity was significant only in the Piedmont/Upper Coastal Plain (Table 29). There were no significant management by density interactions in either region.

Table 29. Analysis of variance results for average branch diameter at heights 16-24 ft of the stem in each region.

	Lower Coastal Plain		**Piedmont/Upper Coastal Plain**	
Source	Type III F	Pr > F	Type III F	Pr > F
Management	1.03	0.3568	10.03	0.0192*
Density	58.00	<.0001*	17.56	<0.0001*
Management*Density	0.35	0.8777	1.69	0.1680

* Significant at $\alpha = 5\%$

In the Piedmont/Upper Coastal Plain the branch basal area per tree for intensive management was on average 14 cm^2 more than for operational management, with the average on the intensive being 79 cm^2/tree, and the average on the operational being 65 cm^2/tree (Figure 32)

For planting density, the 300 tpa and 600 tpa treatments yielded mean branch basal area values significantly greater than those of all other densities (Figure 33). There were no significant differences between the two higher densities (1500, and 1800 tpa) in either region. As the planting density increased, the average branch basal area/tree decreased from 131 cm^2 at 300 tpa to 50 cm^2 at 1800 tpa in the Lower Coastal Plain, and from 95 cm^2 at 300 tpa to 51 cm^2 at 1800 tpa in the Piedmont/Upper Coastal Plain.

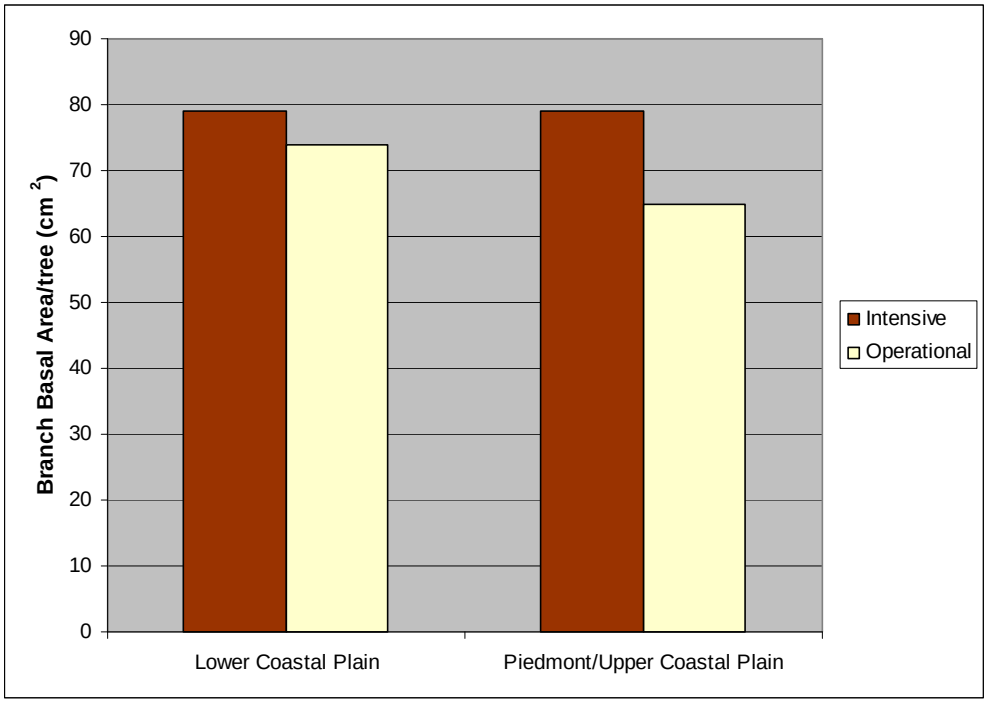


Figure 32. Average branch basal area per tree (cm^2) at heights 16-24 ft of the stem by management regime and region.

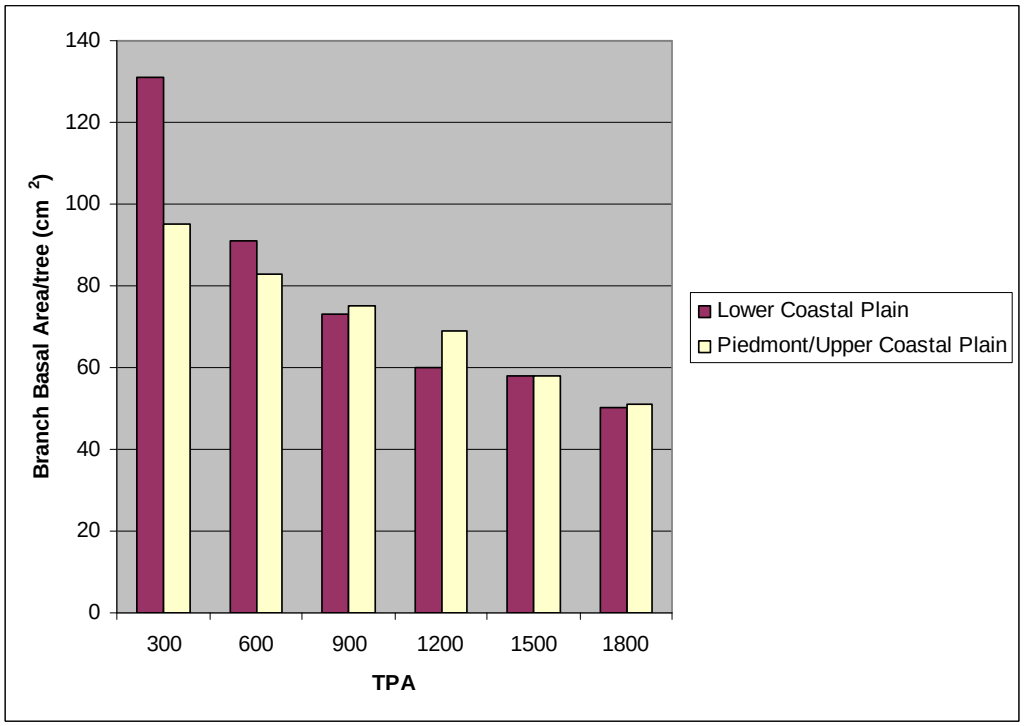


Figure 33. Average branch basal area per tree (cm^2) at heights 16-24 ft of the stem by planting density and region.

There was a trend toward lower average branch basal area/tree values as density increased for both intensive and operational management. At each density, the intensively managed plots had larger average branch basal area/tree than the operational plots (Figure 34). As there were no significant planting density by management regime interactions in either region, pairwise multiple comparisons were not conducted.

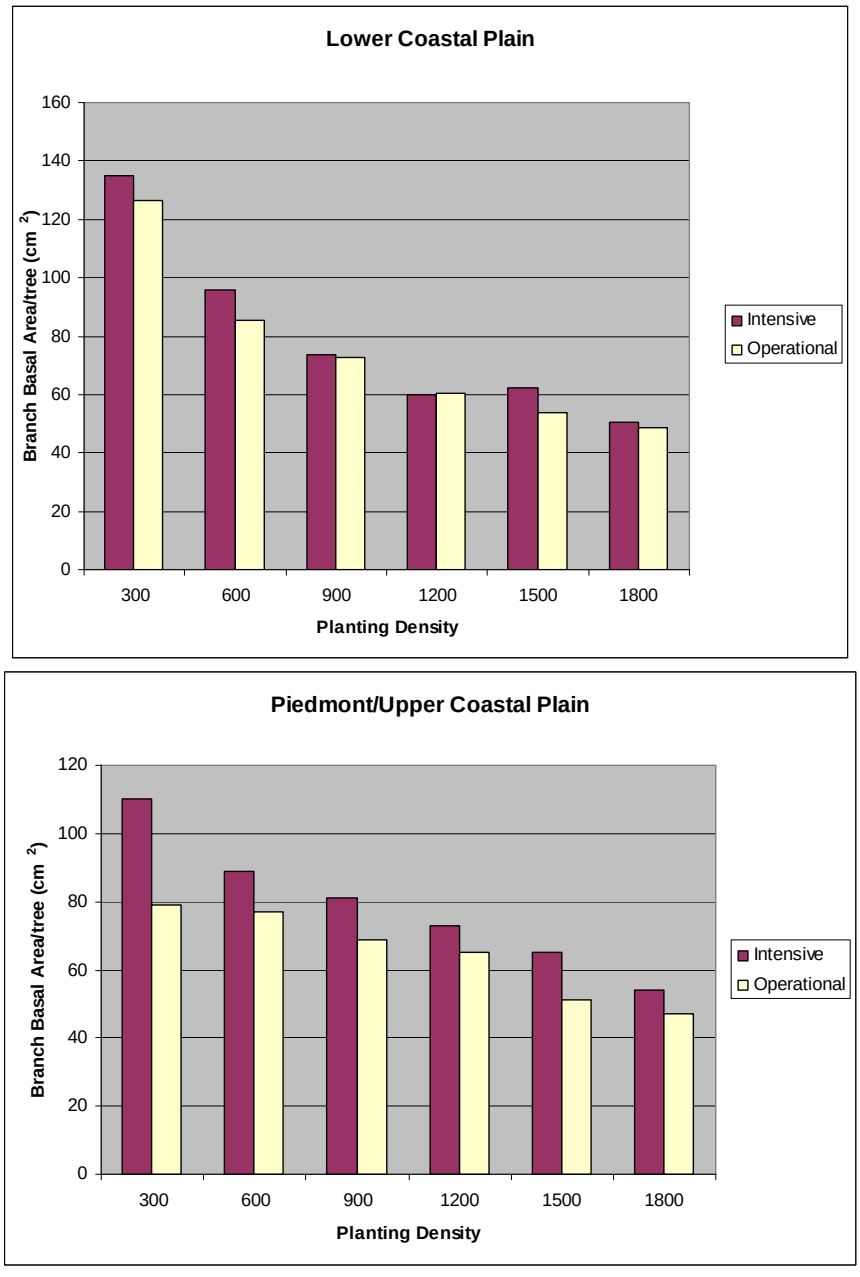


Figure 34. Average branch basal area per tree (cm^2) at heights 16-24 ft of the stem by planting density, management regime and region.

There were significant linear trends of average branch basal area per tree at heights 16-24 ft of the stem across densities for the regions under study (Table 30). In the Lower Coastal Plain, operational management yielded average branch basal area/tree that decreased linearly from 127 cm^2 when the planting density was 300 tpa to 49 cm^2 when the density was 1,800 tpa. For intensive management, the average branch basal area/tree decreased linearly from 135 cm^2 at 300 tpa to 51 cm^2 at 1,800 tpa. In the Piedmont/Upper Coastal Plain, operational management yielded average branch basal area/tree that decreased linearly from 79 cm^2 when the planting density was 300 tpa to 47 cm^2 when the density was 1,800 tpa. For intensive management, the average branch basal area/tree decreased linearly from 110 cm^2 at 300 tpa to 54 cm^2 at 1,800 tpa.

Table 30. Linear contrasts: average branch basal area per tree (cm^2) at heights 16-24 ft of the stem by planting density for each region.

	Lower Coastal Plain		**Piedmont/Upper Coastal Plain**	
Contrast	Type III F	Pr > F	Type III SS	Pr > F
Linear Trend across Density (both Management Regimes)	244.32	<0 .0001*	85.31	<0.0001*
Linear Trend across Density at Intensive Regime	39.03	< 0.0001*	78.56	<0.0001*
Linear Trend across Density at Operational Regime	153.74	< 0.0001*	33.80	<0.0001*

* Significant at $\alpha = 5\%$

3.3. Branch Length

Average length in feet of unbroken branches is summarized across regions, logs, planting densities, and management regimes in Figure 35 and Figure 36.

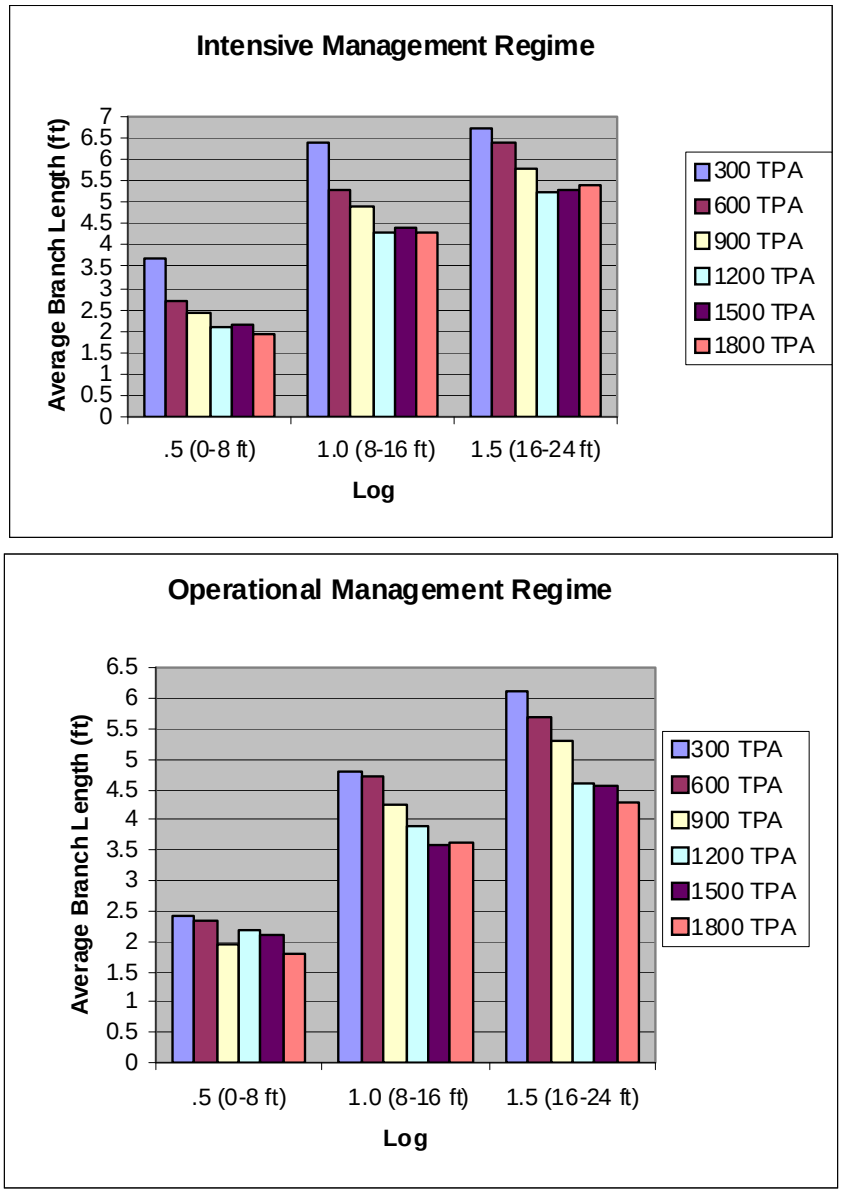


Figure 35. Average branch length (ft) by half-log, management regime, and planting density in the Lower Coastal Plain.

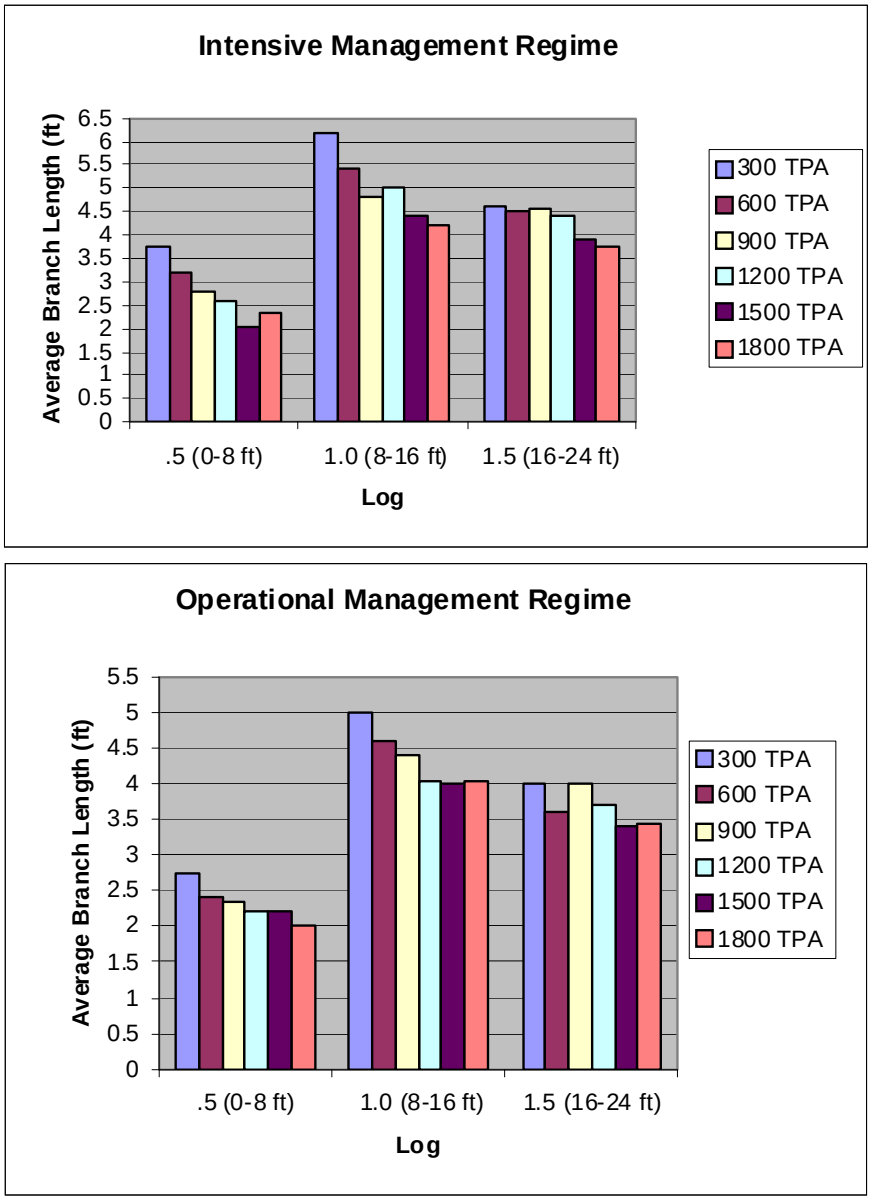


Figure 36. Average branch length (ft) by half-log, management regime, and planting density in the Piedmont/Upper Coastal Plain.

3.3.1. Average branch length for 0-24 ft stem heights

Management and density effects were significant in both regions (Table 31). There was no significant management by density interactions in either region.

Table 31. Analysis of variance results for average branch length (ft) in the lower 24 ft of the stem in each region.

	Lower Coastal Plain		**Piedmont/Upper Coastal Plain**	
Source	Type III F	Pr > F	Type III F	Pr > F
Management	33.63	0.0021*	29.87	0.0016*
Density	15.08	<.0001*	28.57	<.0001*
Management*Density	1.65	0.1832	1.91	0.1230

* Significant at $\alpha = 5\%$

In the Lower Coastal Plain the branch length for intensive management was on average 0.88 ft more than for operational management, with the average on the intensive being 4.85 ft, and the average on the operational being 3.97 ft (Figure 37). In the Piedmont/Upper Coastal Plain the branch length for intensive management was on average 0.60 ft more than for operational management, with the average on the intensive being 3.90 ft, and the average on the operational being 3.30 ft.

For planting density, the 300 tpa treatment yielded mean branch basal area values that were significantly greater than those of all other densities (Figure 38). There were no significant differences between the two higher densities (1500, and 1800 tpa) in either region. As planting density increased, average branch length decreased from 5.22 ft at 300 tpa to 3.92 ft at 1800 tpa in the Lower Coastal Plain, and from 4.21 ft at 300 tpa to 3.17 ft at 1800 tpa in the Piedmont/Upper Coastal Plain region.

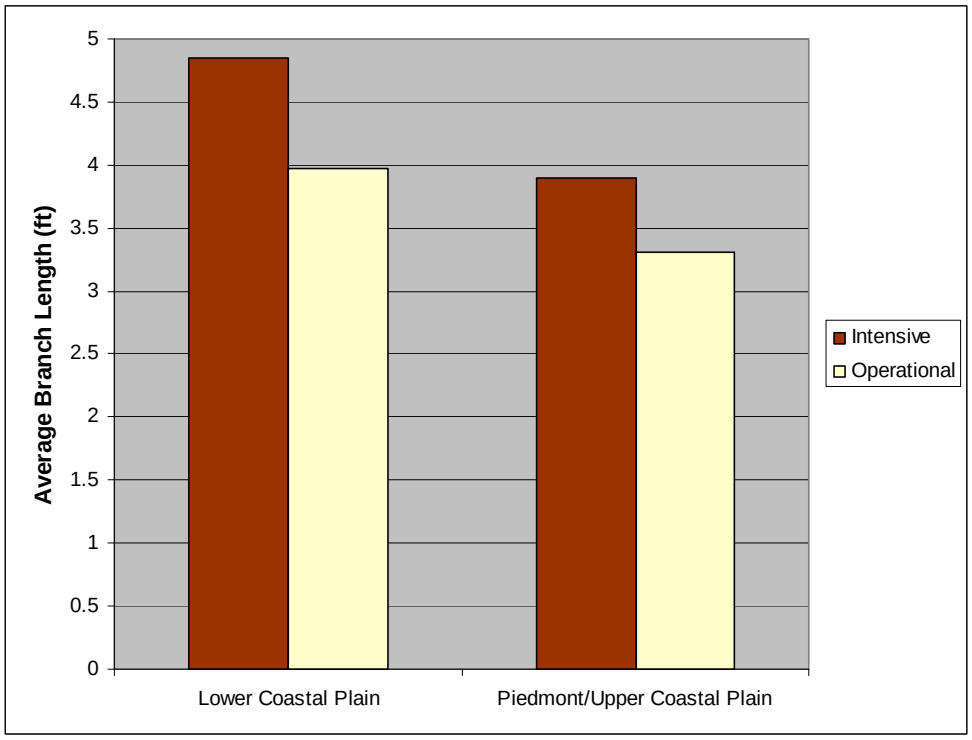


Figure 37. Average branch length (ft) in the lower 24 ft of the stem by management regime and region.

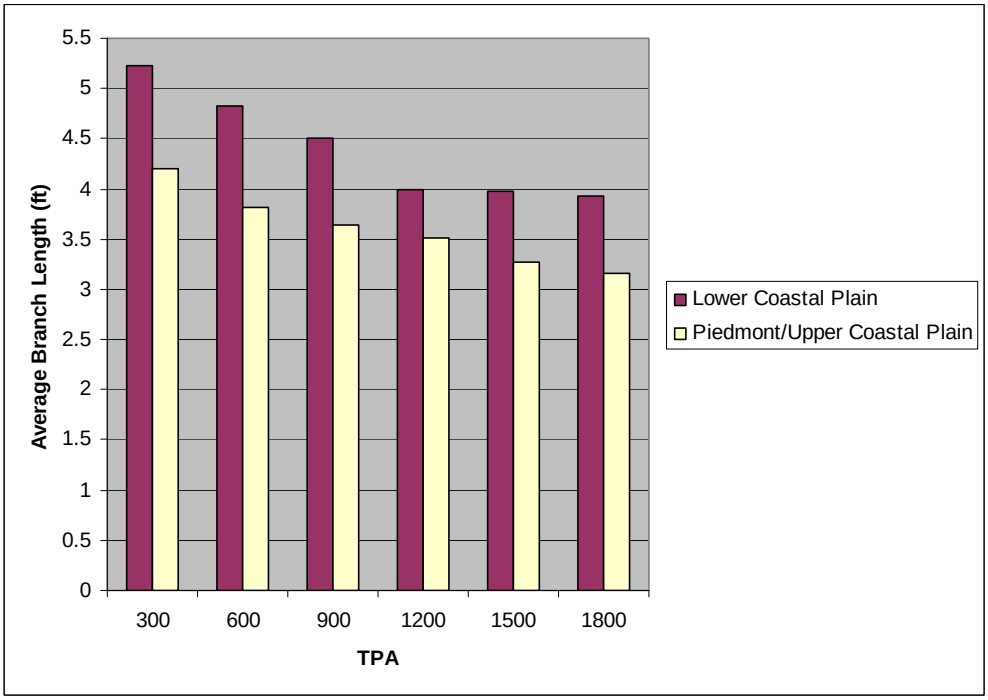


Figure 38. Average branch length (ft) in the lower 24 ft of the stem by planting density and region.

There was a trend toward shorter branches as density increased for both intensive and operational management. At each density, the intensively managed plots had larger average branch length than the operationally managed plots (Figure 39). As there were no significant planting density by management interactions pairwise multiple comparisons were not conducted.

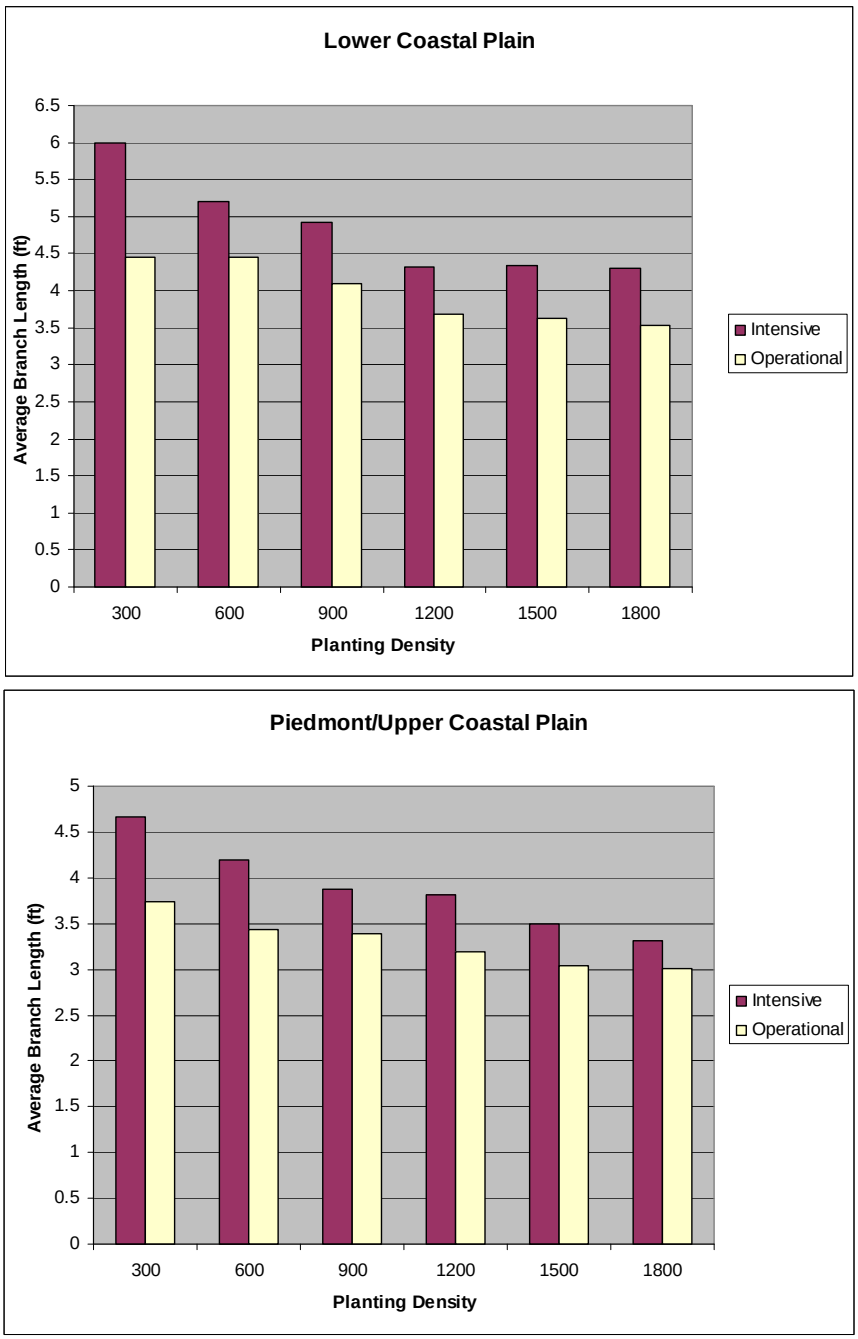


Figure 39. Average branch length (ft) in lower 24 ft of the stem by planting density, management regime and region.

There were significant linear trends in average branch length in the lower 24 ft of the stem across densities in the regions under study (Table 32). In the Lower Coastal Plain, operational management yielded an average branch length that decreased linearly from 4.45 ft when the planting density was 300 tpa to 3.53 ft when the density was 1,800 tpa (Figure 39). For intensive management, the average branch length decreased linearly from 5.99 ft at 300 tpa to 4.30 ft at 1,800 tpa. In the Piedmont/Upper Coastal Plain, operational management yielded an average branch length that decreased linearly from 3.75 ft when the planting density was 300 tpa to 3.00 ft when the density was 1,800 tpa. For intensive management, average length decreased linearly from 4.67 ft at 300 tpa to 3.32 ft at 1,800 tpa.

Table 32. Linear contrasts: average branch length (ft) in the lower 24 ft of the stem by planting density in each region.

	Lower Coastal Plain		**Piedmont/Upper Coastal Plain**	
Contrast	Type III F	Pr > F	Type III SS	Pr > F
Linear Trend across Density (both Management Regimes)	216.07	<.0001*	137.35	<.0001*
Linear Trend across Density at Intensive Regime	122.85	<.0001*	87.85	<.0001*
Linear Trend across Density at Operational Regime	49.07	<.0001*	28.52	<.0001*

* Significant at $\alpha = 5\%$

3.3.2. Average branch length for 0-16 ft stem heights

Management intensity and density effects for the average length of branches in the lower 16 feet of the stem were significant in both regions Table 33. The management by density interaction was significant only in the Lower Coastal Plain.

Table 33. Analysis of variance results for average branch length (ft) in the lower 16 ft of the stem in each region.

	Lower Coastal Plain		**Piedmont/Upper Coastal Plain**	
Source	Type III F	Pr > F	Type III F	Pr > F
Management	21.91	0.0054*	34.81	0.0011*
Density	15.71	<.0001*	34.67	<.0001*
Management*Density	4.19	0.0067*	2.37	0.0627

* Significant at $\alpha = 5\%$

In the Lower Coastal Plain the branch length for intensive management was on average 0.67 ft more than for operational management, with the average on the intensive being 4.03 ft, and the average on the operational being 3.36 ft Figure 40. In the Piedmont/Upper Coastal Plain the branch length for intensive management was on average 0.63 ft more than for operational management, with the average on the intensive being 3.75 ft, and the average on the operational being 3.12 ft.

For planting density, the 300 tpa treatment yielded mean branch length values significantly greater than those of all other densities (Figure 41). There were no significant differences between the three higher densities (1200, 1500, and 1800 tpa) in either region. As planting density increased, average branch length decreased from 4.03 ft at 300 tpa to 3.36 ft at 1800 tpa in the Lower Coastal Plain, and from 3.75 ft at 300 tpa to 3.12 ft at 1800 tpa in the Piedmont/Upper Coastal Plain.

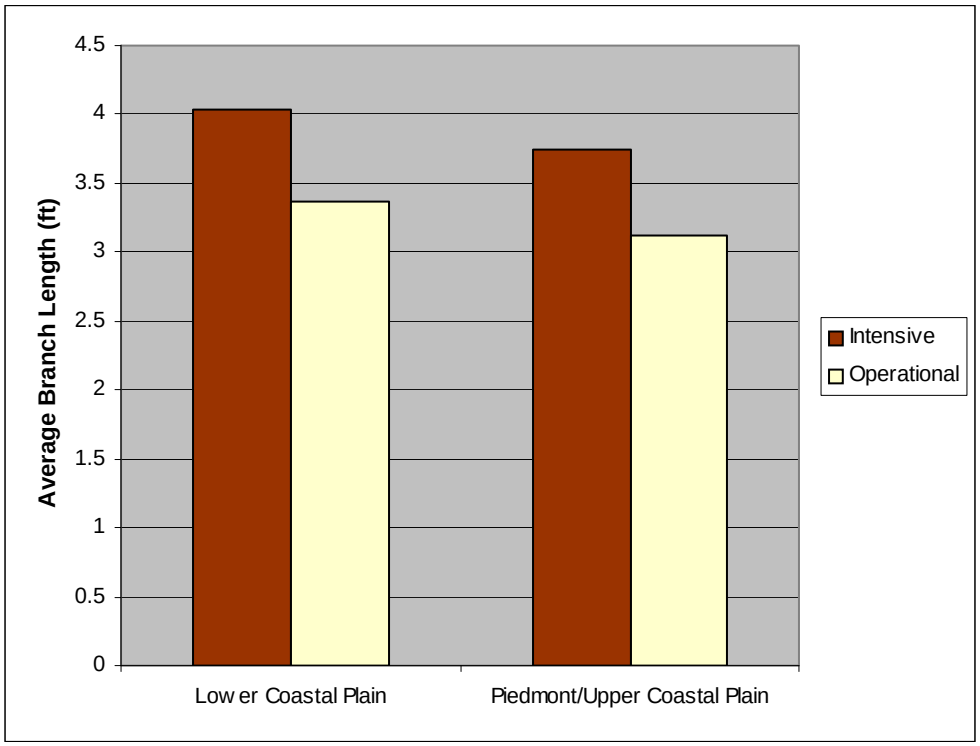


Figure 40. Average branch length (ft) in the lower 16 ft of the stem by management regime and region.

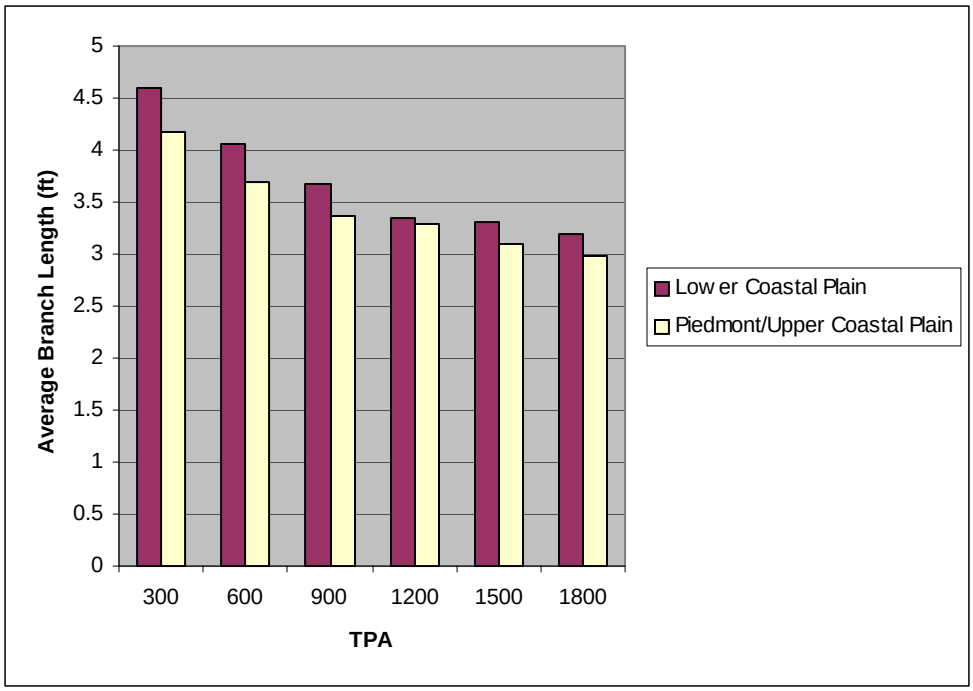


Figure 41. Average branch length (ft) in the lower 16 ft of the stem by planting density and region.

There was a trend toward shorter branches as density increased in both intensive and operational management regimes. At each density, the intensive managed regime plots had larger average branch length than the operational managed plots (Figure 42).

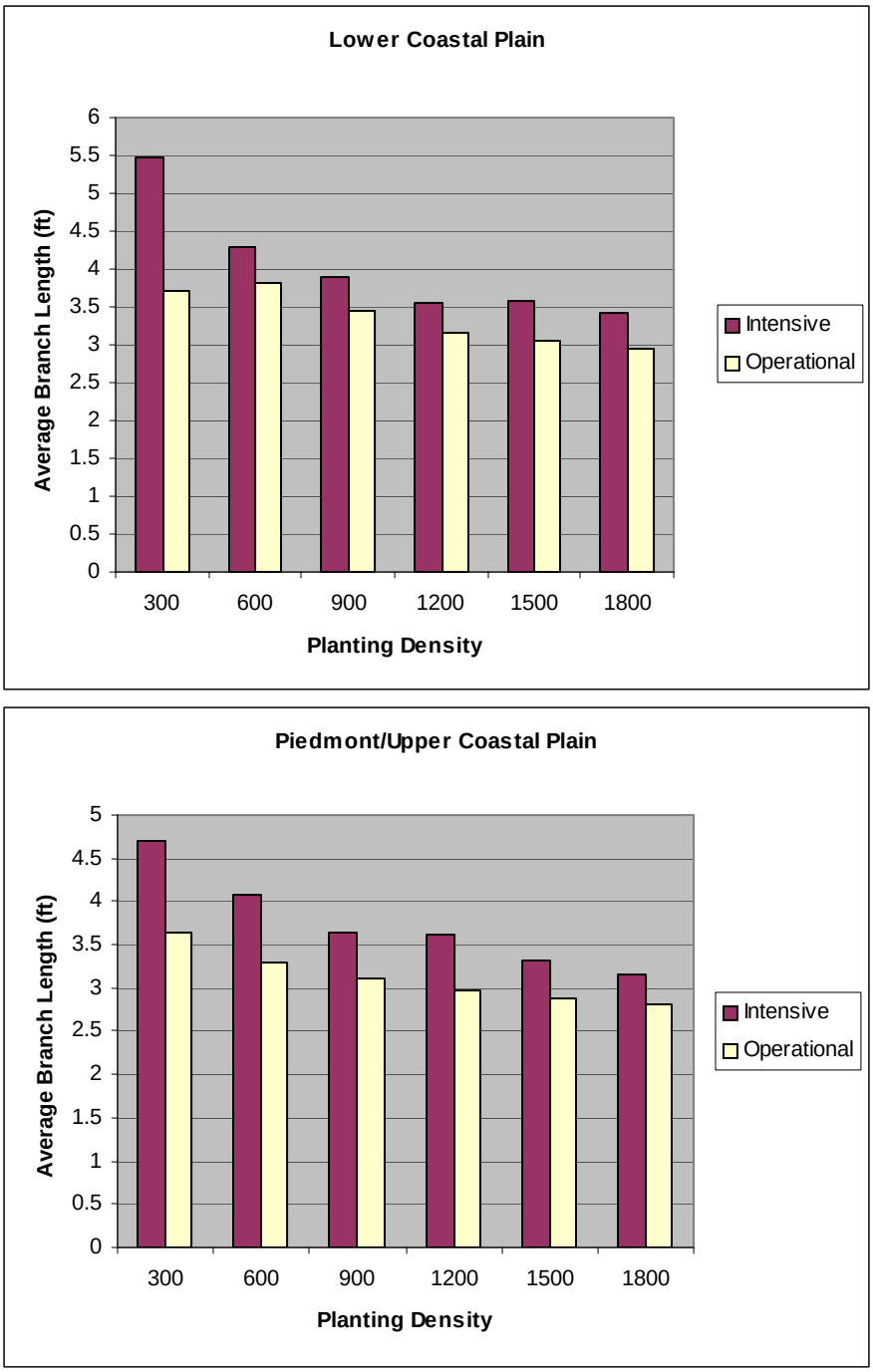


Figure 42. Average branch length (ft) in the lower 16 ft of the stem by planting density, management regime and region.

Results of pairwise multiple comparison tests for the differences among the average branch diameter across the management regime and planting density treatment combinations in the Lower Coastal Plain are presented in Table 34.

Table 34. P-values of Tukey's studentized multiple comparison tests of the differences among the average branch length, in the lower 16 ft of the stem, across all management regime and planting density treatment combinations in the lower coastal plain region.

Lower Coastal Region											
	IN600	**IN900**	**IN1200**	**IN1500**	**IN1800**	**OP300**	**OP600**	**OP900**	**OP1200**	**OP1500**	**OP1800**
IN300	**0.014**	**0.001**	**<.0001**	**<.0001**	**<.0001**	0.5284	**0.0029**	**<.0001**	**<.0001**	**<.0001**	**<.0001**
IN600		0.906	0.0825	**0.036**	**0.006**	0.754	1.000	0.704	0.170	**0.0218**	**0.0015**
IN900			0.8079	0.579	0.185	0.067	0.998	1.000	0.947	0.4432	0.0604
IN1200				1.000	0.988	**0.001**	0.280	0.957	1.000	1.000	0.846
IN1500					1.000	**0.001**	0.141	0.821	1.000	1.000	0.967
IN1800						**<.0001**	**0.028**	0.364	0.921	1.000	1.000
OP300							0.360	**0.027**	**0.0024**	**0.0002**	**<.0001**
OP600								0.968	0.4784	0.091	**0.007**
OP900									0.996	0.698	0.140
OP1200										0.997	0.640
OP1500											0.991

References: first two letters refer to the management regime intensity treatment (IN: intensive, OP: operational Intensive). The last three digits refer to the planting density (300, 600, 900, 1200, 1500, 1800 TPA). Significance differences are in bold and are defined as P-values <0.05.

The intensively managed plots at 300 tpa (IN300) yielded the largest average branch length in the lower 16 ft of the stem, and its value was significantly greater than those of all other treatment combinations but the operationally managed plots at 300 trees per acre (OP300) (Table 34). There were no significant differences among the high planting densities (900, 1200, 1500, and 1800 tpa) within, as well as between, both management regimes.

There were significant linear trends in average branch length in the lower 16 ft of the stem across densities for the regions under study (Table 35). In the Lower Coastal Plain, operational management yielded an average branch length that decreased linearly from 3.72 ft when the planting density was 300 tpa to 2.96 ft when the density was 1,800 tpa (Figure 42). For intensive management, the average branch length decreased linearly from 5.47 ft at 300 tpa to 3.41 ft at 1,800 tpa. In the Piedmont/Upper Coastal Plain, operational management yielded an average branch length that decreased linearly from 3.64 ft when the planting density was 300 tpa to 2.82 ft when the density was 1,800 tpa. For intensive management, the average length decreased linearly from 4.70 ft at 300 tpa to 3.15 ft at 1,800 tpa.

Table 35. Linear contrasts: average branch length (ft) for the lower 16 ft of the stem by planting density for each region.

	Lower Coastal Plain		**Piedmont/Upper Coastal Plain**	
Contrast	Type III F	Pr > F	Type III SS	Pr > F
Linear Trend across Density (both Management Regimes)	70.47	<.0001*	158.67	<.0001*
Linear Trend across Density at Intensive Regime	69.68	<.0001*	97.55	<.0001*
Linear Trend across Density at Operational Regime	16.85	0.0004*	28.98	<.0001*

* Significant at $\alpha = 5\%$

3.3.3. Average branch length for 0-8ft stem height

For the average length of branches in the lower 8 feet of the stem, the management intensity factor was significant at 5% level only in the Piedmont/Upper Coastal Plain (Table 36). The density factor was significant for both regions. There was no significant management intensity by planting density interaction for either region.

Table 36. Analysis of variance results for average branch length (ft) in the lower 8 ft of the stem in each region.

	Lower Coastal Plain		**Piedmont/Upper Coastal Plain**	
Source	Type III F	Pr > F	Type III F	Pr > F
Management	4.39	0.0902	23.53	0.0028*
Density	11.53	<.0001*	28.74	<.0001*
Management*Density	2.46	0.0607	1.69	0.1686

* Significant at $\alpha = 5\%$

In the Piedmont/Upper Coastal Plain the branch length for intensive management was on average 0.59 ft more than for operational management, with the average on the intensive being 2.88 ft, and the average on the operational being 2.29 ft (Figure 43. In the Lower Coastal Plain, the average branch length on the intensive management was 2.49 ft, and the average on the operational was 2.14 ft, the difference being not significant at 5% level (p-value 0.0902).

For planting density, the 300 tpa treatment yielded mean branch basal area values that were significantly greater than those of all other densities (Figure 44). There were no significant differences between the three higher densities (1200, 1500, and 1800 tpa) in either region. As planting density increased, average branch length decreased from 3.04 ft at 300 tpa to 1.94 ft at 1800 tpa for the Lower Coastal Plain, and from 3.25 ft at 300 tpa to 2.17 ft at 1800 tpa for the Piedmont/Upper Coastal Plain.

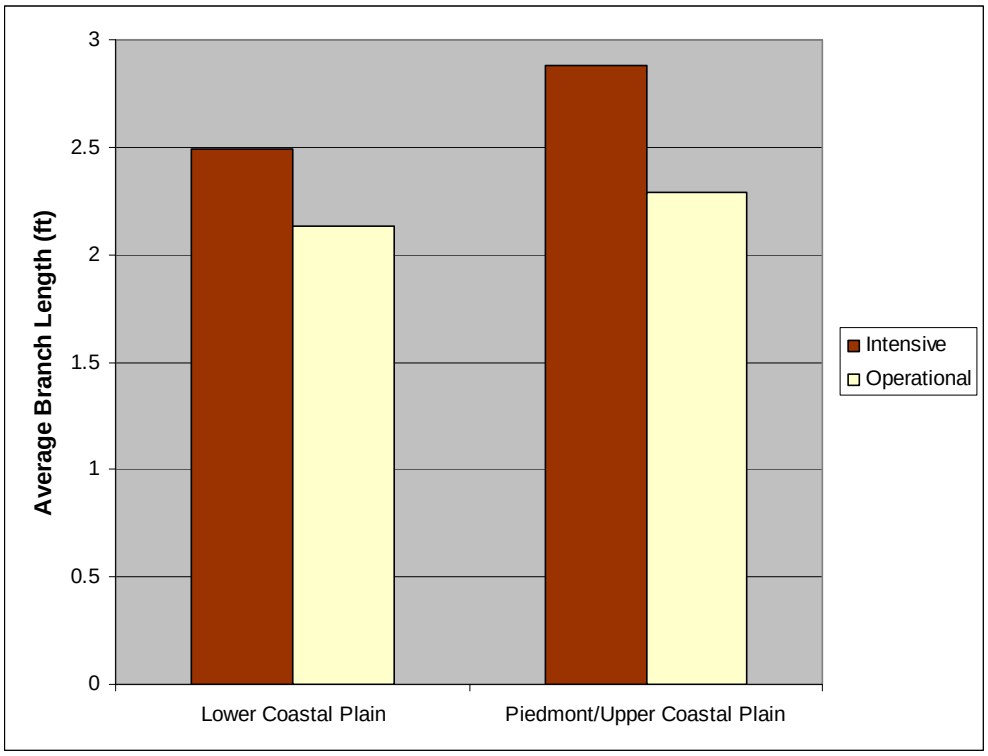


Figure 43. Average branch length (ft) in the lower 8 ft of the stem by management regime and region.

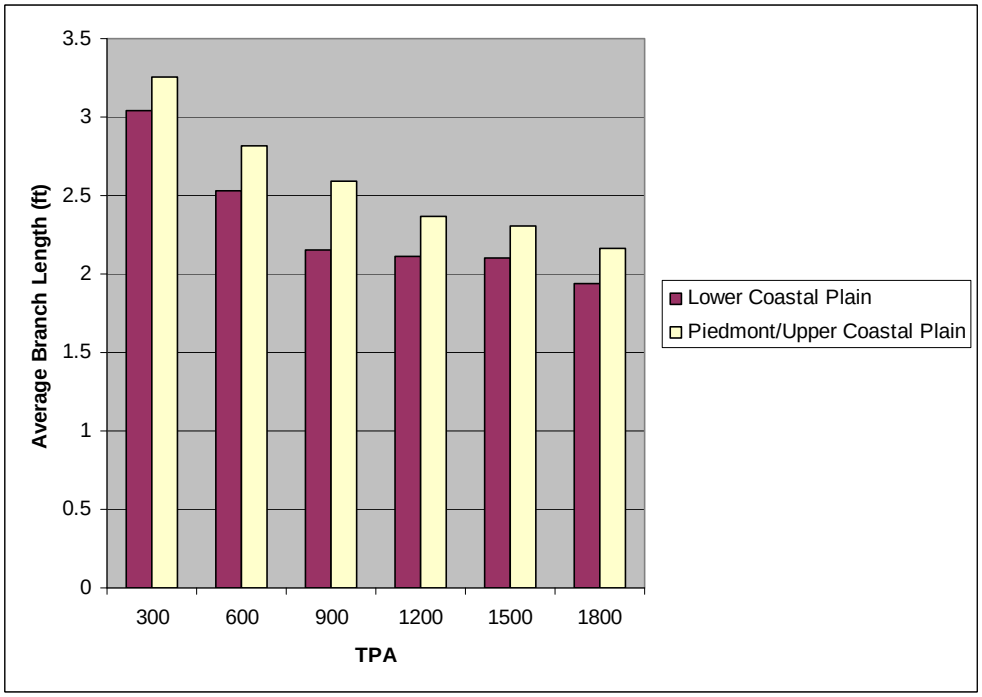


Figure 44. Average branch length (ft) in the lower 8 ft of the stem by planting density and region.

There was a trend toward shorter branches as density increased for both intensive and operational management. At each density, intensively managed plots had larger average branch length than operational managed plots for all but the 1200 tpa treatment in the Lower Coastal Plain (Figure 45). As there were no significant planting density by management regime interactions, pairwise multiple comparisons were not conducted.

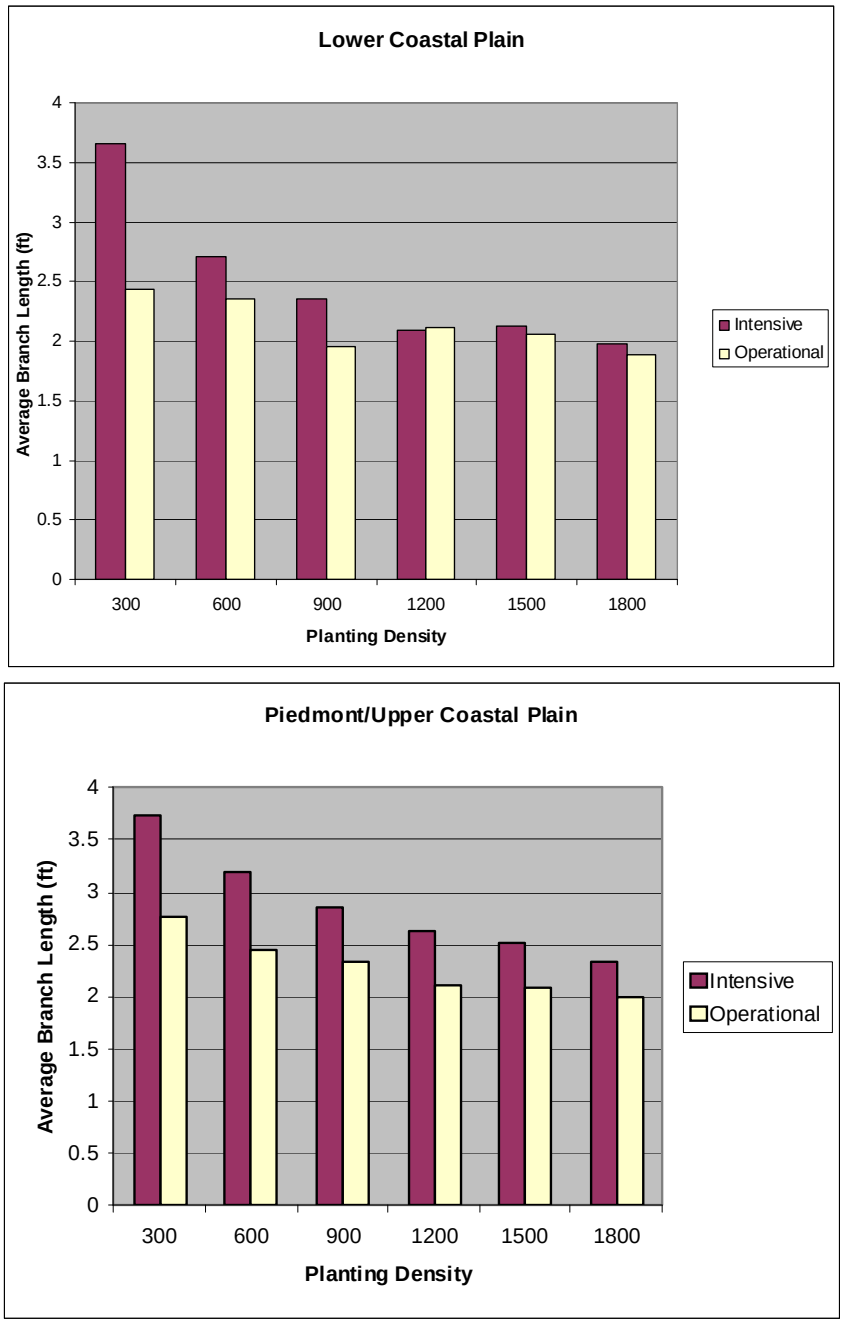


Figure 45. Average branch length (ft) in the lower 8 ft of the stem by planting density, management regime and region.

There were significant linear trends in average branch length in the lower 8 ft of the stem across densities for the regions under study (Table 37). The linear trends were significant in both regions for the intensive management regime and only significant for the operational regime in the Piedmont/Upper Coastal Plain. In the Lower Coastal Plain, intensive management yielded an average branch length that decreased linearly from 3.66 ft when the planting density was 300 tpa to 1.98 ft when the density was 1,800 tpa (Figure 45). In the Piedmont/Upper Coastal Plain, operational management yielded an average branch length that decreased linearly from 2.76 ft when the planting density was 300 tpa to 1.90 ft when the density was 1,800 tpa. For the intensive management regime, the average length decreased linearly from 3.74 ft at 300 tpa to 2.34 ft at 1,800 tpa.

Table 37. Linear contrasts: average branch length (ft) in the lower 8 ft by planting density for each region.

	Lower Coastal Plain		**Piedmont/Upper Coastal Plain**	
Contrast	Type III F	Pr > F	Type III SS	Pr > F
Linear Trend across Density (both Management Regimes)	46.56	<.0001*	132.67	<.0001*
Linear Trend across Density at Intensive Regime	35.16	<.0001*	76.68	<.0001*
Linear Trend across Density at Operational Regime	3.62	0.0688	24.26	<.0001*

* Significant at $\alpha = 5\%$

3.3.4. Average branch length for 8-16 ft stem heights

For the average length of branches at whorl heights 8-16 feet of the stem, the management intensity and density factors were significant (Table 38). There was a significant management by density interaction only in the Piedmont/Upper Coastal Plain.

Table 38. Analysis of variance results for average branch length (ft) at heights 8-16 ft of the stem in each region.

	Lower Coastal Plain		**Piedmont/Upper Coastal Plain**	
Source	Type III F	Pr > F	Type III F	Pr > F
Management	9.49	0.0274*	18.88	0.0048*
Density	13.20	<.0001*	22.70	<.0001*
Management*Density	1.57	0.2039	2.72	0.0386*

* Significant at $\alpha = 5\%$

In the Lower Coastal Plain the branch length for intensive management was on average 0.75 ft more than for operational management, with the average on the intensive being 4.94 ft, and the average on the operational being 4.19 ft (Figure 46). In the Piedmont/Upper Coastal Plain the branch length for intensive management was on average 0.67 ft more than for operational management, with the average on the intensive being 5.03 ft, and the average on the operational being 4.36 ft.

For planting density, the 300 tpa treatment yielded mean branch length values significantly greater than those of all other densities (Figure 47). There were no significant differences between the three higher densities (1200, 1500, and 1800 tpa) in either region. As planting density increased, average branch length decreased from 5.65 ft at 300 tpa to 3.99 ft at 1800 tpa in the Lower Coastal Plain, and from 5.60 ft at 300 tpa to 4.12 ft at 1800 tpa in the Piedmont/Upper Coastal Plain.

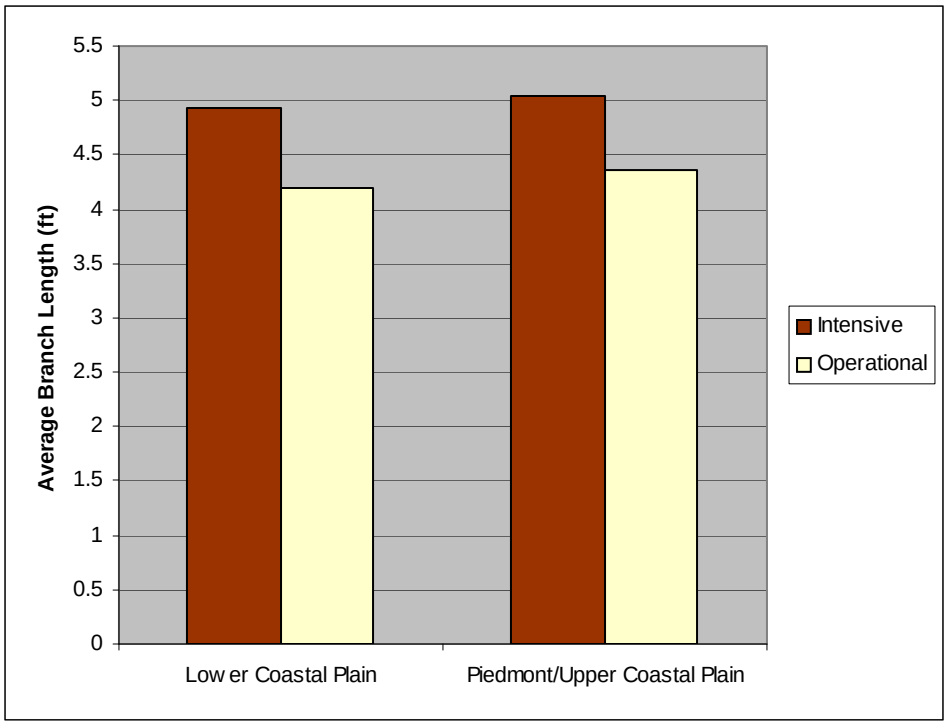


Figure 46. Average branch length (ft) at heights 8-16 ft of the stem by management regime and region.

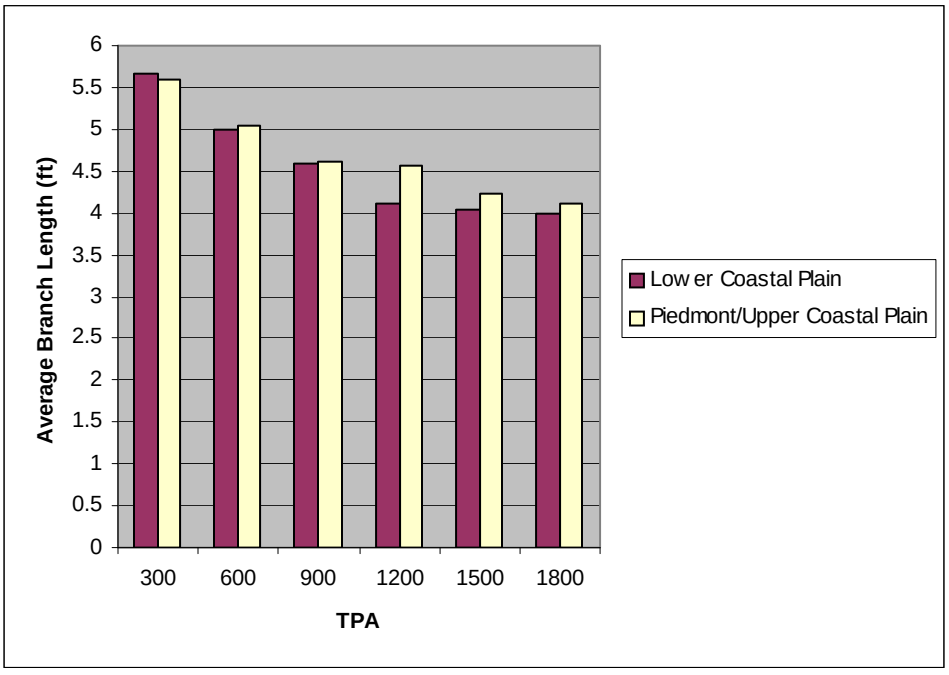


Figure 47. Average branch length (ft) at heights 8-16 ft of the stem by planting density and region.

There was a trend toward shorter branches as density increased for both intensive and operational management. At each density, the intensive managed regime plots had larger average branch length than the operational managed plots (Figure 48).

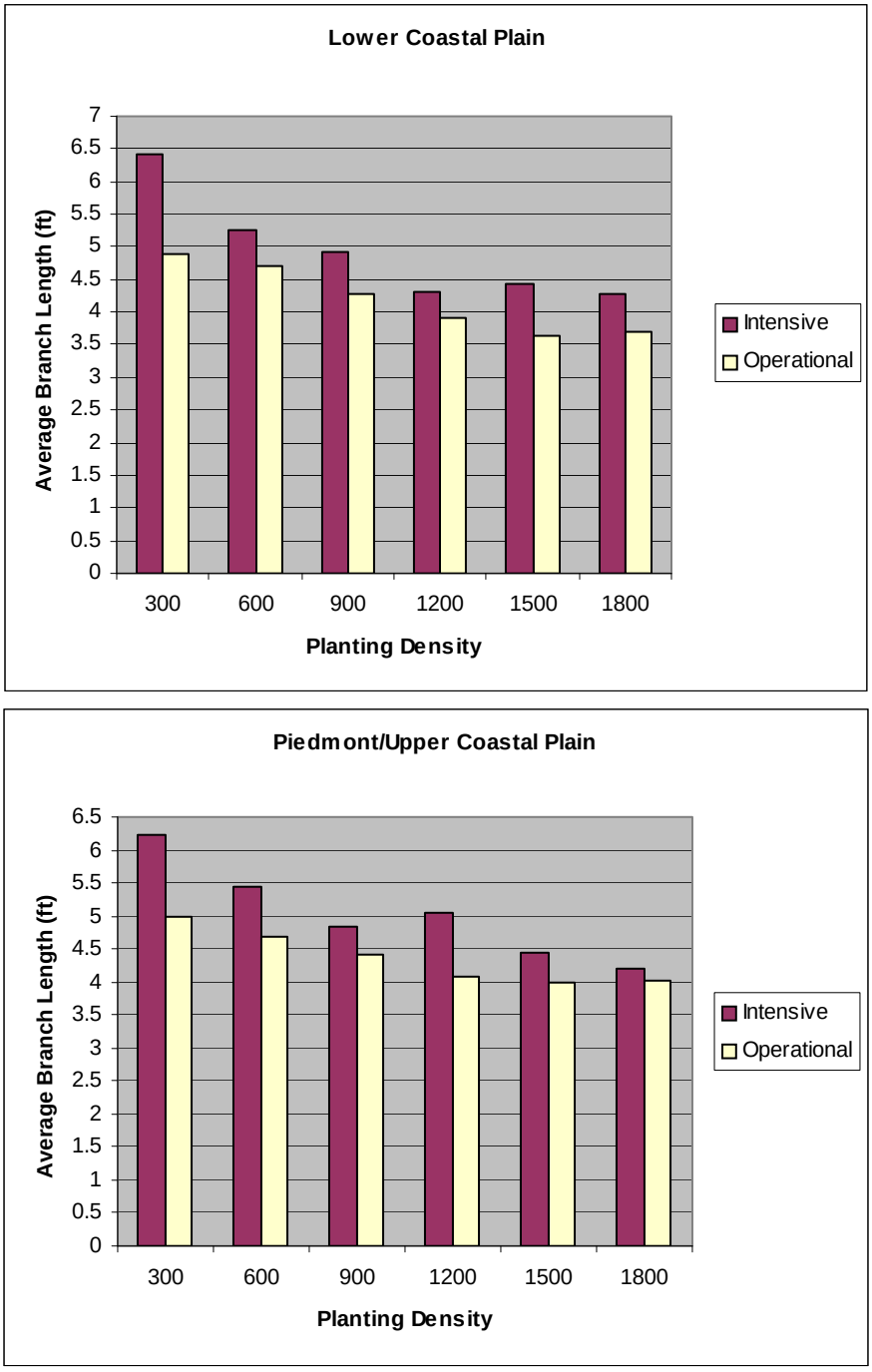


Figure 48. Average branch length (ft) in the range 8-16 ft of the stem by planting density, management regime and region.

Results of pairwise multiple comparison tests for the differences among the average branch diameter across the management regime and planting density treatment combinations in the Piedmont/Upper Coastal Plain are presented in Table 39.

Table 39. P-values of Tukey's studentized multiple comparison tests of the differences among the average branch length, at heights 8-16 ft of the stem, across all management regime and planting density treatment combinations in the lower coastal plain region.

Piedmont/Upper Coastal Region											
	IN600	**IN900**	**IN1200**	**IN1500**	**IN1800**	**OP300**	**OP600**	**OP900**	**OP1200**	**OP1500**	**OP1800**
IN300	0.078	**0.001**	**0.001**	**<.0001**	**<.0001**	**0.001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**
IN600		0.381	0.884	**0.011**	**0.001**	0.737	0.110	**0.007**	**0.001**	**<.0001**	**<.0001**
IN900			0.999	0.871	0.301	1.000	1.000	0.781	0.104	0.052	0.062
IN1200				0.364	0.054	1.000	0.914	0.269	**0.014**	**0.006**	**0.008**
IN1500					0.997	0.541	0.997	1.000	0.915	0.773	0.814
IN1800						0.102	0.716	1.000	1.000	0.999	1.000
OP300							0.979	0.425	**0.028**	**0.013**	**0.016**
OP600								0.988	0.366	0.215	0.247
OP900									0.963	0.865	0.896
OP1200										1.000	1.000
OP1500											1.000

References: first two letters refer to the management regime intensity treatment (IN: intensive, OP: operational Intensive). The last three digits refer to the planting density (300, 600, 900, 1200, 1500, 1800 TPA). Significance differences are in bold and are defined as P-values <0.05.

The intensively managed plots at 300 tpa (IN300) yielded the largest average branch length at heights 8-16 ft of the stem, and its value was significantly greater than those of all other treatment combinations with the exception of the intensively managed plots at 600 trees per acre (IN600) (Table 39). There were no significant differences among the high planting densities (900, 1200, 1500, and 1800 tpa) within, as well as between, management regimes.

There were significant linear trends in average branch length at heights 16-24 ft of the stem across densities for the regions under study (Table 40). In the Lower Coastal Plain, intensive management yielded an average branch length that decreased linearly from 6.41 ft when the planting density was 300 tpa to 4.28 ft when the density was 1,800 tpa (Figure 48). For operational management, average length decreased linearly from 4.90 ft at 300 tpa to 3.70 ft at 1,800 tpa. In the Piedmont/Upper Coastal Plain, intensive management yielded an average branch length that decreased linearly from 6.23 ft when the planting density was 300 tpa to 4.21 ft when the density was 1,800 tpa. For operational management, the average length decreased linearly from 4.98 ft at 300 tpa to 4.02 ft at 1,800 tpa.

Table 40. Linear contrasts: average branch length (ft) at heights 8-16 ft of the stem by planting density for each region.

	Lower Coastal Plain		Piedmont/Upper Coastal Plain	
Contrast	Type III F	Pr > F	Type III SS	Pr > F
Linear Trend across Density (both Management Regimes)	58.66	<.0001*	105.43	<.0001*
Linear Trend across Density at Intensive Regime	54.06	<.0001*	83.23	<.0001*
Linear Trend across Density at Operational Regime	27.00	<.0001*	25.63	<.0001*

* Significant at $\alpha = 5\%$

3.3.5. Average branch length for 16-24 ft stem heights

For the average length of branches at heights 16-24 feet of the stem, the management intensity factor and the density factor were significant (Table 41). There was no significant silvicultural management intensity by planting density interaction in either region.

Table 41. Analysis of variance results for average branch length (ft) at heights 16-24 ft of the stem in each region.

	Lower Coastal Plain		Piedmont/Upper Coastal Plain	
Source	Type III F	Pr > F	Type III F	Pr > F
Management	27.23	0.0034*	6.16	0.0476*
Density	16.79	<.0001*	4.21	0.0051*
Management*Density	0.20	0.9581	0.36	0.8687

* Significant at $\alpha = 5\%$

In the Lower Coastal Plain the branch length for intensive management was on average 0.67 ft more than for operational management, with the average on the intensive being 5.80 ft, and the average on the operational being 5.13 ft (Figure 49). In the Piedmont/Upper Coastal Plain the branch length for intensive management was on average 0.58 ft more than for operational management, with the average on the intensive being 4.28 ft, and the average on the operational being 3.70 ft. See for a graphical comparison of the silvicultural treatment effect on the average branch length among regions.

For planting density, there were no significant differences between the two higher densities (1500, and 1800 tpa) in either region (Figure 50). As planting

density increased, the average branch length decreased from 6.51 ft at 300 tpa to 4.87 ft at 1800 tpa in the Lower Coastal Plain, and from 4.29 ft at 300 tpa to 3.59 ft at 1800 tpa in the Piedmont/Upper Coastal Plain.

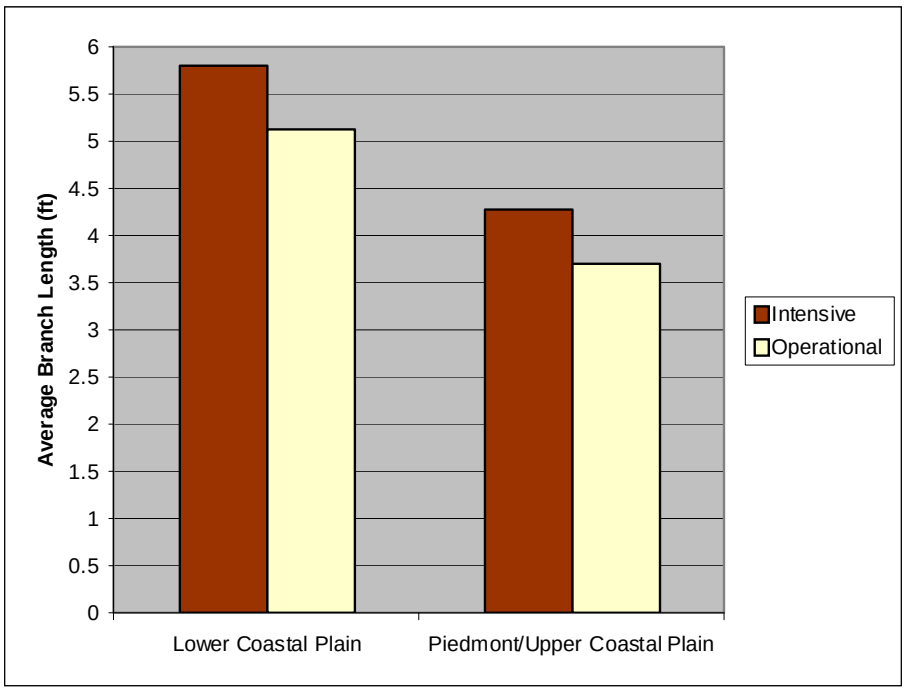


Figure 49. Average branch length (ft) at heights 16-24 ft of the stem by management regime and region.

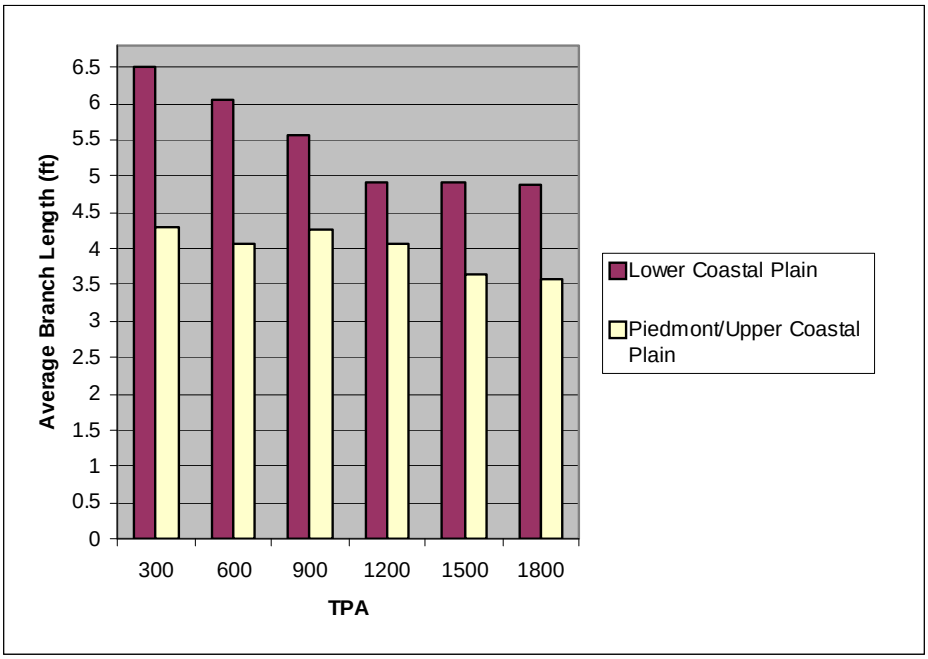
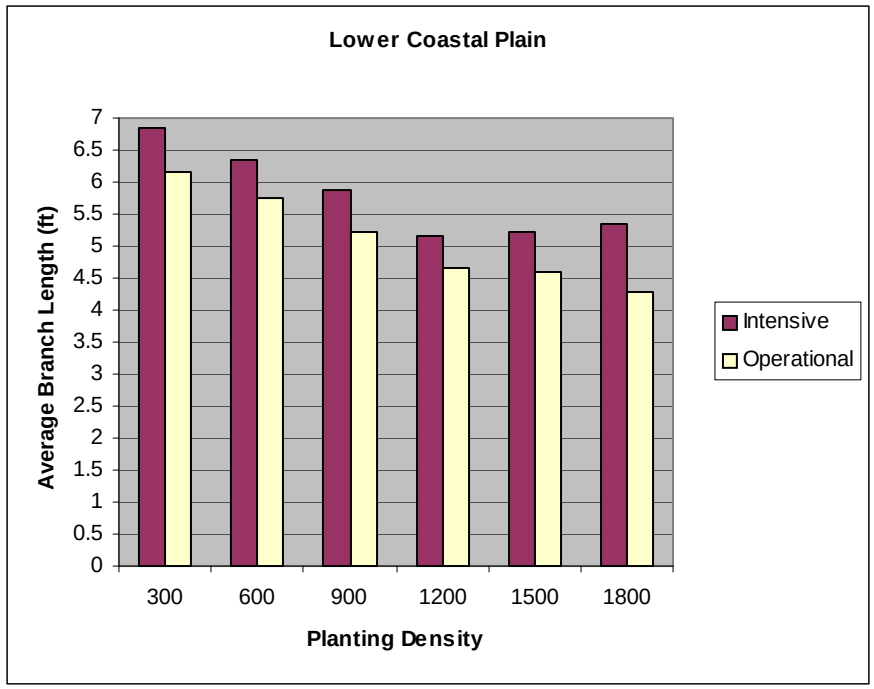


Figure 50. Average branch length (ft) at heights 16-24 ft of the stem by planting density and region.

There was a trend toward shorter branches as density increased for both intensive and operational management. At each density, intensive managed plots had larger average branch length than operational managed plots (Figure 51). As there were no significant planting density by management regime interactions, pairwise multiple comparisons were not conducted.



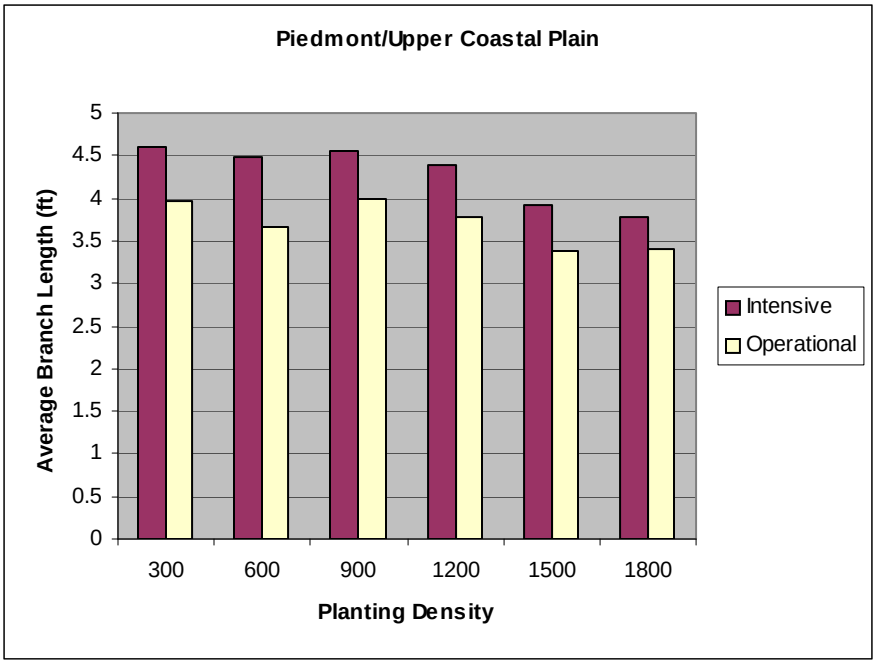


Figure 51. Average branch length (ft) at heights 16-24 ft of the stem by planting density, management regime and region.

There were significant linear trends in the average branch length in the 16-24 ft stem height range across densities for the regions under study (Table 42). In the Lower Coastal Plain, intensive management yielded an average branch length that decreased linearly from 6.85 ft when the planting density was 300 tpa to 5.35 ft when the density was 1,800 tpa (Figure 51). For operational management, the average length decreased linearly from 6.16 ft at 300 tpa to 4.29 ft at 1,800 tpa. In

the Piedmont/Upper Coastal Plain, intensive management yielded an average branch length that decreased linearly from 4.60 ft when the planting density was 300 tpa to 3.77 ft when the density was 1,800 tpa. For operational management, the average length decreased linearly from 3.98 ft at 300 tpa to 3.41 ft at 1,800 tpa.

Table 42. Linear contrasts: average branch length (ft) at heights 16-24 ft of the stem by planting density in each region.

	Lower Coastal Plain		**Piedmont/Upper Coastal Plain**	
Contrast	Type III F	Pr > F	Type III SS	Pr > F
Linear Trend across Density (both Management Regimes)	74.98	<.0001*	16.19	0.0004
Linear Trend across Density at Intensive Regime	33.32	<.0001*	17.19	0.0003
Linear Trend across Density at Operational Regime	41.78	<.0001*	7.15	0.0120

* Significant at $\alpha = 5\%$

3.4. Branch Angle

Average branch angle is summarized across regions, logs, planting densities, and management regimes in Figure 52 and Figure 53.

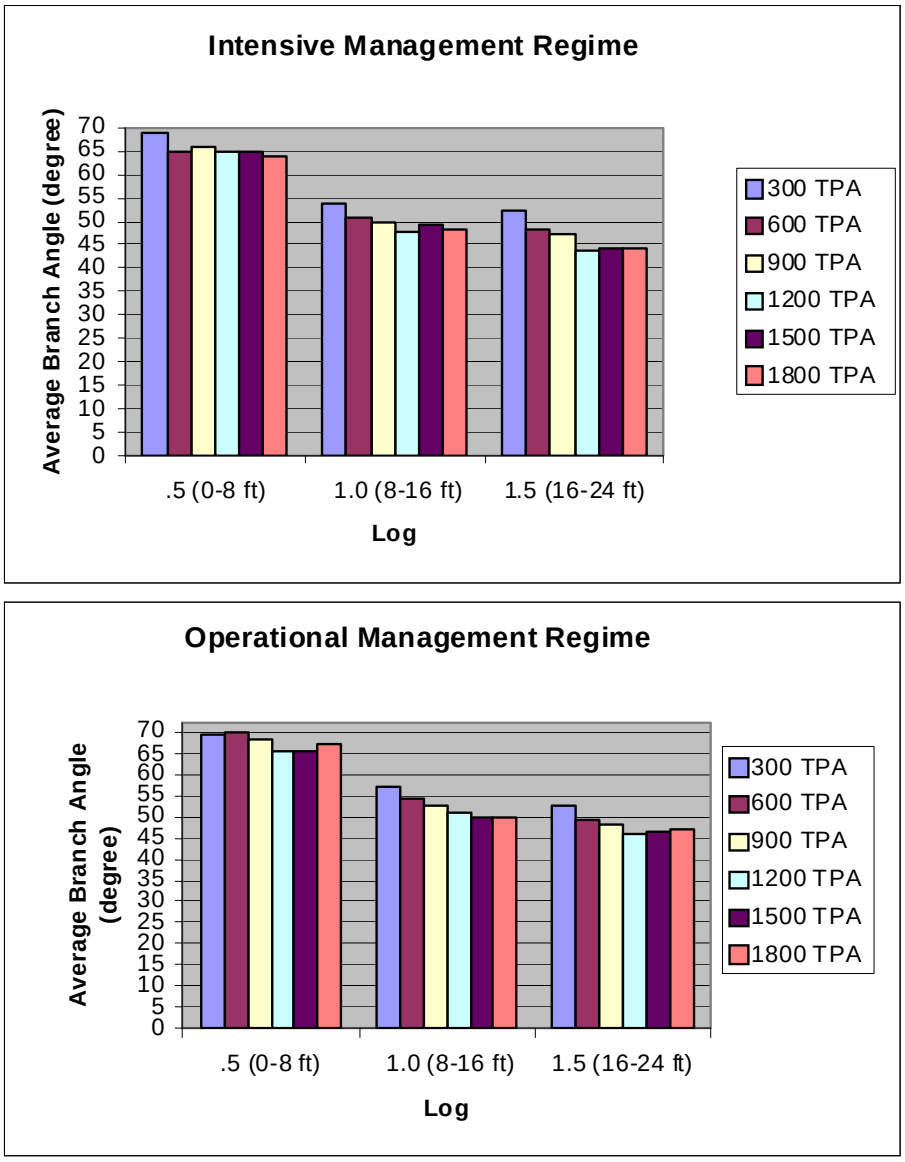


Figure 52. Average branch angle to the stem (degree) by half-log, management regime, and planting density in the Lower Coastal Plain**.**

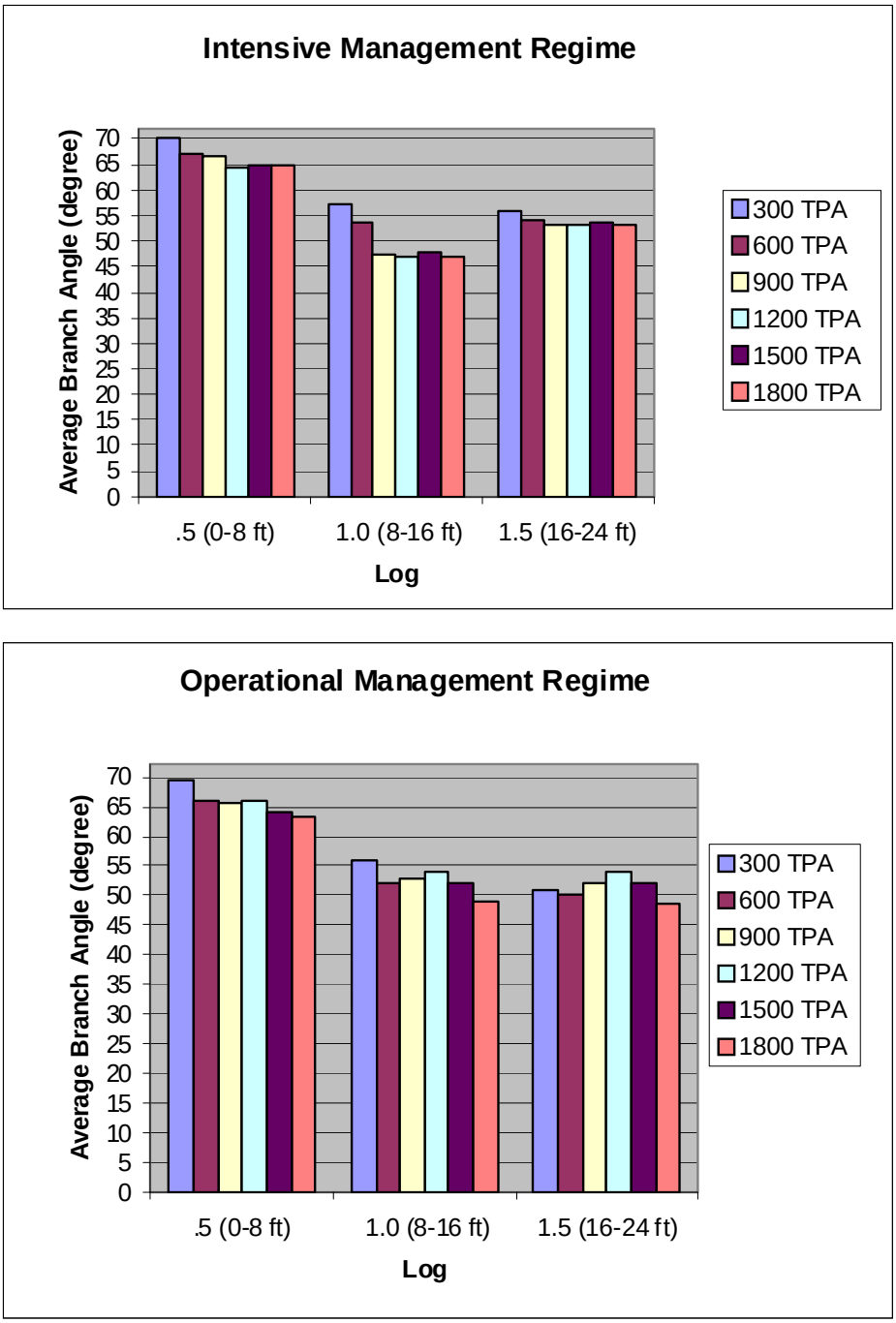


Figure 53. Average branch angle to the stem (degree) by half-log, management regime, and planting density in the Piedmont/Upper Coastal Plain.

3.4.1. Average branch angle for 0-24 ft stem heights

Average branch angle in the lower 24 feet of the stem was significantly affected by planting density in both regions (Table 43). There were no significant differences in branch angle between the two management regimes. There were no significant management by density interactions.

Table 43. Analysis of variance results for average branch angle in the lower 24 ft of the stem in each region.

	Lower Coastal Plain		**Piedmont/Upper Coastal Plain**	
Source	Type III F	Pr > F	Type III F	Pr > F
Management	1.92	0.2250	1.27	0.3032
Density	15.27	<.0001*	10.64	<.0001*
Management*Density	0.81	0.5536	2.08	0.0962

* Significant at $\alpha = 5\%$

In the Lower Coastal Plain, the average branch angle for intensive management was 56º, while it was 57º for operational management (the difference being not significant) (Figure 54). In the Piedmont/Upper Coastal Plain, both management regimes yielded a branch angle of about 59º.

For planting density, the 300 tpa treatment yielded a mean branch angle that was significantly greater than those of all other densities in both regions (Figure 55). As the planting density increased, the average branch angle decreased from 61º at 300 tpa to 55º at 1800 tpa in the Lower Coastal Plain, and from 62º at 300 tpa to 57º at 1800 tpa in the Piedmont/Upper Coastal Plain.

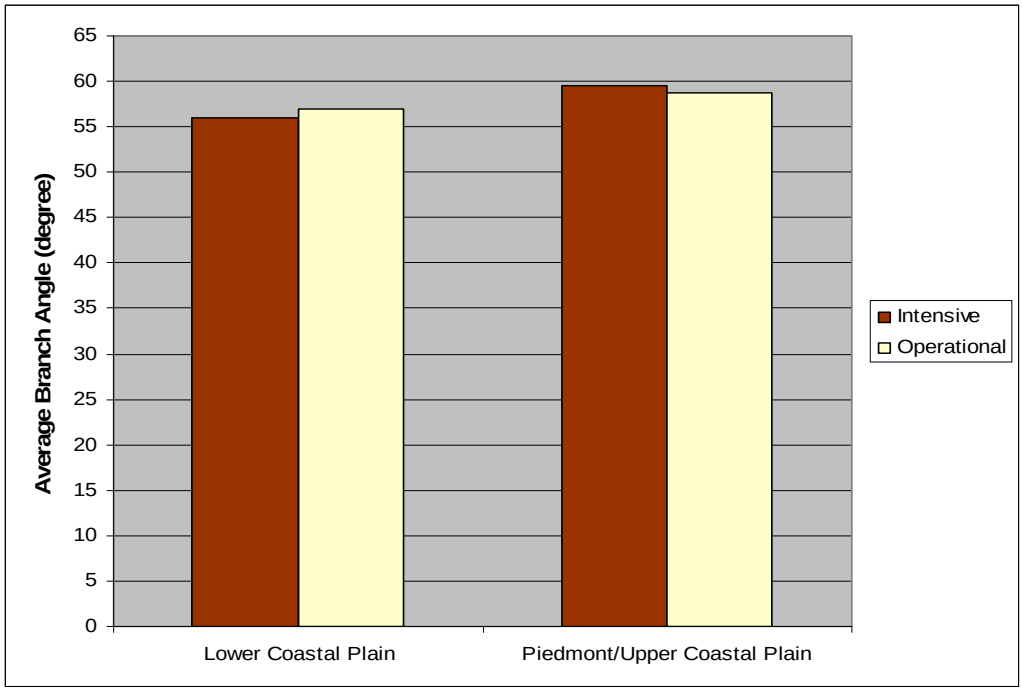


Figure 54. Average branch angle to the stem (degree) in the lower 24 ft by management regime and region.

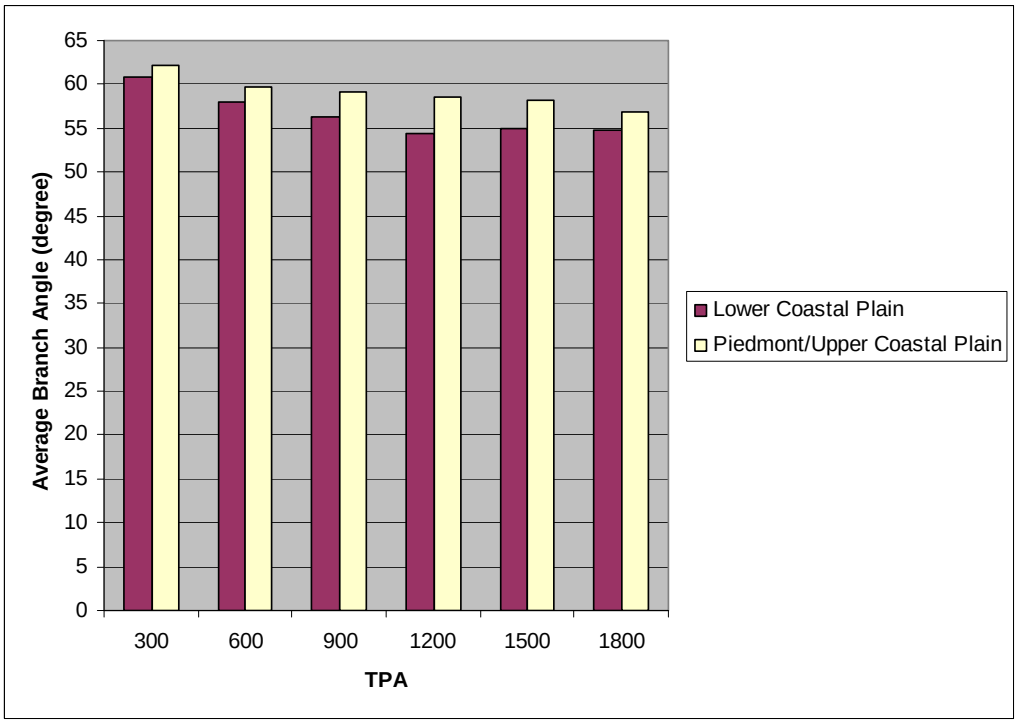


Figure 55. Average branch angle to the stem (degree) in the lower 24 ft by planting density and region.

There was a consistent trend toward lower average branch angle values as density increased for both intensive and operational management (Figure 56). As there were no significant planting density by management regime interactions, pairwise multiple comparisons were then performed.

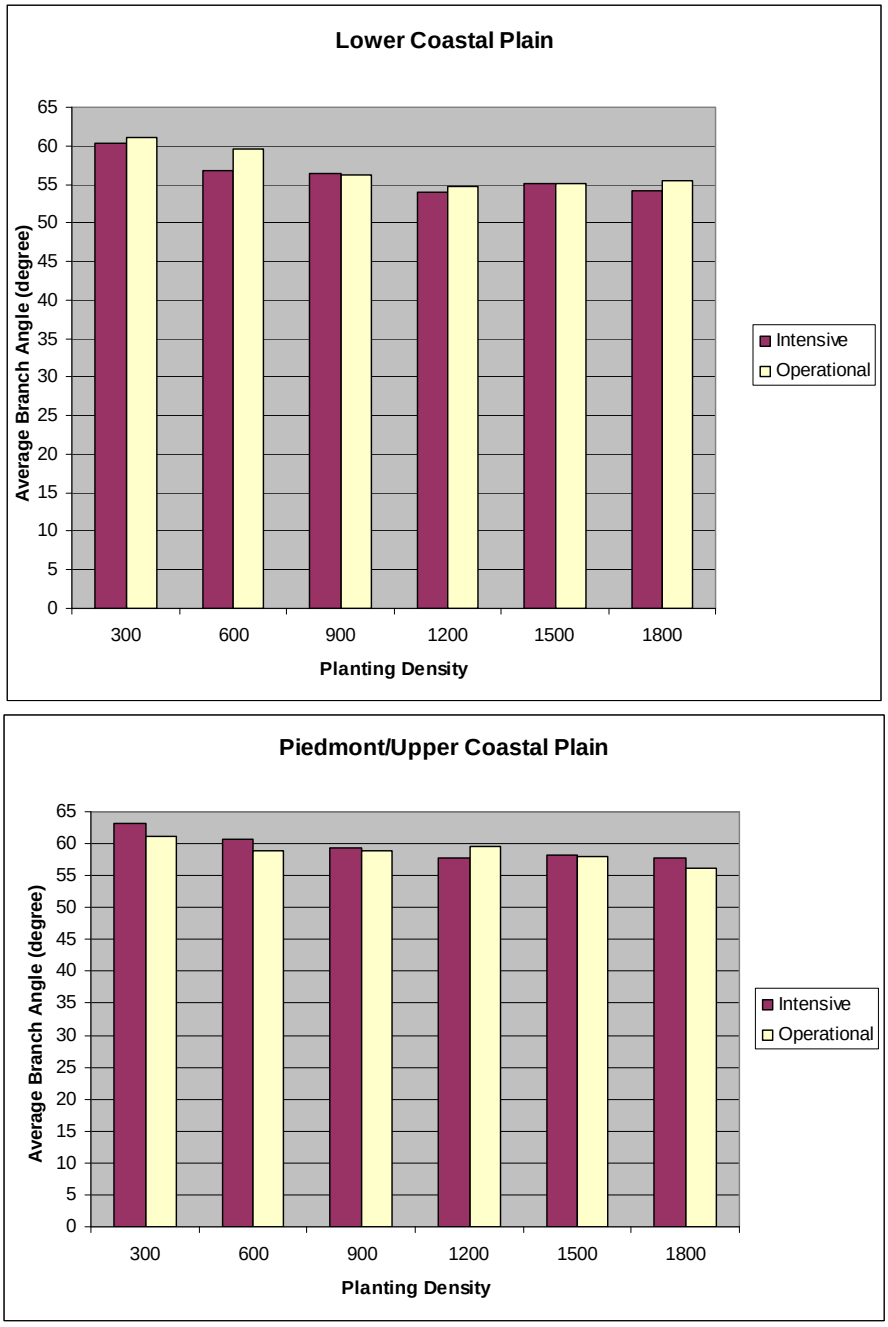


Figure 56. Average branch angle to the stem (degree) in the lower 24 ft by planting density, management regime and region.

There were significant linear trends in the average branch angle in the lower 24 ft of the stem across densities in the regions under study. In the Lower Coastal Plain, operational management yielded an average branch angle that decreased linearly from 61º when the planting density was 300 tpa to 55º when the density was 1,800 tpa (Figure 56). For intensive management, the average branch angle decreased linearly from 60º at 300 tpa to 55º at 1,800 tpa. In the Piedmont/Upper Coastal Plain, operational management yielded an average branch angle that decreased linearly from 61º ft when the planting density was 300 tpa to 56º when the density was 1,800 tpa. For intensive management, the average angle decreased linearly from 63º at 300 tpa to 58º at 1,800 tpa.

Table 44. Linear contrasts: Average branch angle to the stem (degree) in the lower 24 ft of the stem by planting density in each region.

	Lower Coastal Plain		**Piedmont/Upper Coastal Plain**	
Contrast	Type III F	Pr > F	Type III F	Pr > F
Linear Trend across Density (both Management Regimes)	21.07	0.0067*	48.05	<.0001*
Linear Trend across Density at Intensive Regime	17.89	0.0014*	35.80	<.0001*
Linear Trend across Density at Operational Regime	15.67	0.0034*	20.35	<.0001*

* Significant at $\alpha = 5\%$

3.4.2. Average branch angle for 0-16 ft stem heights

Average branch angle in the lower 16 feet of the stem was significantly affected by planting density in both regions (Table 45). There were no significant differences in branch angle between the two management regimes. There were no significant management by density interactions.

Table 45. Analysis of variance results for average branch angle in the lower 16 ft of the stem in each region.

	Lower Coastal Plain		**Piedmont/Upper Coastal Plain**	
Source	Type III F	Pr > F	Type III F	Pr > F
Management	0.33	0.5917	0.06	0.8183
Density	9.82	<.0001*	17.38	<.0001*
Management*Density	1.13	0.3777	1.43	0.2419

* Significant at $\alpha = 5\%$

In the Lower Coastal Plain, the average branch angle to the stem for intensive management was 59º, while it was 60º for operational management (the difference being not significant) (Figure 57). In the Piedmont/Upper Coastal Plain, intensive management yielded an average branch angle of 62º, compared with 61º for the operational regime (the difference being not significant).

For planting density, the 300 tpa treatment yielded a mean branch angle that was significantly greater than those of all other densities (Figure 58). There were no significant differences between the three higher densities (1200, 1500, and 1800 tpa) in either region. As planting density increased, average branch angle decreased from 64º at 300 tpa to 58º at 1800 tpa in the Lower Coastal Plain, and from 65º at 300 tpa to 59º at 1800 tpa in the Piedmont/Upper Coastal Plain.

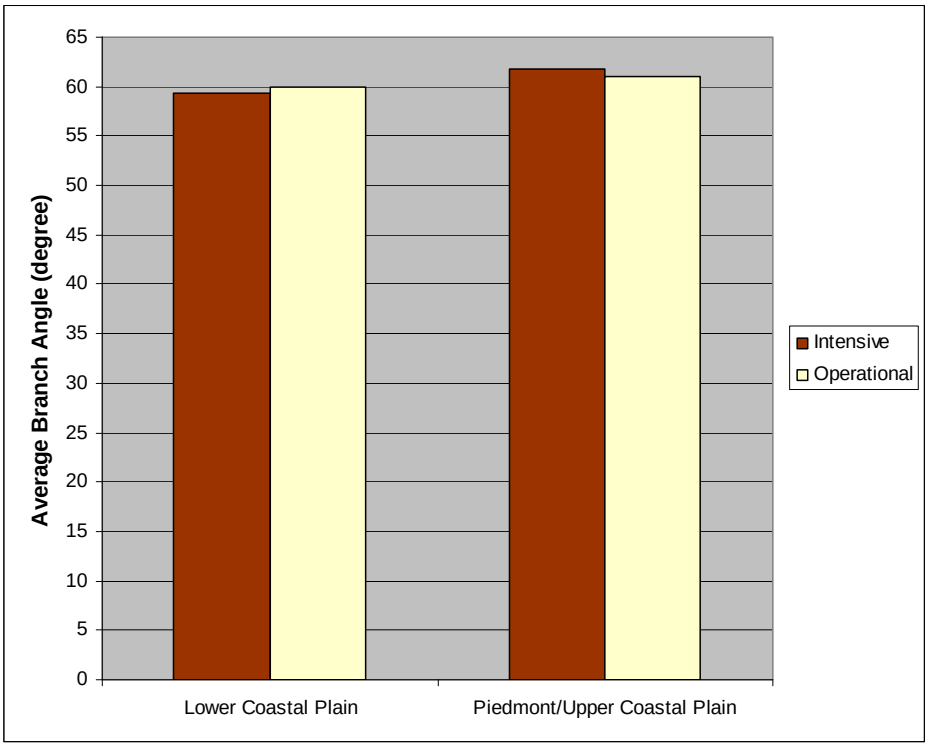


Figure 57. Average branch angle to the stem (degree) in the lower 16 ft by management regime and region.

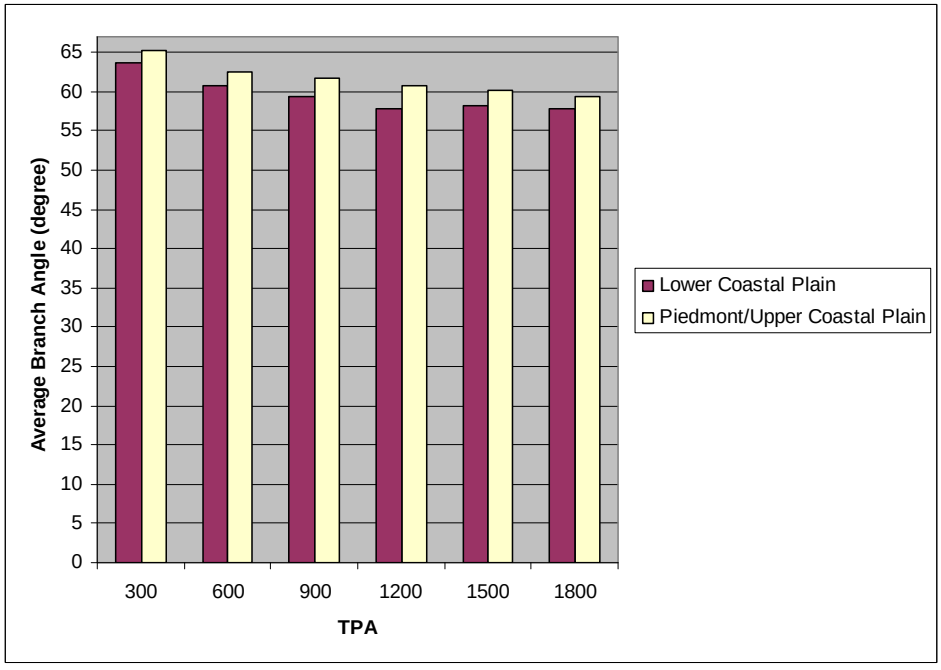


Figure 58. Average branch angle to the stem (degree) in the lower 16 ft by planting density and region.

There was a consistent trend toward lower average branch angle values as density increased for both intensive and operational management (Figure 59). As there were no significant planting density by management regime interactions, pairwise multiple comparisons were not performed

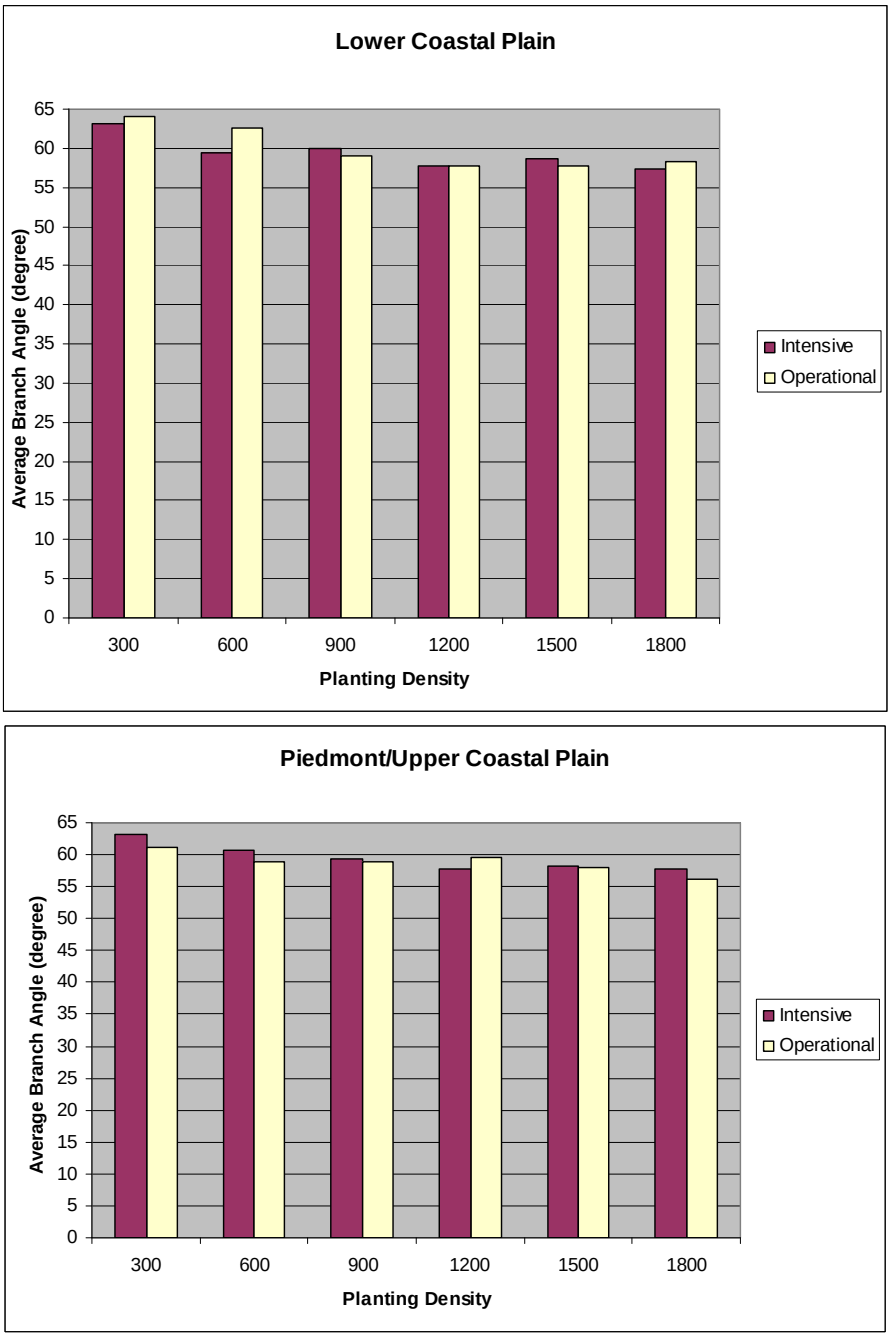


Figure 59. Average branch angle to the stem (degree) in the lower 16 ft by planting density, management regime and region.

There were significant linear trends in the average branch angle in the lower 16 ft of the stem across densities in the regions under study. In the Lower Coastal Plain, operational management yielded an average branch angle that decreased linearly from 64º when the planting density was 300 tpa to 58º when the density was 1,800 tpa (Figure 59). For intensive management average branch angle decreased linearly from 63º at 300 tpa to 57º at 1,800 tpa. In the Piedmont/Upper Coastal Plain, operational management yielded an average branch angle that decreased linearly from 65º ft when the planting density was 300 tpa to 59º when the density was 1,800 tpa. For intensive management, average angle decreased linearly from 66º at 300 tpa to 60º at 1,800 tpa.

Table 46. Linear contrasts: Average branch angle to the stem (degree) in the lower 16 ft of the stem by planting density in each region.

	Lower Coastal Plain		**Piedmont/Upper Coastal Plain**	
Contrast	Type III F	Pr > F	Type III F	Pr > F
Linear Trend across Density (both Management Regimes)	27.57	0.0002*	79.90	<.0001*
Linear Trend across Density at Intensive Regime	19.13	0.0001*	40.40	<.0001*
Linear Trend across Density at Operational Regime	12.47	0.0069*	31.78	<.0001*

* Significant at $\alpha = 5\%$

3.4.3. Average branch angle for 0-8 ft stem heights

Average branch angle in the lower 8 feet of the stem was significantly affected by planting density in both regions (Table 47). There were no significant differences in branch angle between the two management regimes. There were no significant management by density interactions.

Table 47. Analysis of variance results for average branch angle in the lower 8 ft of the stem in each region.

	Lower Coastal Plain		**Piedmont/Upper Coastal Plain**	
Source	Type III F	Pr > F	Type III F	Pr > F
Management	1.45	0.2820	0.17	0.6963
Density	3.67	0.0125*	11.53	<.0001*
Management*Density	0.82	0.5527	1.34	0.2738

* Significant at $\alpha = 5\%$

In the Lower Coastal Plain, average branch angle to the stem for intensive management was 66º, while it was 68º for operational management (the difference being not significant) (Figure 60). In the Piedmont/Upper Coastal Plain, intensive management yielded an average branch angle of 67º, as compared to 66º for the operational regime (the difference being not significant).

For planting density, there were no significant differences between the three higher densities (1200, 1500, and 1800 tpa) in both regions (Figure 61). As planting density increased, average branch angle decreased from 69º at 300 tpa to 65º at 1800 tpa in the Lower Coastal Plain, and from 70º at 300 tpa to 65º at 1800 tpa in the Piedmont/Upper Coastal Plain.

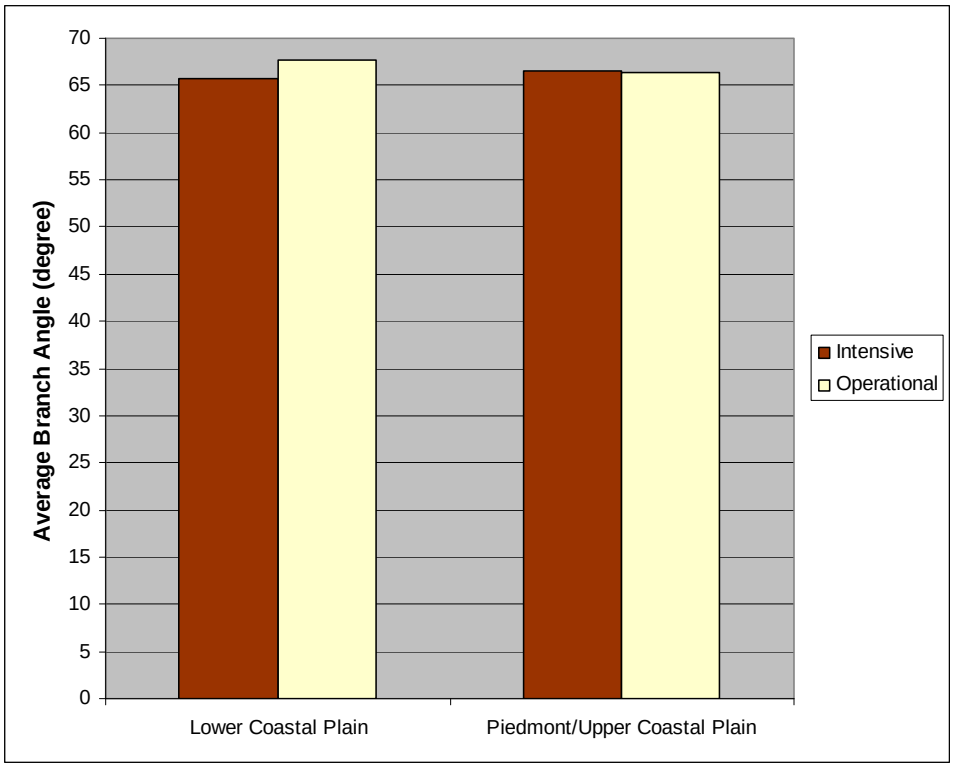


Figure 60. Average branch angle to the stem (degree) in the lower 8 ft by management regime and region.

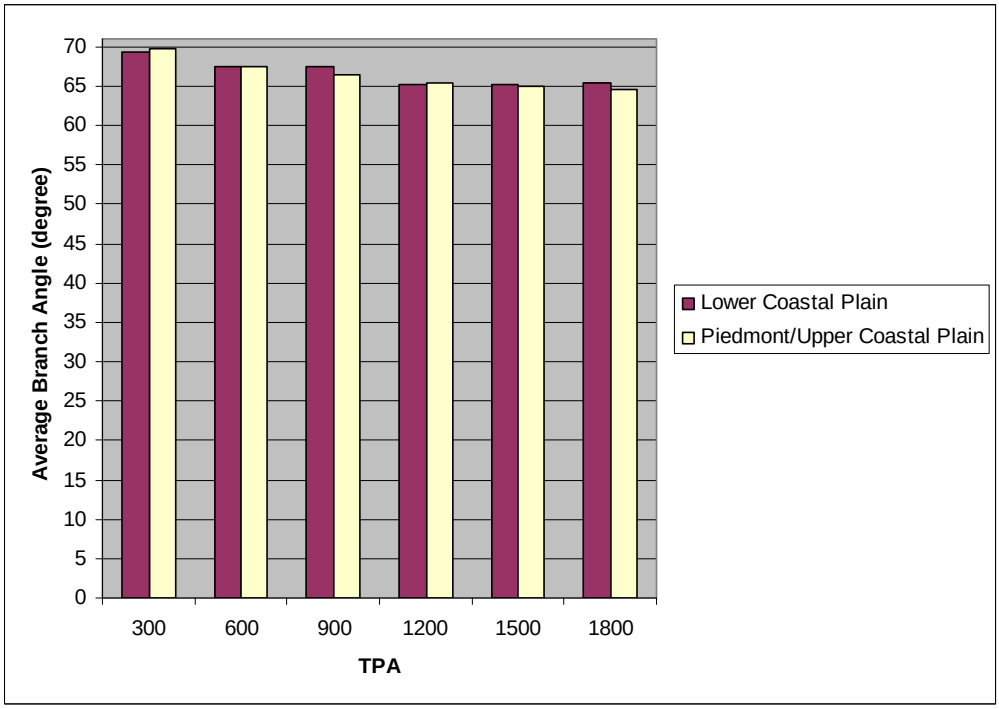


Figure 61. Average branch angle to the stem (degree) in the lower 8 ft by planting density and region.

There was a consistent trend toward lower average branch angle values as density increased for both intensive and operational management (Figure 62). As there were no significant planting density by management regime interactions, pairwise multiple comparisons were not performed.

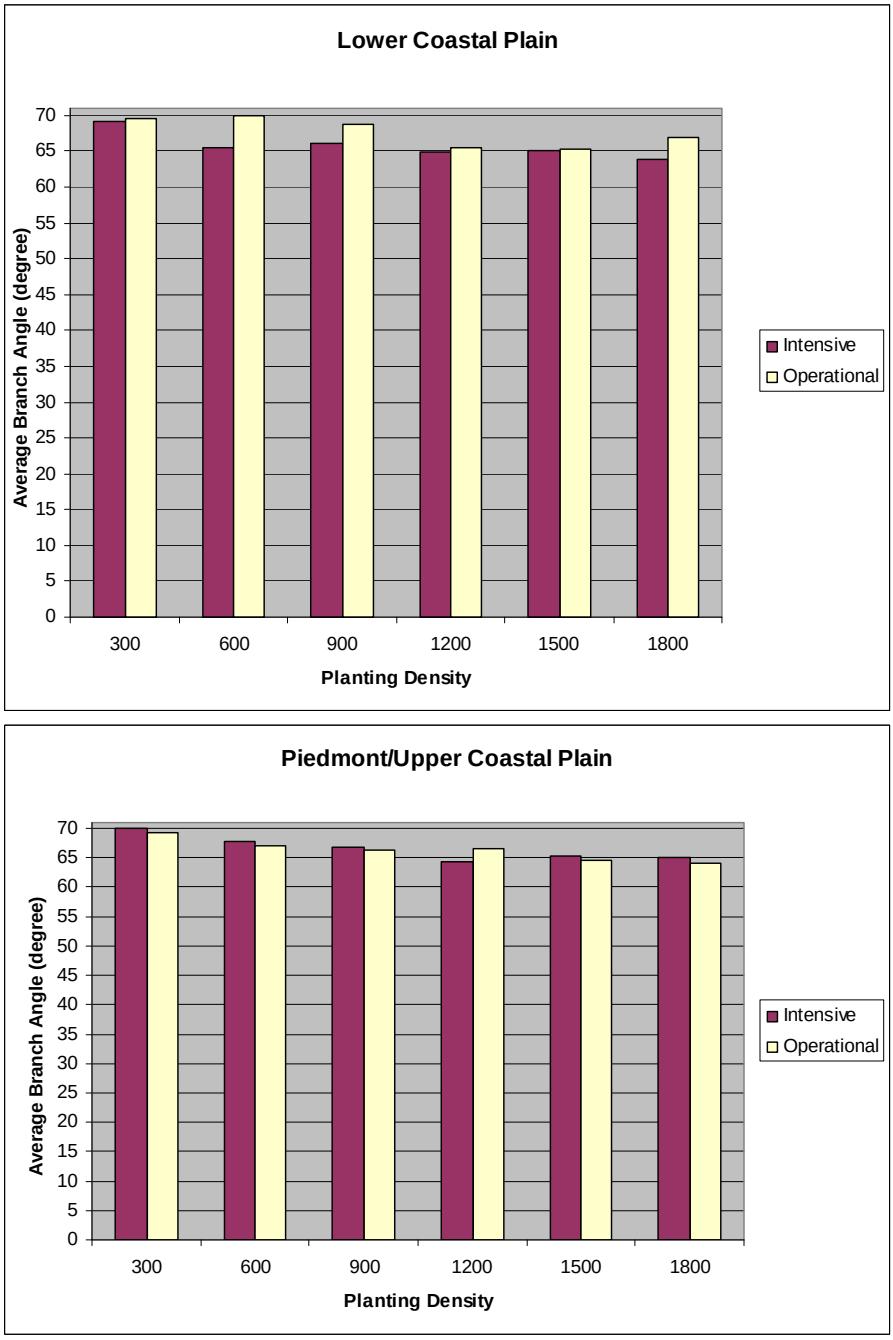


Figure 62. Average branch angle to the stem (degree) in the lower 8 ft by planting density, management regime and region.

There were significant linear trends in the average branch angle in the lower 8 ft of the stem across densities in the regions under study (Table 48). In the Lower Coastal Plain, operational management yielded an average branch angle that decreased linearly from 70º when the planting density was 300 tpa to 67º when the density was 1,800 tpa (Figure 62). For intensive management, average branch angle decreased linearly from 69º at 300 tpa to 64º at 1,800 tpa. In the Piedmont/Upper Coastal Plain, operational management yielded an average branch angle that decreased linearly from 69º ft when the planting density was 300 tpa to 64º when the density was 1,800 tpa. For intensive management, the average angle decreased linearly from 70º at 300 tpa to 65º at 1,800 tpa.

Table 48. Linear contrasts: Average branch angle to the stem (degree) in the lower 8 ft of the stem by planting density in each region.

	Lower Coastal Plain		**Piedmont/Upper Coastal Plain**	
Contrast	Type III F	Pr > F	Type III F	Pr > F
Linear Trend across Density (both Management Regimes)	22.66	0.0009*	52.29	<.0001*
Linear Trend across Density at Intensive Regime	14.47	0.0011*	28.37	<.0001*
Linear Trend across Density at Operational Regime	10.97	0.0084*	27.34	<.0001*

* Significant at $\alpha = 5\%$

3.4.4. Average branch angle for 8-16 ft stem heights

Average branch angle at heights 8-16 ft of the stem was significantly affected by planting density in both regions (Table 49). There were no significant differences in branch angle between the two management regimes. There were no significant management by density interactions.

Table 49. Analysis of variance results for average branch angle at heights 8-16 ft of the stem in each region.

	Lower Coastal Plain		**Piedmont/Upper Coastal Plain**	
Source	Type III F	Pr > F	Type III F	Pr > F
Management	0.26	0.6343	0.06	0.8120
Density	12.57	<.0001*	12.54	<.0001*
Management*Density	1.50	0.2358	1.34	0.2736

* Significant at $\alpha = 5\%$

In the Lower Coastal Plain, both management regimes yielded an average branch angle to the stem of about 50º (Figure 63). In the Piedmont/Upper Coastal Plain, both management regimes yielded a branch angle of about 53º.

For planting density, the 300 tpa treatment yielded a mean branch angle that was significantly greater than those of all other densities in both regions (Figure 64). As planting density increased, average branch angle decreased from 55º at 300 tpa to 48º at 1800 tpa in the Lower Coastal Plain, and from 57º at 300 tpa to 49º at 1800 tpa in the Piedmont/Upper Coastal Plain.

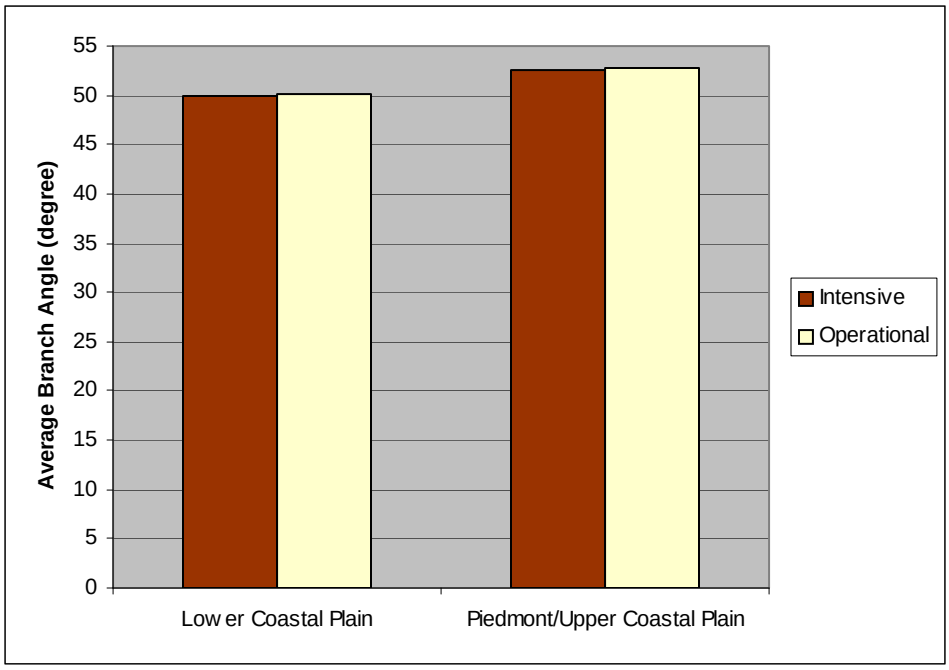


Figure 63. Average branch angle to the stem (degree) at heights 8-16 ft of the stem by management regime and region.

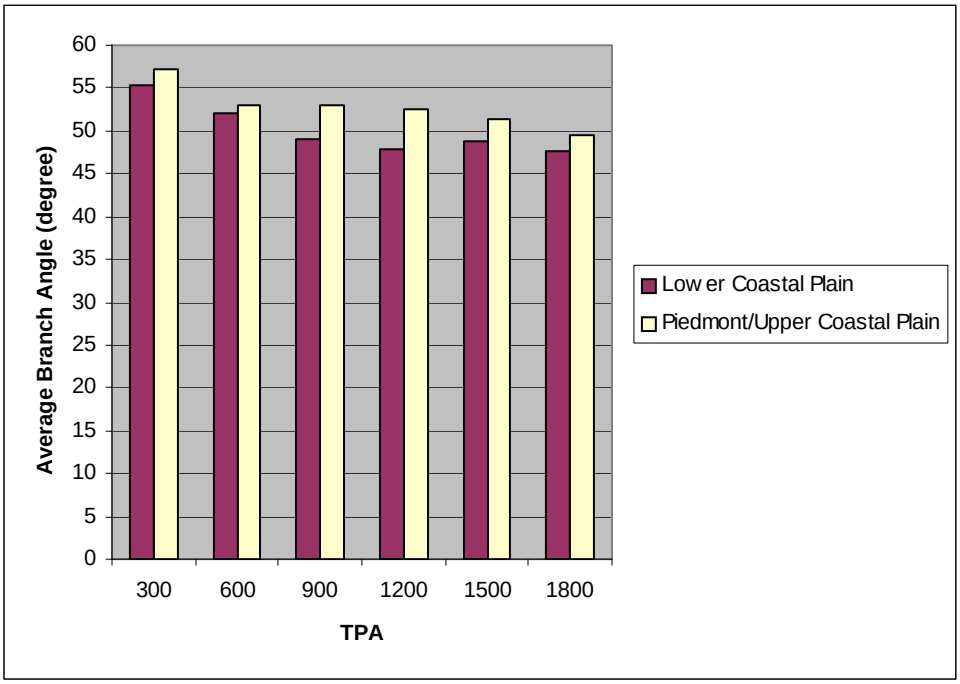


Figure 64. Average branch angle to the stem (degree) at heights 8-16 ft of the stem by planting density and region.

There was a consistent trend toward lower average branch angle values as

density increased for both intensive and operational management (Figure 65). As there were no significant planting density by management regime interactions, pairwise multiple comparisons were not performed.

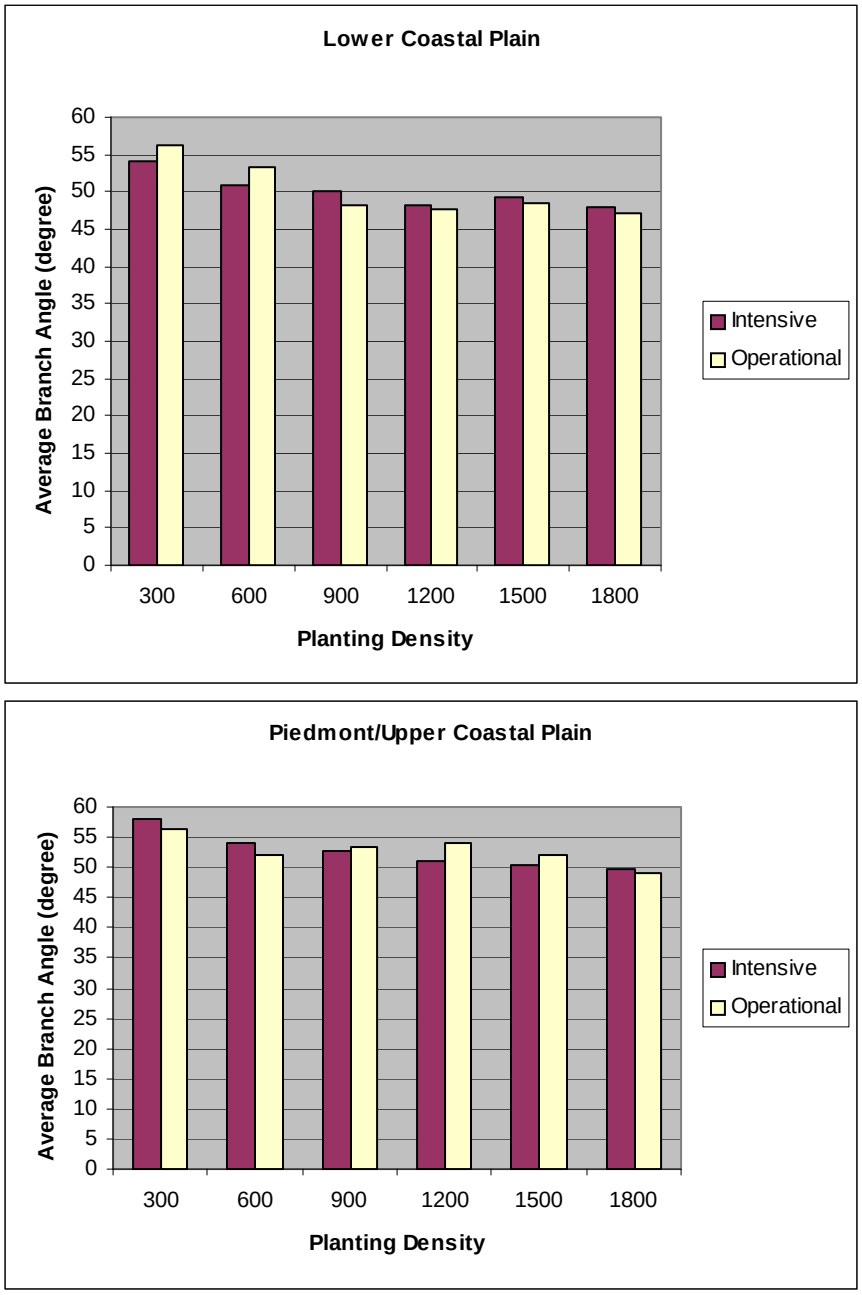


Figure 65. Average branch angle to the stem (degree) at heights 8-16 ft of the stem by planting density, management regime and region.

There were significant linear trends in the average branch angle in the lower 8 ft of the stem across densities in the regions under study (Table 50). In the Lower Coastal Plain, operational management yielded an average branch angle that decreased linearly from 56º when the planting density was 300 tpa to 47º when the density was 1,800 tpa (Figure 65). For intensive management, branch angle decreased linearly from 54º at 300 tpa to 48º at 1,800 tpa. In the Piedmont/Upper Coastal Plain, operational management yielded an average branch angle that decreased linearly from 56º ft when the planting density was 300 tpa to 49º when the density was 1,800 tpa. For intensive management, average angle decreased linearly from 58º at 300 tpa to 50º at 1,800 tpa.

Table 50. Linear contrasts: Average branch angle to the stem (degree) at heights 8-16 ft of the stem by planting density in each region.

	Lower Coastal Plain		**Piedmont/Upper Coastal Plain**	
Contrast	Type III F	Pr > F	Type III F	Pr > F
Linear Trend across Density (both Management Regimes)	21.58	0.0017*	53.01	<.0001*
Linear Trend across Density at Intensive Regime	12.78	0.0023*	28.81	<.0001*
Linear Trend across Density at Operational Regime	9.36	0.0158*	12.87	0.0012*

* Significant at $\alpha = 5\%$

3.4.5. Average branch angle for 16-24 ft stem heights

For the average branch angle at heights 16-24 ft of the stem, the management factor was significant only in the Piedmont/Upper Coastal Plain, while the planting density factor was significant only in the Lower Coastal Plain (Table 51). The management by density interactions were not significant in either region.

Table 51. Analysis of variance results for average branch angle at heights 16-24 ft of the stem in each region.

	Lower Coastal Plain		**Piedmont/Upper Coastal Plain**	
Source	Type III F	Pr > F	Type III F	Pr > F
Management	3.26	0.1310	10.63	0.0173*
Density	13.63	<.0001*	1.87	0.1299
Management*Density	0.47	0.7952	2.31	0.0690

* Significant at $\alpha = 5\%$

In the Piedmont/Upper Coastal Plain, intensive management yielded an average branch angle of 53º as compared with 51º for the operational regime (Figure 66).

In the Lower Coastal Plain branch angle for the 300 tpa and 1800 tpa treatments were significantly different from each other (Figure 67). As planting density increased, average branch angle decreased from 52º at 300 tpa to 46º at 1800 tpa.

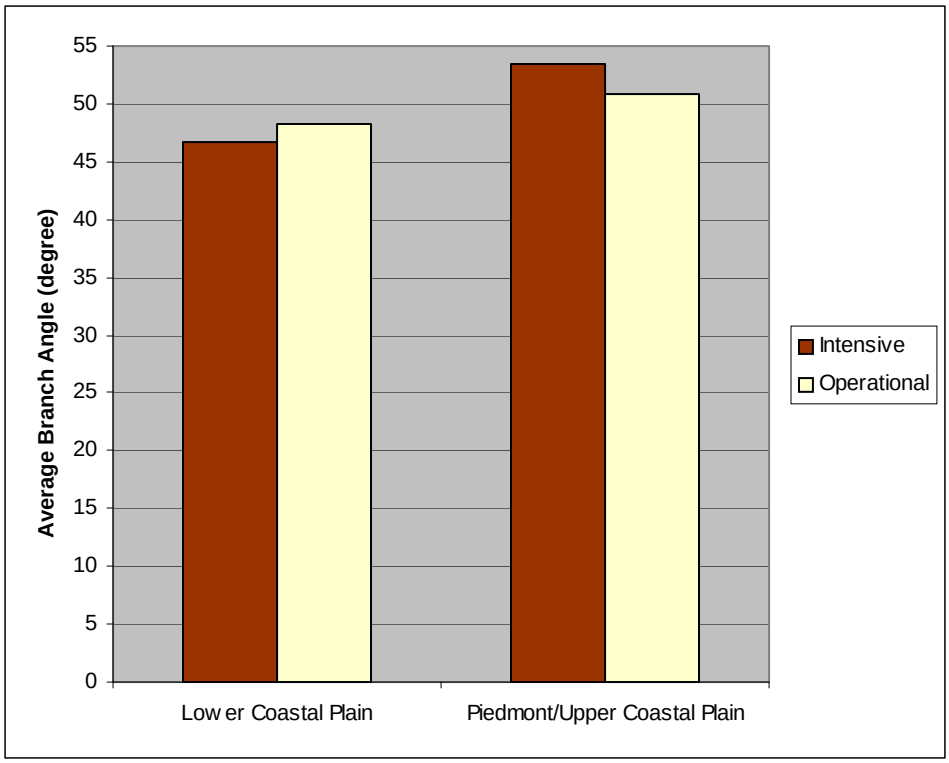


Figure 66. Average branch angle to the stem (degree) at heights 16-24 ft of the stem by management regime and region.

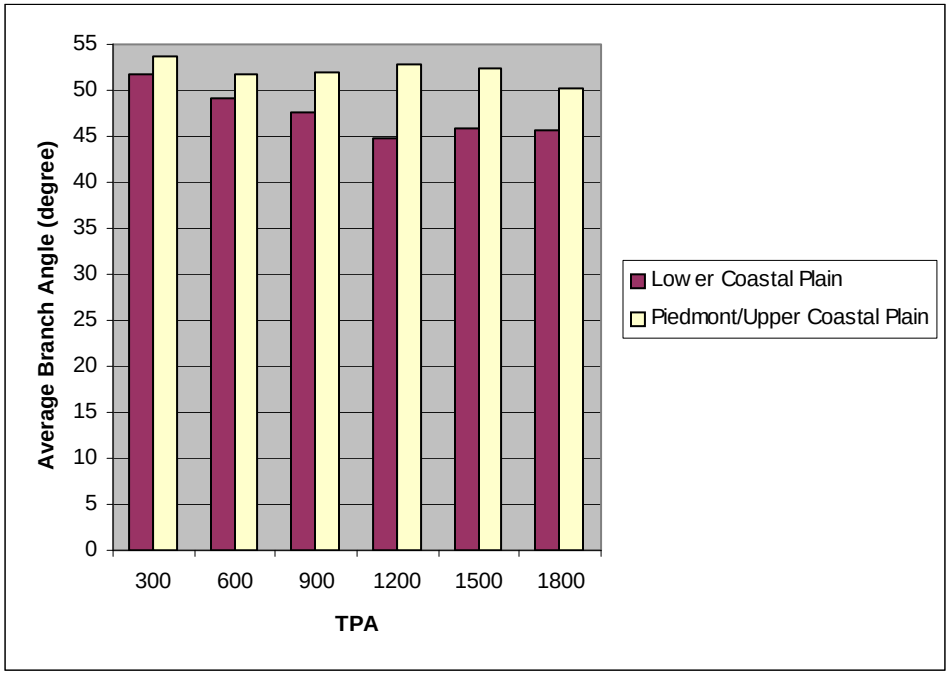


Figure 67. Average branch angle to the stem (degree) at heights 16-24 ft of the stem by planting density and region.

There was a consistent trend toward lower average branch angle values as density increased, for both intensive and operational management, in the Lower Coastal Plain (Figure 68). As there were no significant planting density by management regime interactions, pairwise multiple comparisons were not conducted.

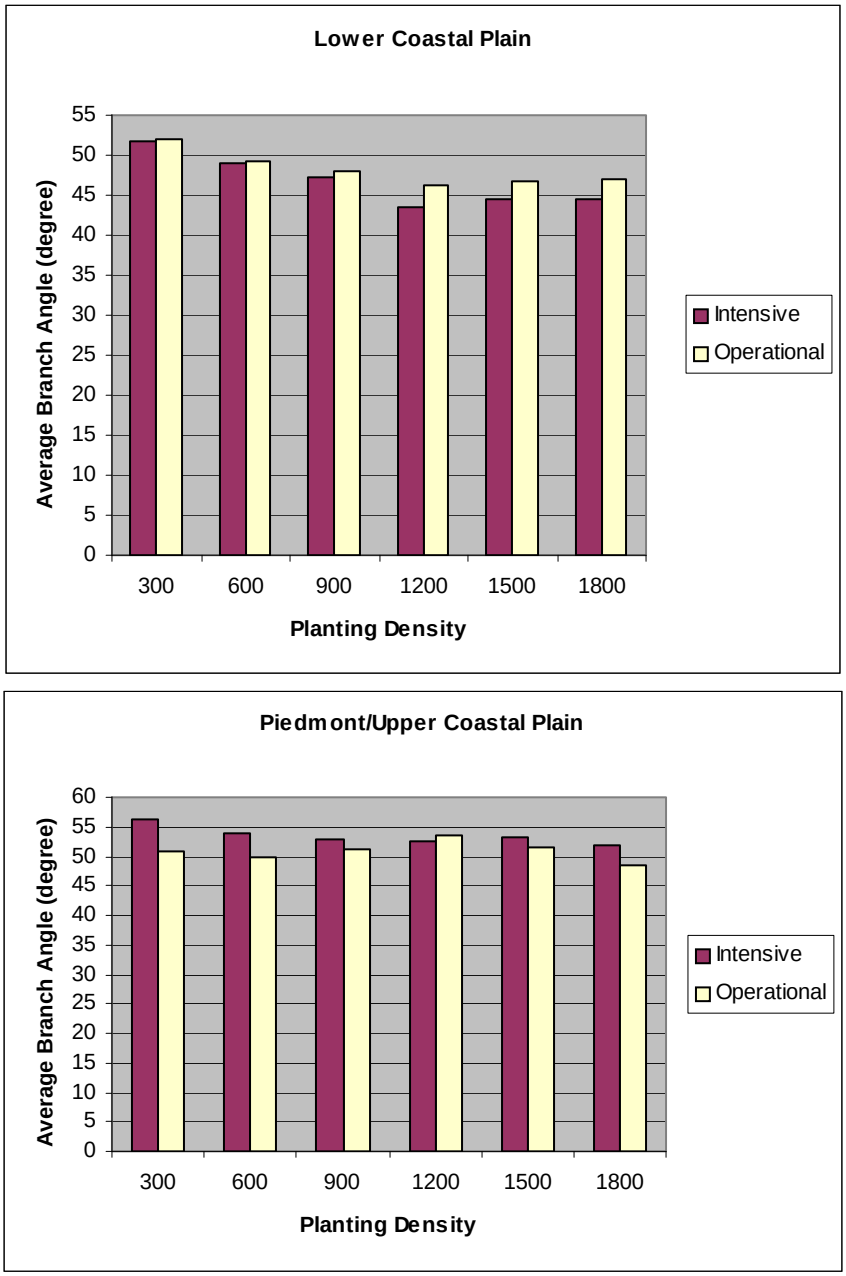


Figure 68. Average branch angle to the stem (degree) at heights 16-24 ft of the stem by planting density, management regime and region.

There were significant linear trends in average branch angle at heights 16-24 ft of the stem across densities in the regions under study (Table 52). In the Lower Coastal Plain, operational management yielded an average branch angle that decreased linearly from 52º when the planting density was 300 tpa to 47º when the density was 1,800 tpa (Figure 68). For intensive management, average branch angle decreased linearly from 52º at 300 tpa to 44º at 1,800 tpa. In the Piedmont/Upper Coastal Plain, only the intensive management regime yielded a significant linear contrast with branch angles that decreased linearly from 56º at 300 tpa to 52º at 1,800 tpa.

Table 52. Linear contrasts: Average branch angle to the stem (degree) at heights 16-24 ft of the stem by planting density in each region.

	Lower Coastal Plain		**Piedmont/Upper Coastal Plain**	
Contrast	Type III F	Pr > F	Type III F	Pr > F
Linear Trend across Density (both Management Regimes)	5.58	0.037*	4.34	0.0459*
Linear Trend across Density at Intensive Regime	6.78	0.0053*	8.10	0.0079*
Linear Trend across Density at Operational Regime	1.71	0.0217*	2.31	0.0690

* Significant at $\alpha = 5\%$

3.5. Total Number of Branches

The average total number of branches per tree is summarized across regions, logs, planting densities, and management regimes in Figure 69 and Figure 70.

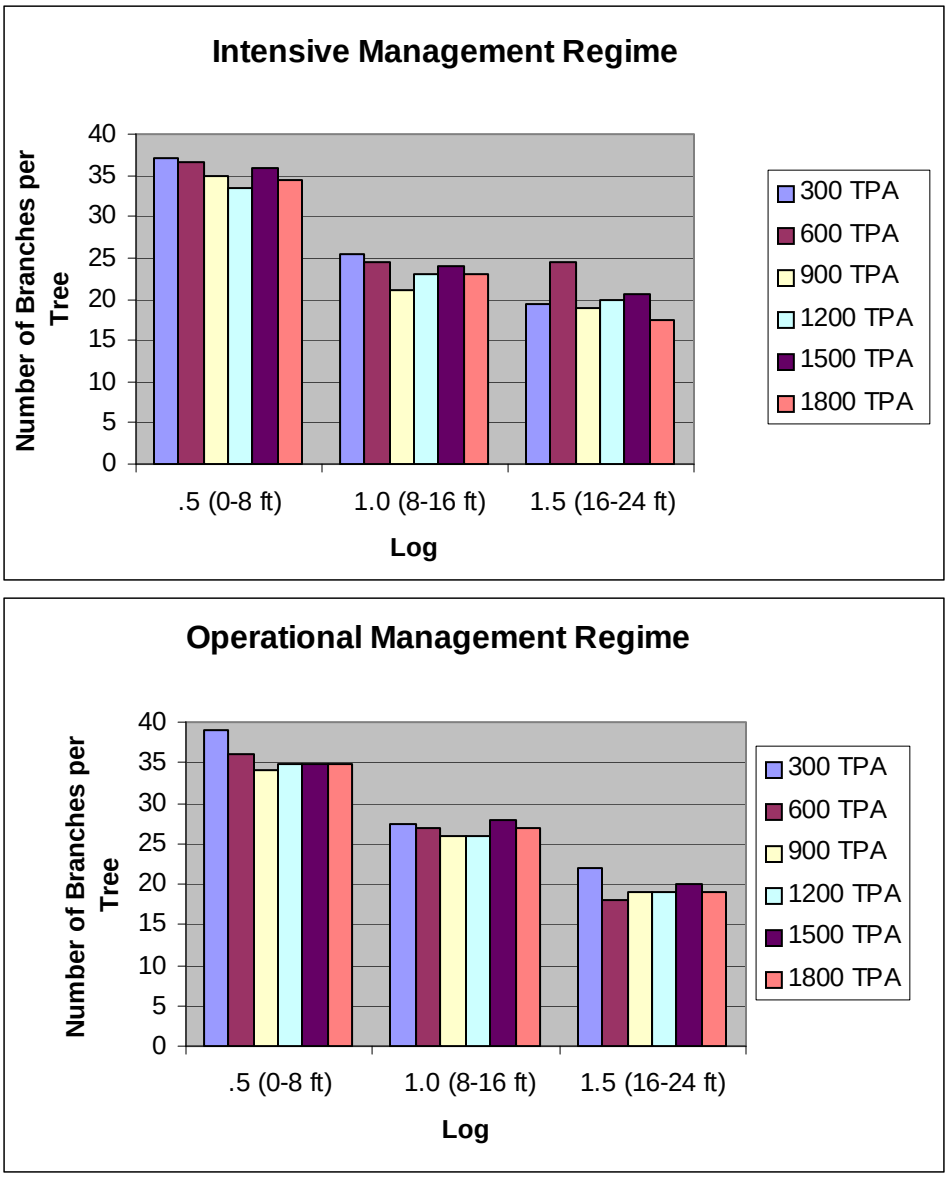


Figure 69. Average total number of branches per tree by half-log, management regime, and planting density in the Lower Coastal Plain.

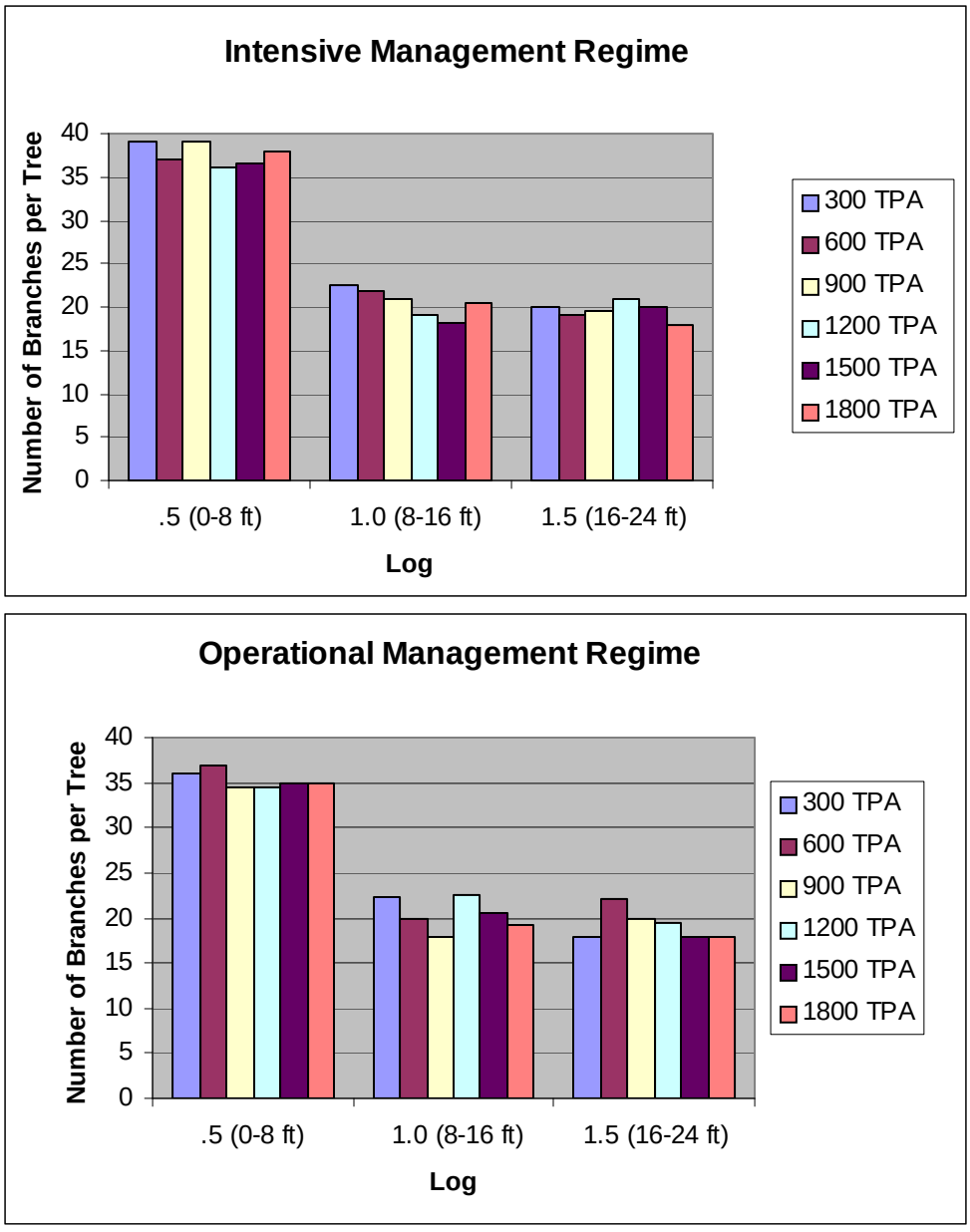


Figure 70. Average total number of branches per tree by half-log, management regime, and planting density in the Piedmont/Upper Coastal Plain.

3.5.1. Average total number of branches per tree for 0-24 ft stem heights

There were no significant differences in the total number of branches in the lower 24 feet of the stem due to management intensity, planting density, or their interaction (Table 53). The average number of branches per tree in the Lower Coastal Plain was 79 for the intensive regime and 81 for the operational regime. In the Piedmont/Upper Coastal Plain branches per tree numbered 77 for the intensive regime and 75 for the operational regime. Silvicultural treatment means are presented in Figure 71 and planting density means are presented in Figure 72.

Table 53. Analysis of variance results for average number of branches per tree in the lower24 ft of the stem in each region.

	Lower Coastal Plain		**Piedmont/Upper Coastal Plain**	
Source	Type III F	Pr > F	Type III F	Pr > F
Management	1.64	0.2570	4.80	0.0782
Density	1.87	0.0981	0.89	0.5003
Management*Density	0.66	0.6538	2.69	0.1960

* Significant at $\alpha = 5\%$

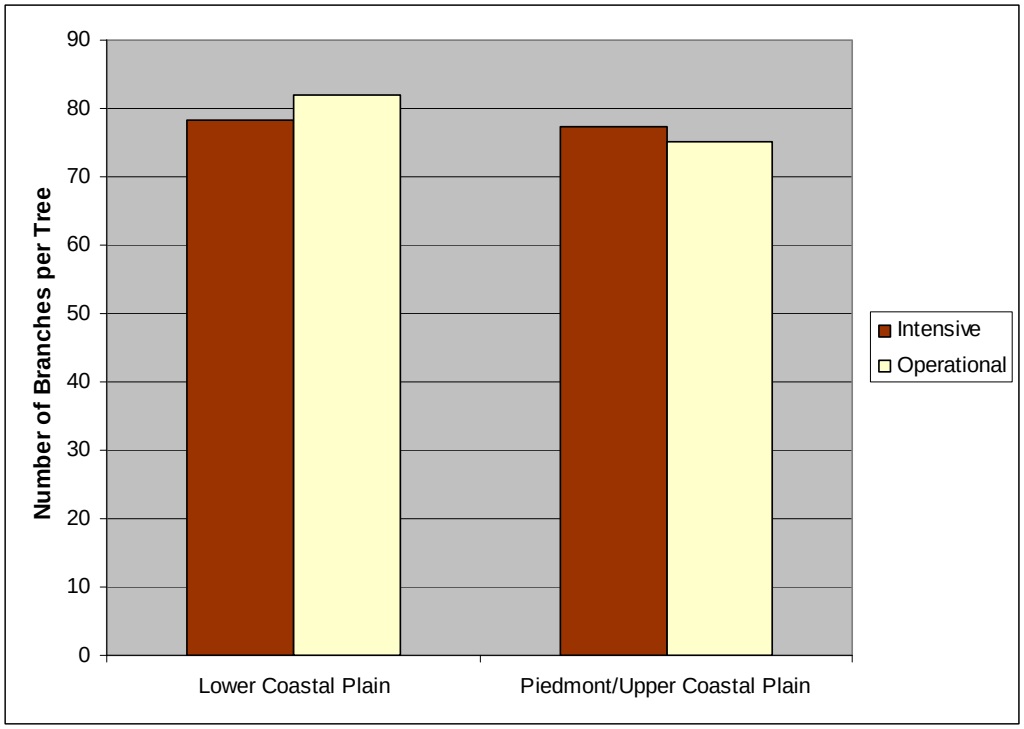


Figure 71. Average number of branches per tree in lower 24 ft of the stem by management regime and region.

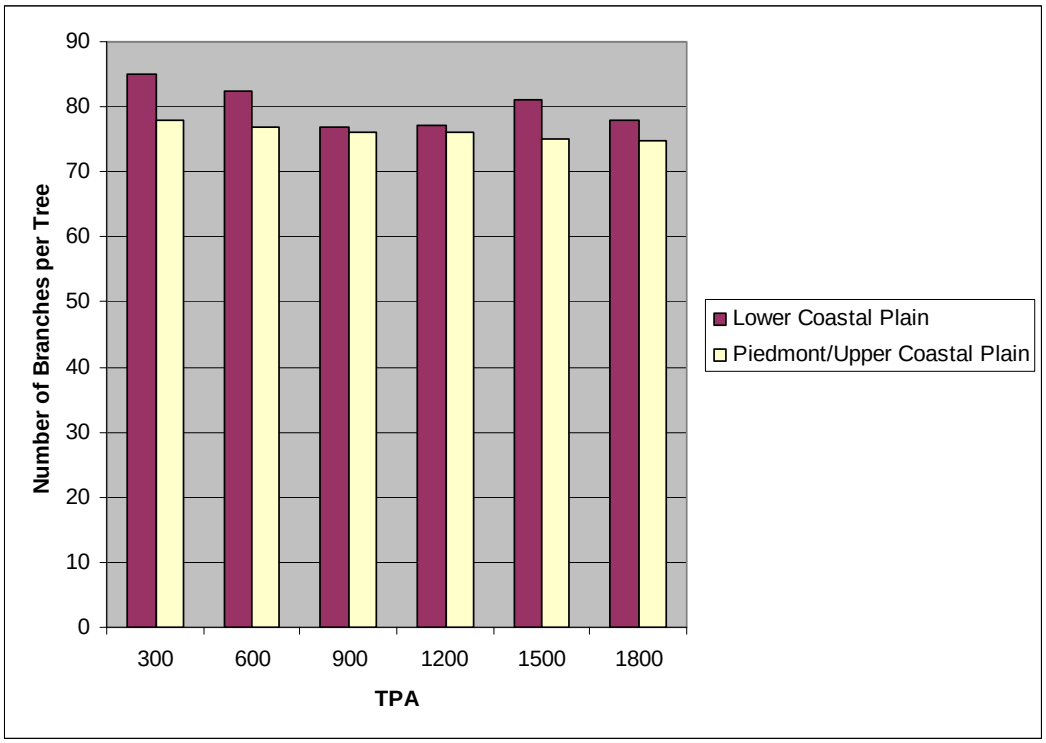


Figure 72. Average number of branches per tree in the lower 24 ft of the stem by planting density and region.

The average number of branches per tree in the lower 24 ft of the stem for each management regime and planting density treatment combination are presented in Figure 73. As there were no significant planting density by management regime interactions in either region, multiple comparisons were not conducted.

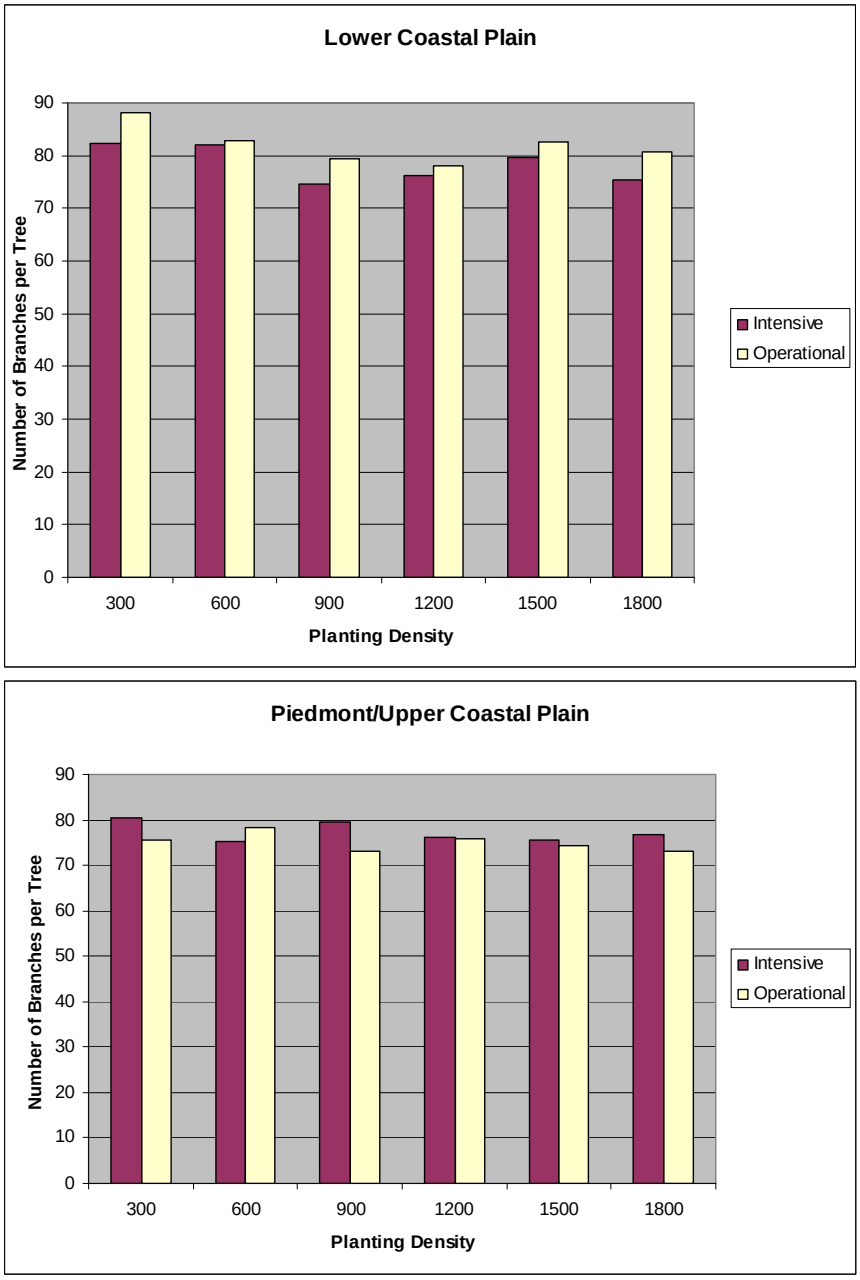


Figure 73. Average number of branches per tree in the lower 24 ft of the stem by planting density, management regime and region.

There were no significant linear trends for the average number of branches per tree in the lower 24 ft of the stem across densities in the regions under study (Table 54).

Table 54. Linear contrasts: average number of branches per tree in the lower 24 ft of the stem by planting density in each region.

	Lower Coastal Plain		Piedmont/Upper Coastal Plain	
Contrast	Type III F	Pr > F	Type III SS	Pr > F
Linear Trend across Density (both Management Regimes)	3.70	0.1022	4.16	0.0502
Linear Trend across Density at Intensive Regime	2.39	0.077	2.41	0.1308
Linear Trend across Density at Operational Regime	3.47	0.0679	1.15	0.2923

* Significant at $\alpha = 5\%$

3.5.2. Average total number of branches per tree at 0-16 ft stem heights

There were no significant differences in the total number of branches per tree in the lower 16 feet of the stem due to management intensity, planting density, nor their interaction (Table 55). The average number of branches per tree in the Lower Coastal Plain was 61 for the intensive regime and 59 for the operational regime. In the Piedmont/Upper Coastal Plain the average number of branches was 77 for the intensive regime and 75 for the operational regime. Silvicultural treatment means are presented in Figure 74 and planting density means are presented in Figure 75.

Table 55. Analysis of variance results for average number of branches per tree in the lower 16 ft of the stem in each region.

	Lower Coastal Plain		**Piedmont/Upper Coastal Plain**	
Source	Type III F	Pr > F	Type III F	Pr > F
Management	1.71	0.2957	2.71	0.1636
Density	3.44	0.0722	1.86	0.1092
Management*Density	0.39	0.9013	1.24	0.0610

* Significant at $\alpha = 5\%$

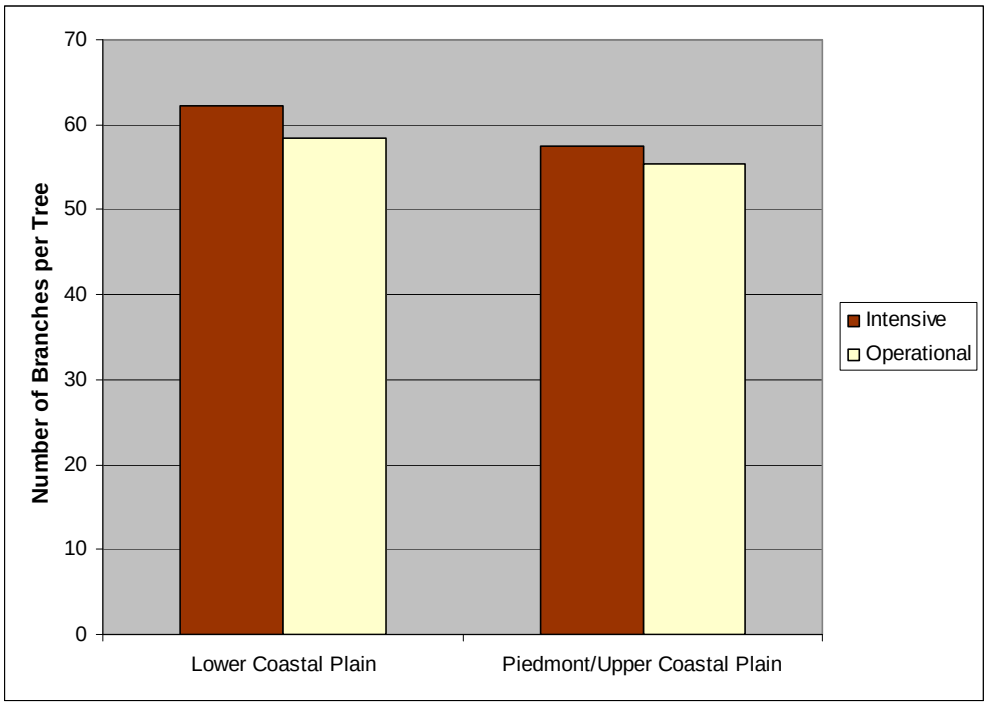


Figure 74. Average number of branches per tree in the lower 16 ft of the stem by management regime and region.

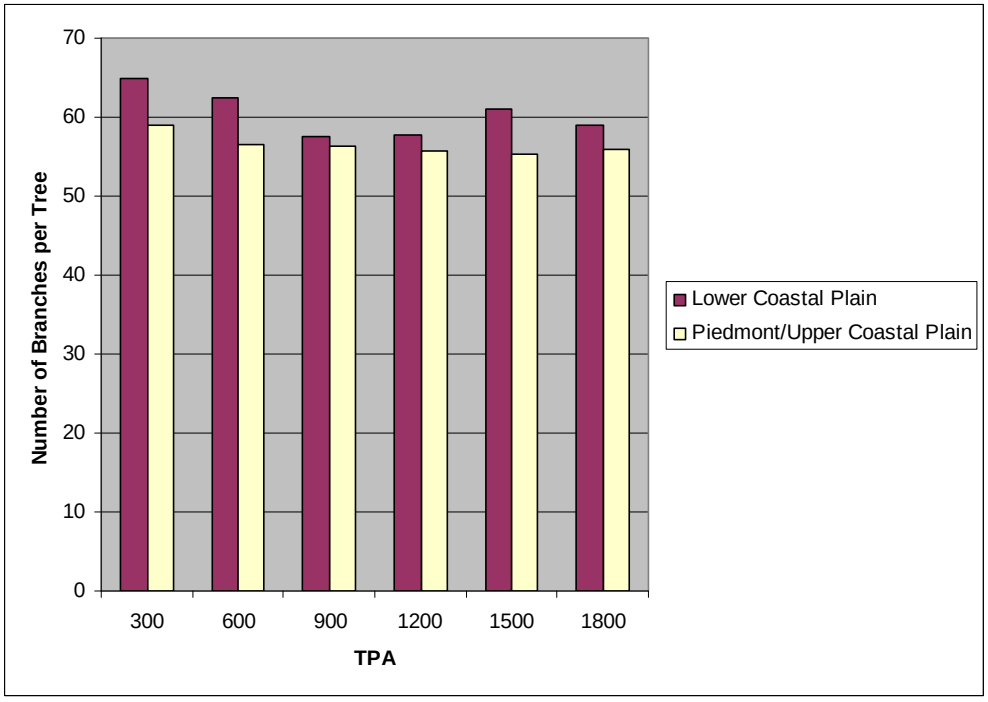


Figure 75. Average number of branches per tree in the lower 16 ft of the stem by planting density and region.

The average number of branches per tree in the lower 16 ft of the stem for each management regime and planting density treatment combination are presented in Figure 76. As there were no significant planting density by management regime interactions in either region, multiple comparisons were not conducted.

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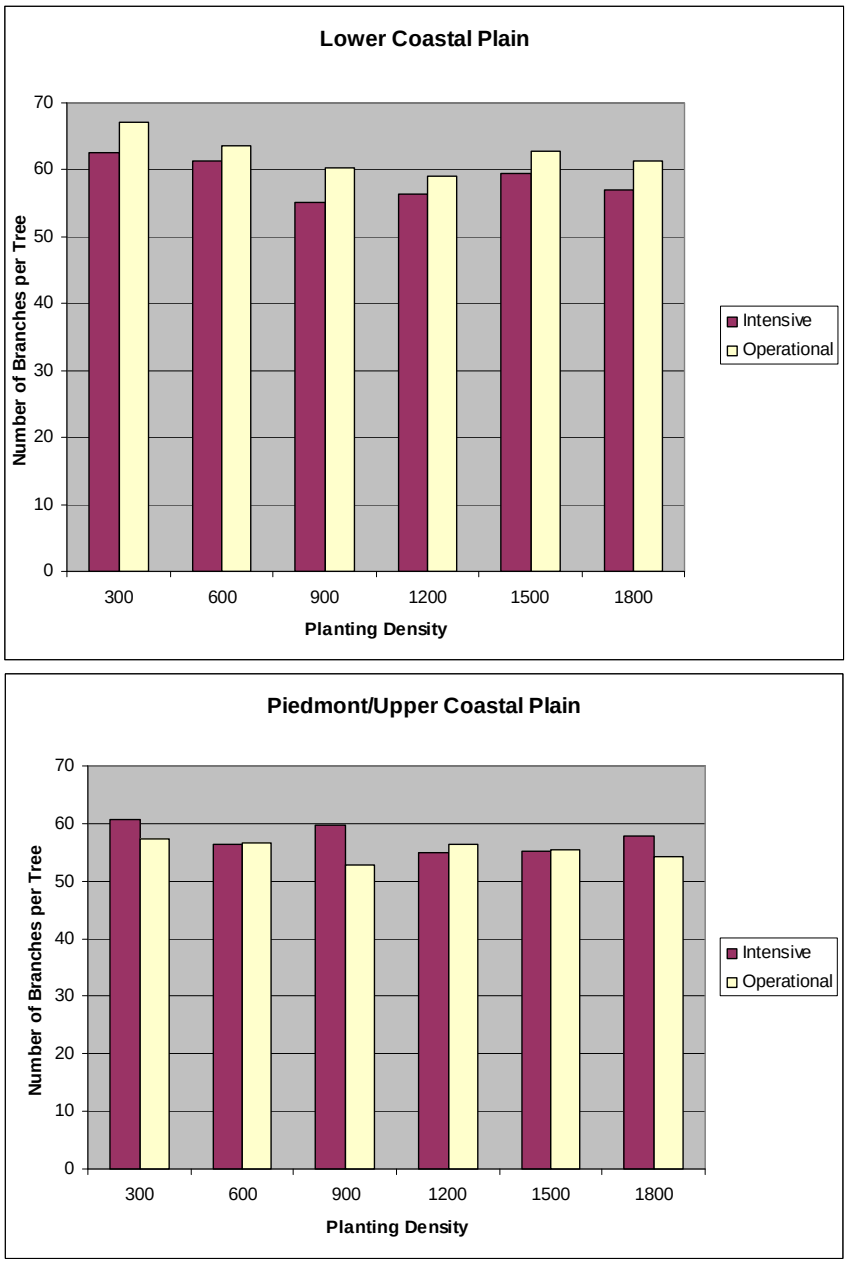


Figure 76. Average number of branches per tree in the lower 16 ft of the stem by planting density, management regime and region.

There were no significant linear trends for the average number of branches per tree in the lower 16 ft of the stem across densities in the regions under study (Table 56).

Table 56. Linear contrasts: average number of branches per tree in the lower 16 ft of the stem by planting density in each region.

	Lower Coastal Plain		**Piedmont/Upper Coastal Plain**	
Contrast	Type III F	Pr > F	Type III SS	Pr > F
Linear Trend across Density (both Management Regimes)	2.47	0.0601	3.16	0.0891
Linear Trend across Density at Intensive Regime	2.19	0.0602	4.92	0.0519
Linear Trend across Density at Operational Regime	3.84	0.0561	1.04	0.3168

* Significant at $\alpha = 5\%$

3.5.3. Average total number of branches per tree for 0-8 ft stem height

There were no significant differences in the total number of branches in the lower 8 feet of the stem due to management intensity, planting density, or their interaction (Table 57). The average number of branches per tree in the Lower Coastal Plain was 35 for both management regimes. In the Piedmont/Upper Coastal Plain average branch number was 37 for the intensive regime and 35 for the operational regime. Silvicultural treatment means are presented in Figure 77 and planting density means are presented in Figure 78.

Table 57. Analysis of variance results for average number of branches per tree in the lower 8 ft of the stem in each region.

	Lower Coastal Plain		**Piedmont/Upper Coastal Plain**	
Source	Type III F	Pr > F	Type III F	Pr > F
Management	0.1104	0.7840	3.98	0.0924
Density	1.27	0.0608	1.45	0.2331
Management*Density	0.53	0.7735	1.12	0.3197

* Significant at $\alpha = 5\%$

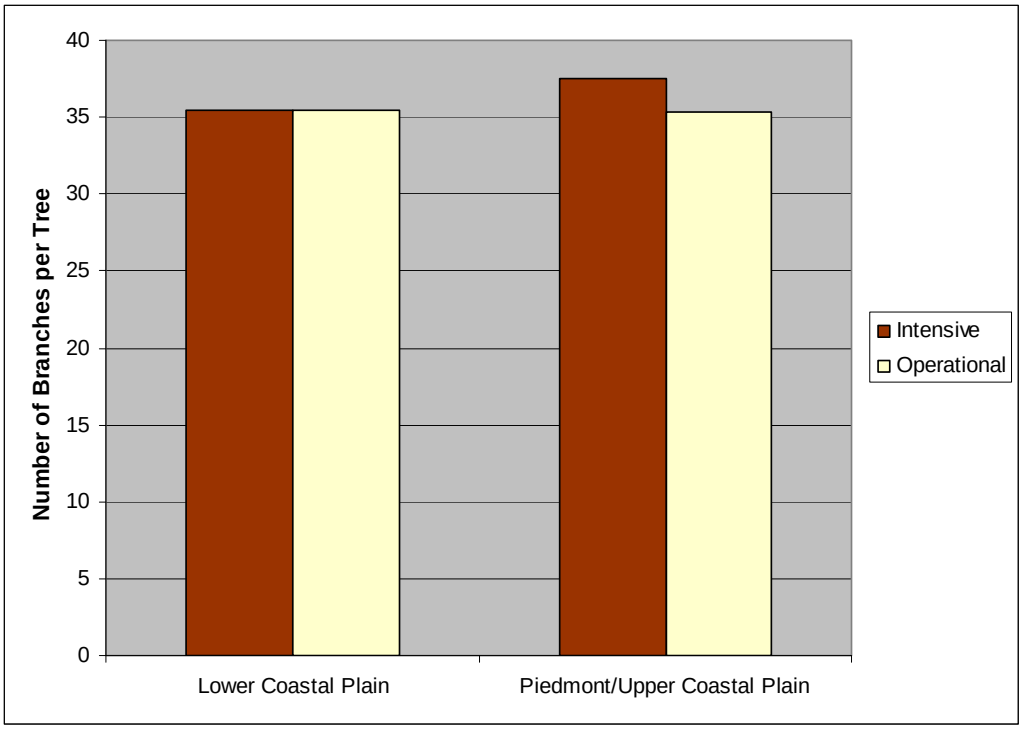


Figure 77. Average number of branches per tree in the lower 8 ft of the stem by management regime and region

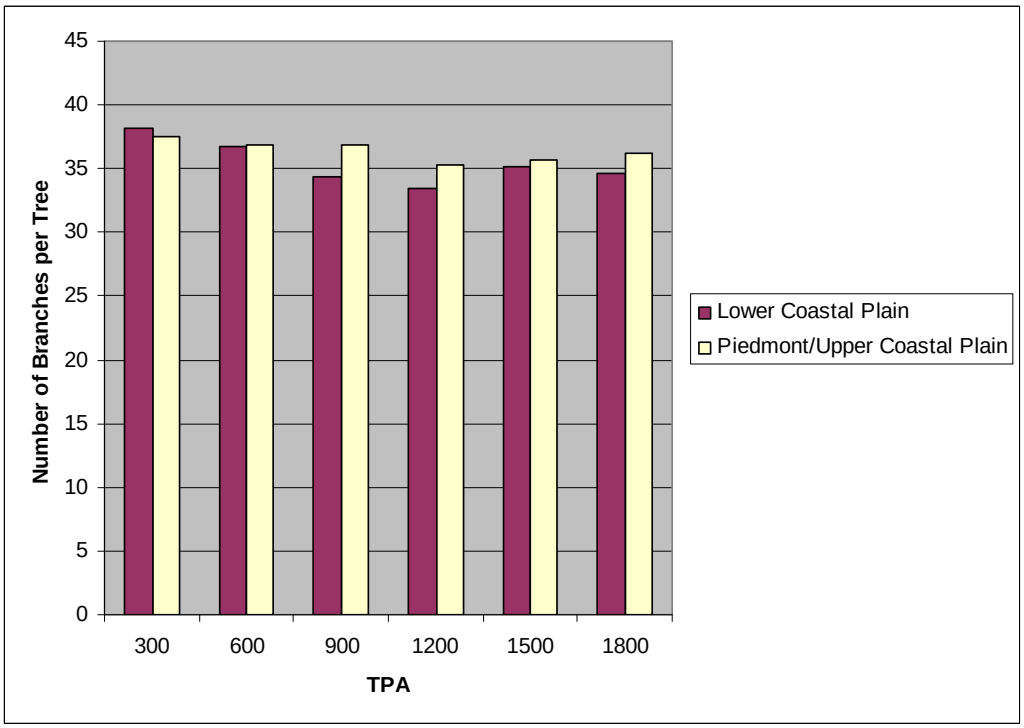


Figure 78. Average number of branches per tree in lower 8 ft of the stem by planting density and region.

The average number of branches per tree in the lower 8 ft of the stem for each management regime and planting density treatment combination are presented in Figure 79. As there were no significant planting density by management regime interactions in either region, multiple comparisons were not conducted.

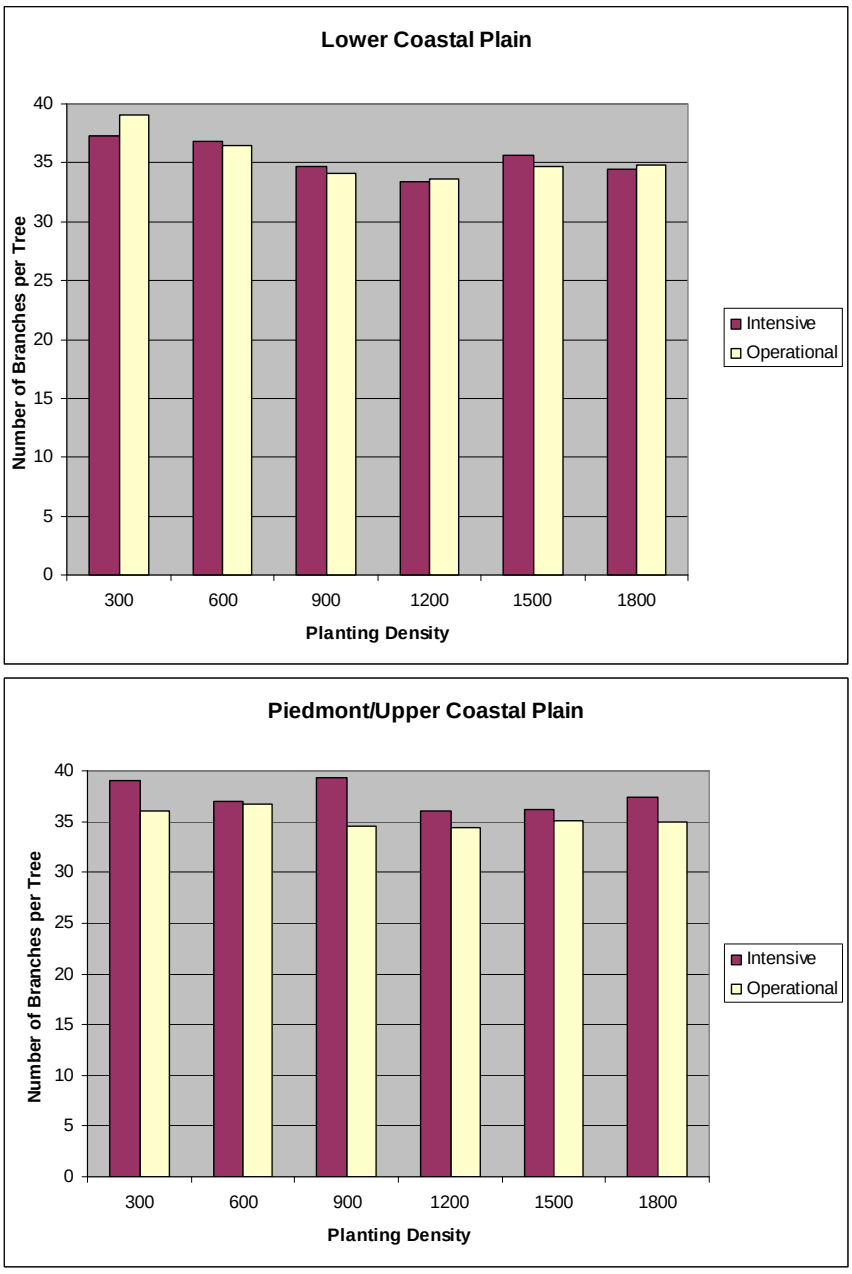


Figure 79. Average number of branches per tree in the lower 8 ft of the stem by planting density, management regime and region.

There were no significant linear trends for the average number of branches per tree in lower 8 ft of the stem across densities in the regions under study (Table 58).

Table 58. Linear contrasts: average number of branches per tree in the lower 8 ft of the stem by planting density in each region.

	Lower Coastal Plain		**Piedmont/Upper Coastal Plain**	
Contrast	Type III F	Pr > F	Type III SS	Pr > F
Linear Trend across Density (both Management Regimes)	4.77	0.0708	3.20	0.0592
Linear Trend across Density at Intensive Regime	3.11	0.0989	2.67	0.1126
Linear Trend across Density at Operational Regime	3.07	0.0709	0.99	0.3267

* Significant at $\alpha = 5\%$

3.5.4. Average total number of branches per tree for 8-16 ft stem heights

There were no significant differences in the total number of branches per tree at heights 8-16 ft of the stem due to management intensity, planting density, nor their interaction (Table 59). The average number of branches per tree in the Piedmont/Upper coastal region was 20 for both management regimes. In the Lower Coastal Plain average branch number was 26 for the operational regime and 24 for the intensive regime. Silvicultural treatment means are presented in Figure 80 and planting density means are presented in Figure 81.

Table 59. Analysis of variance results for average number of branches per tree at heights 8-16 ft of the stem in each region.

	Lower Coastal Plain		**Piedmont/Upper Coastal Plain**	
Source	Type III F	Pr > F	Type III F	Pr > F
Management	3.59	0.1167	0.08	0.7920
Density	1.51	0.2228	1.81	0.1391
Management*Density	0.78	0.5653	1.05	0.0527

* Significant at $\alpha = 5\%$

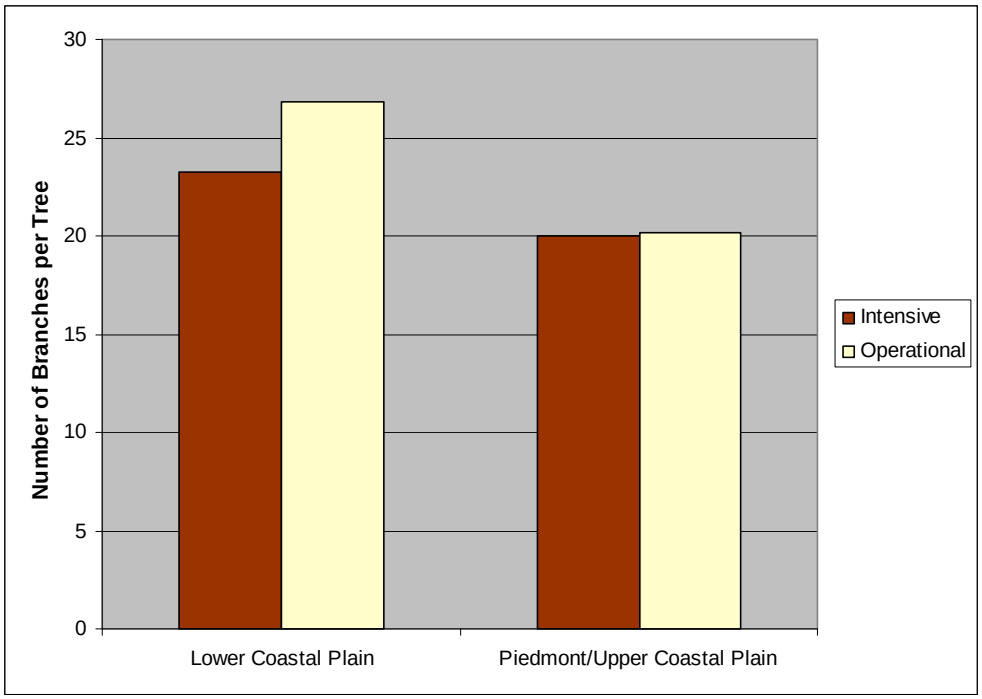


Figure 80. Average number of branches per tree at heights 8-16 ft of the stem by management regime and region.

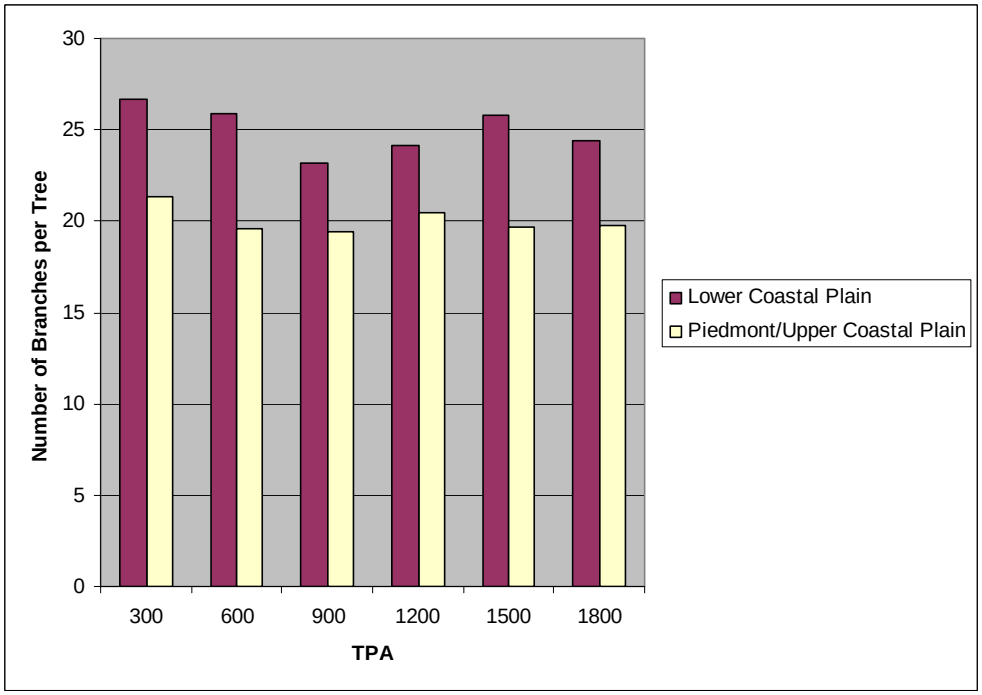


Figure 81. Average number of branches per tree at heights 8-16 ft of the stem by planting density and region.

The average number of branches per tree in the lower 8-16 ft of the stem for each management regime and planting density treatment combination are presented in Figure 82. As there were no significant planting density by management regime interactions in either region, multiple comparisons were not conducted.

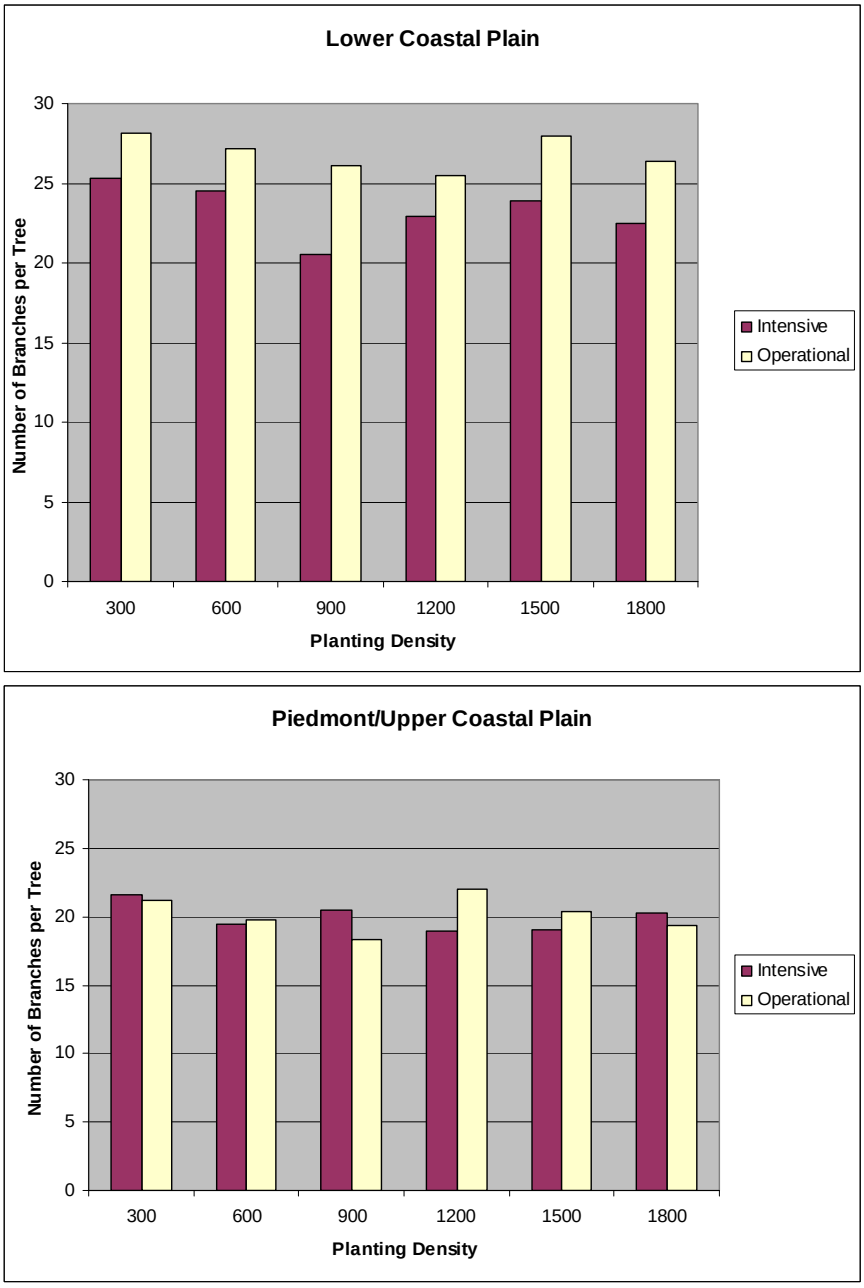


Figure 82. Average number of branches per tree at heights 8-16 ft of the stem by planting density, management regime and region.

There were no significant linear trends for the average number of branches per tree at heights 8-16 ft of the stem across densities in the regions under study (Table 60).

Table 60. Linear contrasts: average number of branches per tree at heights 8-16 ft of the stem by planting density in each region.

	Lower Coastal Plain		**Piedmont/Upper Coastal Plain**	
Contrast	Type III F	Pr > F	Type III SS	Pr > F
Linear Trend across Density (both Management Regimes)	2.91	0.1249	1.76	0.1947
Linear Trend across Density at Intensive Regime	4.62	0.8931	2.75	0.1075
Linear Trend across Density at Operational Regime	1.27	0.4882	0.22	0.6389

* Significant at $\alpha = 5\%$

3.5.5. Average total number of branches per tree for 16-24 ft stem heights

There were no significant differences in the total number of branches per tree at heights 16-24 ft of the stem due to management intensity, planting density, or their interaction (Table 61). The average number of branches per tree was about 19 across all management regimes and regions. Silvicultural treatment means are presented in Figure 83 and planting density treatment means are presented in Figure 84.

Table 61. Analysis of variance results for average number of branches per tree at heights 16-24 ft of the stem in each region.

	Lower Coastal Plain		**Piedmont/Upper Coastal Plain**	
Source	Type III F	Pr > F	Type III F	Pr > F
Management	0.02	0.9341	0.01	0.9543
Density	0.58	0.7169	0.71	0.6186
Management*Density	1.03	0.3958	1.49	0.2222

* Significant at $\alpha = 5\%$

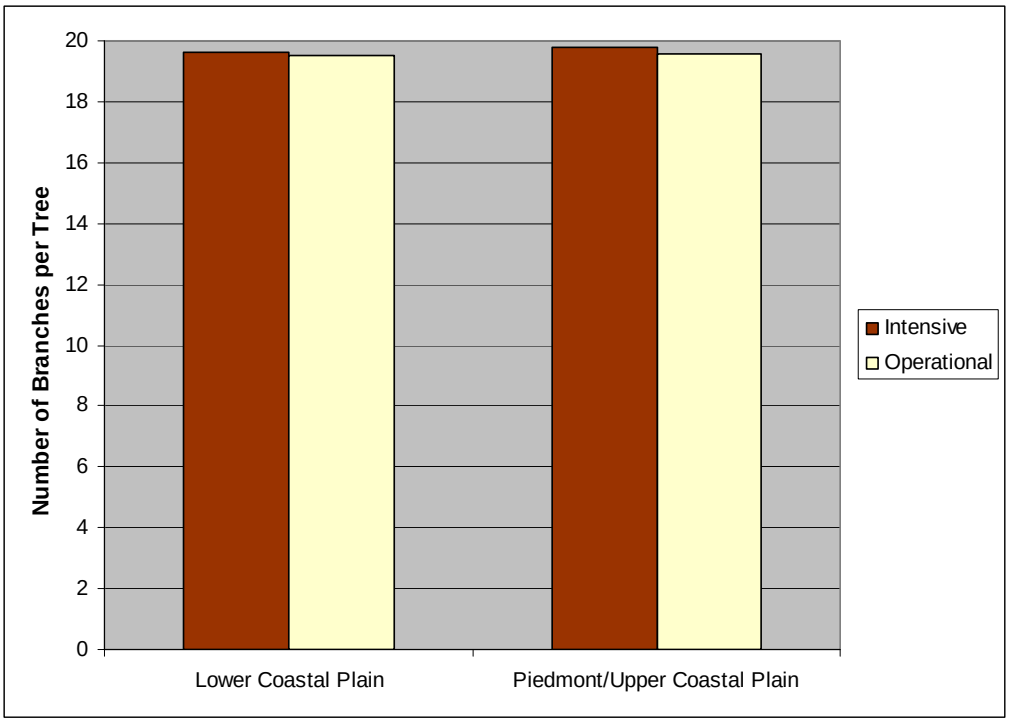


Figure 83. Average number of branches per tree at heights 16-24 ft of the stem by management regime and region

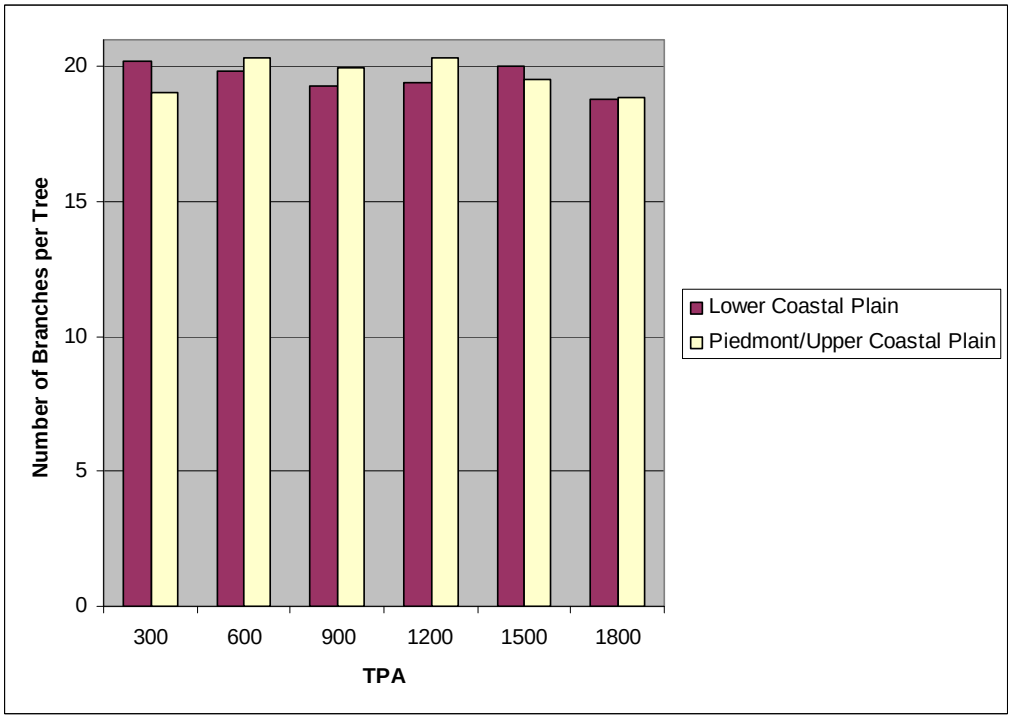


Figure 84. Average number of branches per tree at heights 16-24 ft of the stem height by planting density and region.

The average number of branches per tree at heights 16-24 ft of the stem for each management regime and planting density treatment combination are presented in Figure 85. As there were no significant planting density by management regime interactions in either region, multiple comparisons were not conducted.

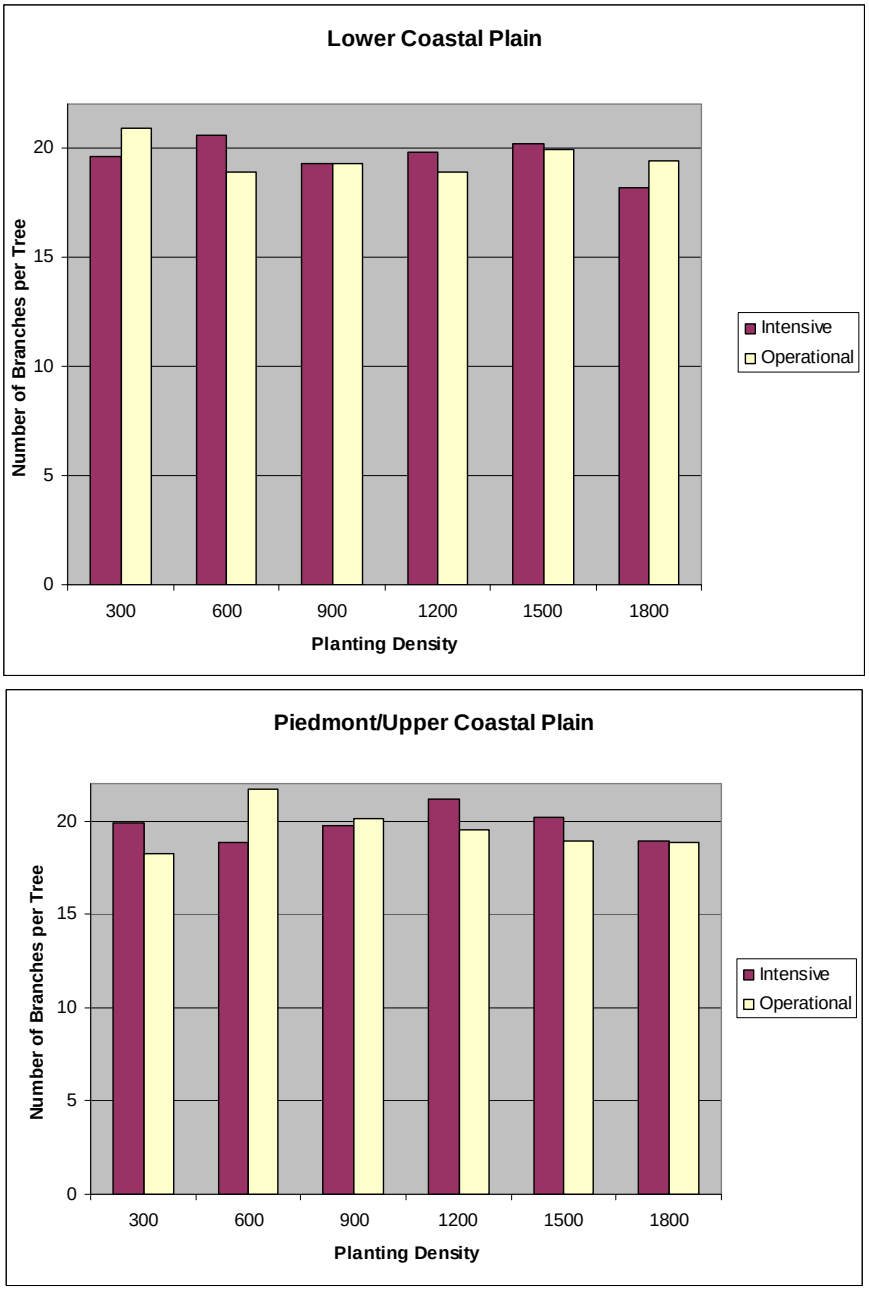


Figure 85. Average number of branches per tree at heights 16-24 ft of the stem by planting density, management regime and region.

There were no significant linear trends for the average number of branches per tree at heights 16-24 ft of the stem across densities in the regions under study (Table 62).

Table 62. Linear contrasts: average number of branches per tree at heights 16-24 ft of the stem by planting density in each region.

	Lower Coastal Plain		**Piedmont/Upper Coastal Plain**	
Contrast	Type III F	Pr > F	Type III SS	Pr > F
Linear Trend across Density (both Management Regimes)	1.39	0.1938	0.56	0.4604
Linear Trend across Density at Intensive Regime	4.08	0.8792	0.05	0.8277
Linear Trend across Density at Operational Regime	1.89	0.4497	0.60	0.4463

* Significant at $\alpha = 5\%$

3.6. Total Number of Live Branches

The average number of live branches per tree in the lower 24 feet of stem is summarized across regions, logs, planting densities, and management regimes in Figure 86 and Figure 87.

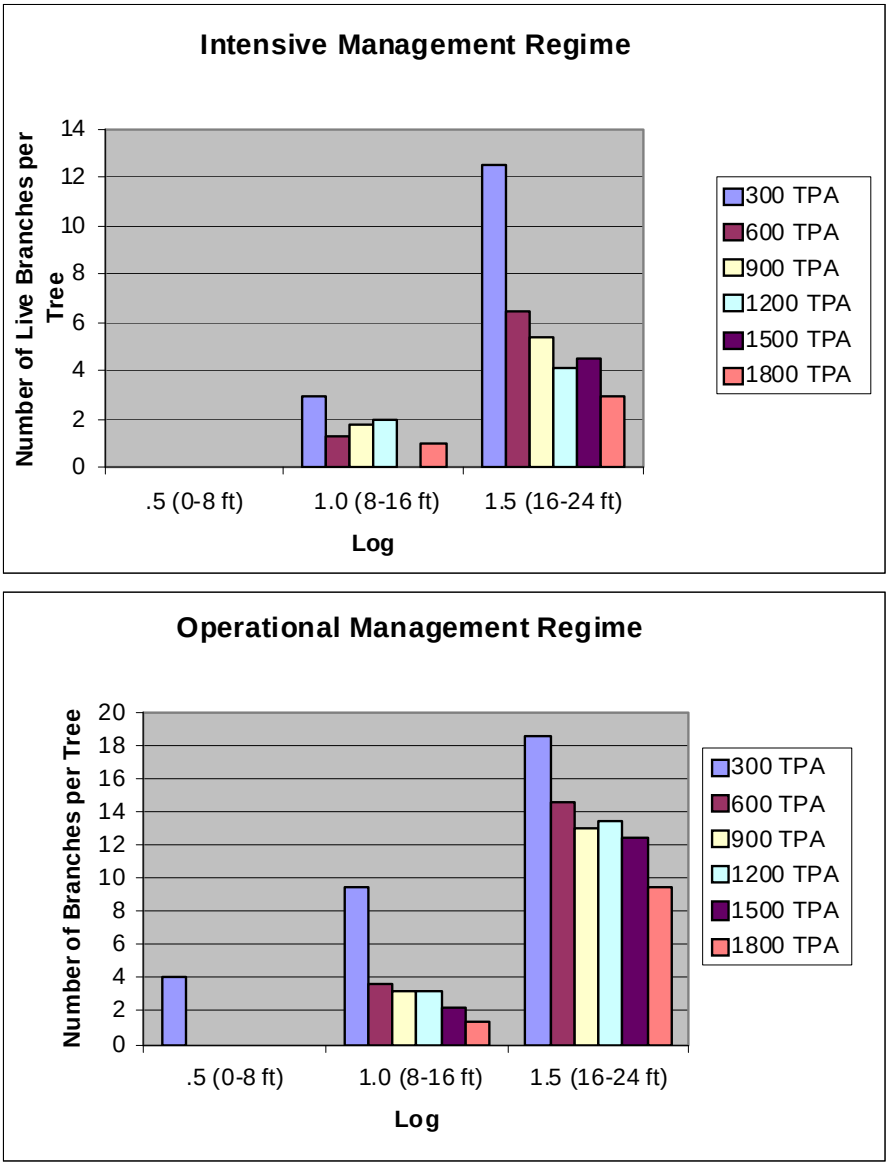


Figure 86. Average total number of live branches per tree by half-log, management regime, and planting density in the Lower Coastal Plain.

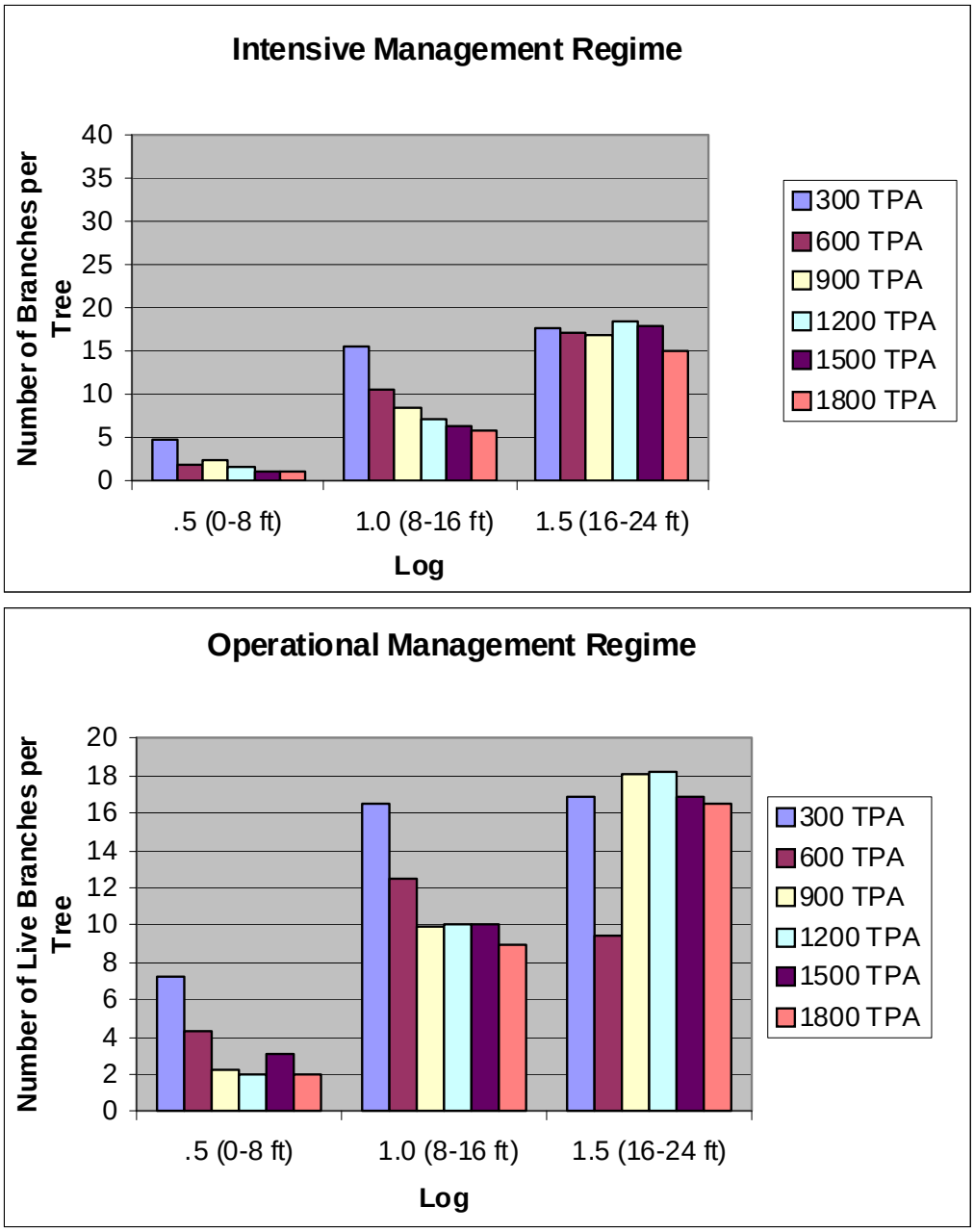


Figure 87. Average total number of live branches per tree by half-log, management regime, and planting density in the Piedmont/Upper Coastal Plain.

3.6.1. Average total number of live branches per tree for 0-24 ft stem heights

For average total number of live branches per tree in the lower 24 feet of the stem, the management effect was significant in the Lower Coastal Plain and nearly significant in the Piedmont/Upper Coastal Plain, the planting density effect was significant in both regions and the management by density interaction was significant only in the Lower Coastal Plain (Table 63). In the Lower Coastal Plain the number of live branches per tree for operational management was on average 10 units more than for intensive management, with the average for operational being 17 live branches/tree, and the average for intensive being 7 live branches/tree (Figure 88). The average number of live branches per tree in the Piedmont/Upper Coastal Plain decreased from 30 for the operational regime to 27 live branches per tree for intensive management.

For planting density, the 300 tpa treatment yielded a number of live branches that was significantly greater than those of all other densities in both regions. As planting density increased, average number of live branches per tree decreased from 21 at 300 tpa to 7 at 1800 tpa in the Lower Coastal Plain, and from 38 at 300 tpa to 23 at 1800 tpa in the Piedmont/Upper Coastal Plain (Figure 89).

Table 63. Analysis of variance results for average number of live branches per tree in the lower 24 ft of the stem in each region.

	Lower Coastal Plain		**Piedmont/Upper Coastal Plain**	
Source	Type III F	Pr > F	Type III F	Pr > F
Management	7.93	0.0347*	5.44	0.0582
Density	20.69	<.0001*	28.04	<.0001*
Management*Density	3.64	0.0431*	1.45	0.2066

* Significant at $\alpha = 5\%$

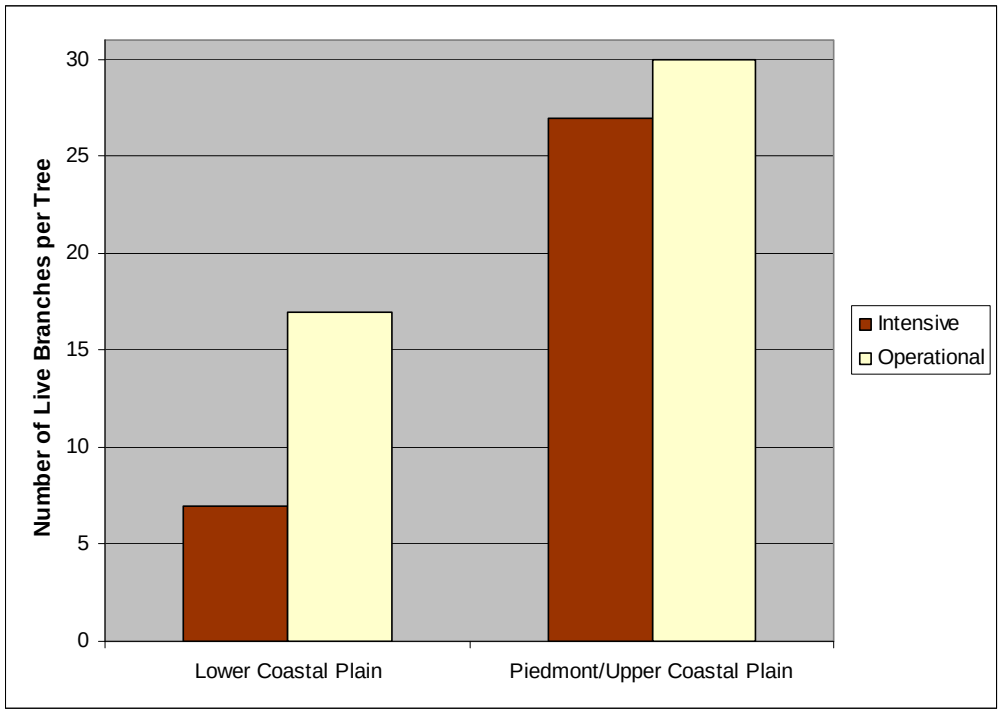


Figure 88. Average number of live branches per tree in the lower 24 ft of the stem by management regime and region.

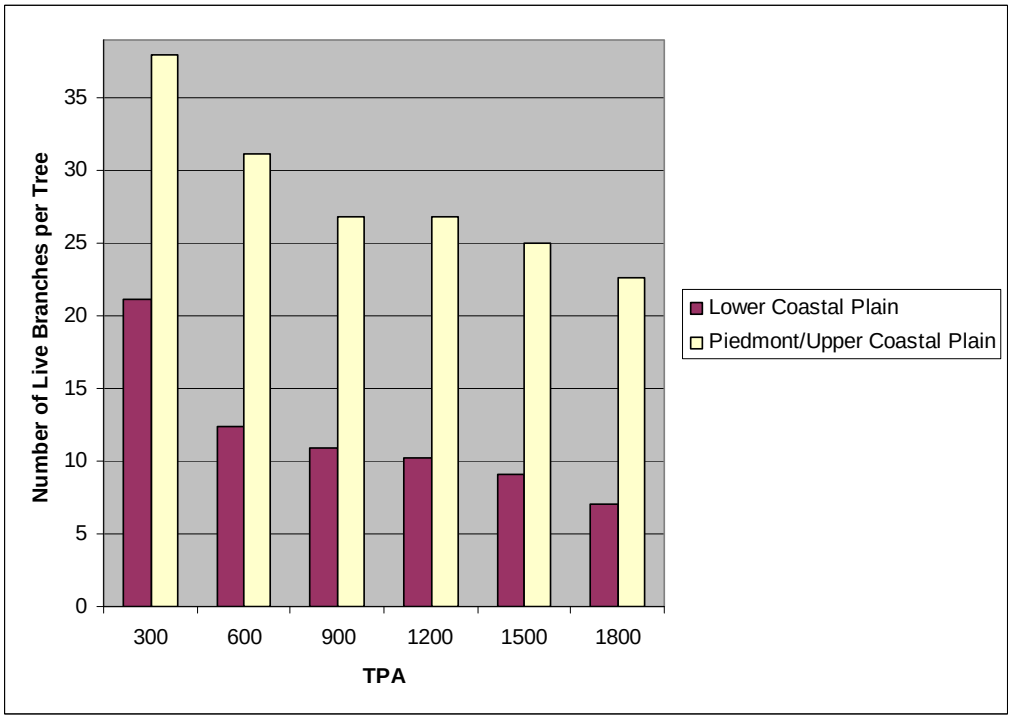


Figure 89. Average number of live branches per tree in the lower 24 ft of the stem by planting density and region.

There was a trend toward lower number of live branches as density increased for both intensive and operational management. At each density, the operationally managed plots had larger average number of live branches per tree than the intensively managed plots, and, in the Lower Coastal Plain, the difference tended to decrease as the density increased (Figure 90).

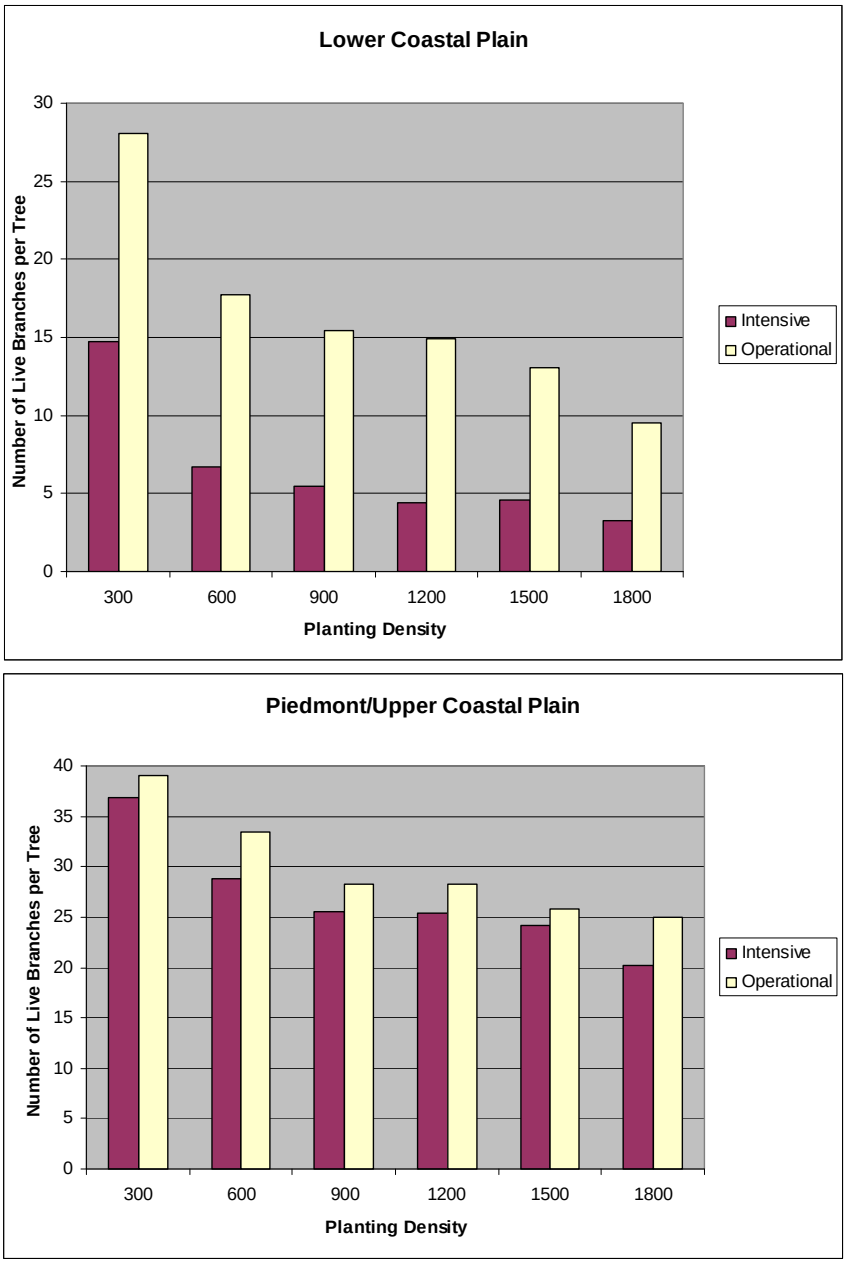


Figure 90. Average number of live branches per tree in the lower 24 ft of the stem by planting density, management regime and region.

In the Lower Coastal Plain, the operational management regime at 300 tpa (OP300) yielded the largest number of live branches per tree at heights 0-24 ft of the stem, and it was significantly different from those of all other treatment combinations (Table 64). Within the intensively managed plots, no significant differences were observed in the number of live branches at 600, 900, 1200, 1500, and 1800 tpa.

Table 64. P-values of Tukey's studentized multiple comparison tests of the differences among the average number of live branches in the lower 24 ft of the stem, across all management regime and planting density treatment combinations in the Lower Coastal Plain.

Lower Coastal Region											
	IN600	**IN900**	**IN1200**	**IN1500**	**IN1800**	**OP300**	**OP600**	**OP900**	**OP1200**	**OP1500**	**OP1800**
IN300	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	0.816	0.855	0.731	0.730	**0.034**
IN600		0.583	0.886	0.522	0.575	**<.0001**	**0.003**	**0.002**	**0.001**	**0.002**	0.606
IN900			0.837	0.984	0.919	**<.0001**	**<.0001**	**<.0001**	**0.002**	**<.0001**	0.928
IN1200				0.824	0.891	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	1.000
IN1500					0.928	**<.0001**	**<.0001**	**0.002**	**<.0001**	**<.0001**	0.962
IN1800						**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	0.998
OP300							**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**
OP600								0.932	0.971	0.991	**0.004**
OP900									0.977	0.996	**0.041**
OP1200										0.953	**0.039**
OP1500											0.977

References: first two letters refer to the management regime intensity treatment (IN: intensive, OP: operational Intensive). The last three digits refer to the planting density (300, 600, 900, 1200, 1500, 1800 TPA). Significance was defined as P-values <0.05.

There were significant linear trends in the average number of live branches per tree in the lower 24 ft of the stem across densities for the regions under study (Table 65). In the Lower Coastal Plain, operational management yielded an average number of live branches per tree that decreased linearly from 28 when the planting density was 300 tpa to 10 when the density was 1,800 tpa (Figure 90). For intensive management, the average number of live branches per tree decreased linearly from 15 at 300 tpa to 3 at 1,800 tpa. In the Piedmont/Upper Coastal Plain, operational management yielded an average number that decreased linearly from 39 when the planting density was 300 tpa to 25 when the density was 1,800 tpa. For intensive management, the average number of live branches per tree decreased linearly from 37 at 300 tpa to 20 at 1,800 tpa.

Table 65. Linear contrasts: average number of live branches per tree in the lower 24 ft of the stem by planting density in each region.

	Lower Coastal Plain		**Piedmont/Upper Coastal Plain**	
Contrast	Type III F	Pr > F	Type III SS	Pr > F
Linear Trend across Density (both Management Regimes)	66.39	<.0001*	119.41	<.0001*
Linear Trend across Density at Intensive Regime	40.13	<.0001*	100.85	<.0001*
Linear Trend across Density at Operational Regime	139.06	<.0001*	89.02	<.0001*

* Significant at $\alpha = 5\%$

3.6.2. Total number of live branches per tree for 0-16 ft stem heights

For the average total number of live branches per tree in the lower 16 feet of the stem, the management effect was significant in the Lower Coastal Plain, the planting density effect was significant in each region, and the management by planting density interaction was not significant (Table 66). In the Lower Coastal Plain, the number of live branches per tree for operational management was on average 2 more than for intensive management, with the average for operational being 5, and the average for intensive being 3 live branches/tree Figure 91.

For planting density, the 300 tpa treatment yielded a number of live branches that was significantly greater than those of all other densities in both regions (Figure 92). As planting density increased, average number of live branches per tree decreased from 7 at 300 tpa to 1 at 1800 tpa in the Lower Coastal Plain, and from 21 at 300 tpa to 8 branches/tree at 1800 tpa in the Piedmont/Upper Coastal Plain.

Table 66. Analysis of variance results for average number of live branches per tree in the lower 16 ft of the stem in each region.

	Lower Coastal Plain		**Piedmont/Upper Coastal Plain**	
Source	Type III F	Pr > F	Type III F	Pr > F
Management	7.50	0.0299*	3.45	0.1116
Density	6.46	0.0004*	43.34	<.0001*
Management*Density	13.85	0.2386	0.63	0.6744

* Significant at $\alpha = 5\%$

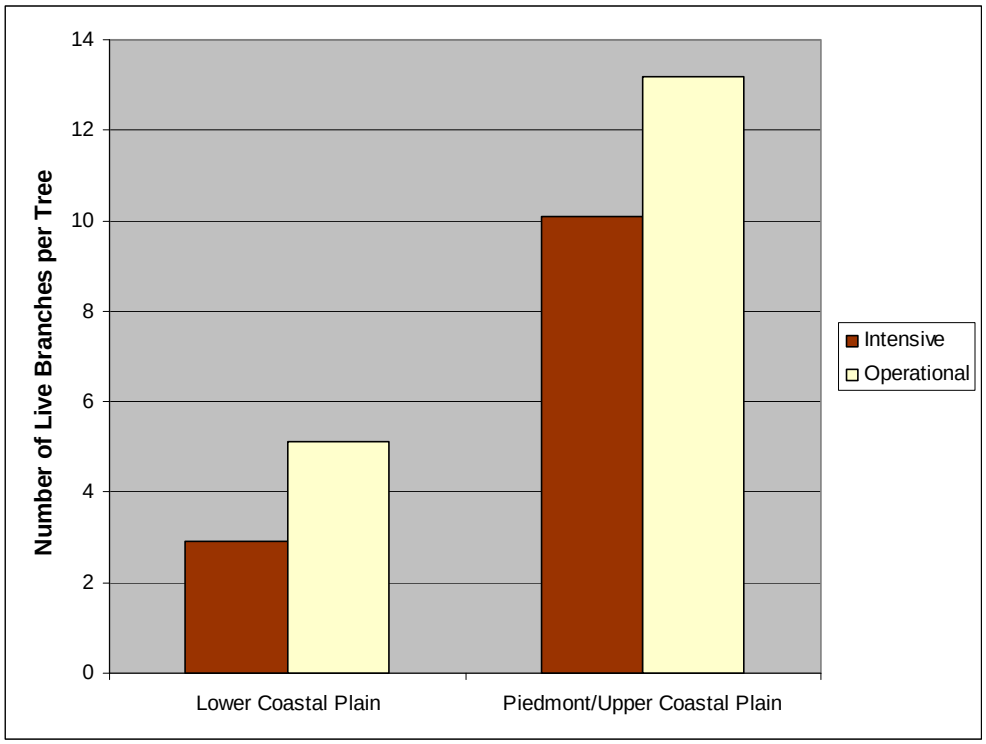


Figure 91. Average number of live branches per tree in the lower 16 ft of the stem by management regime and region.

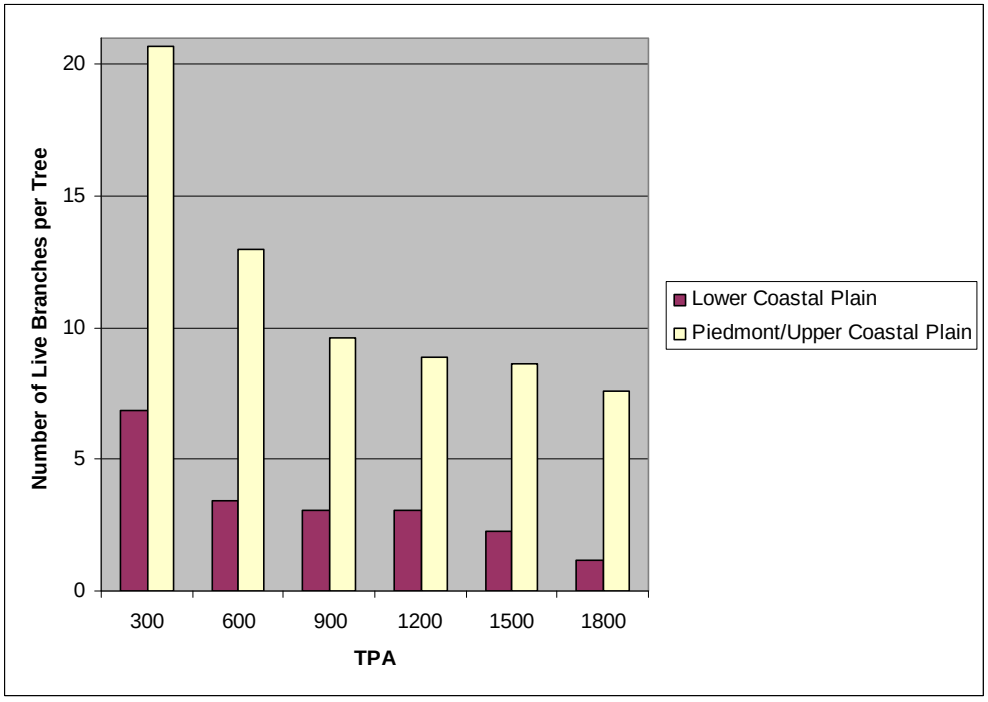


Figure 92. Average number of live branches per tree in the lower 16 ft of the stem by planting density and region.

There was a trend toward lower average number of live branches per tree as density increased for both intensive and operational management. At each density, the operationally managed plots had larger average number of live branches per tree than the intensively plots, but the difference tended to decrease as the density increased (Figure 93). Pairwise multiple comparisons were not performed as there were no significant planting density by management regime interactions in either region.

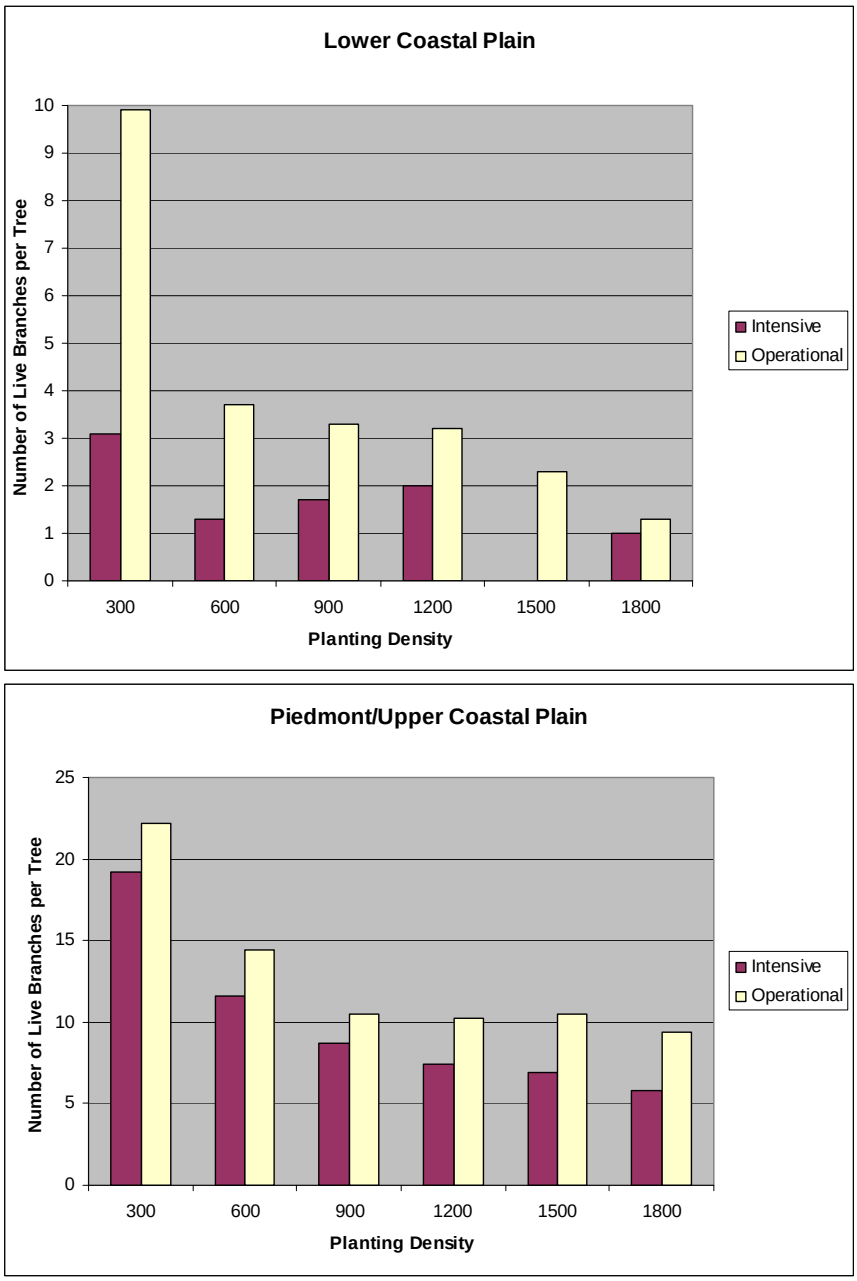


Figure 93. Average number of live branches per tree in the lower 16 ft of the stem by planting density, management regime and region.

There was a significant linear trend of average number of live branches per tree at heights 0-16 ft of the stem across densities in the Piedmont/Upper Coastal Plain (Table 67). Notice that the treatment corresponding to the intensive silvicultural regime at 1500 tpa resulted in no observations in each of the locations corresponding to the Lower Coastal Plain. The contrasts were not estimable for this region. In the Piedmont/Upper Coastal Plain, operational management yielded an average number of live branches per tree that decreased linearly from 22 when the planting density was 300 tpa to 9 when the density was 1,800 tpa. For intensive management, average number of live branches/tree decreased linearly from 19 at 300 tpa to 6 at 1,800 tpa.

Table 67. Linear contrasts: average number of live branches per tree in the lower 16 ft of the stem by planting density in each region.

	Lower Coastal Plain		**Piedmont/Upper Coastal Plain**	
Contrast	Type III F	Pr > F	Type III SS	Pr > F
Linear Trend across Density (both Management Regimes)	NA	NA	130.69	<.0001*
Linear Trend across Density at Intensive Regime	NA	NA	146.93	<.0001*
Linear Trend across Density at Operational Regime	NA	NA	119.42	<.0001*

Significant at $\alpha = 5\%$
NA: not estimable value

3.6.3. Total number of live branches per tree for 0-8 ft stem heights

In the Piedmont/Upper Coastal Plain, the average total number of live branches per tree in the lower 8 feet of the stem was significantly affected by planting density but not by management intensity or the management by planting density interaction (Table 68). In the Lower Coastal Plain the only treatment combination that had live branches on this section of the stem was the operational regime at 300 tpa. No statistical analysis was performed in this region.

In the Piedmont/Upper Coastal Plain, the number of live branches per tree for operational management was on average 5, while it was 3 for intensive management regime. For the significant planting density factor, the 300 tpa treatment yielded a number of live branches that was significantly greater than those of all other densities (Figure 94). As the planting density increased, the average number of live branches per tree decreased from 6 at 300 tpa to 2 at 1800 tpa.

Table 68. Analysis of variance results for average number of live branches per tree in the lower 8 ft of the stem in each region.

	Lower Coastal Plain		**Piedmont/Upper Coastal Plain**	
Source	Type III F	Pr > F	Type III F	Pr > F
Management	NA	NA	0.10	0.7642
Density	NA	NA	13.20	<.0001*
Management*Density	NA	NA	4.20	0.0968

* Significant at $\alpha = 5\%$
NA: not estimable

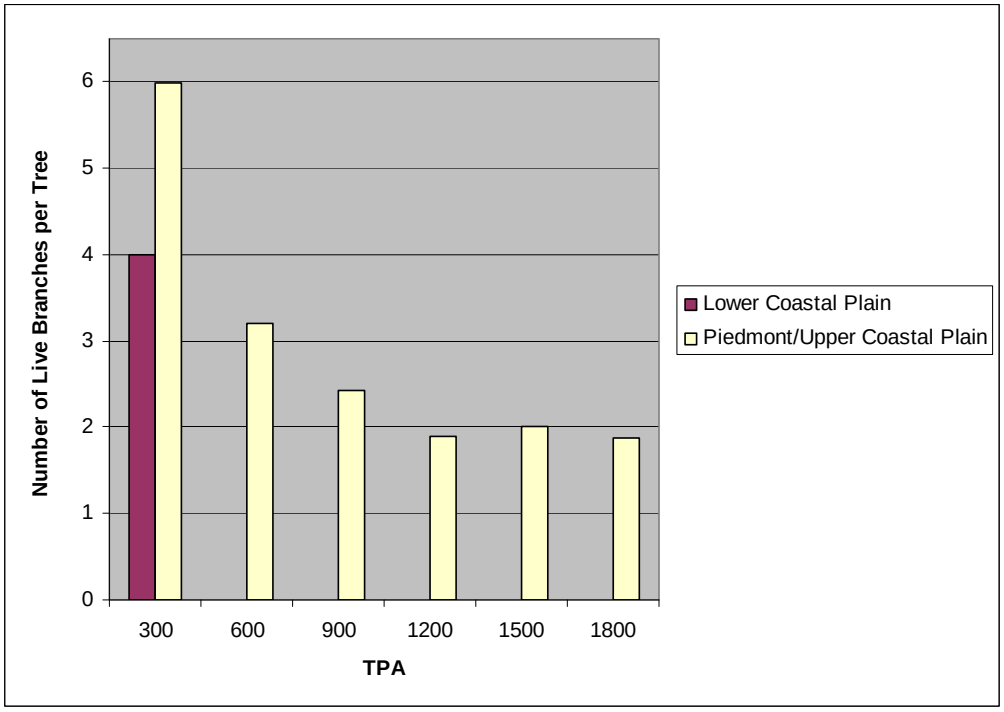


Figure 94. Average number of live branches per tree in the lower 8 ft of the stem by planting density and region.

In the Piedmont/Upper Coastal Plain there was a trend toward lower average number of live branches per tree as density increased for both intensive and operational management regimes. At each density, operationally managed plots had a larger average number of live branches per tree than intensively managed plots (Figure 95). Pairwise multiple comparisons were not performed as were no significant planting density by management regime interactions. Contrasts testing linear trends of the average number of branches per tree at heights 0-8 ft of the stem were not estimable in either region.

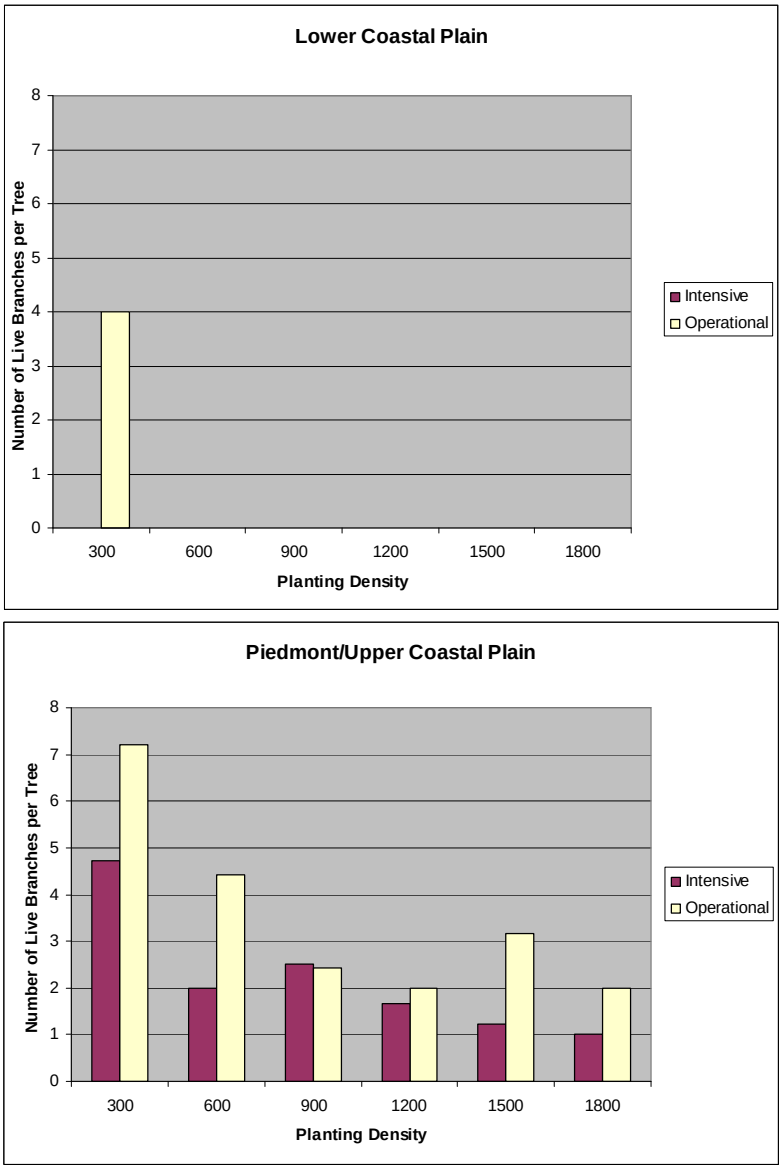


Figure 95. Average number of live branches per tree in the lower 8 ft of the stem by planting density, management regime and region.

3.6.4. Total number of live branches per tree for 8-16 ft stem heights

For the average total number of live branches per tree at heights 8-16 ft of the stem, the management effect was significant in the Lower Coastal Plain, the planting density effect was significant in both regions, and the management by planting density interaction was not significant (Table 69). In the Lower Coastal Plain, the number of live branches per tree for operational management was on average 2 more than for intensive management, with the average in the intensive being 5, and the average in the operational being 3 (Figure 96). In the Piedmont/Upper Coastal Plain the operational regime had an average of 11 live branches/tree while the intensive had an average of 9 live branches per tree (p-value = 0.0869).

For planting density, the 300 tpa treatment yielded a number of live branches that was significantly greater than those of all other densities in both regions (Figure 97). As planting density increased, average number of live branches per tree decreased from 7 at 300 tpa to 1 at 1800 tpa in the Lower Coastal Plain, and from 16 at 300 tpa to 7 branches/tree at 1800 tpa in the Piedmont/Upper Coastal Plain.

Table 69. Analysis of variance results for average number of live branches per tree at heights 8-16 ft of the stem in each region.

	Lower Coastal Plain		**Piedmont/Upper Coastal Plain**	
Source	Type III F	Pr > F	Type III F	Pr > F
Management	10.61	0.0159*	4.13	0.0869
Density	7.25	0.0002*	24.32	<.0001*
Management*Density	4.04	0.2766	1.37	0.2334

* Significant at $\alpha = 5\%$

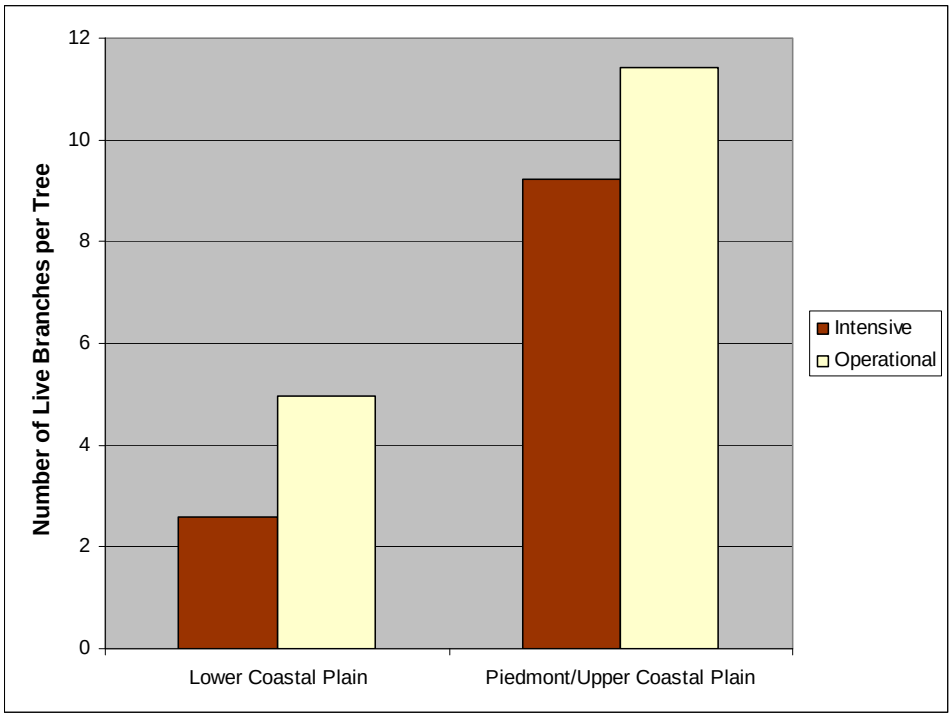


Figure 96. Average number of live branches per tree at heights 8-16 ft of the stem by management regime and region.

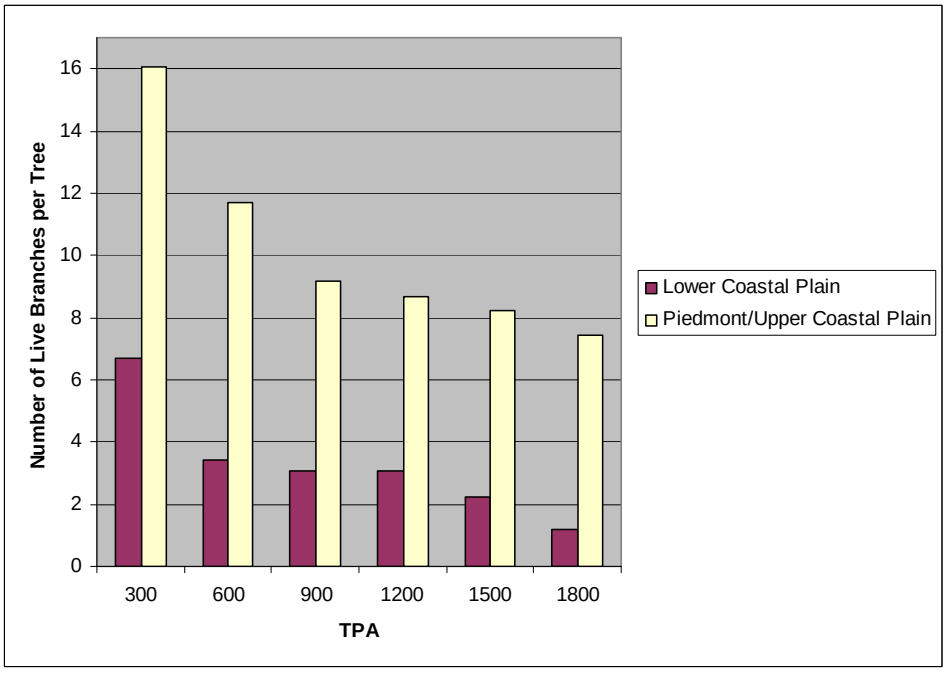


Figure 97. Average number of live branches per tree at heights 8-16 ft of the stem by planting density and region.

There was a trend toward lower average number of live branches per tree as density increased for both intensive and operational management (Figure 98). At each density, the operationally managed plots had larger average number of live branches per tree than the intensively managed plots. In the Lower Coastal Plain the intensive silvicultural regime at 1500 tpa did not have live branches. Pairwise multiple comparisons were not conducted as there were no significant planting density by management regime interactions.

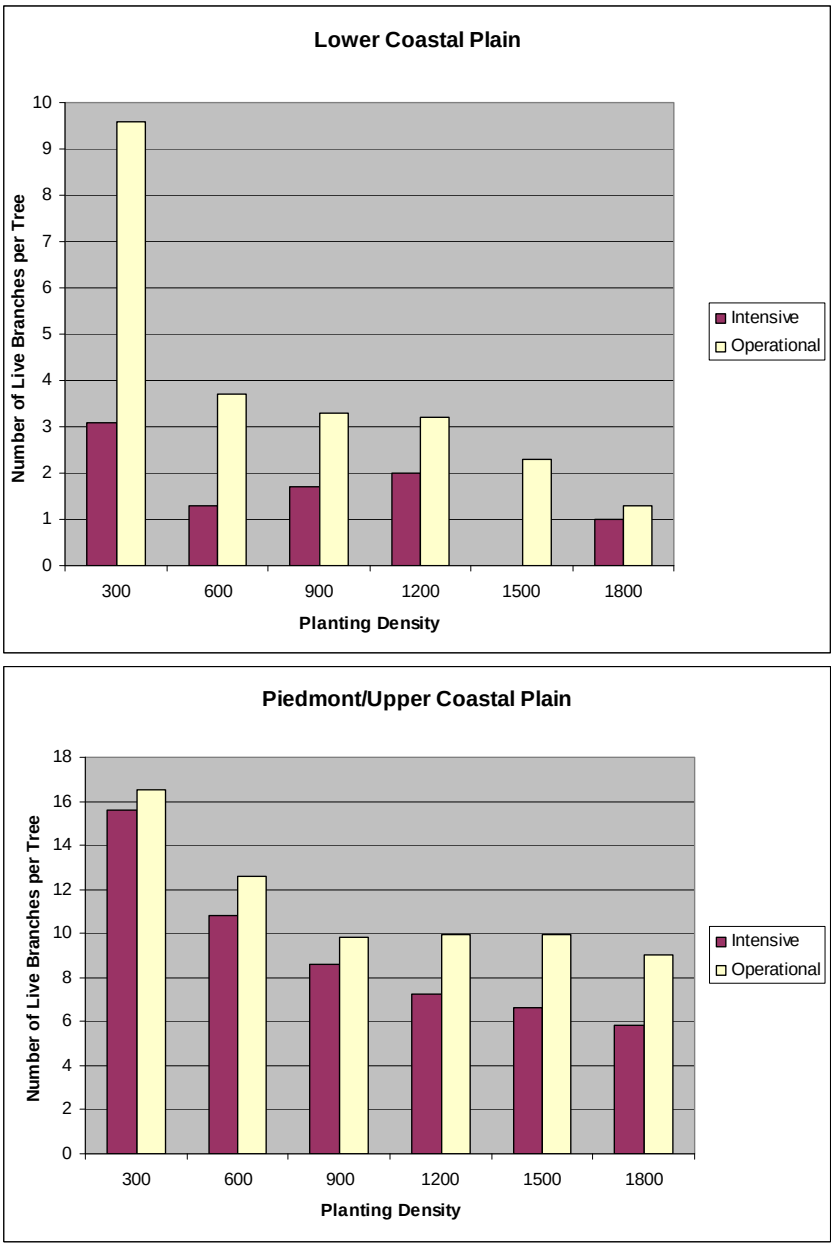


Figure 98. Average number of live branches per tree at heights 8-16 ft of the stem by planting density, management regime and region.

There was a significant linear trend of average number of live branches per tree at heights 8-16 ft of the stem across densities in the Piedmont/Upper Coastal Plain (Table 70). Observe that the treatment corresponding to the intensive silvicultural regime with 1500 tpa resulted in no observations in each of the locations corresponding to the Lower Coastal Plain. The contrasts were not estimable in this region. In the Piedmont/Upper Coastal Plain, operational management yielded an average number of live branches per tree that decreased linearly from 17 when the planting density was 300 tpa to 9 when the density was 1,800 tpa. For intensive management, average number of live branches/tree decreased linearly from 16 at 300 tpa to 6 at 1,800 tpa.

Table 70. Linear contrasts: average number of live branches per tree at heights 8-16 ft of the stem by planting density in each region.

	Lower Coastal Plain		**Piedmont/Upper Coastal Plain**	
Contrast	Type III F	Pr > F	Type III SS	Pr > F
Linear Trend across Density (both Management Regimes)	NA	NA	81.64	<.0001*
Linear Trend across Density at Intensive Regime	NA	NA	151.90	<.0001*
Linear Trend across Density at Operational Regime	NA	NA	82.61	<.0001*

Significant at $\alpha = 5\%$
NA: not estimable value

3.6.5. Total number of live branches per tree for 16-24 ft stem heights

For the average total number of live branches per tree at heights 16-24 ft of the stem the management effect and planting density effect were significant in the Lower Coastal Plain but not in the Piedmont/Upper Coastal Plain. The management by planting density interaction was not significant in either region (Table 71). In the Lower Coastal Plain the number of live branches per tree for operational management was on average 2 units more than for intensive management, with the average on the operational being 7 live branches/tree, and the average on the intensive being 5 (Figure 99). The average number of live branches per tree in the Piedmont/Upper Coastal Plain decreased from 18 for the operational regime to 17 live branches per tree for the intensive management regime, the difference not being significant.

For planting density in the Lower Coastal Plain, the 300 tpa treatment yielded a number of live branches that was significantly greater than those of all other densities (Figure 100). As planting density increased, average number of live branches per tree decreased from 16 at 300 tpa to 7 at 1800 tpa.

Table 71. Analysis of variance results for average number of live branches per tree at heights 16-24 ft of the stem in each region.

	Lower Coastal Plain		**Piedmont/Upper Coastal Plain**	
Source	Type III F	Pr > F	Type III F	Pr > F
Management	84.67	0.0002*	0.58	0.4748
Density	16.02	<.0001*	1.47	0.2288
Management*Density	0.89	0.500	0.67	0.6871

* Significant at $\alpha = 5\%$

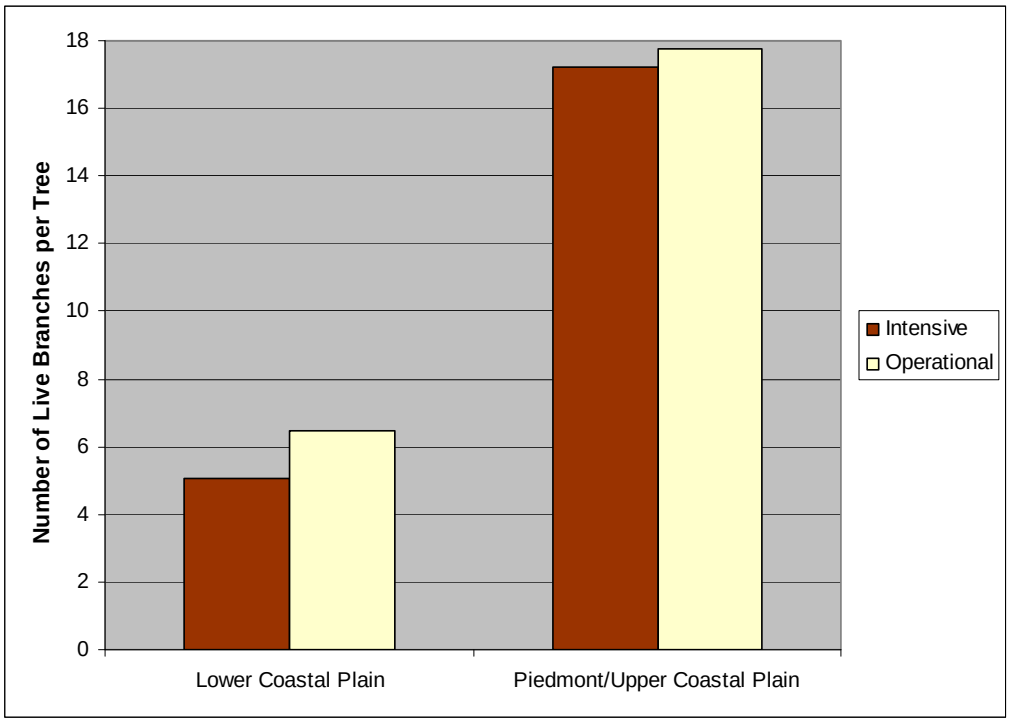


Figure 99. Average number of live branches per tree at heights 16-24 ft of the stem by management regime and region.

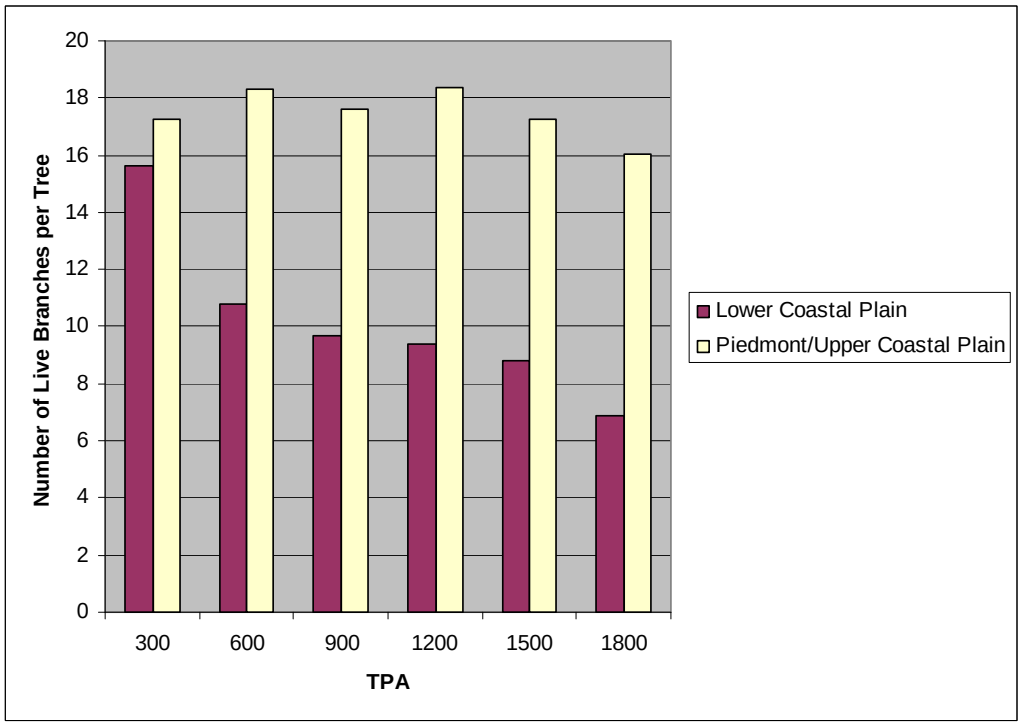


Figure 100. Average number of live branches per tree at heights 16-24 ft of the stem by planting density and region.

Plantations in the Lower Coastal Plain region showed a trend toward lower number of live branches as density increased for both intensive and operational management regimes (Figure 101). In this region, the operational managed plots had larger average number of live branches per tree than the intensive managed plots at each density. No clear pattern was observed in the Piedmont/Upper Coastal Plain. Pairwise multiple comparisons were not performed as there were no significant planting density by management regime interactions.

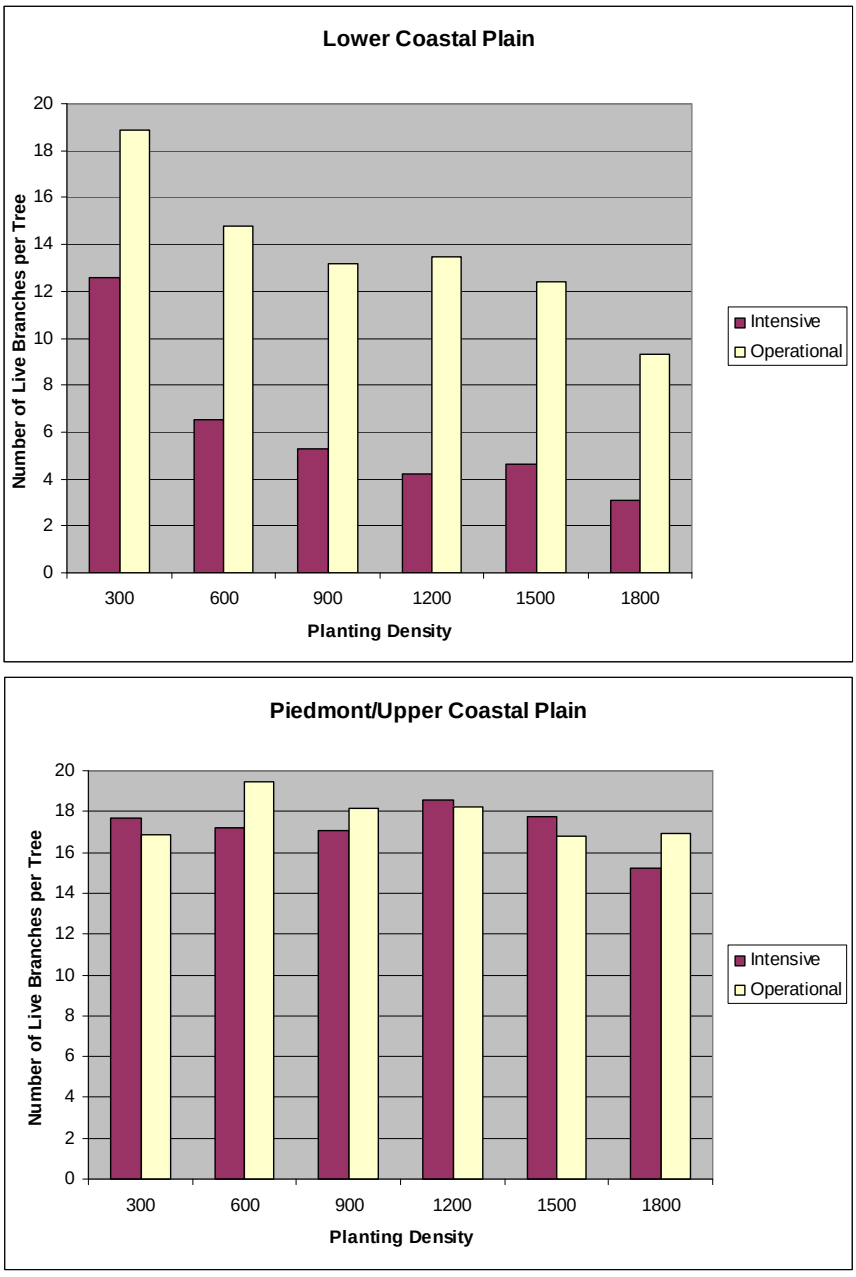


Figure 101. Average number of live branches per tree at heights 16-24 ft of the stem by planting density, management regime and region.

There is a significant linear trend in the average number of live branches per tree at heights 16-24 ft of the stem across densities in the Lower Coastal Plain (Table 72). Operational management yielded an average number of live branches per tree that decreased linearly from 19 when the planting density was 300 tpa to 9 when the density was 1,800 tpa. For the intensive management regime, the average number of live branches per tree decreased linearly from 13 at 300 tpa to 3 at 1,800 tpa. The linear contrasts were not significant in the Piedmont/Upper Coastal Plain.

Table 72. Linear contrasts: average number of live branches per tree at heights 16-24 ft of the stem by planting density in each region.

	Lower Coastal Plain		**Piedmont/Upper Coastal Plain**	
Contrast	Type III F	Pr > F	Type III SS	Pr > F
Linear Trend across Density (both Management Regimes)	17.02	0.0074*	3.26	0.0810
Linear Trend across Density at Intensive Regime	14.11	0.0089*	3.26	0.0809
Linear Trend across Density at Operational Regime	16.06	0.0081*	1.62	0.2123

* Significant at $\alpha = 5\%$

3.7. Average Total Number of Dead Branches

The average total number of dead branches per tree in the lower 24 feet of each stem across regions, logs, planting densities, and management regimes is summarized in Figure 102 and Figure 103.

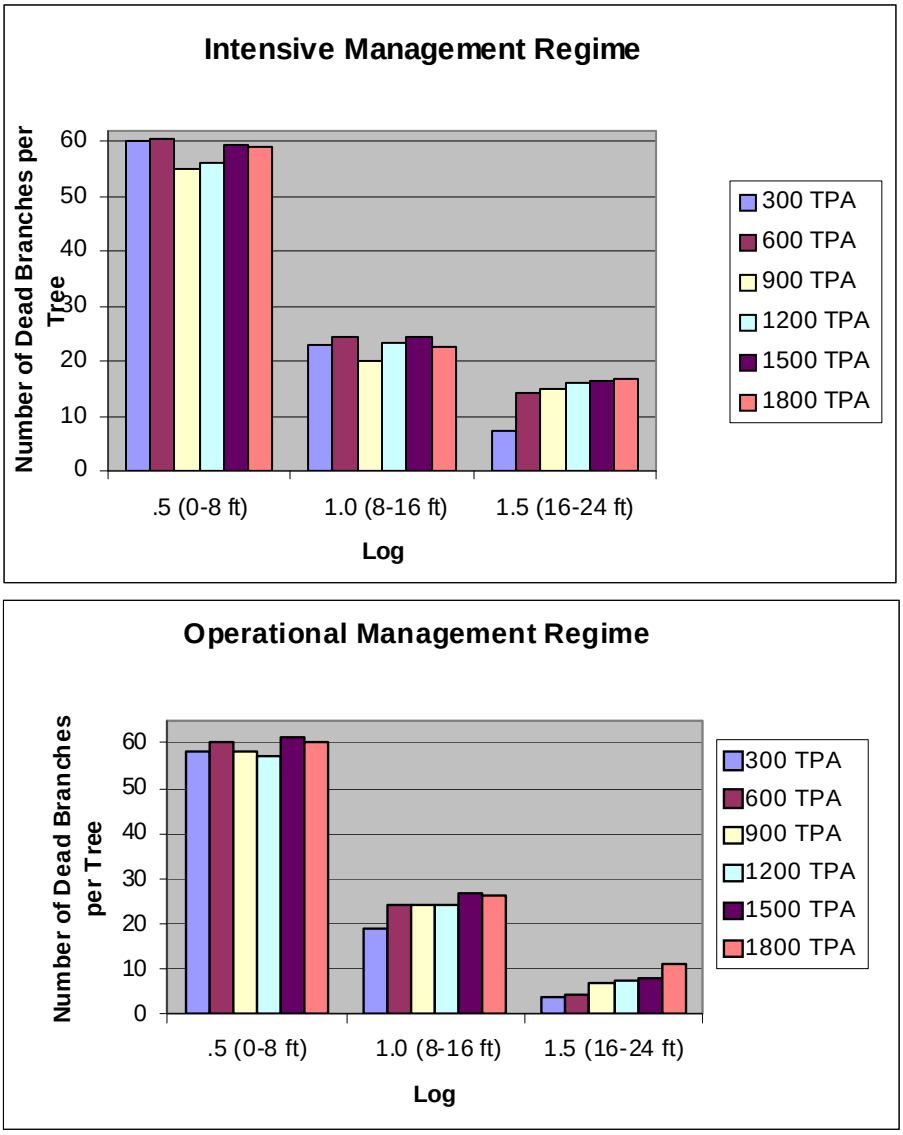


Figure 102. Average total number of dead branches per tree by half-log, management regime, and planting density in the Lower Coastal Plain.

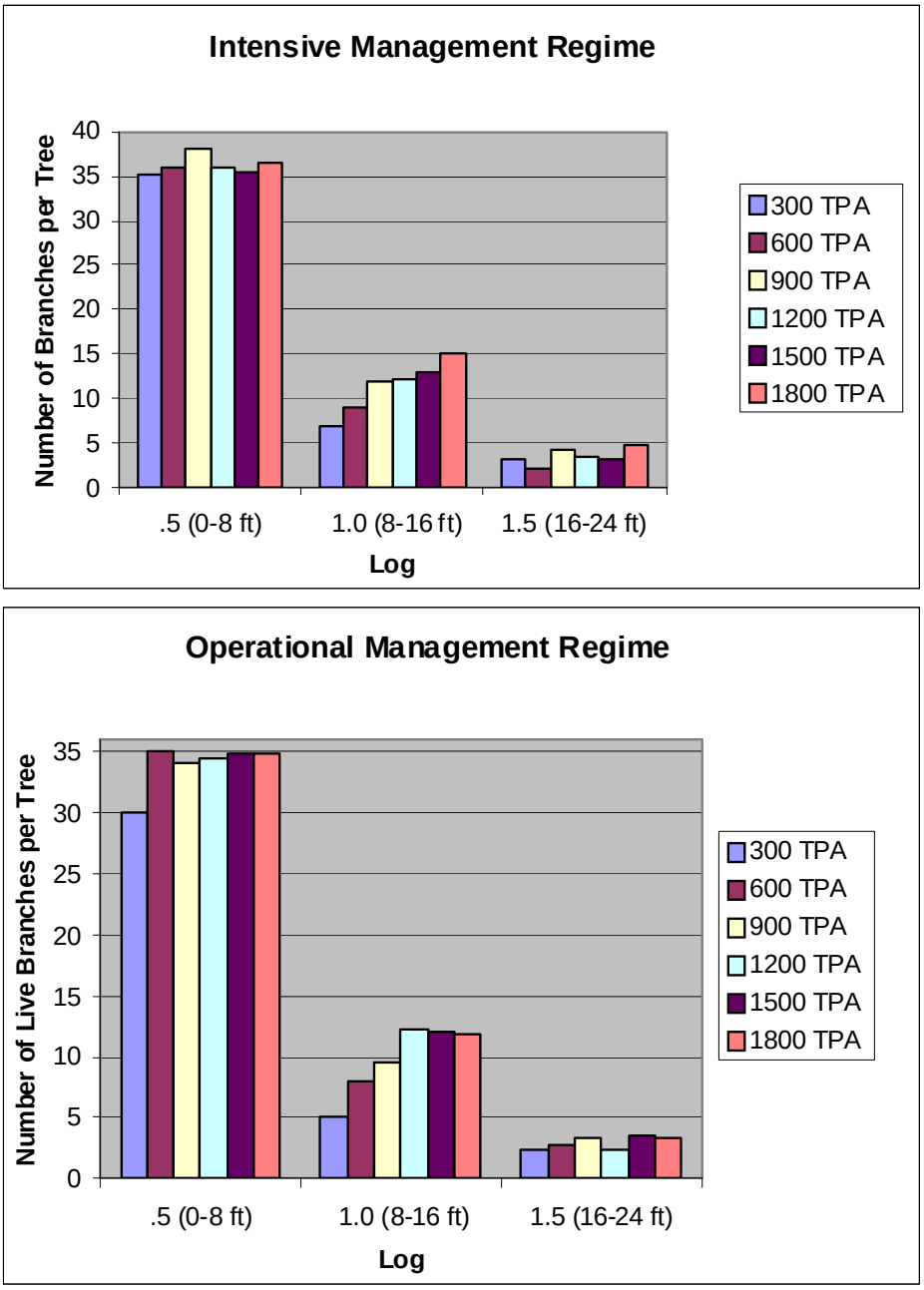


Figure 103. Average total number of dead branches per tree by half-log, management regime, and planting density in the Piedmont/Upper Coastal Plain.

3.7.1. Average total number of dead branches per tree for 0-24 ft stem heights

For the average total number of dead branches per tree in the lower 24 feet of the stem, the management effect was significant in the Piedmont/Upper Coastal Plain, the planting density effect was significant in both regions, and the management by plantation density interaction was not significant (Table 73). In the Piedmont/Upper Coastal Plain the number of live branches per tree for intensive management was on average 5 units more than for operational management, with the average on the intensive being 50 dead branches/tree, and the average on the operational being 45 dead branches/tree (Figure 104). The average number of dead branches per tree in the Lower Coastal Plain decreased from 73 in the intensive regime to 66 dead branches per tree in the operational management regime, a non-significant difference.

For planting density, there were significant differences between 300 tpa and the two higher densities (1500 and 1800 tpa) in both regions (Figure 105). As planting density increased, average number of dead branches per tree increased from 64 at 300 tpa to 73 at 1800 tpa in the Lower Coastal Plain, and from 40 at 300 tpa to 52 at 1800 tpa in the Piedmont/Upper Coastal Plain.

Table 73. Analysis of variance results for average number of dead branches per tree in the lower 24 ft of the stem in each region.

	Lower Coastal Plain		**Piedmont/Upper Coastal Plain**	
Source	Type III F	Pr > F	Type III F	Pr > F
Management	3.74	0.1110	13.28	0.0105*
Density	3.16	0.0238*	22.75	<.0001*
Management*Density	1.50	0.2242	1.97	0.1711

* Significant at $\alpha = 5\%$

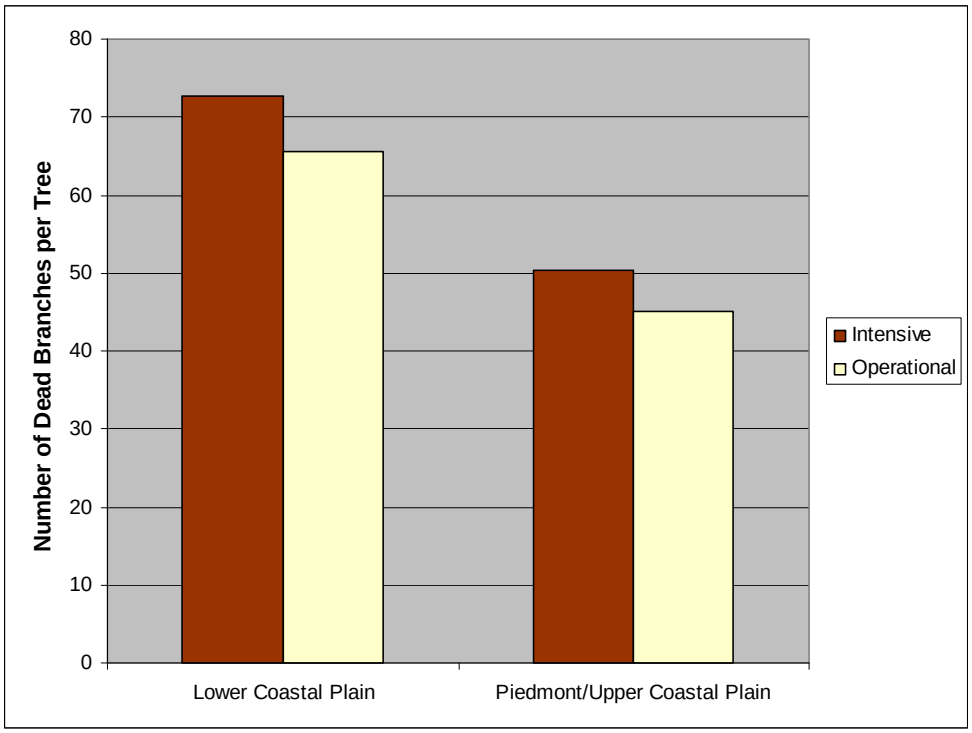


Figure 104. Average number of dead branches per tree in the lower 24 ft of the stem by management regime and region.

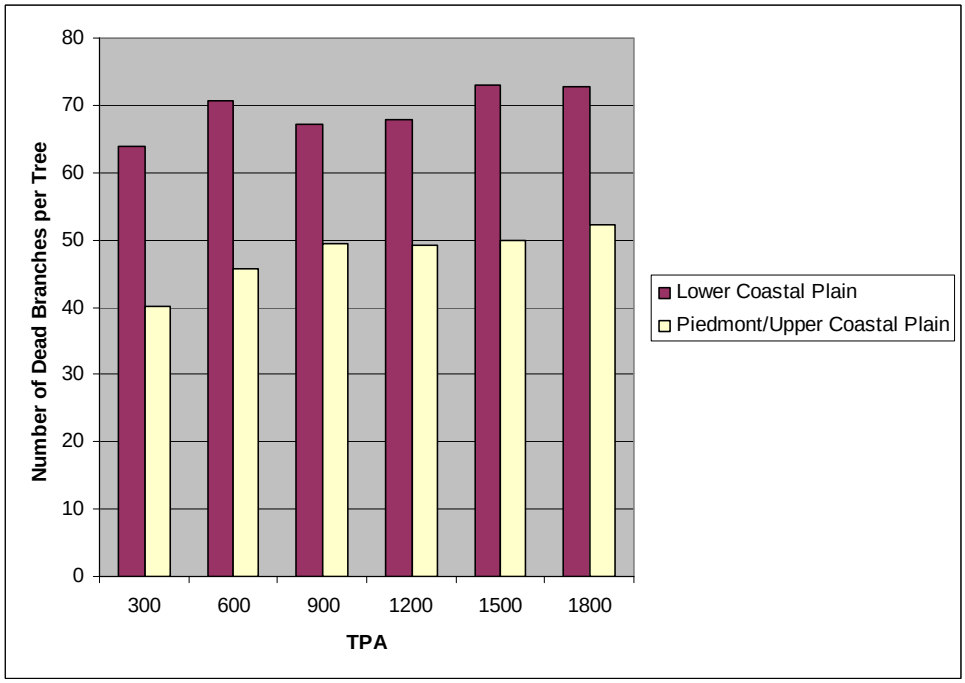


Figure 105. Average number of dead branches per tree in the lower 24 ft of the stem by planting density and region.

There was a trend toward higher number of dead branches as density increased for both intensive and operational management. At each density, intensive managed plots had larger average number of dead branches per tree than operational managed plots (Figure 106). Pairwise multiple comparisons were not conducted as there was no significant planting density by management regime interaction.

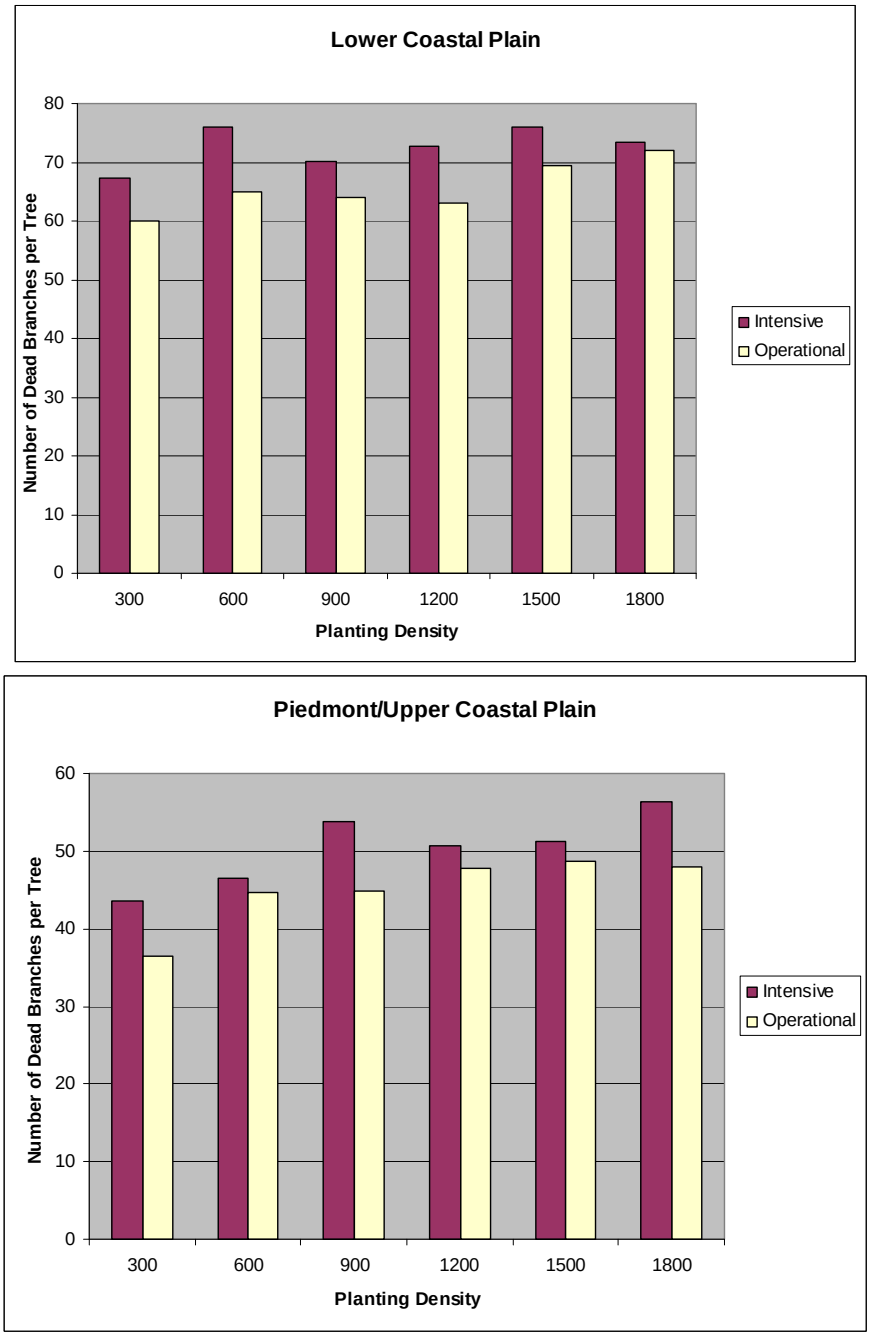


Figure 106. Average number of dead branches per tree in the lower 24 ft of the stem by planting density, management regime and region.

There were significant linear trends in the average number of dead branches per tree at heights 0-24 ft of the stem across densities in the regions under study (Table 74). In the Lower Coastal Plain, operational management yielded an average number of dead branches per tree that increased linearly from 60 when the planting density was 300 tpa to 72 when the density was 1,800 tpa (Figure 106). For intensive management, the average number of dead branches per tree increased linearly from 67 at 300 tpa to 74 at 1,800 tpa. In the Piedmont/Upper Coastal Plain, operational management yielded an average number that increased linearly from 36 when the planting density was 300 tpa to 48 when the density was 1,800 tpa. For intensive management, average number of dead branches per tree increased linearly from 44 at 300 tpa to 56 at 1,800 tpa.

Table 74. Linear contrasts: average number of dead branches per tree in the lower 24 ft of the stem by planting density for each region.

	Lower Coastal Plain		**Piedmont/Upper Coastal Plain**	
Contrast	Type III F	Pr > F	Type III SS	Pr > F
Linear Trend across Density (both Management Regimes)	9.84	0.0043*	93.91	<.0001*
Linear Trend across Density at Intensive Regime	5.71	0.0247*	23.01	<.0001*
Linear Trend across Density at Operational Regime	17.92	0.0003*	24.57	<.0001*

* Significant at $\alpha = 5\%$

3.7.2. Average total number of dead branches per tree for 0-16 ft stem heights

For the average number of dead branches per tree in the lower 16 ft of the stem. Effects of management, planting density, and their interaction were significant in the Piedmont/Upper Coastal Plain but not in the Lower Coastal Plain Table 75. In the Piedmont/Upper Coastal Plain the number of live branches per tree for intensive management was on average 5 units more than for operational management, with the average in the intensive being 48 dead branches/tree, and the average in the operational being 43 dead branches/tree Figure 107.

For planting density in the same region, the 300 tpa treatment yielded a number of dead branches that was significantly less than those of all other densities (Figure 108). There were no significant differences between the two higher densities (1500 and 1800 tpa). As planting density increased, average number of dead branches per tree increased from 38 at 300 tpa to 49 at 1800 tpa.

Table 75. Analysis of variance results for average number of dead branches per tree in the lower 16 ft of the stem in each region.

	Lower Coastal Plain		**Piedmont/Upper Coastal Plain**	
Source	Type III F	Pr > F	Type III F	**Pr > F**
Management	0.14	0.7195	9.08	0.0233*
Density	1.27	0.3076	23.16	<.0001*
Management*Density	0.87	0.5176	2.61	0.0245*

* Significant at $\alpha = 5\%$

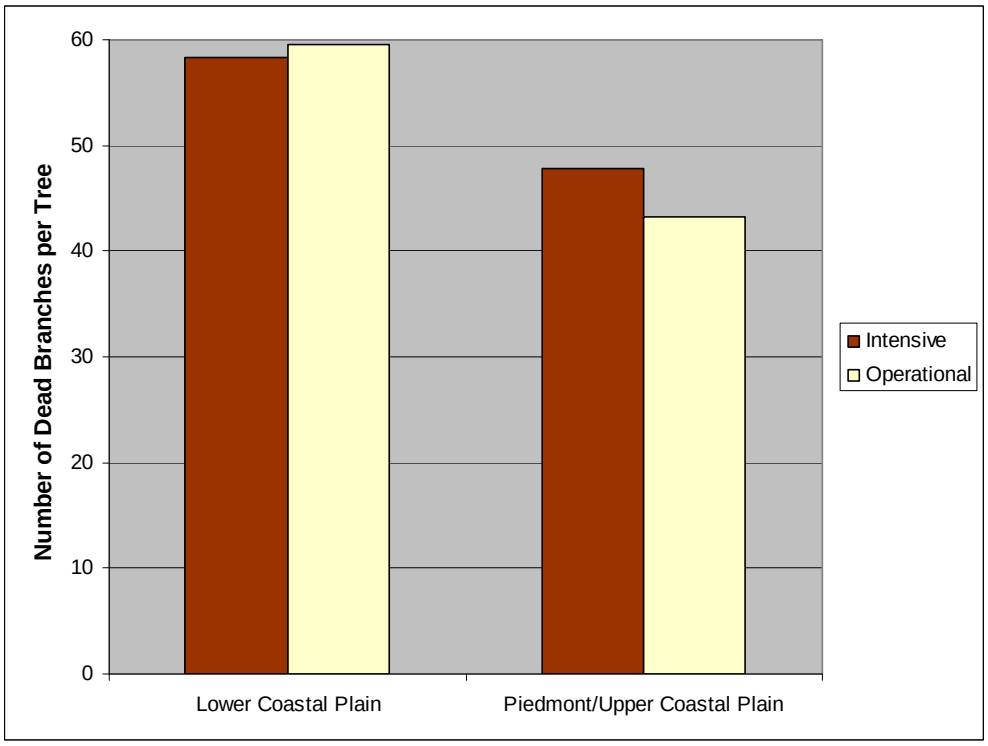


Figure 107. Average number of dead branches per tree in the lower 16 ft of the stem by management regime and region.

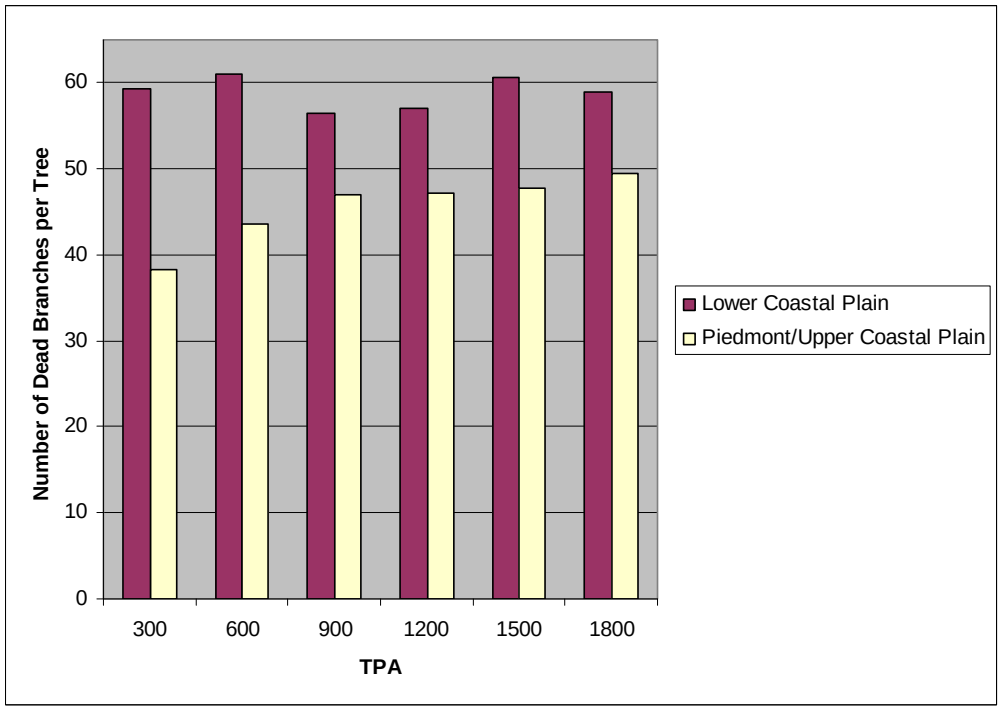


Figure 108. Average number of dead branches per tree in the lower 16 ft of the stem by planting density and region.

There was a trend toward higher number of dead branches as density increased for both intensive and operational management in the Piedmont/Upper Coastal Plain (Figure 109). At each density, the intensively managed plots had larger average number of dead branches per tree than the operationally managed plots. No pattern was observed in the number of dead branches per tree in the Lower Coastal Plain region.

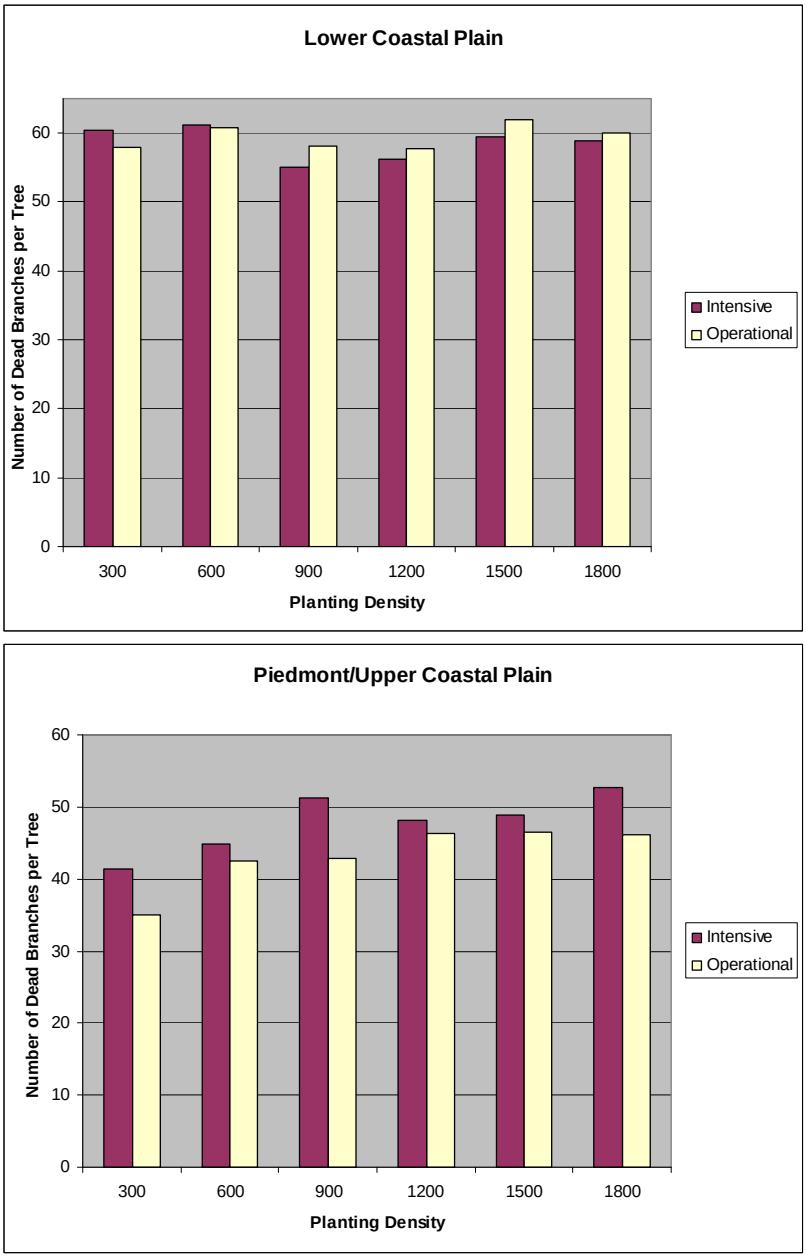


Figure 109. Average number of dead branches per tree in the lower 16 ft of the stem by planting density, management regime and region.

Results from pairwise multiple comparison tests for the differences among the average branch diameter across the management regime and planting density treatment combinations in the Piedmont/Upper Coastal Plain are presented in Table 76. The operationally managed plots at 300 tpa (OP300) yielded the lowest average number of dead branches per tree in the lower 16 ft of the stem, and their average was significantly different from those of all other treatment combinations but IN300, OP600, and OP900. There were no significant differences among the four higher planting densities (900, 1200, 1500, and 1800 tpa) within a management regime, and across management regimes.

Table 76. P-values of Tukey's studentized multiple comparison tests of the differences among the number of dead branches per tree in the lower 16 ft of the stem, across all management regime and planting density treatment combinations for the Piedmont/Upper Coastal Plain.

Piedmont/Upper Coastal Region											
	IN600	**IN900**	**IN1200**	**IN1500**	**IN1800**	**OP300**	**OP600**	**OP900**	**OP1200**	**OP1500**	**OP1800**
IN300	0.952	**0.010**	0.271	0.149	**0.003**	0.198	1.000	1.000	0.643	0.597	0.690
IN600		0.235	0.974	0.890	0.105	**0.008**	0.995	0.999	1.000	1.000	1.000
IN900			0.931	0.988	1.000	**<.0001**	**0.024**	**0.043**	0.610	0.655	0.562
IN1200				1.000	0.747	**0.001**	0.467	0.621	1.000	1.000	1.000
IN1500					0.902	**<.0001**	0.287	0.417	0.998	0.999	0.996
IN1800						**<.0001**	**0.009**	**0.016**	0.356	0.396	0.317
OP300							0.097	0.057	**0.001**	**0.001**	**0.002**
OP600								1.000	0.847	0.812	0.879
OP900									0.936	0.914	0.954
OP1200										1.000	1.000
OP1500											1.000

References: first two letters refer to the management regime intensity treatment (IN: intensive, OP: operational Intensive). The last three digits refer to the planting density (300, 600, 900, 1200, 1500, 1800 TPA). Significance differences are in bold and are defined as P-values <0.05.

There were significant linear trends in the average number of dead branches per tree in the lower 16 ft of the stem across densities in the Piedmont/Upper Coastal Plain (Table 77). In this region, operational management yielded an average number of dead branches per tree that increased linearly from 35 when the planting density was 300 tpa to 46 when the density was 1,800 tpa. For intensive management, the average number of dead branches per tree increased linearly from 41 at 300 tpa to 53 at 1,800 tpa.

Table 77. Linear contrasts: average number of dead branches per tree in the lower 16 ft of the stem by planting density for each region.

	Lower Coastal Plain		**Piedmont/Upper Coastal Plain**	
Contrast	Type III F	Pr > F	Type III SS	Pr > F
Linear Trend across Density (both Management Regimes)	4.84	0.214	92.88	<.0001*
Linear Trend across Density at Intensive Regime	3.71	0.137	19.94	0.0001
Linear Trend across Density at Operational Regime	6.92	0.314	27.90	<.0001*

* Significant at $\alpha = 5\%$

3.7.3. Average total number of dead branches per tree for 0-8 ft stem heights

For the average number of dead branches per tree in the lower 8 feet of the stem, the management, density, and management by planting density interaction were significant effects in the Piedmont/Upper Coastal Plain while only the planting density effect was significant in the Lower Coastal Plain (Table 78). In the Piedmont/Upper Coastal Plain the number of live branches per tree for intensive management was on average 3 units more than for operational management, with the average on the intensive being 37 dead branches/tree, and the average on the operational being 34 dead branches/tree Figure 110.

For planting density, in the Piedmont/Upper Coastal Plain the 300 tpa treatment yielded a mean number of dead branches that was significantly less than those of all other densities (Figure 111). There were no significant differences among the three higher densities (1200, 1500, and 1800 tpa) in this region. In contrast to the finding in the Piedmont/Upper Coastal Plain, the average number of dead branches per tree in the Lower Coastal Plain, for the 300 tpa treatment was significantly greater than that for 1200 tpa and 1800 tpa. In the Piedmont/Upper Coastal Plain, as planting density increased the average number of dead branches per tree increased from 33 at 300 tpa to 36 at 1800 tpa. No clear pattern was observed n the Lower Coastal Plain.

Table 78. Analysis of variance results for average number of dead branches per tree in the lower 8 ft of the stem in each region.

	Lower Coastal Plain		**Piedmont/Upper Coastal Plain**	
Source	Type III F	Pr > F	Type III F	Pr > F
Management	0.00	0.9836	11.20	0.0151*
Density	5.66	0.0012*	2.83	0.0321*
Management*Density	0.38	0.8579	2.21	0.0528

* Significant at $\alpha = 5\%$

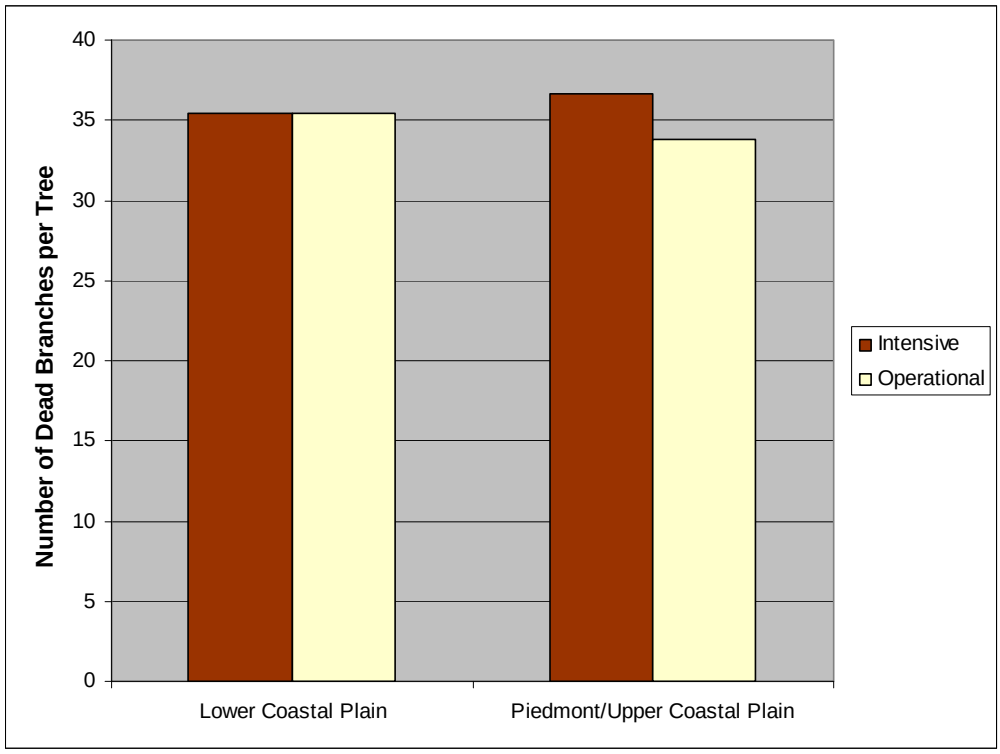


Figure 110. Average number of dead branches per tree in the lower 8 ft of the stem by management regime and region.

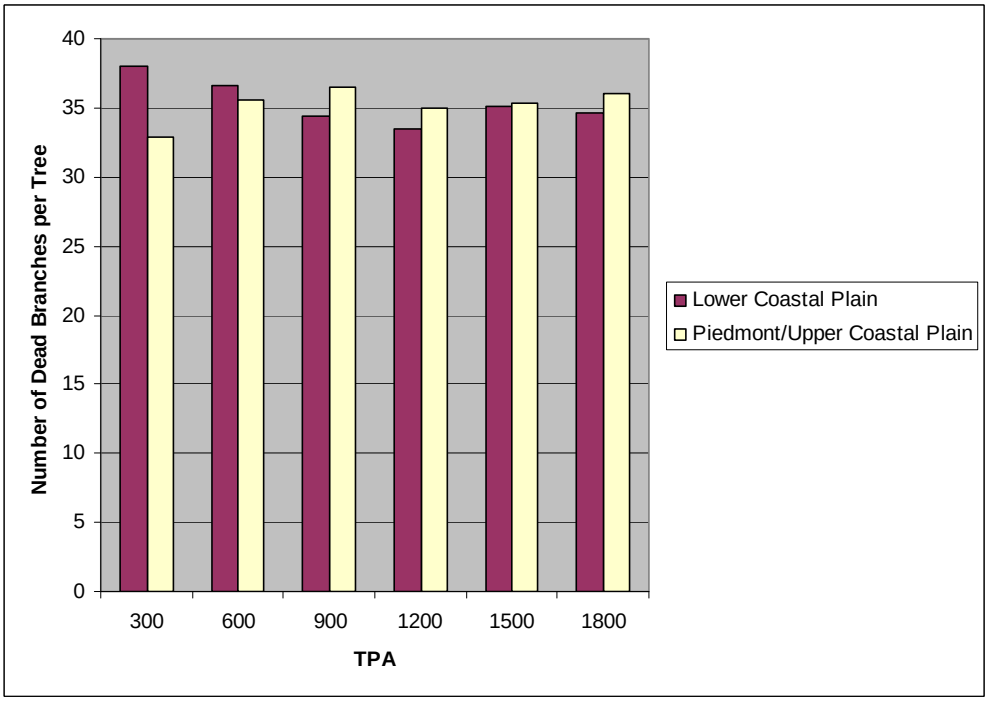


Figure 111. Average number of dead branches per tree in the lower 8 ft of the stem by planting density and region.

In the Piedmont/Upper Coastal Plain, there was a trend toward greater number of dead branches as density increased for both intensive and operational management (Figure 112). At each density, intensively managed plots had greater average number of dead branches per tree than operationally managed plots. No clear pattern was observed in the number of dead branches per tree in the Lower Coastal Plain. Pairwise multiple comparisons were not performed as there was no significant planting density by management regime interactions in either region.

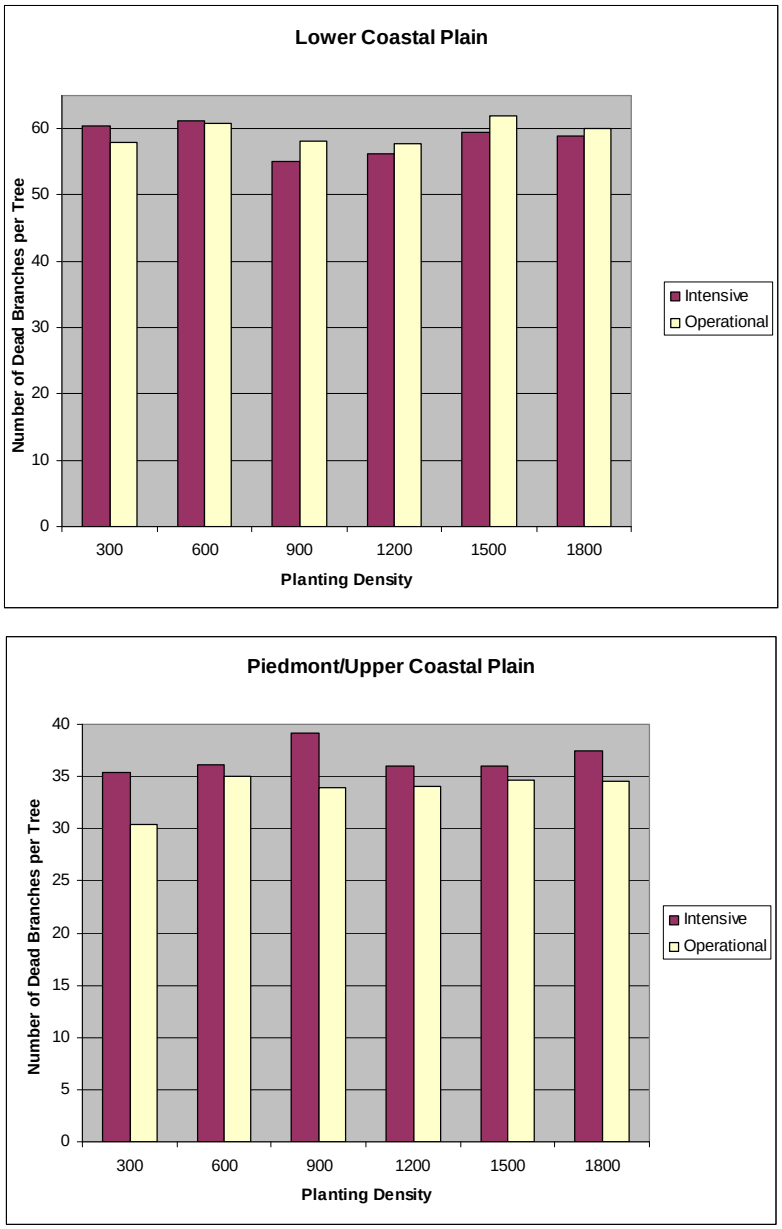


Figure 112. Average number of dead branches per tree in the lower 8 ft of the stem by planting density, management regime and region.

There is a significant linear trend in the average number of dead branches per tree in the lower 8 ft of the stem across densities in the Lower Coastal Plain (Table 79).

Table 79. Linear contrasts: average number of dead branches per tree in the lower 8 ft of the stem by planting density for each region.

	Lower Coastal Plain		**Piedmont/Upper Coastal Plain**	
Contrast	Type III F	Pr > F	Type III SS	Pr > F
Linear Trend across Density (both Management Regimes)	17.01	0.0004*	3.72	0.0631
Linear Trend across Density at Intensive Regime	4.38	0.0466*	0.09	0.7664
Linear Trend across Density at Operational Regime	9.56	0.0048*	3.76	0.0620

* Significant at $\alpha = 5\%$

3.7.4. Average total number of dead branches per tree for 8-16 ft stem height

For the average number of dead branches per tree at heights 8-16 feet of the stem, the management effect was not significant in either region, the density effect was significant only in the Piedmont/Upper Coastal Plain, and the management by planting density interaction was significant only in the Lower Coastal Plain (Table 80). Average number of dead branches by cultural regime and region are presented in Figure 113. In the Piedmont/Upper Coastal Plain, the 300 tpa treatment yielded a mean number of dead branches that was significantly less than those of all other densities (Figure 114. There were no significant differences between the four higher densities (900, 1200, 1500, and 1800 tpa). As planting density increased, average number of dead branches per tree increased from 6 at 300 tpa to 13 at 1800 tpa.

The significant management by planting density interaction in the Lower Coastal Plain in average number of dead branches per tree at 8-16 ft stem heights reflects a greater number of dead branches for intensive than for operational management at the 300 tpa treatment and a lesser number for intensive than for operational management at planting densities greater than 600 tpa (Figure 115).

Table 80. Analysis of variance results for average number of dead branches per tree at heights 8-16 ft of the stem in each region.

	Lower Coastal Plain		**Piedmont/Upper Coastal Plain**	
Source	Type III F	Pr > F	Type III F	Pr > F
Management	0.37	0.5696	3.29	0.1191
Density	1.96	0.1197	23.38	<.0001*
Management*Density	4.05	0.0078*	1.61	0.1551

* Significant at $\alpha = 5\%$

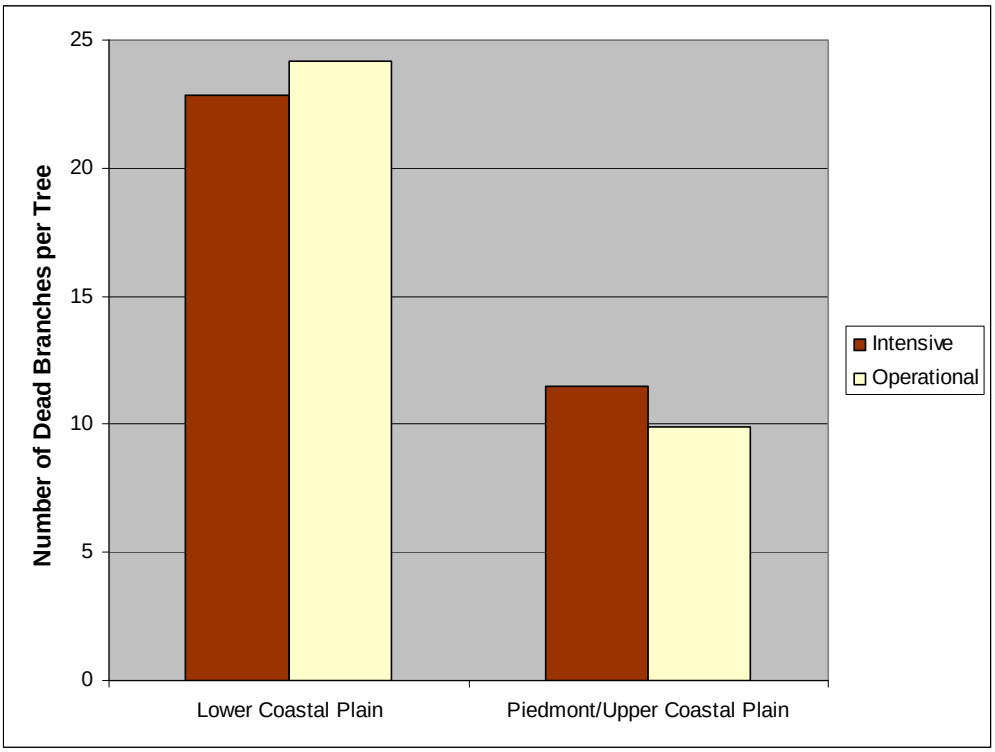


Figure 113. Average number of dead branches per tree at heights 8-16 ft of the stem by management regime and region.

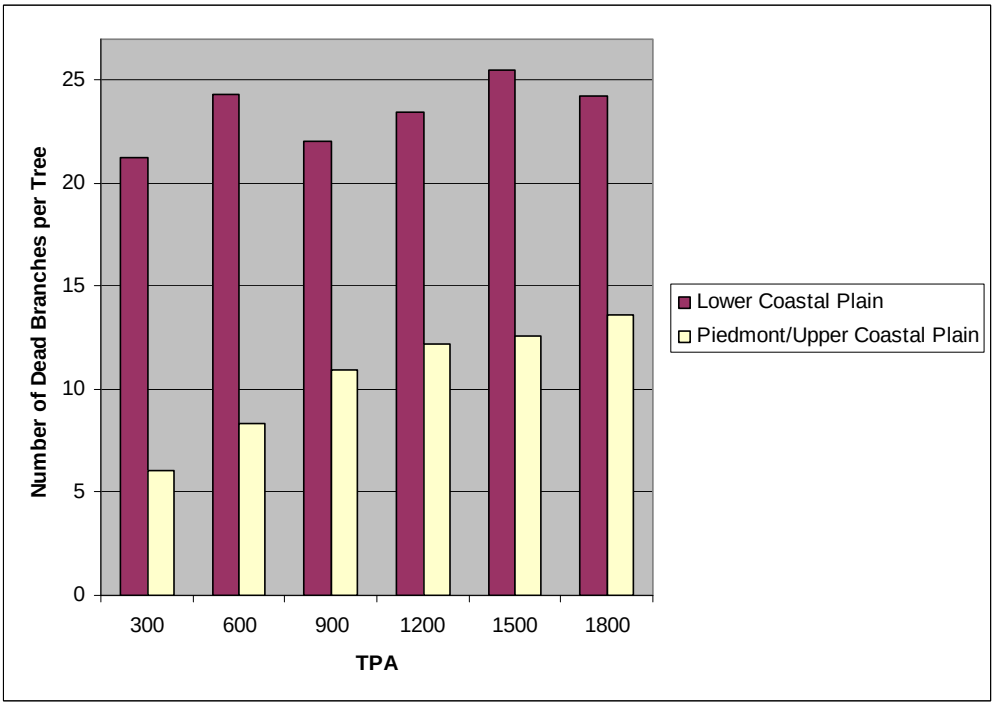


Figure 114. Average number of dead branches per tree at heights 8-16 ft of the stem by planting density and region.

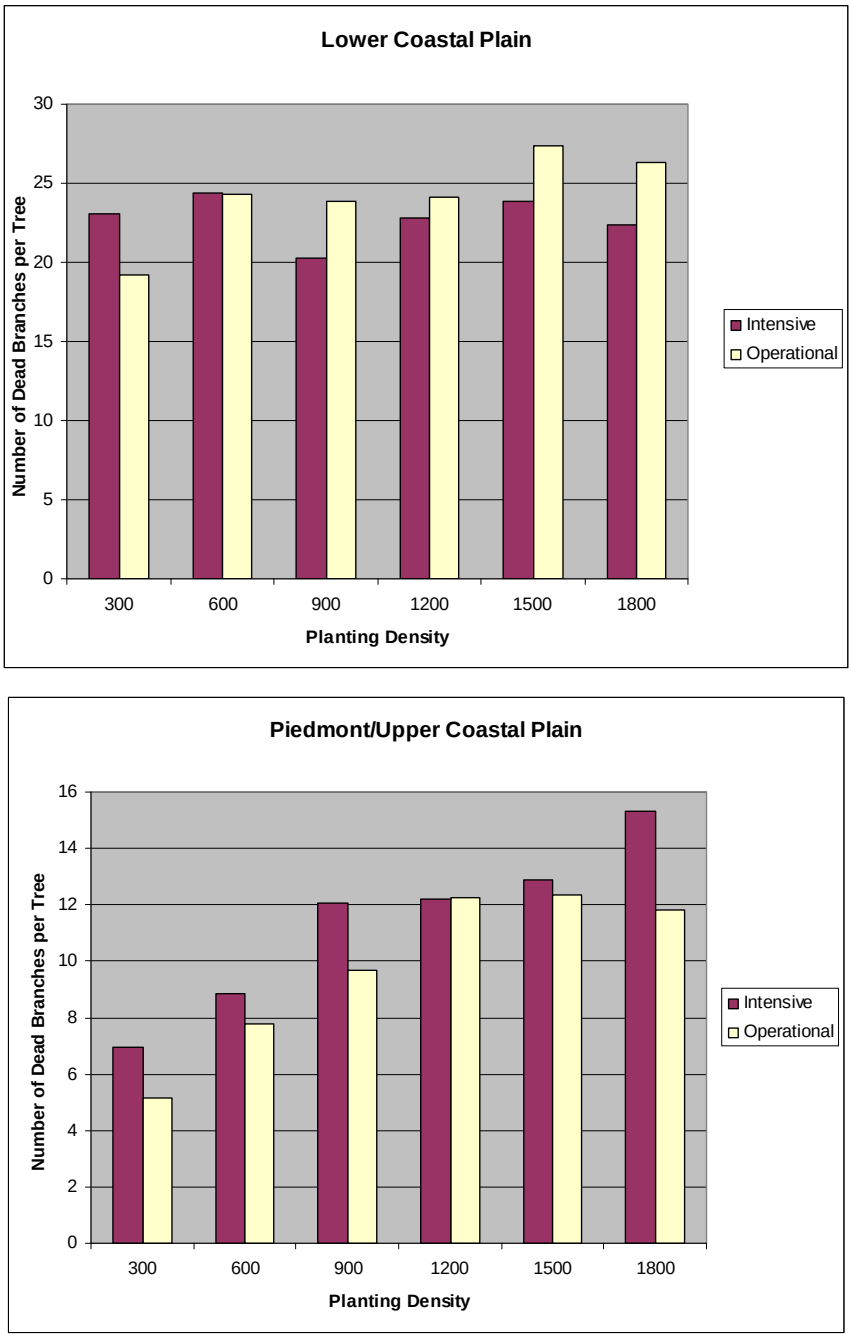


Figure 115. Average number of dead branches per tree at heights 8-16 ft of the stem by planting density, management regime and region.

Results from pairwise multiple comparisons in the Lower Coastal Plain are reported in Table 81. The operationally managed plots at 300 tpa (OP300) yielded the lowest average number of dead branches per tree at heights 8-16 ft of the stem, and its average was significantly less than those of all other planting densities within the operationally managed plots. There were no significant differences among planting densities for the intensively managed plots.

Table 81. P-values of Tukey's studentized multiple comparison tests of the differences among the number of dead branches per tree, at heights 8-16 of the stem, across all management regime and planting density treatment combinations in the Upper Coastal Plain.

Lower Coastal Region											
	IN600	**IN900**	**IN1200**	**IN1500**	**IN1800**	**OP300**	**OP600**	**OP900**	**OP1200**	**OP1500**	**OP1800**
IN300	0.718	0.894	1.000	0.994	1.000	0.214	0.807	0.914	0.996	**0.047**	0.273
IN600		0.298	0.896	0.996	0.769	**0.010**	1.000	1.000	0.668	0.613	0.968
IN900			0.758	0.716	0.812	0.981	0.390	0.218	0.694	**0.001**	**0.004**
IN1200				0.997	1.000	0.107	0.899	0.981	0.991	0.113	0.4228
IN1500					0.993	0.104	0.998	1.000	1.000	0.287	0.597
IN1800						0.182	0.783	0.777	0.998	0.069	0.291
OP300							**0.024**	**0.012**	**0.011**	**0.001**	**0.002**
OP600								1.000	0.999	0.218	0.744
OP900									1.000	0.654	0.975
OP1200										0.289	0.691
OP1500											0.984

References: first two letters refer to the management regime intensity treatment (IN: intensive, OP: operational Intensive). The last three digits refer to the planting density (300, 600, 900, 1200, 1500, 1800 TPA). Significance differences are in bold and are defined as P-values <0.05.

There were significant linear trends in the average number of dead branches per tree at heights 8-16 ft of the stem across densities in the regions under study (Table 82). The only population evaluated that did not have a significant linear trend of dead branches with planting density was for intensively managed plots in the Lower Coastal Plain. In the Lower Coastal Plain, operational management yielded an average number of dead branches per tree that increased linearly from 19 when the planting density was 300 tpa to 26 when the density was 1,800 tpa (Figure 115). In the Piedmont/Upper Coastal Plain, operational management yielded an average number that increased linearly from 5 when the planting density was 300 tpa to 12 when the density was 1,800 tpa. For intensive management, the average number of dead branches per tree increased linearly from 7 at 300 tpa to 15 at 1,800 tpa.

Table 82. Linear contrasts: average number of dead branches per tree at heights 8-16 ft of the stem by planting density in each region.

	Lower Coastal Plain		**Piedmont/Upper Coastal Plain**	
Contrast	Type III F	Pr > F	Type III SS	Pr > F
Linear Trend across Density (both Management Regimes)	4.44	0.0452*	108.55	<.0001*
Linear Trend across Density at Intensive Regime	0.06	0.8030	73.73	<.0001*
Linear Trend across Density at Operational Regime	20.34	0.0001*	68.85	<.0001*

* Significant at $\alpha = 5\%$

3.7.5. Average total number of dead branches per tree for 16-24 ft stem heights

For the average number of dead branches per tree at heights 16-24 ft, the management effect and the planting density effect were significant in both regions while the management by planting density interaction was not significant (Table 83). In the Lower Coastal Plain the number of dead branches per tree for intensive management was on average 8 units more than for operational management, with the average on the intensive being 15 dead branches/tree, and the average on the operational being 7 dead branches/tree (Figure 116). The average number of dead branches per tree in the Piedmont/Upper Coastal Plain decreased from 4 for the intensive regime to 3 for the operational regime.

For planting density, in the Lower Coastal Plain, the 300 tpa treatment yielded a mean number of dead branches significantly less than those of all other densities but 600 tpa (Figure 117). There were no significant differences among the four higher densities (900, 1200, 1500, and 1800 tpa) in either region. As planting density increased, average number of dead branches per tree increased from 6 at 300 tpa to 14 at 1800 tpa for the Lower Coastal Plain, and from 3 at 300 tpa to 4 at 1800 tpa for the Piedmont/Upper Coastal Plain.

Table 83. Analysis of variance results for average number of dead branches per tree at heights 16-24 ft of the stem in each region.

	Lower Coastal Plain		**Piedmont/Upper Coastal Plain**	
Source	Type III F	Pr > F	Type III F	Pr > F
Management	48.86	0.0009*	5.90	0.0159*
Density	7.05	0.0003*	2.77	0.0185*
Management*Density	1.74	0.1615	2.35	0.0514

* Significant at $\alpha = 5\%$

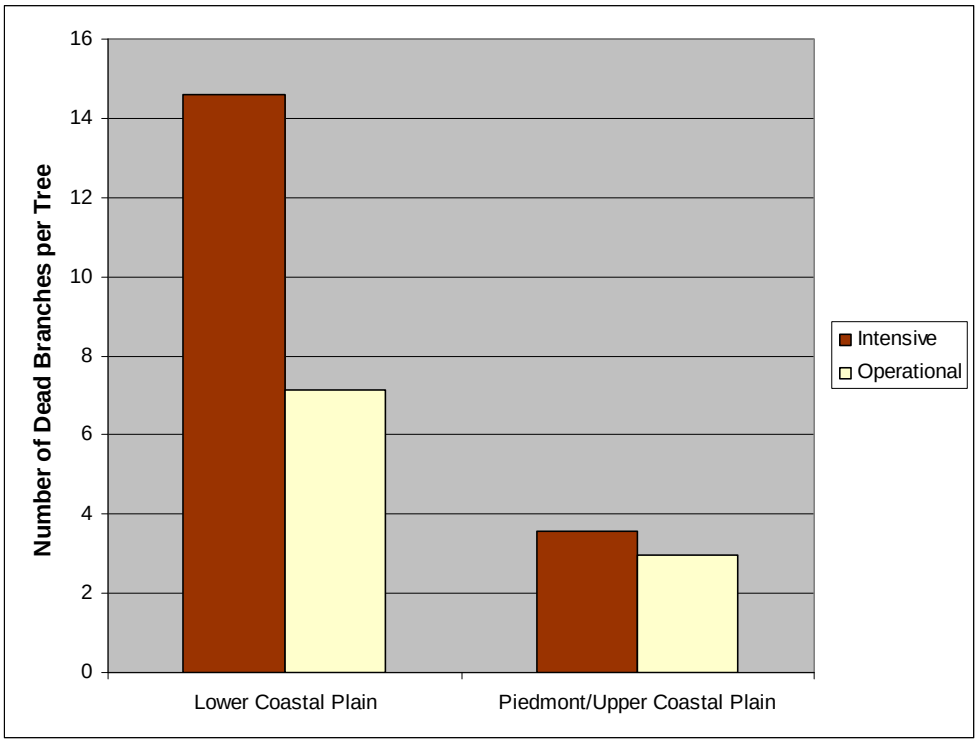


Figure 116. Average number of dead branches per tree at tree heights 16-24 ft of the stem by management regime and region.

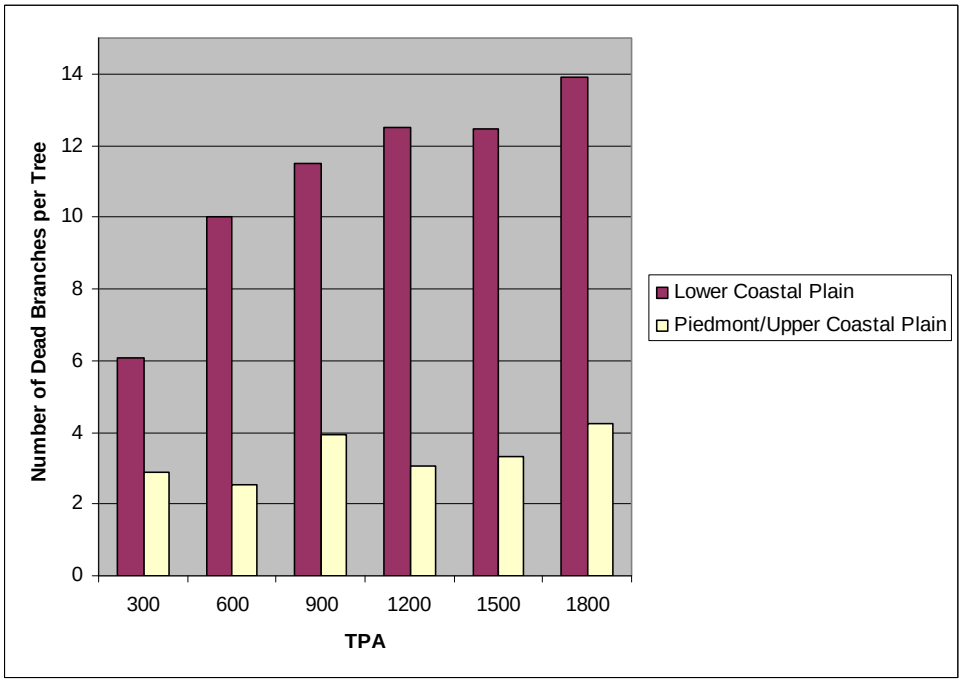
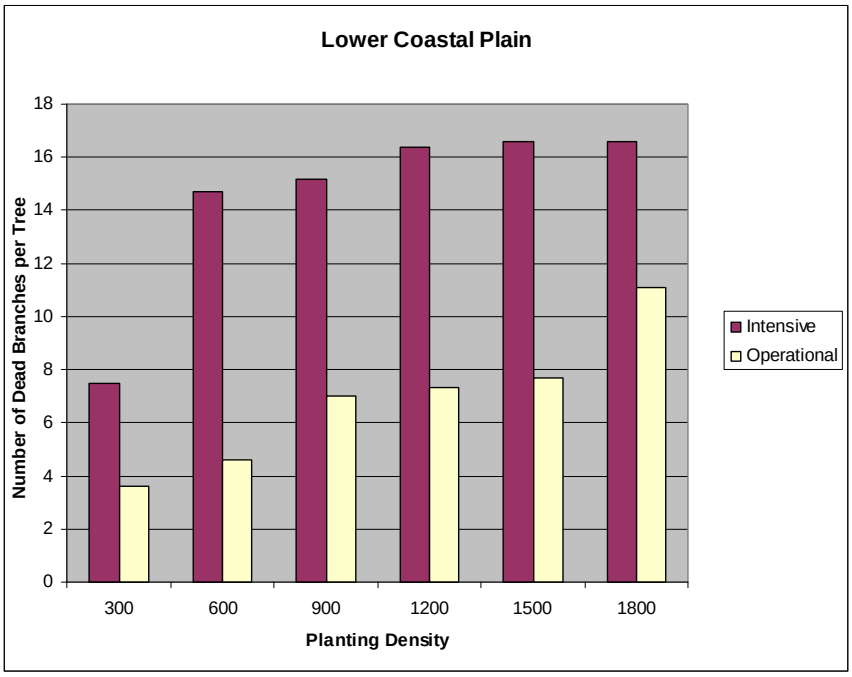


Figure 117. Average number of dead branches per tree at tree heights 16-24 ft of the stem by planting density and region.

There was a trend toward higher number of dead branches as density increased for both intensive and operational management in the Lower Coastal Plain. At each density, the intensively managed plots had larger average number of dead branches per tree than the operationally managed plots. No clear pattern was observed in the number of dead branches per tree in the Piedmont/Lower Coastal Plain, where the range of variation across densities was just 2-5 dead branches per tree (Figure 118).



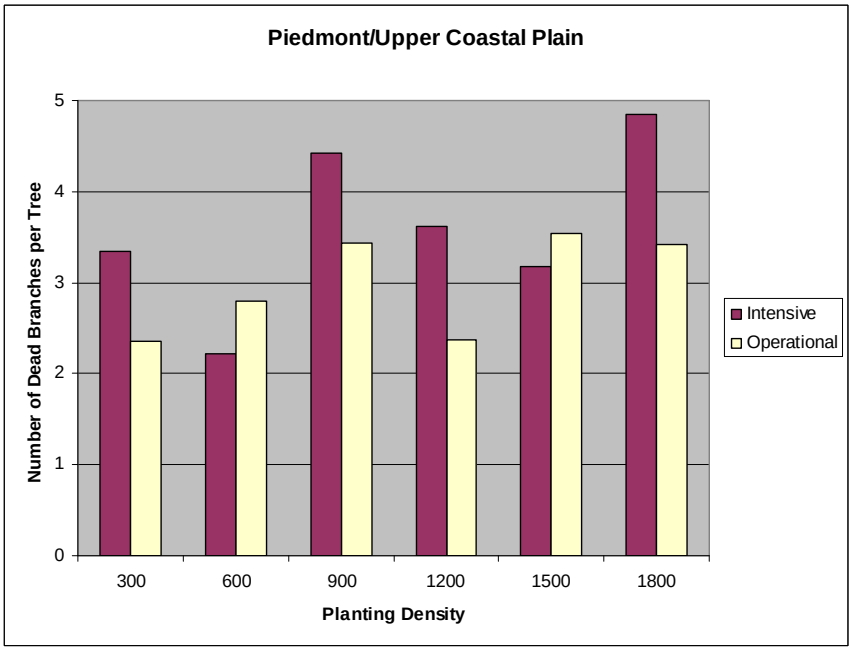


Figure 118. Average number of dead branches per tree at tree heights 16-24 ft of the stem by planting density, management regime and region.

There were significant linear trends for the average number of dead branches per tree at heights 16-24 ft of the stem and planting density overall and for the separate regimes in the Lower Coastal Plain and only for the intensive regime in the Piedmont/Upper Coastal Plain (Table 84). In the Lower Coastal Plain, operational management yielded an average number of dead branches per tree that increased linearly from 4 when the planting density was 300 tpa to 11 when the density was 1,800 tpa, while the increase for intensive management was from 8 to 17. In the Piedmont/Upper Coastal Plain, intensive management yielded an average number of dead branches that increased linearly from 3 when the planting density was 300 tpa to 5 when the density was 1,800 tpa.

Table 84. Linear contrasts: average number of dead branches per tree at heights 16-24 ft of the stem by planting density in each region.

	Lower Coastal Plain		**Piedmont/Upper Coastal Plain**	
Contrast	Type III F	Pr > F	Type III SS	Pr > F
Linear Trend across Density (both Management Regimes)	32.81	<.0001*	3.61	0.0671
Linear Trend across Density at Intensive Regime	28.96	<.0001*	5.93	0.0210*
Linear Trend across Density at Operational Regime	14.46	0.0008*	0.65	0.4260

* Significant at $\alpha = 5\%$

4. DISCUSSION

The observed reductions in branch size (i.e. branch diameter, branch basal area, and branch length) with an increase in initial planting density confirm the results of previous studies (Mäkinen and Colin, 1998; Alcorn et al, 2007; Ulvcrona et al., 2007). It has been reported that stand density can control branch size because these factors are more an expression of environment than genotype (Briggs et al., 2007). One of the most important factors regulating the diameters of branches is the recession of the live crown as a result of increasing competition at higher planting density levels (Ballard and Long, 1988). Light availability appears to be the primary driving factor for branch diameter growth (Weiskittel et al., 2007). There were no significant differences on branch size (length and diameter) among the higher planting densities (1200 tpa and above) in either region of this study, suggesting that light availability for the lower 24 ft of the stem is similar in these densities as the stand approaches ages 7 and 8 years. The average branch diameter increased toward the upper sections of the stem, coinciding with previous results (Roeh and Maguire, 1977). Branch basal area per tree is a function of branch diameter; hence the results were similar for both response variables.

Branch length decreased as planting density increased for both intensive and operational management. Like branch diameter, branch length also increased toward the upper sections of the stem, as would we expected given the strong branch length-branch diameter direct relationship within each tree (Roeh and Maguire, 1977).

Stand density significantly affected branch angle as measured relative to the stem. Across all stem sections assessed, the angle of branches tended to decline with increasing stocking. However, there were no significant differences in branch angle among the higher planting densities (1200, 1500, and 1800 tpa). The reduction of branch angle with increasing planting density is consistent with findings for different species (Alcorn et al., 2007). It has been reported that the decrease in branch angle at high densities is an adaptation that maximizes leaf area display for light capture and minimizes self-shading (Alcorn et al., 2007). The average angle of branches increased toward the lower sections of the stem. This corroborates earlier findings that claim that the increase of branch angle from the apex toward the base of the crown is due to gradients in growth regulators paralleling distance from the tree apex, the increasing proportion of light received from the side versus top, and the increasing mass of foliage by the branches (Roeh and Maguire, 1977).

In the present study, the total number of branches on the lower 24 ft was not significantly affected by planting density or the management regime factor. These results are in agreement with those of Baldwin et al. (2000) finding that the total number of branches was constant across different planting densities in loblolly pine plantations. It has been proposed that the number of branches present in a tree is

determined mainly by genetic factors with environmental conditions playing a minor role (Briggs et al., 2007).

Stand density was a strong determinant of branch mortality. The number of live branches in the lower 24 ft of the stem significantly declined as densities increased for both management regimes. Accordingly, the number of dead branches increased with planting density. These results are similar to those found in previous studies (Mäkinen and Colin, 1998; Weiskittel et al., 2007). Branches tend to stay alive for a longer time in less dense stands than in highly dense stands. Crown recession and branch death due to competition is delayed at low densities, and branches growing in that type of stand live longer than branches growing in high stocking stands. The average number of live branches increased toward the upper sections of the stem, while the average number of dead branches increased toward the low sections of the stem.

Documented crown and branch responses to silvicultural treatments including fertilization and vegetation control have been inconsistent and varied greatly (Mäkinen et al., 2004; Weiskittel et al., 2007). In our study, branch size and branch mortality were found to be responsive to the cultural treatment. The intensive management regime generally increased the mean branch diameter, branch basal area per tree, branch length, and the number of dead branches in the lower 24 ft of the stem as compared to these attributes for the operational regime. The intensive regime generally decreased the number of live branches. No significant management regime effect was found on branch angle or total number of branches.

5. CONCLUSIONS

Branch growth and mortality is critical to both quality and quantity of timber produced from plantations; however detailed studies of branch responses in loblolly pine to silvicultural treatments are lacking. A total of 66,426 branches on 850 trees were analyzed for branch characteristics in this study, representing a variety of sites throughout the Southeast USA. Branch size and branch mortality characteristics were affected by planting density and silvicultural treatments. Increasing planting density from 300 to 1800 trees per acre significantly reduced mean branch diameter, branch basal area per tree, branch length, branch angle relative to the stem, and the number of live branches per tree. The number of dead branches per tree was increased with greater planting densities. The intensive management regime significantly increased mean branch diameter, branch basal area per tree, branch length, and the number of dead branches per tree as compared to these attributes with the operational regime. The intensive regime reduced the number of live branches and had no effect on the branch angle. Neither planting density nor management regime or their interaction had an effect on the total number of branches.

6. LITERATURE CITED

Alcorn, P.J., Pyttel, P., Bauhusb, J., Smith, R., Thomas, D., James, R., Nicotra, A. 2007. Effects of initial planting density on branch development in 4-year-old plantation grown Eucalyptus pilularis and Eucalyptus cloeziana trees.For. Ecol. Manage. 252 (2007), pp. 41–51.

Baldwin Jr., B., Peterson, K., Clark, A., Ferguson, R., Strub, M., and Bower, D. 2000. The effects of spacing and thinning on stand and tree characteristics of 38-year-old Loblolly Pine, For. Ecol. Manage. 137 (2000), pp. 91–102.

Ballard, L., and Long, J. 1988. Influence of stand density on log quality of lodgepole pine. Can. J. For. Res. 18: 911–916.

Borders, B.E. and Bailey, R.L., 2001. Loblolly pine-pushing the limits of growth. S.J. Appl. For. 25, pp. 69–74

Borders, B.E., Will, R.E., Markewitz, D., Clark, A., Hendrick, R., Teskey, R.O. and Zhang, Y., 2004. Effect of complete competition control and annual fertilization on stem growth and canopy relations for a chronosequence of loblolly pine plantations in the lower coastal plain of Georgia. For. Ecol. Manage. 192, pp.21- 37.

Briggs, D., Ingaramo, L. & Turnblom, E. 2007. Number and diameter of breast-height region branches in a Douglas-fir spacing trial and linkage to log quality. Forest Products Journal 57: 28–34.

Clark, A. and Saucier, J.R. 1989. Influence of initial planting density, geographic location, and species on juvenile wood formation in southern pine. Forest Prod. J. 39 (7/8): 42-48.

Clark, A., Borders, B.E., and Daniels, R.F. 2004. Impact of vegetation control and annual fertilization on properties of loblolly pine wood at age 12, 2004. For. Prod. J. 54, pp. 90–96.

Faust, T. D., Clark III, A., Courchene, C. E.; Shiver, B. D., and Belli, M. L. 1999. Effect of Intensive Forest Management Practices on Wood Properties and Pulp Yield of Young, Fast Growing Southern Pine. TAPPI International Environmental Conference Proceedings, April 18-21, 1999, Nashville, Tenn. Vol. 2, pp. 501-512.

Harrison, M. and M. Kane. 2008. PMRC Coastal Plain Culture / Density Study: Age 12 Analysis. PMRC Technical Report 2008-1. 89pp.

Jokela, E.J., Dougherty, P.M., and Martin, T.A., 2004. Production dynamics of intensively managed loblolly pine stands in the southern United States: a synthesis of seven long-term experiments, For. Ecol. Manage. 192 (2004), pp. 117–130.

Kantola, A., and Mäkelä,A. 2004. Crown development in Norway spruce (Picea abies (L.) Karst.), Trees 18 (2004), pp. 408–421.

Mäkinen H., and Colin, F. 1998. Predicting branch angle and branch diameter of Scots pine from usual tree measurements and stand structural information. Can J For Res 28:1686–1696

Mäkinen, H., Ojansuu, R. , Sairanen, P., and Yli-Kojola, H. 2004. Predicting branch characteristics of Norway spruce (Picea abies (L.) Karst.) from simple stand and tree measurements, Forestry 76 (2004), pp. 525–546.

Martin, T.A. and Jokela, E.J., 2004. Stand development and production dynamics of loblolly pine under a range of cultural treatments in north-central Florida, USA. For. Ecol. Manage. 192, pp. 39–58.

Medhurst, J.L., and Beadle, C.L., 2001. Crown structure and leaf area index development in thinned and unthinned Eucalyptus nitens plantations. Tree Physiol. 21, 989–999.

Mora, C. R. Effects of Early Intensive Silviculture on Wood Properties of Loblolly Pine. 2003. M.S. Thesis. Dept. of Forestry, North Carolina State Univ., Raleigh, NC. 81pp.

Pienaar, L.V. and B.D. Shiver. 1993. Early results from an old-field loblolly pine spacing study in the Georgia piedmont with competition control. Southern Journal of Applied Forestry. 17(4):193-196.

Roeh, R., and Maguire,D. 1977. Crown profile models based on branch attributes in coastal Douglas-fir, For. Ecol. Manag. 96 (1997), pp. 77–100.

Shiver, B.D., and Martin, S.W., 2002. Twelve-year results of a loblolly pine site preparation study in the Piedmont and Upper Coastal Plain of South Carolina, Georgia, and Alabama. South. J. Appl. For. 26(1): 32-36.

Trincado, G. 2006. Dynamic modeling of branches and knot formation in loblolly pine (Pinus taeda L.) trees. Ph.D. thesis, Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

Ulvcrona, K., Claesson, S., Sahlen, K., and Lundmark, T. 2007. The effects of timing of pre-commercial thinning and stand density on stem form and branch characteristics of Pinus sylvestris. Forestry 80:323–335.

Umeki, K. 1995.A comparison of crown asymmetry between Picea abies and Betula maximowicziana. Can. J. Forest Res. 25:1876-1880.

Weiskittel, D.A. Maguire and R.A. Monserud, Response of branch growth and mortality to silvicultural treatments in coastal Douglas-fir plantations: implications for predicting tree growth, Forest Ecology and Management **251** (2007), pp. 182–194.

Will, R.E.; Narahari, N.; Teskey, R.O.; Shiver, B.D.; Wosotowsky, M., 2006. Effects of planting density on the Biomass partitioning of intensively managed loblolly pine stands on the Piedmont and upper Coastal plain of Georgia. Gen. Tech. Rep. SRS-92. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. pp.78.

Zhao, D., M. Kane, and W.M. Harrison. 2008. SAGS Culture Density Study: Results through age 10. PMRC Technical Report 2008-3. 33pp.