THE B.F. GRANT SPACING STUDY:

RESULTS THROUGH AGE 19

Plantation Management Research Cooperative
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1 INTRODUCTION

Loblolly pine plantations established on abandoned agricultural fields represent a significant potential resource for landowners and the forest industry in Georgia. In recent years, the USDA's Conservation Reserve Program (CRP) has motivated the establishment of loblolly pine plantations on marginal agricultural land across the state. As of July 2000, approximately 265,000 acres in Georgia were under contract and designated as "Tree Practice Acres" under the CRP.

Growth and yield models and information on spacing, thinning and silvicultural treatments are necessary to properly manage and evaluate old-field plantations. Clutter and Lenhart (1968) published a site index model for old-field loblolly pine plantations in the Georgia Piedmont. These plantations were established primarily as part of the soil bank program in the 1950's. The model was based on stem analysis data on 141 trees ranging in age from 12 to 32 years. Golden *et al.* (1981) developed site index equations for old-field loblolly pine based on data from a wide geographical range. None of the data came from the Georgia Piedmont. The resulting models, however, compared favorably with those developed by Clutter and Lenhart (1968).

As a further extension of this work, these authors published cubic foot yield tables for old-field, loblolly pine plantations in the Georgia Piedmont (Lenhart and Clutter, 1971). A survival function, basal area distribution equation and a height/diameter function were part of this work. Individual-tree volume equations (Bailey and Clutter, 1970) were used to build volume tables for different merchantability limits.

A study to provide growth and yield information for genetically-improved loblolly pine planted on an old-field site in the Georgia Piedmont was installed in 1983 at the B.F. Grant Memorial Forest. This forest, located in Putnam County, Georgia, is maintained by the Warnell School of Forest Resources at the University of Georgia. The B.F. Grant spacing study was installed for the following purposes:

- To investigate stand dynamics and yield for different planting density treatments,
- To investigate the effects of thinning on growth and yield as compared to unthinned counterpart stands of various densities, and
- To demonstrate the growth potential of an intensively managed, old-field loblolly pine plantation in the Georgia Piedmont.

This report details the analysis of the B.F. Grant Spacing Study through age 19 with these objectives in mind.

2 STUDY DESCRIPTION

The study is located on a gently sloping hilltop that had been planted to soybeans in previous years. Soils in the area are dominated by Typic Kanhapludults (Cecil Series) and Rhodic Kaniudults (Davidson Series). The study was hand planted in March, 1983 at a 6 ft. by 6 ft. spacing with improved loblolly pine seedlings supplied by the Georgia Forestry Commission nursery. In May of 1983, a farm tractor was used to mow herbaceous competition between rows, and, one month later, to broadcast spray Oust (sulphometuron-methyl) herbicide with a boom sprayer at a rate of eight ounces per acre. Herbaceous competition consisted primarily of Johnson grass (*Sorghum halepense*) and vetch (*Vicia* spp.). In the following July, 24 fifth-acre plots were installed, each with a tenth-acre interior measurement plot. Four plots were randomly assigned to each of six stocking levels, namely, 100, 200, 400, 600, 800 and 1000 trees per acre. Surviving seedlings on each plot were reduced to the required number by systematic selection to avoid bias and to assure uniform spacing.

A second herbicide release treatment with eight ounces of Oust was applied in May, 1984 to control recurrent herbaceous competition in the second growing season. One year later in May, 1985, wildlings of both loblolly pine and sweetgum (*Liquidambar styraciflua*) that had seeded in from neighboring stands were eliminated on all plots. In subsequent years, directed sprays of glyphosate were used to eliminate all competing vegetation. As a result of these treatments, all plots have been growing essentially free of competing vegetation throughout the life of the study. No supplemental fertilization has been applied to the study at any time.

Early in the 15th growing season of the B.F. Grant Spacing Study (in 1997), eight plots were selectively thinned from below. Trees were selected for thinning according to their relative size, presence of disease, tree form and final spacing considerations. Residual trees per acre prescriptions on the thinned plots were intended to match the current, average number of trees per acre on corresponding unthinned plots. Table 1 shows the thinning prescriptions for each of the eight plots.

3 MEASUREMENTS AND RESULTS

Total heights for all trees were measured at ages 3, 5, 8, 10, 12, 14, 17 and 19 years. Breast-height diameters (dbh) were measured at the same time with the exception of the age three measurement. Average stand characteristics by initial stocking density are shown below. Bear in

Table 1. Thinning prescriptions for B.F. Grant Spacing Study plots.

Plot Number	Initial Density	Trees/ac before thinning	Trees/ac after thinning
1	600	530	200
3	600	500	200
4	400	390	200
9	800	630	410
12	400	390	200
15	1000	940	400
17	800	730	400
22	1000	940	390

mind that, for initial stocking densities of 400 trees per acre and greater, averages by density consist of four observations (plots) prior to the thinning and two observations after the thinning. A separate analysis was carried out for the thinned plots and is described below.

3.1 Survival

Survival values over time for each initial stocking density are shown in Table 2. From the initial spacing through age 19, the average survival rate for all plots is 89%.

Table 2. Survival by age and initial stocking density for unthinned B.F. Grant Spacing Study plots.

Age	Initial Stocking Density					
	100	200	400	600	800	1000
5	100	200	400	590	782	990
8	100	200	400	588	780	960
10	100	200	398	572	762	925
12	100	200	398	565	740	912
14	100	200	395	550	720	888
17	100	200	395	570	715	740
19	100	198	395	565	695	715

Note the increase in trees per acre between the 14th and 17th growing seasons for the plots with initial stocking density of 600 trees per acre. As mentioned previously, the average survival prior to the thinning at age 15 is based on four plots, while the average survival of unthinned plots after age 15 is based on two plots.

3.2 Height

The average dominant height (H_d) for all plots after the 19th growing season was 66.77 feet. This height was used to compute an average site index (*SI*) value for the B.F. Grant Spacing Study using the following equation from Lenhart and Clutter (1968):

$$\log_{10}(SI) = 1.0907 + 10^{-2.911/Age}\left[-2.0226 + 1.3075\log_{10}(Hd) + 14.9136/Age\right] \tag{1}$$

The site index estimate (base age 25 years) for the B.F. Grant Spacing Study is 79 feet. Average heights (all crown classes) by age and initial stocking density are shown in Table 3 and illustrated in Figure 1.

Table 3. Average height (feet) by age and initial stocking density for unthinned B.F. Grant Spacing Study plots.

Age	Initial Stocking Density					
	100	200	400	600	800	1000
3	10.2	11.2	12.8	12.3	11.5	11.5
5	16.5	17.8	19.9	19.6	18.1	18.4
8	28.2	29.6	33.2	33.0	31.1	31.9
10	36.6	40.3	43.0	41.8	40.0	40.1
12	43.5	46.3	49.7	49.1	45.7	45.4
14	49.8	53.1	55.5	54.7	52.4	50.3
17	58.9	60.9	62.6	60.0	58.6	60.7
19	62.5	65.7	66.7	62.7	62.6	65.9

No clear trend appears when considering average height by initial stocking density. Prior to the thinning at age 15, the plots with 200-600 trees per acre had the highest average heights, with the 1000 trees per acre plots among the lowest in average height. In the years after the thinning, the trend remains the same for the 200-400 trees per acre plots, but the 600 trees per acre plots have fallen behind in terms of average height. The two 1000 trees per acre plots that remained unthinned now have an average height comparable to the 200-600 trees per acre plots. At all but one measurement (17 years), the 100 trees per acre plots had the lowest average height. Statistical analysis shows no significant differences in average height among the various spacing treatments.

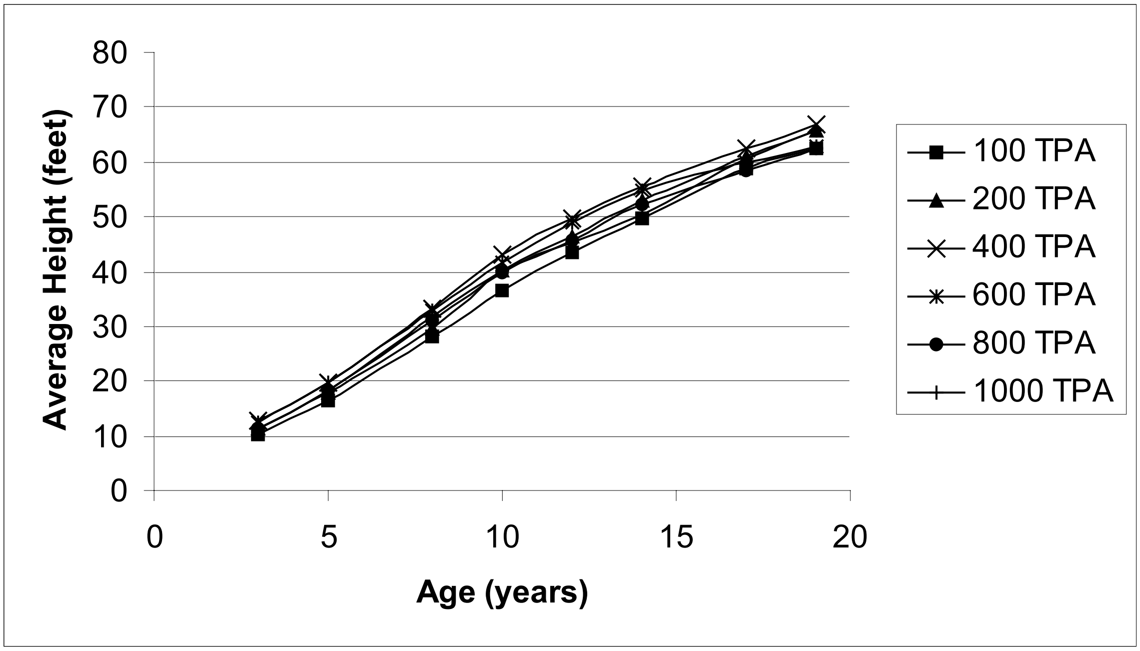


Figure 1. Average height by initial stocking density for the unthinned B.F. Grant Spacing Study plots.

3.3 Average DBH

Average DBH's by stocking density for the unthinned plots are shown in Table 4 and Figure 2.

Table 4. Average DBH (inches) by age and initial stocking density for unthinned B.F. Grant Spacing Study plots.

Age	Initial Stocking Density					
	100	200	400	600	800	1000
5	3.6	4.0	4.2	3.8	3.5	3.3
8	7.8	7.8	7.0	6.0	5.5	5.1
10	9.9	9.2	8.0	6.8	6.2	5.8
12	11.1	10.0	8.5	7.3	6.7	6.1
14	12.0	10.6	8.9	7.7	7.0	6.3
17	13.2	11.6	9.4	8.0	7.6	7.4
19	13.7	11.9	9.8	8.4	7.8	7.7

A clear trend in average DBH by initial stocking density has persisted throughout the life of the spacing study. Average DBH's after 19 growing seasons range from 13.7 inches for the 100 trees per acre plots to 7.7 inches for the 1000 trees per acre plots. Prior to the thinning at age 15, the average DBH of the four 1000 trees per acre plots was nearly 0.5" smaller than the average

DBH of the four 800 trees per acre plots. For the two plots for each stocking level (800 and 1000) that remained after the thinning, the average DBH of the 1000 trees per acre plots has approached and is now nearly equal to the average DBH of the 800 trees per acre plots.

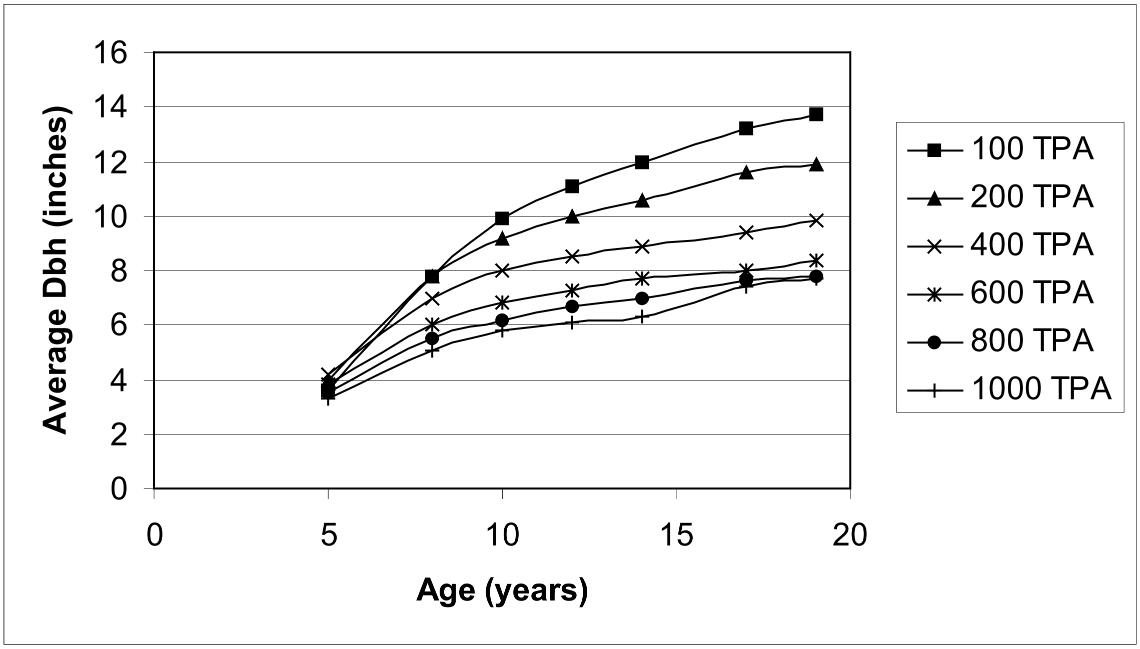


Figure 2. Average DBH by initial stocking density for the unthinned B.F. Grant spacing study plots.

3.4 Per-Acre Basal Area

Per-acre basal areas by initial stocking density for the unthinned plots are shown in Table 5 and illustrated in Figure 3.

Table 5. Per-acre basal area (ft^2) by age and initial stocking density for unthinned B.F. Grant Spacing Study plots.

Age	Initial Stocking Density					
	100	200	400	600	800	1000
5	7.4	18.1	39.6	46.8	53.4	61.1
8	34.3	67.0	108.9	119.1	132.6	139.0
10	53.9	94.2	140.9	150.2	165.5	172.6
12	67.6	111.9	159.8	168.8	185.7	191.2
14	79.3	125.7	174.1	182.4	199.0	202.0
17	95.8	149.3	196.0	206.7	230.6	225.4
19	104.1	156.0	211.4	221.0	243.1	236.8

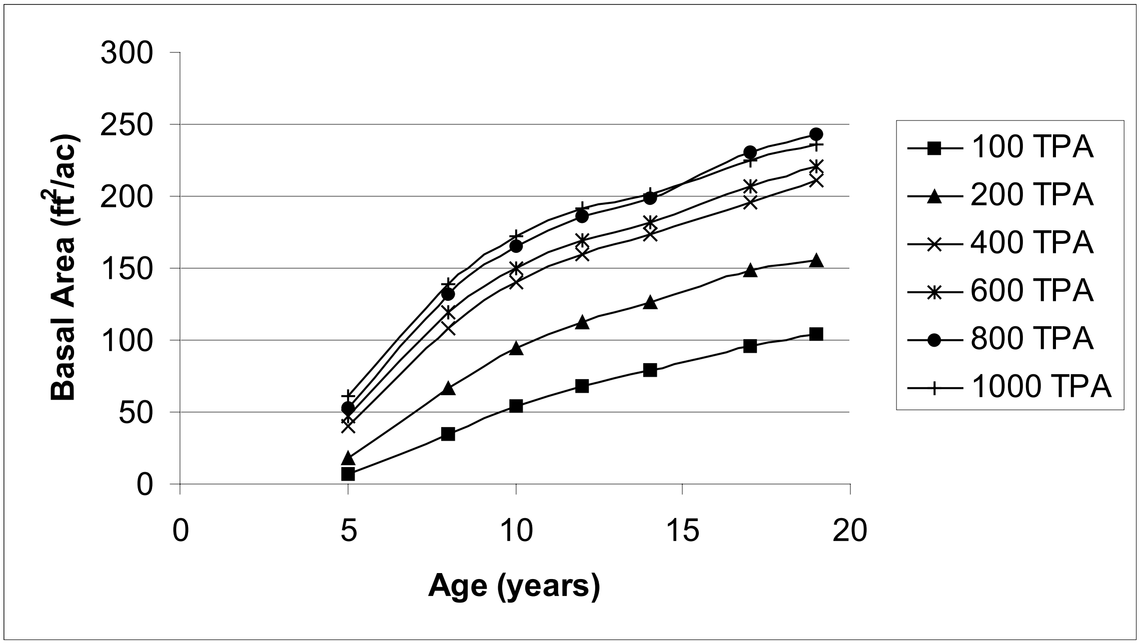


Figure 3. Average per-acre basal area (ft^2) by initial stocking density for the unthinned B.F. Grant Spacing Study plots.

As often theorized, the basal areas of "fully stocked" stands of different initial densities should approach some common asymptote or carrying capacity. Although not there yet, the average per-acre basal areas for the 400-1000 trees per acre plots are of similar magnitudes and seem to be approaching some common asymptote. By contrast, the 100 and 200 trees per acre plots seem to be understocked and will likely never reach the level of the fully stocked plots. After 19 growing seasons, the average per-acre basal area of the 400-1000 trees per acre plots was 75% greater than the average of the 100 and 200 trees per acre plots.

3.5 Per-Acre Merchantable Volume

Merchantable volumes (o.b.) for trees greater than 4.5" DBH to a 2" top (o.b.) were calculated with the following equation from Pienaar *et al*. (1987):

$$VOB_m = 0.00401246 DBH^{1.829011} HT^{0.969142} - 0.00249374 \left[\frac{2^{3.684725}}{DBH^{1.684725}} \right] (HT - 4.5) \qquad \textbf{(2)}$$

Average per-acre merchantable volumes by initial density are shown in Table 6 and illustrated in Figure 4. Merchantable volume MAI development (cords @ 78 ft^3/cord) is shown in Figure 5.

Table 6. Per-acre merchantable volume (ft^3) by age and initial stocking density for unthinned B.F. Grant Spacing Study plots.

Age	Initial Stocking Density					
	100	200	400	600	800	1000
8	434	880	1581	1687	1659	1652
10	892	1710	2709	2796	2886	2878
12	1330	2343	3580	3737	3764	3726
14	1790	3030	4374	4536	4673	4483
17	2364	3893	5452	5610	6269	6360
19	2700	4356	6198	6238	6954	7114

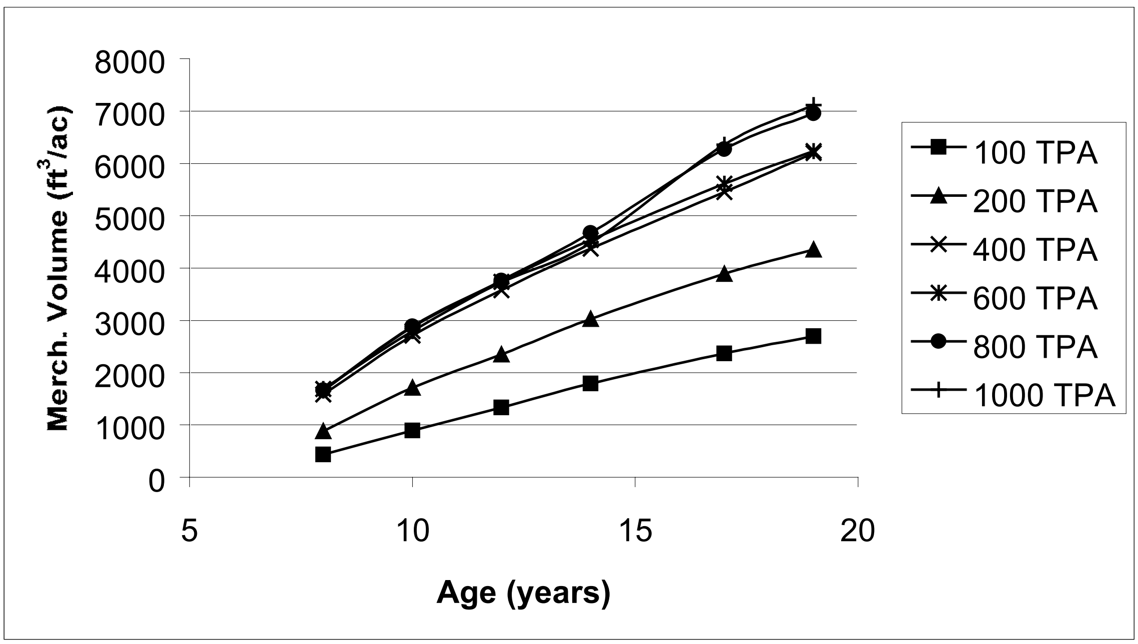


Figure 4. Average per-acre merchantable volume (ft^3) by initial stocking density for the B.F. Grant Spacing Study plots.

Prior to the thinning at age 15, the 400-1000 trees per acre plots had nearly identical average per-acre merchantable volumes. The averages of the two unthinned plots at each stocking level show some differentiation after age 15. This could be due to the plots that were chosen for thinning. According to the evidence in the merchantable volumes, it seems that the best of the 400 and 600 trees per acre plots were thinned and the worst of the 800 and 1000 trees per acre plots were thinned.

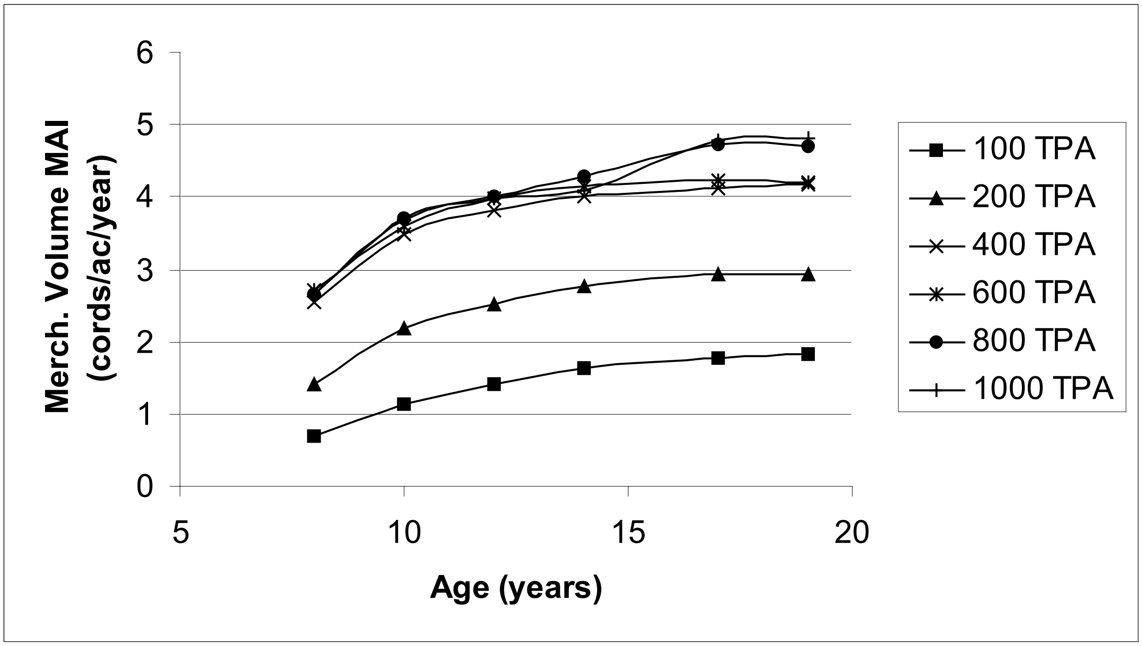


Figure 5. Average merchantable volume MAI's (cords @ 78 ft^3/cord) by initial stocking density for the B.F. Grant Spacing Study plots.

The MAI development curves shown in Figure 5 support the same conclusions as the volume growth curves. Given that the average MAI's for all four plots of density levels of 400 trees per acre and above were nearly equal prior to the thinning, this evidence suggests that the choice of plots to be thinned may have been unintentionally biased with respect to stocking density. It remains to be seen if this bias will be maintained, dissipate or increase over time.

3.6 Timber Revenues

Although merchantable volumes are nearly equal for initial stocking densities of 400 trees per acre and over, the tree size distributions are quite different and will affect product distributions and timber revenues. An analysis of revenues was based on the age 19 data and projected stand characteristics and yields at age 25. Growth and projections for the thinned and unthinned plots were carried out using the system of equations described by Borders *et al.*, 2001. Merchantable green weights by product were computed using the whole-stand yield and product breakdown models from Harrison and Borders, 1996. Merchantable green weight (tons/ac o.b.) were calculated for the following product classes:

Pulpwood – trees >= 4.5" Dbh to a 2" top,
Chip-N-Saw – trees >= 8" Dbh to a 6" top,
Sawtimber – trees > 12.5" Dbh to a 6" top.

Studies have shown that fast-grown loblolly pine plantations such as the B.F. Grant Spacing study produce trees that may be largely unsuitable for solid wood production. Relatively young trees from fast-grown plantations contain high proportions of juvenile wood and exhibit excessive longitudinal shrinkage (Ying *et.al*, 1994). Trees grown at low densities (100-400 trees/acre) also retain branches with large basal diameters. The resulting knots reduce grade and negatively impact value. To account for these properties that adversely affect solid wood production, percentages were applied to deduct yield from chip-n-saw and sawtimber products and add the deducted yields to pulpwood. Table 7 shows the degrade percentages by initial stocking density.

Table 7. Percentages used to deduct from solid wood products and add to pulpwood yields.

Initial Stocking Density	Degrade Percentage
100	100
200	75
400	50
600	25
800	20
1000	10

Product prices were obtained from Timber Mart-South, south-wide average prices from the 4th quarter of 2001. These were \$6.20/ton for pine pulpwood, \$23.72/ton for pine chip-n-saw and \$35.95/ton for pine sawtimber. All thinning yields were allocated to pulpwood. The revenue derived from thinning was compounded at a 6% rate to the end of the rotation considered. Average timber revenues by initial stocking density and thinning status for the 19 and 25-year rotations are shown in Figures 6 and 7.

At the current age of 19 years, timber revenues from all plots ranged from \$388 to \$3406 per acre. The highest average revenues were obtained from the thinned plots with initial stocking densities of 600, 800 and 1000 trees per acre. For the projected yields at age 25, timber revenues from all plots ranged from \$819 to \$5549 per acre. The 1000 trees per acre unthinned had the highest average revenue. These plots were projected to yield significant amounts of chip-n-saw volume by age 25. The 400 unthinned, 600 thinned and unthinned and the 800 thinned and unthinned all had projected revenues between \$4000 and \$4500 per acre.

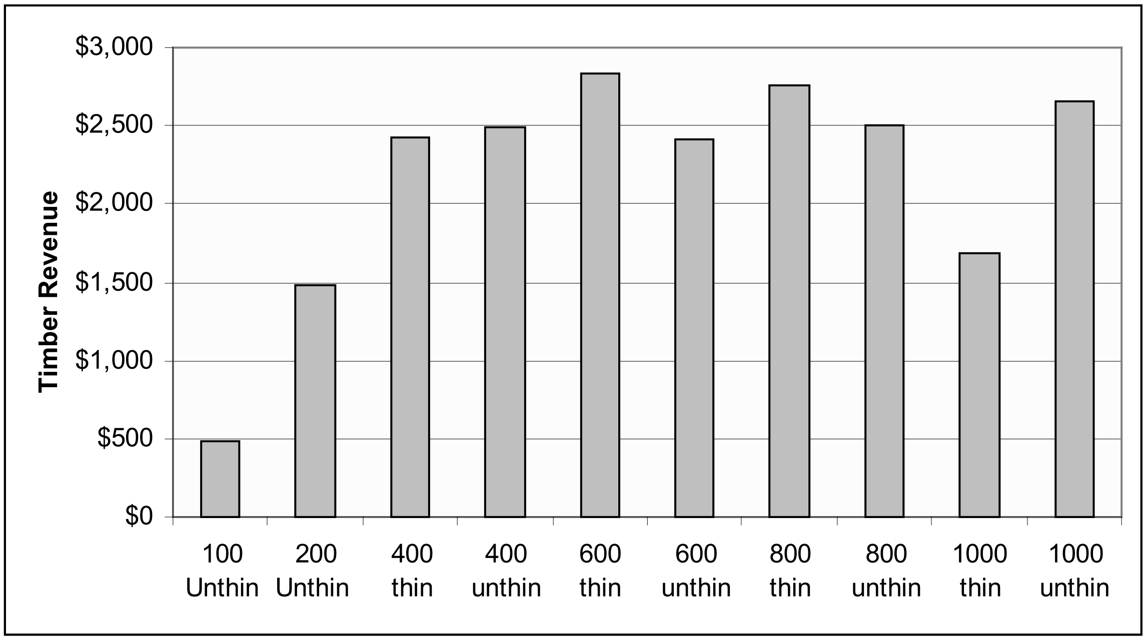


Figure 6. Average timber revenues at age 19 by initial stocking density and thinning status.

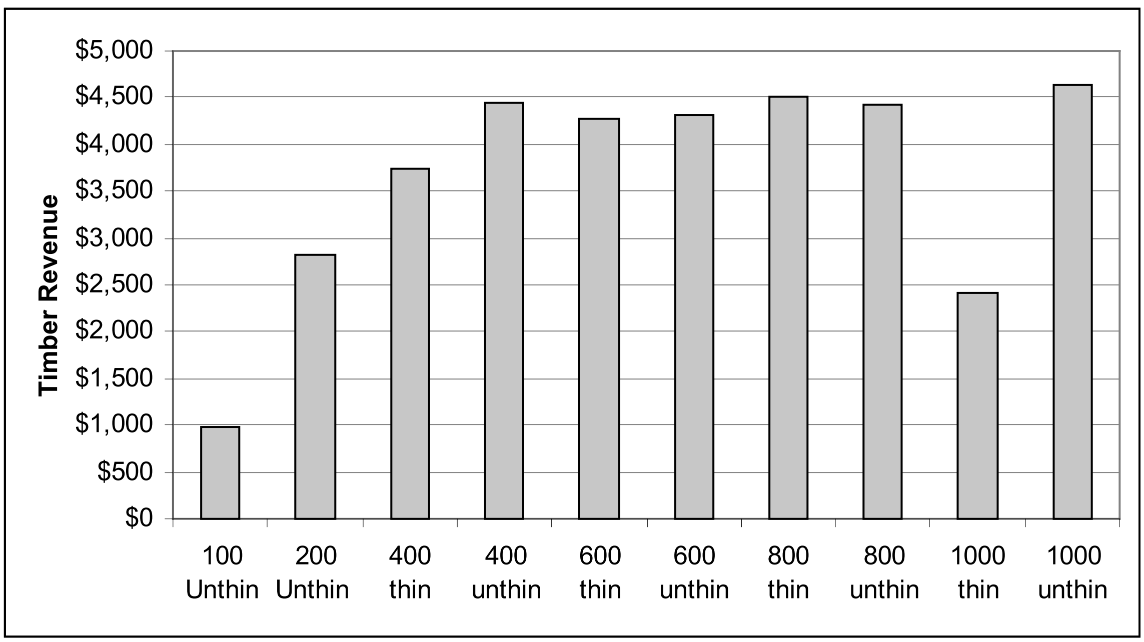


Figure 7. Average timber revenues at age 19 by initial stocking density and thinning status.

3.7 Limiting Density Relationships

Reineke (1933) recognized that the relationship between the number of trees per acre and average tree size with reference to a predetermined limit was useful as a stand density index. For even-aged stands of many species, the limiting relationship between the number of trees per acre and quadratic mean Dbh (D_q) was found to appear linear in logarithmic coordinates with a slope of approximately –1.6. For stands in the limiting condition, the stand density index (SDI) is often expressed as the expected number of trees per acre when D_q is equal to 10 inches. The SDI for loblolly pine has been commonly accepted to be 450 trees per acre. Stand stocking is often expressed as a percentage of maximum SDI. As stand D_q increases with age and approaches the maximum SDI, trees begin to die due to the increased intra-species competition, thus creating space for subsequent growth in D_q (Harrington, 2000).

Dean and Baldwin (1993) developed thinning prescriptions based on percent of SDI values for loblolly pine. They found that self-thinning of loblolly pine began to occur at 50% to 55% of maximum SDI. Based on this observation, they recommended that, to manage stands for conditions of full stocking, absence of self-thinning and adequate volume for operational thinning, stands should be thinned at 45% of maximum SDI, leaving a residual density of 30% of maximum SDI.

A stand density measure based on the average distance between trees and average dominant height was termed relative spacing by Beekhuis (1966). Relative spacing developed from the observation that fully-stocked stands shared similar ratios of average distance between trees to average dominant height. If square spacing is assumed, relative spacing is calculated as

$$RS = \frac{\sqrt{43560 / TPA}}{H_d} \tag{3}$$

Regardless of site quality and initial age, plantations of a given species seem to approach some asymptotic relative spacing level as they grow older. For any given average dominant height, the lower limit of relative spacing establishes a maximum number of trees per acre to be expected at any given age (Clutter *et al.*, 1983).

SDI, percent of maximum SDI and relative spacing values were calculated for the B.F. Grant Spacing Study plots. These are shown for the unthinned plots in Figures 8 and 9 and in Table 8. The plots with initial densities of 800 and 1000 trees per acre have “broken through” the accepted stand density index level for loblolly pine of 450. The 600 trees per acre plots have achieved 96% of maximum SDI and the 400 trees per acre plots are at 86% after 19 years.

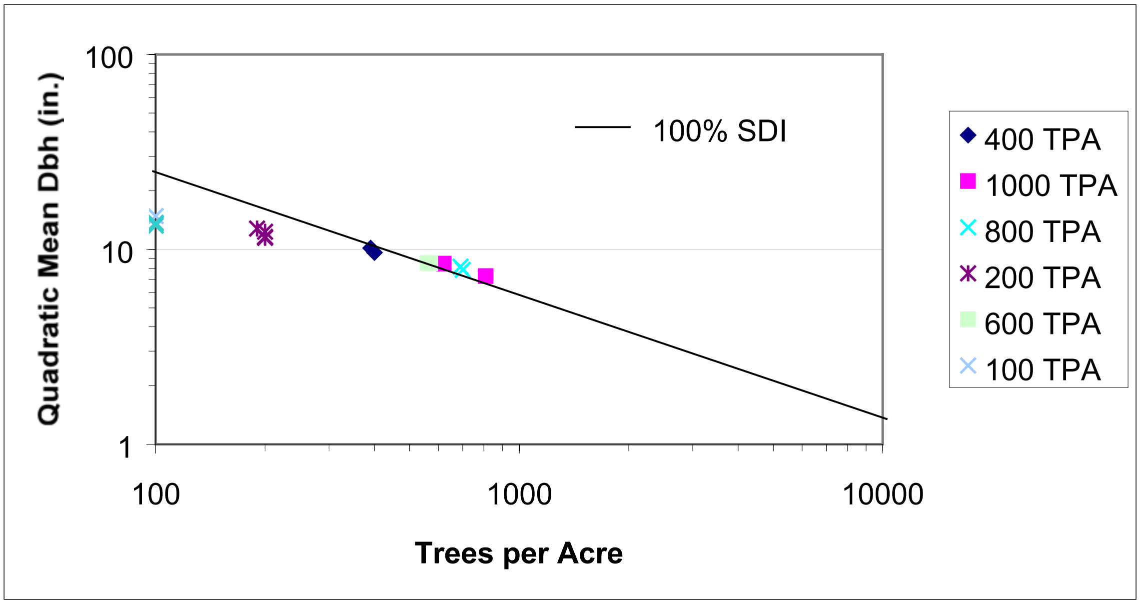
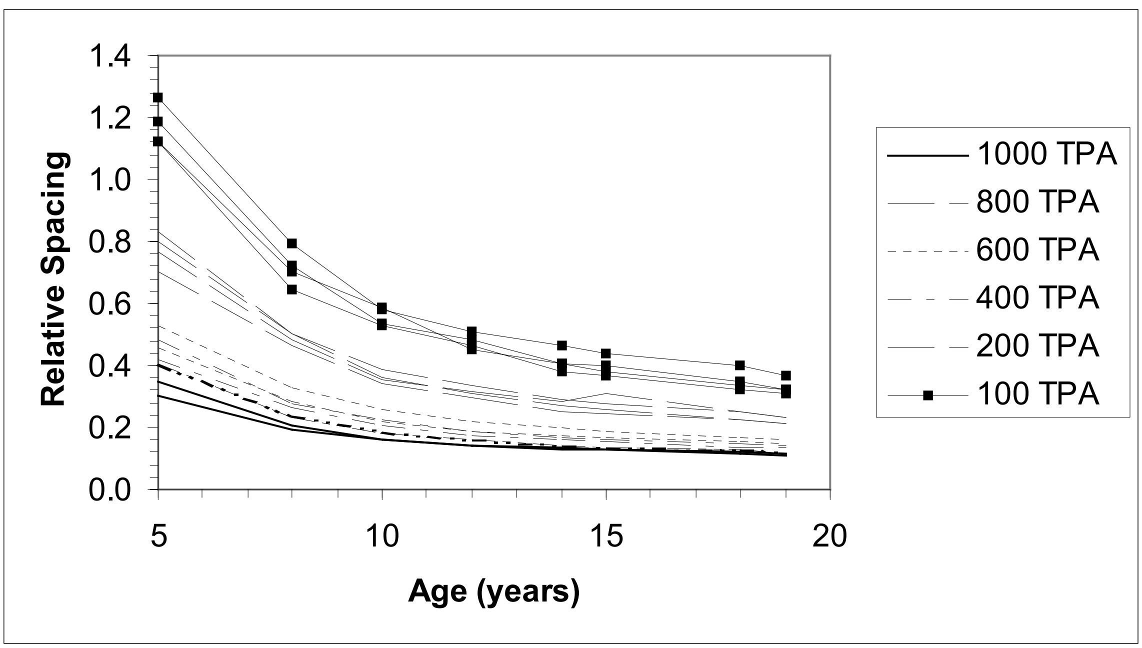


Figure 8. Quadratic mean Dbh over trees per acre (log x log scale) at age 19 for the unthinned B.F. Grant Spacing Study plots. Maximum SDI line for loblolly pine is also illustrated.

Figure 9. Relative spacing values over age for the unthinned B.F. Grant Spacing Study



plots.

Table 8. Average spacing and spacing indexes by initial planting density and age for the unthinned B.F. Grant Spacing Study plots.

Density	Age	TPA	Dq	SDI	% SDI	RS
100	8	100	7.9	68.9	15.3	0.7157
100	14	100	12.0	134.8	30.0	0.4146
100	19	100	13.8	167.6	37.2	0.3298
200	8	200	7.8	135.2	30.0	0.4872
200	14	200	10.7	223.8	49.7	0.2757
200	19	198	12.0	265.5	59.0	0.2225
400	8	400	7.0	225.4	50.1	0.3067
400	14	400	8.9	331.4	73.6	0.1871
400	19	395	9.9	388.9	86.4	0.1530
600	8	585	5.9	253.6	56.4	0.2729
600	14	575	7.6	370.5	82.3	0.1635
600	19	565	8.5	433.1	96.3	0.1367
800	8	790	5.6	309.0	68.7	0.2346
800	14	740	7.1	427.3	95.0	0.1414
800	19	695	8.0	487.1	108.2	0.1209
1000	8	920	5.3	336.0	74.7	0.2002
1000	14	820	6.8	433.5	96.3	0.1311
1000	19	715	7.8	478.9	106.4	0.1135

The relative spacing trends for the unthinned plots seem to fall into three groups: the 100 trees per acre plots, the 200 trees per acre plots and all others. The higher density plots seem to be rapidly approaching an asymptotic relative spacing level of approximately 0.12. It is conceivable that the 100 and 200 trees per acre plots are also approaching the same asymptotic relative spacing level, but it will probably take a long time for the height growth to compensate for the lack of any mortality.

Stand density index and relative spacing values for the thinned plots, at the time of thinning, are shown in Table 9. Percent of maximum SDI values prior to thinning ranged from 70.1% to 105.3%. According to the guidelines recommended by Dean and Baldwin (1993), the thinning of the B.F. Grant Spacing Study plots could have been carried out much earlier to avoid the degree of suppression as expressed in the SDI values. The plots have not, however, experienced a high degree of mortality indicative of excessive stand density. The unthinned 400 trees per acre plots, between the ages of 8 and 19, increased from 50.1% of maximum SDI to 86.4%. During this same interval, only five trees per acre were lost to mortality on the average. The unthinned 600 trees per acre plots lost only 5.8% of trees by the time these plots had reached 96.3% of maximum SDI at age 19. These observations are quite different from previously published results indicating that density-related mortality begins at about 50% of maximum SDI for loblolly pine plantations (Dean and Baldwin, 1996). The lack of competing vegetation must have some significant impact on the carrying capacity for pine trees. The percent SDI values prior to thinning seem to be related to thinning response. This will be discussed in a subsequent section.

Table 9. Spacing and spacing indexes by initial planting density and age for the thinned B.F. Grant Spacing Study plots.

Plot	Density	Age	Thin	TPA	Dq	SDI	% SDI	RS
1	600	15	Before	530	8.0	368.5	81.9	0.1497
1	600	15	After	200	8.9	165.4	36.7	0.2317
3	600	15	Before	490	8.5	377.7	83.9	0.1451
3	600	15	After	200	9.5	185.2	41.2	0.2219
4	400	15	Before	390	9.4	352.9	78.4	0.1710
4	400	15	After	200	10.0	201.1	44.7	0.2377
9	800	15	Before	630	7.8	424.7	94.4	0.1374
9	800	15	After	410	8.5	315.5	70.1	0.1690
12	400	15	Before	390	9.2	339.9	75.5	0.1829
12	400	15	After	200	9.6	187.6	41.7	0.2585
15	1000	15	Before	940	6.2	439.8	97.7	0.1356
15	1000	15	After	400	6.6	206.4	45.9	0.2062
17	800	15	Before	730	6.9	407.3	90.5	0.1444
17	800	15	After	400	7.5	251.6	55.9	0.1918
22	1000	15	Before	940	6.5	473.9	105.3	0.1284
22	1000	15	After	390	7.1	224.7	49.9	0.1987

4 THINNING ANALYSIS

The thinnings carried out on the B.F. Grant Spacing Study plots were specified along the lines of the CCT thinning experiments conceived by O'Connor (1935). The CCT design involves thinning a stand to the number of trees per acre observed in an unthinned stand at the same age as the age of thinning. This unthinned counterpart stand must also be identical, in terms of site quality, to the thinned stand. In the case of the B.F. Grant Spacing Study, unthinned plots with initial densities of 200 and 400 trees per acre had densities of 200 and 400 trees per acre, respectively, at age 15 when the thinning was executed. As shown in Table 1, two plots of the 400 and 600 initial densities were thinned to approximately 200 trees per acre, and the two plots of 800 and 1000 initial densities were thinned to approximately 400 trees per acre. The premise, proposed by O'Connor (1935) and described by Pienaar (1979), states that a thinned stand will, after thinning, approach the unthinned counterpart stand in terms of per-acre basal area over time. The B.F. Grant Spacing Study plots were thinned according to this prescription in order to test this premise and to test the models previously developed by Harrison and Borders (1996) that make use of this concept.

The relationship between the basal area of the thinned stand after thinning and the basal area of the unthinned counterpart at the same age is described with a competition index (CI) defined as follows:

$$CI = \frac{BA_u - BA_{at}}{BA_u} = 1 - \frac{BA_{at}}{BA_u} \qquad \textbf{(4)}$$

where: CI = competition index,

BA_u = basal area of the unthinned counterpart,

BA_{at} = basal are of the thinned stand immediately after thinning.

The competition index expresses the relative degree to which competition affects average tree size in the thinned and unthinned stands.

Growth response due to thinning can be expressed in terms of a projected competition index, causing the projected basal area of the thinned stand to approach that of the unthinned counterpart over time. The following equations were used to compute predicted per-acre basal areas of the thinned plots at age 19 (Harrison and Borders, 1996):

$$\ln(BA) = \Big(-0.8556 - \frac{36.0503}{Age} + 0.2991\ln(TPA) + 0.9802\ln(Hd) + 3.3092\frac{\ln(TPA)}{Age} + 3.7872\frac{\ln(Hd)}{Age} \Big) + (2.7183\, Age\, e^{-0.04\,Age}) \qquad \textbf{(5)}$$

$$CI_2 = CI_1 e^{-0.0765(Age_2 - Age_1)} \qquad \textbf{(6)}$$

$$BA_{t_2} = BA(1 - CI_2) \qquad \textbf{(7)}$$

Equation (5) is used to predict the basal area of the unthinned counterpart stand (BA) given the trees per acre (TPA), average dominant height (Hd) and Age. Equation (6) is used to project the competition index (CI_2) from the competition index at the time of thinning (CI_1), the projection age (Age_2) and the thinning age (Age_1). The projected basal area of the thinned stand is computed from the future basal area of the unthinned counterpart (BA) and the projected competition index (CI_2) using equation (7).

Figures 10-17 show the per-acre basal area growth curves for each of the thinned plots, before and after the thinning. Also, each figure includes the basal area growth curve of the appropriate unthinned counterpart. The unthinned counterpart basal area curves represent the average of the unthinned 200 or 400 trees per acre plots over time. The figures also show the predicted per-acre basal area of the thinned plots using the methods described previously.

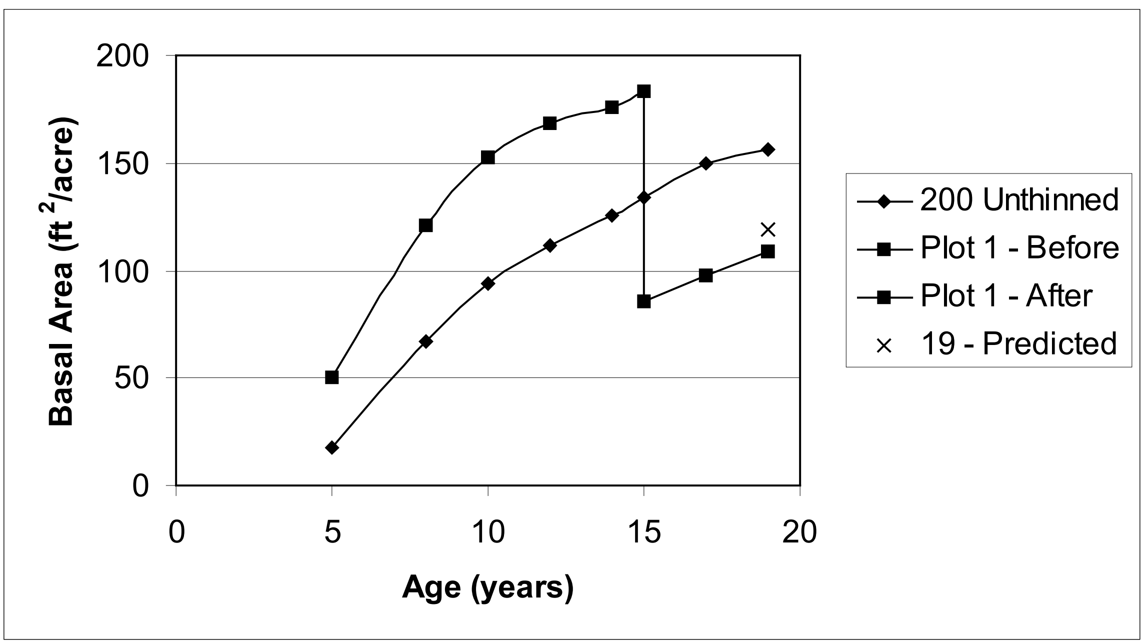


Figure 10. Basal area growth curve for Plot 1 (530-200 tpa) and the basal area growth curve for the average of the unthinned, 200 trees per acre plots.

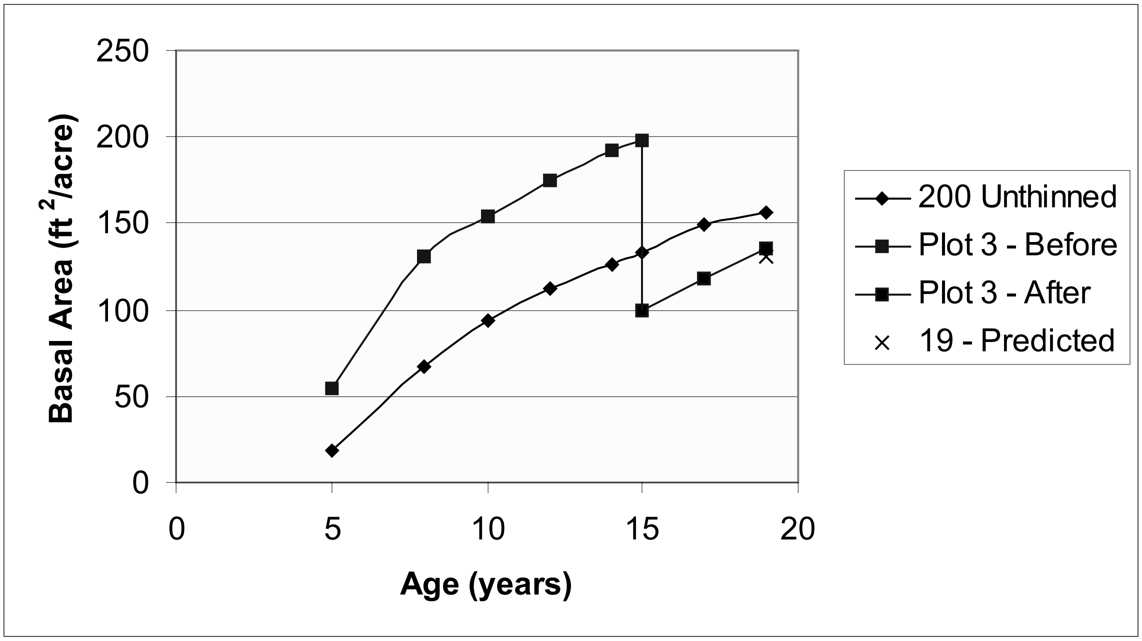


Figure 11. Basal area growth curve for Plot 3 (500-200 tpa) and the basal area growth curve for the average of the unthinned, 200 trees per acre plots.

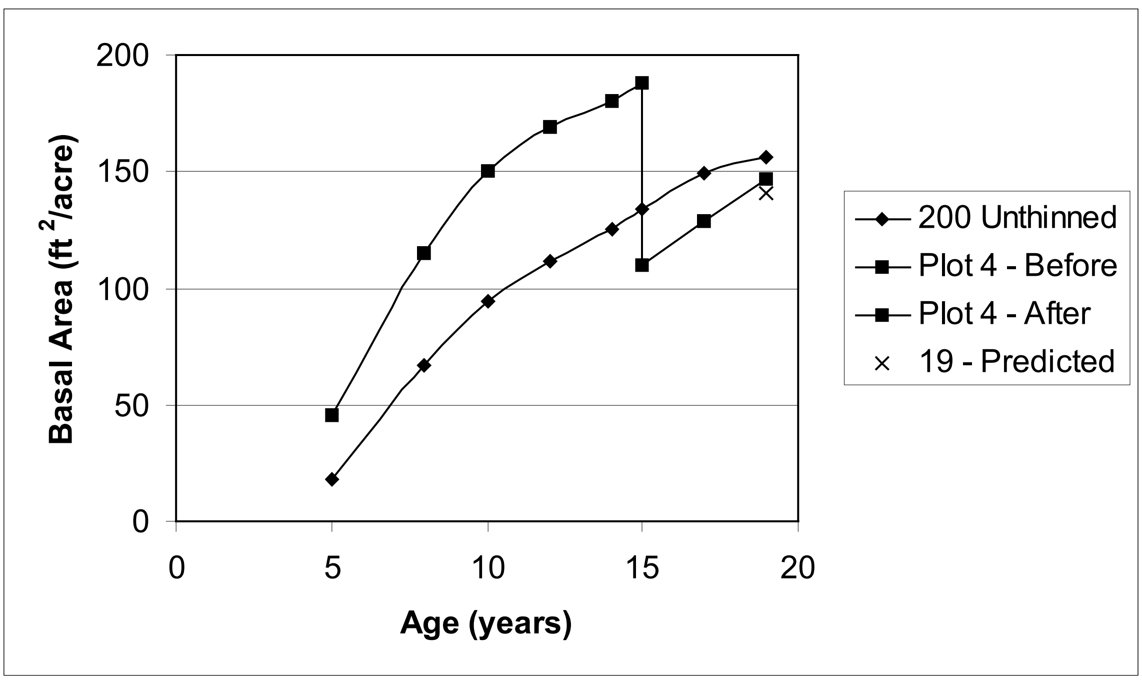


Figure 12. Basal area growth curve for Plot 4 (390-200 tpa) and the basal area growth curve for the average of the unthinned, 200 trees per acre plots.

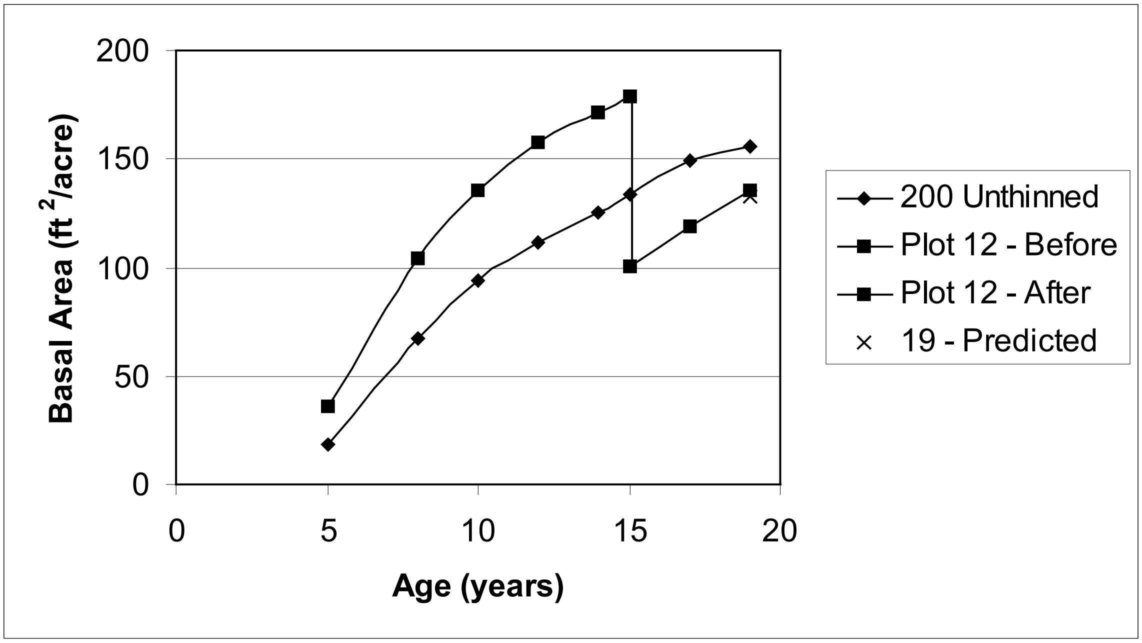


Figure 13. Basal area growth curve for Plot 12 (390-200 tpa) and the basal area growth curve for the average of the unthinned, 200 trees per acre plots.

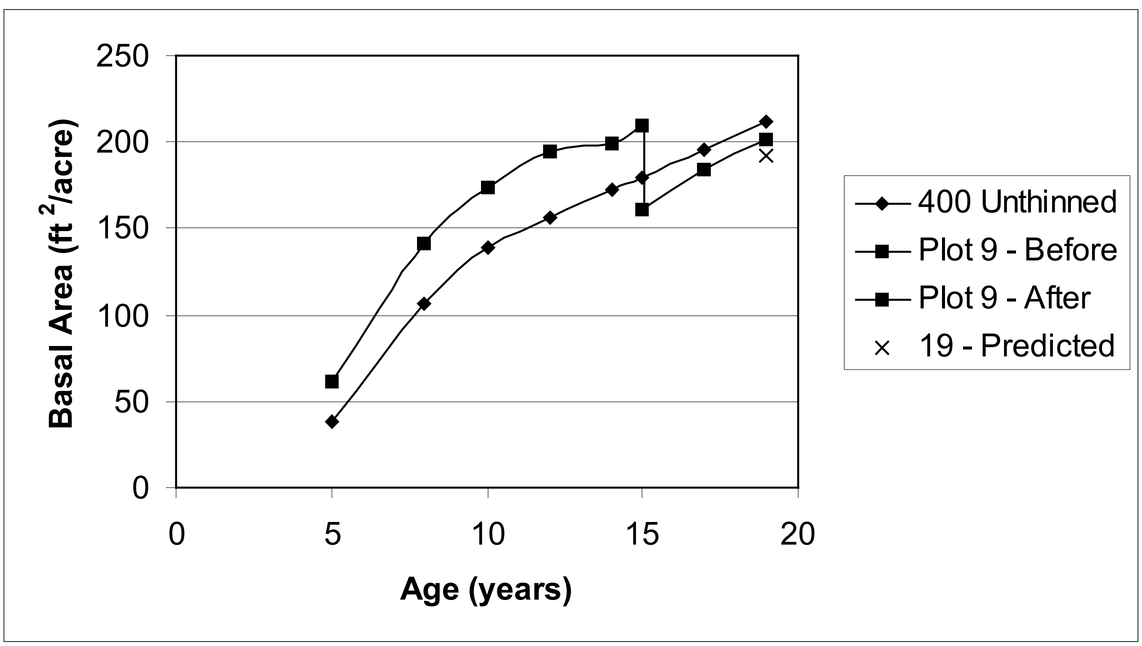


Figure 14. Basal area growth curve for Plot 9 (630-410 tpa) and the basal area growth curve for the average of the unthinned, 400 trees per acre plots.

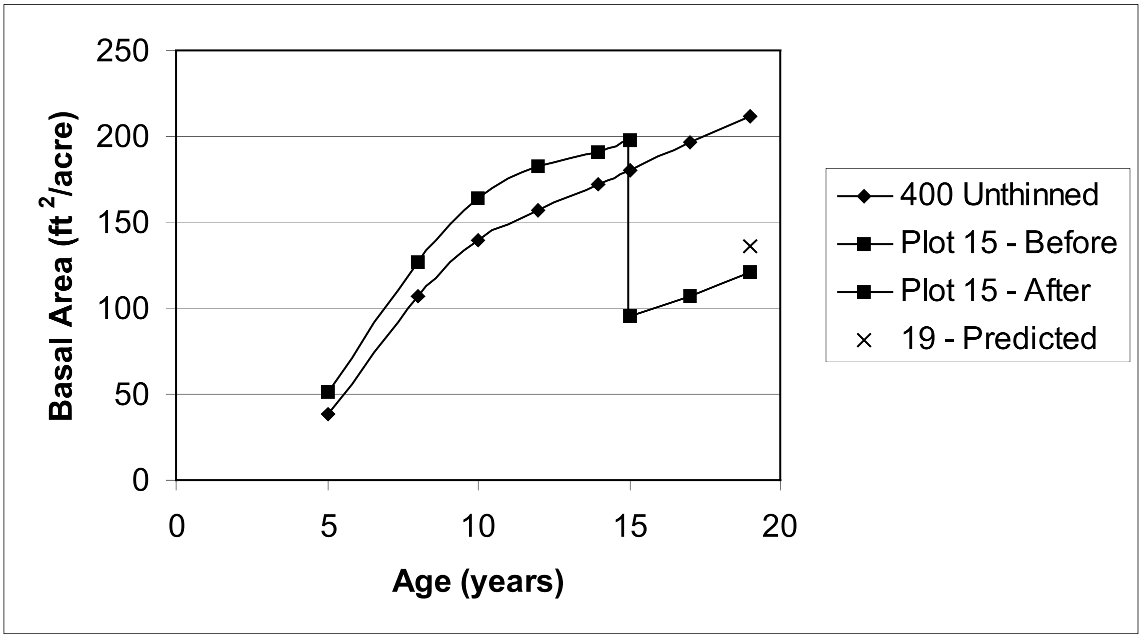


Figure 15. Basal area growth curve for Plot 15 (940-400 tpa) and the basal area growth curve for the average of the unthinned, 400 trees per acre plots.

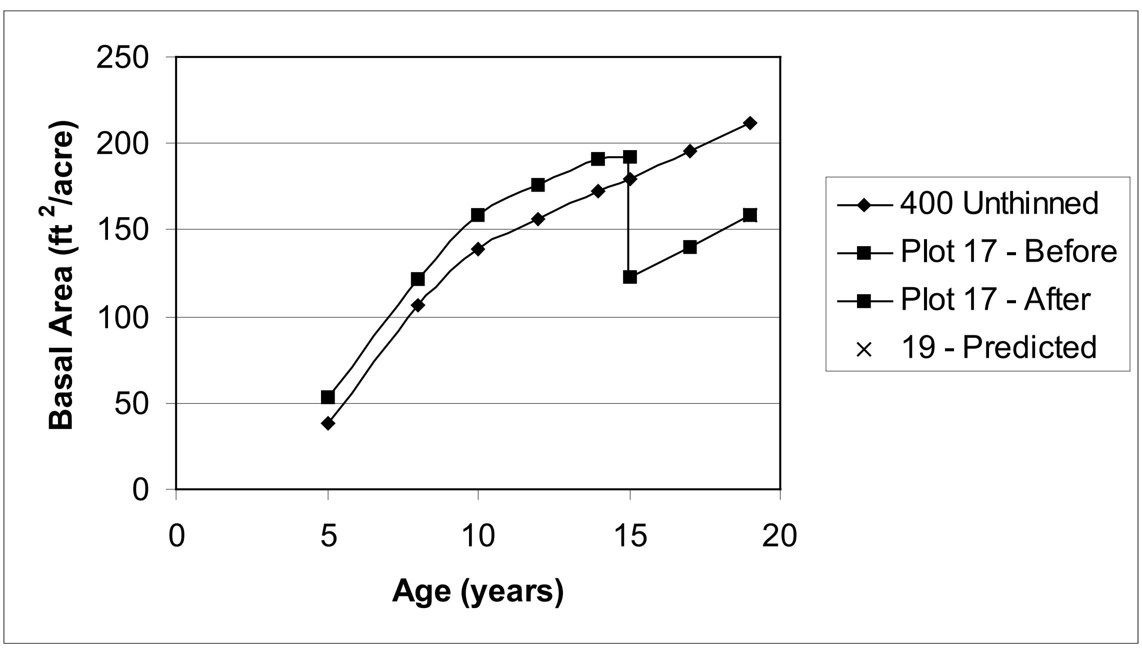


Figure 16. Basal area growth curve for Plot 17 (730-400 tpa) and the basal area growth curve for the average of the unthinned, 400 trees per acre plots.

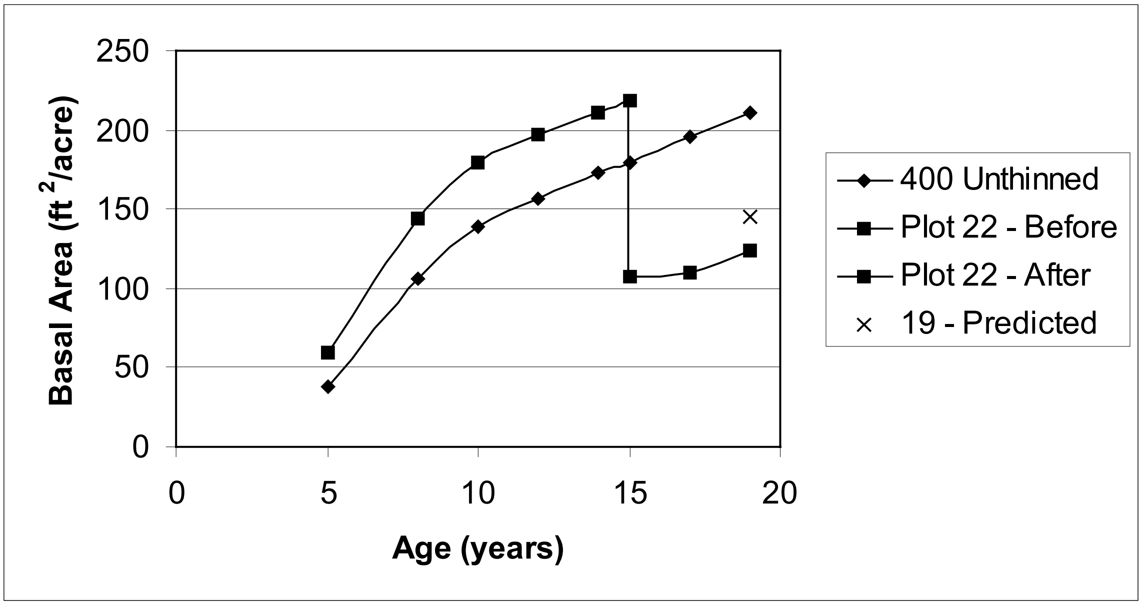


Figure 17. Basal area growth curve for Plot 22 (940-390 tpa) and the basal area growth curve for the average of the unthinned, 400 trees per acre plots.

The competition index immediately after thinning (CI_1) was computed using the per-acre basal observed on each thinned plot and the average observed basal area of the appropriate set of unthinned counterpart plots at age 15 (Equation 4). The future per-acre basal areas of the unthinned counterparts were computed using Equation (5) and the observed numbers of trees per acre and average dominant heights at age 19. The results are shown in Table 10.

Table 10. Observed and projected competition indexes and per-acre basal areas (ft^2) to predict the per-acre basal area of the thinned B.F. Grant Spacing Study plots at age 19.

Plot (Thin)	Observed (Age 15)			Projected (Age 19)		
	BA_{t15}	BA_{u15}	CI_1	BA_{u19}	CI_2	BA_{t19}
1 (530-200)	85.95	133.57	.3565	161.88	.2626	119.37
3(500-200)	99.08	133.57	.2582	161.88	.1902	131.09
4 (390-200)	109.08	133.57	.1779	161.88	.1310	140.66
12 (390-200)	100.66	133.57	.2464	161.88	.1814	132.50
9 (630-410)	161.22	179.84	.1035	207.90	.0726	192.05
15 (940-400)	95.13	179.84	.4710	207.90	.3469	135.78
17 (730-400)	122.21	179.84	.3204	207.90	.2360	158.84
22 (940-390)	106.82	179.84	.4060	207.90	.2990	145.73

Residuals were calculated for the projected per-acre basal areas of the thinned plots. The projected basal areas and residuals are shown in Table 11.

Table 11. Observed, projected and residual per-acre basal areas (ft^2) for the thinned B.F. Grant Spacing Study plots at age 19.

Plot (Thin)	Intensity (BA_{rem}/BA_{bef})	Observed BA_{t19}	Projected BA_{t19}	Residual BA_{t19}
1 (530-200)	53.2%	108.6	119.37	-10.77
3(500-200)	49.9%	135.1	131.09	4.00
4 (390-200)	41.5%	146.9	140.66	6.24
12 (390-200)	43.8%	135.9	132.50	3.40
9 (630-410)	23.2%	201.1	192.05	9.05
15 (940-400)	52.0%	120.9	135.78	-14.88
17 (730-400)	36.3%	158.3	158.84	-0.54
22 (940-390)	51.0%	123.6	145.73	-22.13

It appears that the model works well for modest basal area proportion removals. When the removal proportion exceeded 50%, the model tended to overpredict the response to thinning. For the 25-40% removals, the model worked very well.

An equation is available to predict thinning intensity in per-acre basal area as a function of the thinning intensity expressed in terms of trees per acre. This equation was suggested by Field *et al*. (1978) and was fit to Piedmont loblolly pine plantation data as part of the system of equations presented by Harrison and Borders (1996):

$$BA_t = BA_b \left(\frac{TPA_t}{TPA_b} \right)^{1.2345} \quad \textbf{(8)}$$

where: BA_t = per-acre basal area removed in thinning,

Ba_b = per-acre basal area before thinning,

TPA_t = trees per acre removed in thinning,

TPA_b = trees per acre before thinning.

Equation (8) was used to predict the per-acre basal area removed for the thinned B.F. Grant Spacing Study plots. These predictions were compared to observed basal areas and the results are shown in Table 12.

Table 12. Observed, predicted and residual per-acre basal area removed (ft^2) for the thinned B.F. Grant Spacing Study plots at age 19.

Plot (Thin)	Observed BA Removed	Predicted BA Removed	Residual BA Removed
1 (530-200)	97.58	102.26	-4.68
3(500-200)	98.79	105.32	-6.53
4 (390-200)	77.87	77.24	0.63
12 (390-200)	78.41	73.70	4.71
9 (630-410)	48.66	57.27	-8.61
15 (940-400)	103.02	99.96	3.06
17 (730-400)	69.76	72.04	-2.28
22 (940-390)	111.02	112.40	-1.38

5 DISCUSSION AND CONCLUSIONS

The B.F. Grant Spacing Study was established in 1983 to investigate the effects of initial stocking density on tree dimension and yield and to demonstrate the growth potential of old field loblolly pine plantations in the Georgia Piedmont. The complete control of competing vegetation was carried out to maximize this potential. Although never specifically addressed, it seems that residual fertility from previous agricultural practices has, so far, eliminated the need for fertilization. Early in the 15th growing season, a thinning was carried out on one half of the higher density plots to investigate thinning responses as compared to unthinned counterpart plots at the same location.

The effects of density on tree dimension and yield for the B.F. Grant Spacing Study generally follow some widely observed patterns of plantation growth. In the range from 100 to 1000 trees per acre, average height seems to be little affected by density. The standard deviation in average height was 1.9 feet over all density treatments. Average DBH is highly correlated with density, ranging from 7.7 inches for the 1000 trees per acre plots to 13.7 inches for the 100 trees per acre plots after 19 growing seasons.

The per-acre basal areas and merchantable volumes of the “fully-stocked” plots (400-1000 trees per acre) seem to be approaching common asymptotic levels over time. Unfortunately, this picture seems to have been distorted by the thinning treatment. It appears that the best of the 400 and 600 trees per acre plots and the worst of the 800 and 1000 trees per acre plots were

thinned. The per-acre basal areas of the highest density plots are approaching levels rarely observed in loblolly pine stands in the southeastern United States.
We assume that past hypotheses regarding stand density index and relative spacing were formed from observations of stands with various types and levels of competing vegetation. The B.F. Grant Spacing Study, with no competing vegetation, seems to be tracking along similar trends, but the magnitude of accepted density index levels may be in question. The plots with the highest initial densities (800 and 1000 trees per acre) have achieved well over 90% of the accepted SDI value of 450 for loblolly pine after 19 growing seasons. The degree of suppression of the thinned plots prior to thinning was 70% to 105% of maximum SDI as opposed to 45% recommended by Dean and Baldwin (1993). The plots with the lowest pre-thinning SDI values seemed to exhibit the greatest thinning response.

In general, the thinned plots are developing according to the premise conceived by O'Connor (1935). The per-acre basal areas of the thinned plots, after thinning, are approaching the basal area levels of the appropriate unthinned counterparts. The rate at which the approach occurs is a function of the thinning intensity and the projection period. This concept is illustrated in the basal area growth curves shown in Figures 10-17 and is encapsulated in the competition index projection model (Equation (6)). Residuals from the after-thinning basal area projection system had relatively low bias but relatively high magnitude. This may be a function of the competition index projection or the projection of future per-acre basal area of the unthinned counterpart; probably a combination of both components. The prediction of basal area removed as a function of the number of trees removed performed well. The results were nearly unbiased and the average residual was 1.88 ft^2/acre.

Old field loblolly pine plantations studied by Lenhart and Clutter (1971) were established in the 1950's and 1960's and received no additional weed control treatments in most cases. These plantations had an average site index of 62 feet and average MAI's of approximately two cords/acre/year. The B.F. Grant Spacing Study, with MAI's approaching five cords/acre/year and a site index of 79 feet, demonstrates the potential of modern old field loblolly pine plantations where competing vegetation can be effectively controlled. This level of growth also ensures maximum flexibility in density management. The study was thinned at age 15, but the higher density plots could have been thinned with reasonable tree dimensions and yields as early as age 10. The lower density plots (100 and 200 trees per acre) achieved a significant amount of chip-n-saw sized material by age 10. It is questionable, however, whether or not the material is suitable for solid wood products. The quality of wood from these fast-grown plantations will be extensively studied in the future.

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