MS33 THINNING STUDY:

NINE-YEAR POST THINNING ANALYSIS

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1 INTRODUCTION

As natural pine forests in the Southeastern United States become increasingly scarce, forest industry in the region are relying more and more heavily on pine plantations as their primary softwood resource. In light of this fact, concern has been expressed as to the long-term availability of timber suitable for sawtimber and peeler production. Thinning these southern pine plantations is considered as one way to help ensure the sustained production of solid wood products. The MS33 Thinning Study[1] was proposed in 1981 with the objective of providing data to shed light on questions concerning the thinning of slash and loblolly pine plantations in the Southeastern United States. Specifically, the study was designed to address the method, intensity and timing of thinning.

Between 1981 and 1984, 14 loblolly and seven slash pine installations were established in the lower coastal plain, upper coastal plain and Piedmont regions of South Carolina, Georgia, Florida and Alabama. Initial thinnings were carried out in two age groups, age 13-15 and age 16-18 years. Nine years after the thinning treatments were carried out, 11 installations remain for analysis. These consist of one loblolly and six slash pine installations in the lower coastal plain and four loblolly installations in the Piedmont and upper coastal plain.

2 STUDY DESCRIPTION AND DATA

At each study location, the following treatments were applied:

▸Thinning Method

0 Selective thinning (S)

1 Row thinning (R)

2 Row-select combination (C)

▸Thinning Intensity

0 Remove 50% of trees at time of thinning

1 Remove 40% of trees at time of thinning

2 Remove 33% of trees at time of thinning

▸Thinning Repetition

0 Thin once (T1)

1 Thin twice with nine-year interval (T2)

Table 1 shows the row removal and percent selective removal for the different treatments.

[1] The MS33 Thinning Study was funded entirely under the McIntyre-Stennis project 33. Cooperating companies include Great Southern Paper, Georgia Pacific Corporation, Westvaco Corporation, ITT Rayonier, Resource Management Services, Container Corporation, Champion International, Union Camp Corporation, Georgia Kraft, International Paper, Evergreen Timber, St. Joe Paper Company and MacMillan Bloedel.

Table 1. Row removal and percent selective removal for different thinning methods and intensities.

Thinning Method	Thinning Intensity (% remaining)		
	50%	60%	66%
Selective thinning			
Rows Removed	none	none	None
% Selective Removal	100	100	100
Row thinning			
Rows Removed	2nd	2nd and 5th	3rd
% Selective Removal	0	0	0
Row-Select Combination			
Rows Removed	3rd	4th	5th
% Selective Removal	34.0	37.5	39.0

The thinning treatment plots (including an unthinned "check") were arranged in factorial combinations in incomplete blocks of 10 plots each. One complete replication consists of two blocks. This design gives complete, although unbalanced, data on the main factors and all two-factor interactions unconfounded with blocks. For this nine-year analysis, where the second thinning is not considered, the design provides a complete factorial organization of treatments with each block representing one complete replication.

Each treatment plot measures ½ acre in size with an interior ¼ acre measurement plot. Tree measurements are carried out at three year intervals and consist of dbh to the nearest 0.1 inch on all trees and total height to the nearest foot on a subsample across the diameter distribution. The presence of fusiform stem cankers is recorded as well as a subjective measure of stem quality. A tree is identified as a potential sawtimber-quality tree given that its stem is sufficiently free of cankers, crook, sweep, fork and breakage so that at least one 16-foot sawlog could be obtained from the tree at some time in the future.

2.1 Loblolly Pine Data

Nine years after thinning, four loblolly pine installations remain in the Piedmont and upper coastal plain region and one installation remains in the lower coastal plain. The single lower coastal plain installation will henceforth be ignored since meaningful interpretations of results will be impossible from these limited data. The ages of the loblolly pine installations used in this analysis range from 23.7 to 25.6 years with a mean of 24.7 years. Tables 2 and 3 show average stand characteristics for the loblolly pine plots by thinning type and intensity.

2.1.1 Unthinned stands

Eight unthinned plots remain in the Piedmont and upper coastal plain. Of these, four are in the younger age class and four are in the older age class. At the time of study establishment, stand densities ranged from 316 to 827 trees per acre with a mean of 511. Basal area per acre ranged from 69 to 177 ft^2 with a mean of 124 ft^2. Average dominant heights on these plots ranged from 35 to 53 feet with a mean of 43 feet.

Nine years later, stand densities on these plots ranged from 225 to 586 trees per acre with a mean of 392. Basal areas ranged from 109 to 182 ft^2 with a mean of 152 ft^2. Site index was calculated using the Harrison and Borders (1996) equation and ranged from 52 to 80 feet with a mean of 63.6 feet.

2.1.2 Thinned stands

Seventy-two thinned treatment plots remain in the Piedmont and upper coastal plain. These are also equally distributed between the young and older age classes. After the thinning treatments were carried out on these plots, stand density ranged from 140 to 445 trees per acre with a mean of 296. Basal area ranged from 31 to 137 ft^2/ac with a mean of 78 ft^2/ac. Average dominant heights ranged from 33 to 56 feet with a mean of 44 feet.

Nine years after the thinning, these plots ranged in density from 136 to 390 trees per acre with a mean of 262. Basal area ranged from 56 to 168 ft^2/ac with a mean of 116 ft^2/ac. As one may expect, the average site index for the thinned plots was nearly identical to that of the unthinned at 63.4 feet.

Table 2. Average stand characteristics by thinning type immediately after thinning and nine years after thinning for loblolly pine.

Thinning Type	Immediately after thinning				Nine years after thinning			
	TPA	BA	Dq	MVOL	TPA	BA	Dq	MVOL
Select	288	83	7.2	1728	263	123	9.4	3589
Combo.	298	78	6.9	1603	270	118	9.0	3340
Row	302	74	6.7	1447	253	107	8.9	2962
No Thin	512	124	6.7	2486	392	152	8.6	4329

Table 3. Average stand characteristics by thinning intensity immediately after thinning and nine years after thinning for loblolly pine.

Intensity % left	Immediately after thinning				Nine years after thinning			
	TPA	BA	Dq	MVOL	TPA	BA	Dq	MVOL
66	338	88	6.9	1784	291	124	9.0	3546
60	292	79	7.1	1607	260	117	9.1	3340
50	259	68	6.9	1385	235	106	9.1	3004
0	512	124	6.7	2486	392	152	8.6	4329

2.2 Slash Pine Data

Six slash pine installations remain in the lower coastal plain region nine years after thinning. Three installations were thinned between the ages of 13 and 15 and the other three were thinned between 16 and 18 years of age. The ages of the slash pine installations used in this analysis range from 22.3 to 26.7 years with a mean of 24.6 years. Tables 4 and 5 show average stand characteristics immediately after thinning and nine years hence by thinning type and intensity.

2.2.1 Unthinned stands

Twelve unthinned slash pine plots remain in the lower coastal plain. At the time of study establishment, stand densities ranged from 220 to 475 trees per acre with a mean of 392. Basal area per acre ranged from 42 to 102 ft^2 with a mean of 70 ft^2. Average dominant heights on these plots ranged from 32 to 50 feet with a mean of 41 feet.

Nine years later, stand densities on these plots ranged from 172 to 372 trees per acre with a mean of 304. Basal areas ranged from 71 to 125 ft^2 with a mean of 104 ft^2. Site index was calculated using the Pienaar, et.al. (1996) equation and ranged from 47 to 67 feet with a mean of 58.5 feet.

2.2.2 Thinned stands

One hundred and eight slash pine thinned treatment plots remain in the lower coastal plain region. Immediately after the thinning treatments were carried out on these plots, stand density ranged from 101 to 379 trees per acre with a mean of 238. Basal area ranged from 25 to 77 ft^2/ac with a mean of 44 ft^2/ac. Average dominant heights ranged from 32 to 51 feet with a mean of 41 feet.

Nine years after the thinning, these plots ranged in density from 90 to 309 trees per acre with a mean of 213. Basal area ranged from 40 to 108 ft^2/ac with a mean of 68 ft^2/ac. The average site index for the thinned plots was very close to that of the unthinned at 57.8 feet.

Table 4. Average stand characteristics by thinning type immediately after thinning and nine years after thinning for slash pine.

Thinning Type	Immediately after thinning				Nine years after thinning			
	TPA	BA	Dq	MVOL	TPA	BA	Dq	MVOL
Select	240	48	6.1	914	220	76	8.0	1985
Combo.	231	42	5.8	768	210	67	7.7	1716
Row	243	42	5.7	742	209	66	7.7	1641
No Thin	392	70	5.8	1270	334	96	7.4	2471

Table 5. Average stand characteristics by thinning intensity immediately after thinning and nine years after thinning for slash pine.

Intensity % left	Immediately after thinning				Nine years after thinning			
	TPA	BA	Dq	MVOL	TPA	BA	Dq	MVOL
66	265	50	5.9	914	233	75	7.8	1956
60	238	44	5.8	781	214	68	7.7	1732
50	210	39	5.9	728	191	65	8.0	1655
0	392	70	5.8	1270	334	96	7.4	2471

3 RESULTS

Analysis of variance on treatment effects and one-degree-of-freedom orthogonal contrasts were used to test for differences in per-acre total volume, merchantable volume, sawtimber volume, per-acre basal area and quadratic mean Dbh nine years after thinning. Sawtimber volume was defined as the volume of trees identified as potential sawtimber trees to an 8" top (o.b.). Analyses were also carried out for post-thinning growth of the same variables as a percentage of initial size. Sawtimber volume growth was analyzed in absolute terms, however, since many stands had no sawtimber volume immediately after thinning. Mortality, as a percentage of trees per acre immediately after thinning, was also analyzed.

An analysis of net present values for regimes represented by the various treatments was done. In order to compute net present values, a harvest of each plot was simulated and converted to a

per-acre basis. The prices and product breakdown specifications are shown in Table 6. Thinning volumes were assumed to consist of pulpwood, only. Product volumes for the clearcut were computed with whole-stand product breakdown functions from Harrison and Borders (1996) for loblolly and Pienaar, et.al. (1996) for slash pine. Thinning values were compounded to the clearcut age (nine years after thinning) and the total value was discounted to the beginning of the rotation using a 6% discount rate. No additional costs or incomes were considered.

Table 6. Product prices and breakdown specifications used for net present value calculations.

Product	$/cord Thinning	$/cord Clearcut	Minimum Dbh	Top Diameter
Sawtimber	--	122	12	8
Chip-N-Saw	--	101	8	6
Pulpwood	19	40	4	2

3.1 Loblolly Pine Results

The thinning treatment had a significant effect on per-acre basal area nine years after thinning. The contrast analysis showed that the unthinned treatments had significantly more basal area than the average of all thinned treatments as well as the mean of each thinning type. The selectively thinned treatments had significantly more per-acre basal area than the row thinned treatments. The least intensive thinning treatment (66% remaining) had significantly more per-acre basal area than the most intensive thinning treatment (50% remaining). Figures 1-6 show the means for the analysis variables by thinning type and intensity. Thinning types in these figures are N (no thinning), R (row thinning), C (combination thinning) and S (selective thinning from below).

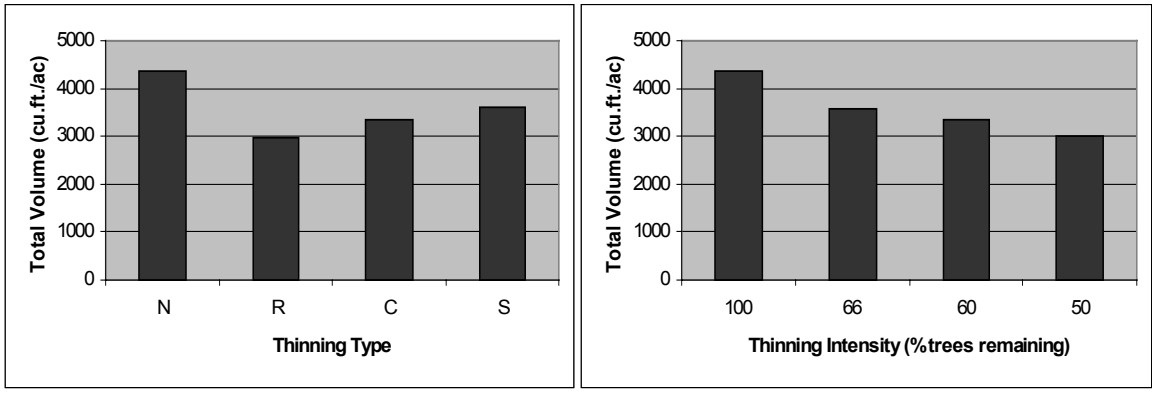

Figure 1. Per-acre total volume by thinning type and intensity nine years after thinning for loblolly pine.

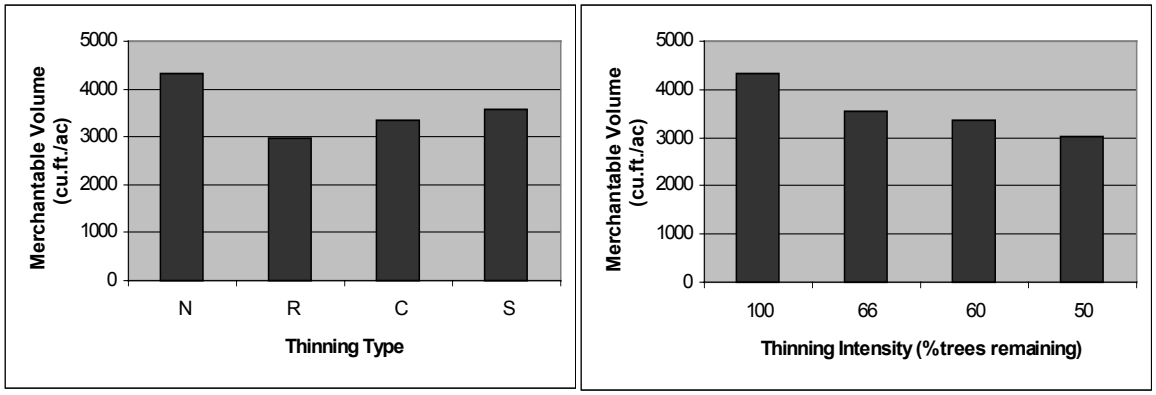

Figure 2. Per-acre merchantable volume (trees > 4.5” Dbh to a 2” top o.b.) by thinning type and intensity nine years after thinning for loblolly pine.

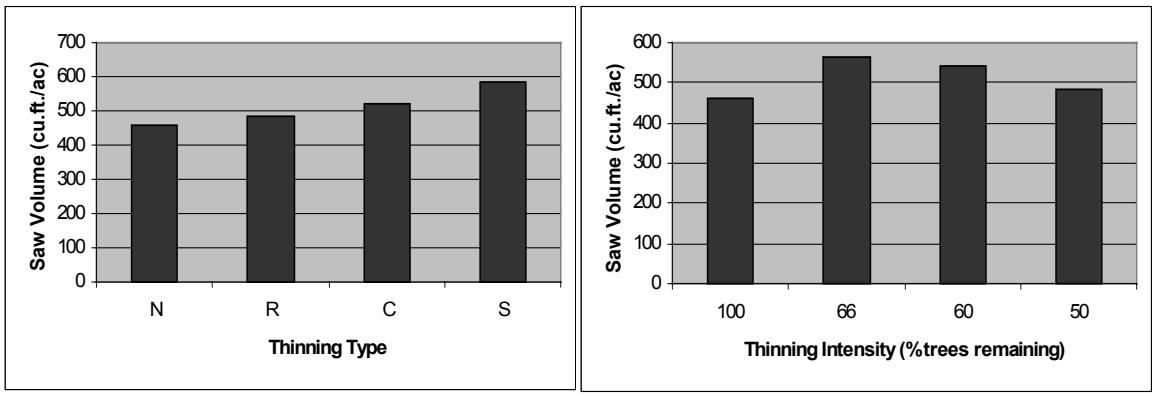

Figure 3. Per-acre sawtimber volume (trees identified as sawtimber to an 8” top o.b.) by thinning type and intensity nine years after thinning for loblolly pine.

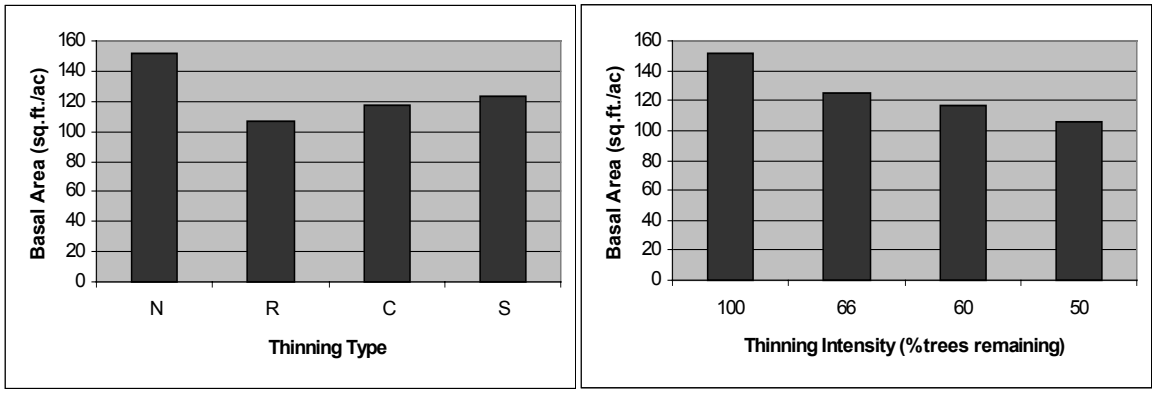

Figure 4. Per-acre basal area by thinning type and intensity nine years after thinning for loblolly pine.

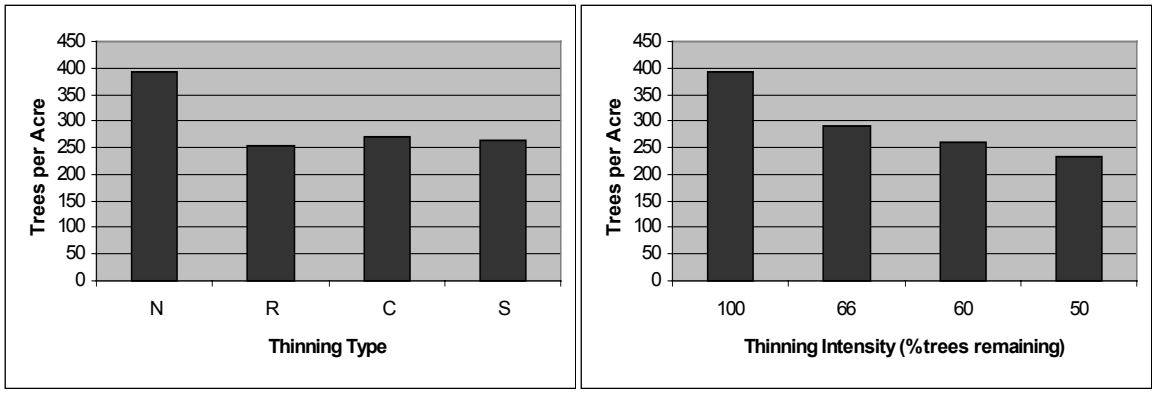

Figure 5. Number of trees per acre by thinning type and intensity nine years after thinning for loblolly pine.

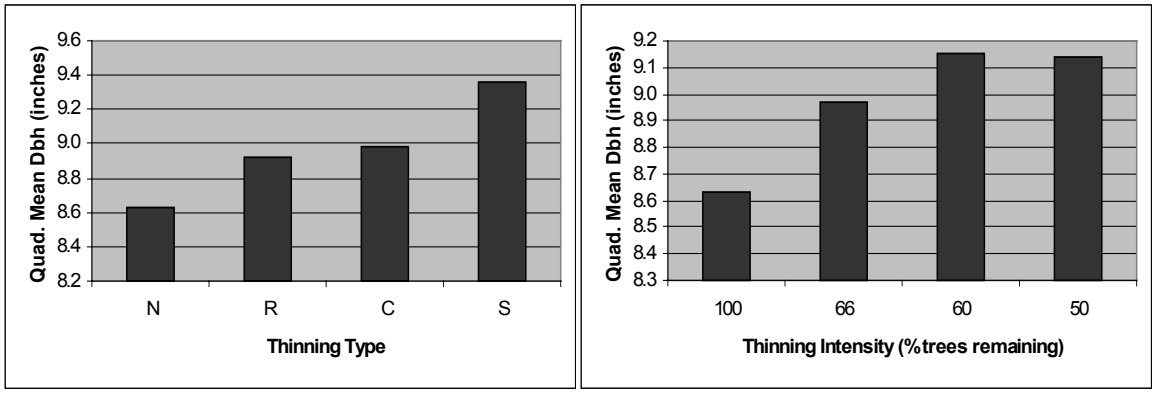

Figure 6. Quadratic mean Dbh by thinning type and intensity nine years after thinning for loblolly pine.

Net present values for regimes represented by the thinning treatments are shown in Figure 7. There were no significant differences in NPV's due to the thinning treatments.

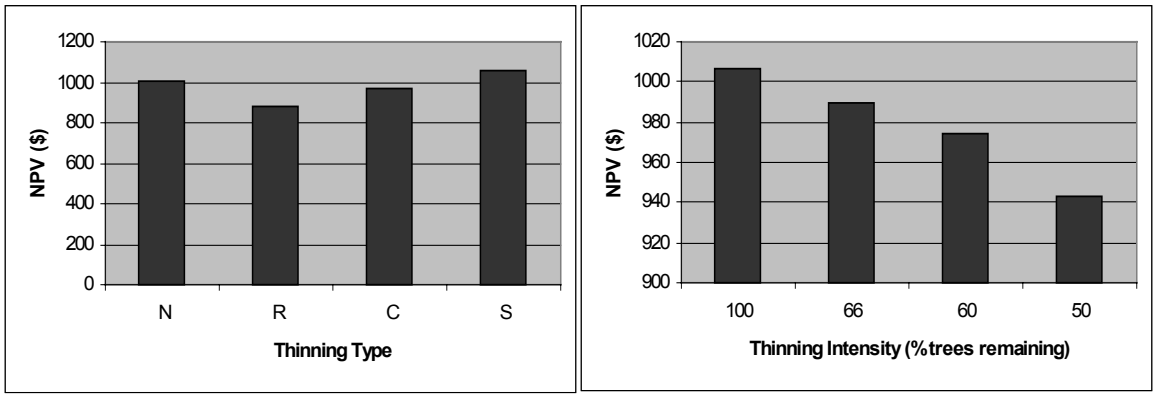

Figure 7. Per-acre net present values by thinning type and intensity for loblolly pine.

Nine-year growth after thinning was expressed on a percentage basis as a function of the size immediately after thinning. The thinning treatments had significant effects on per-acre basal area growth and mortality. Contrast analysis showed that for per-acre basal area, the average growth of all the thinned treatments as well as each thinning treatment type was greater than the growth of the unthinned treatment. The growth of the least intensive thinning treatment (66% remaining) was greater than the growth of the most intensive thinning treatment (50% remaining). The unthinned treatments had significantly more mortality than the average of the thinned treatments and the select and combination thinning types separately. The row thinning treatments had significantly more mortality than the combination and select thinning treatments. Figures 8-12 show the average nine-year growth percentages for total volume, merchantable volume, basal area, mortality and quadratic mean Dbh. Figure 13 shows the growth in sawtimber volume in absolute terms (ft^3/ac).

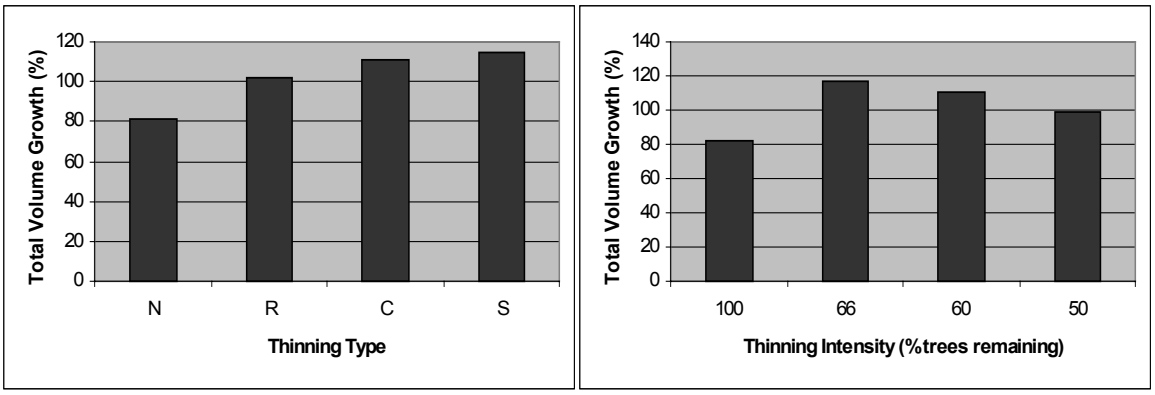

Figure 8. Nine-year per-acre total volume growth by thinning type and intensity on a percentage basis for loblolly pine.

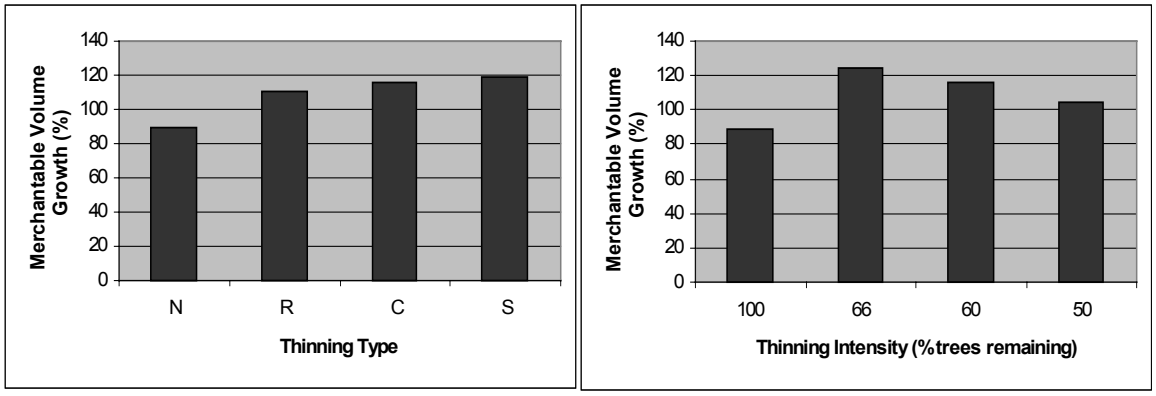

Figure 9. Nine-year per-acre merchantable volume growth by thinning type and intensity on a percentage basis for loblolly pine.

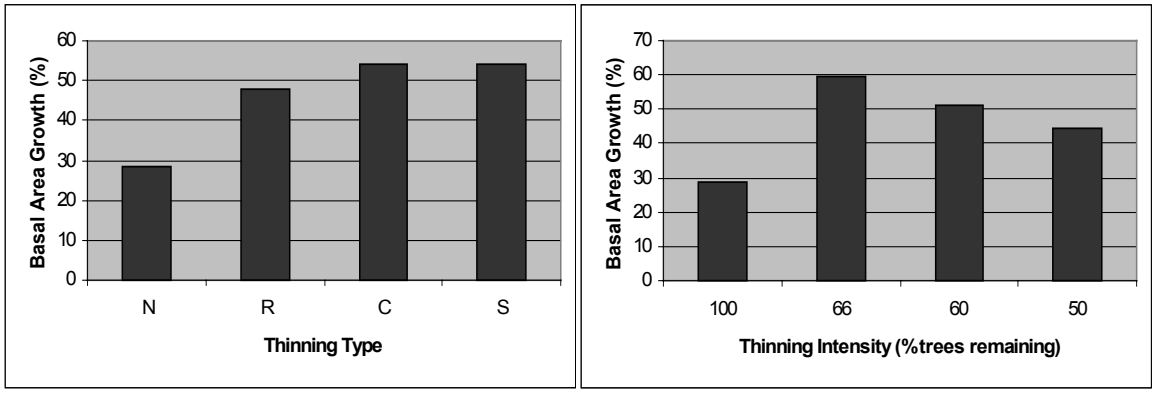

Figure 10. Nine-year per-acre basal area growth by thinning type and intensity on a percentage basis for loblolly pine.

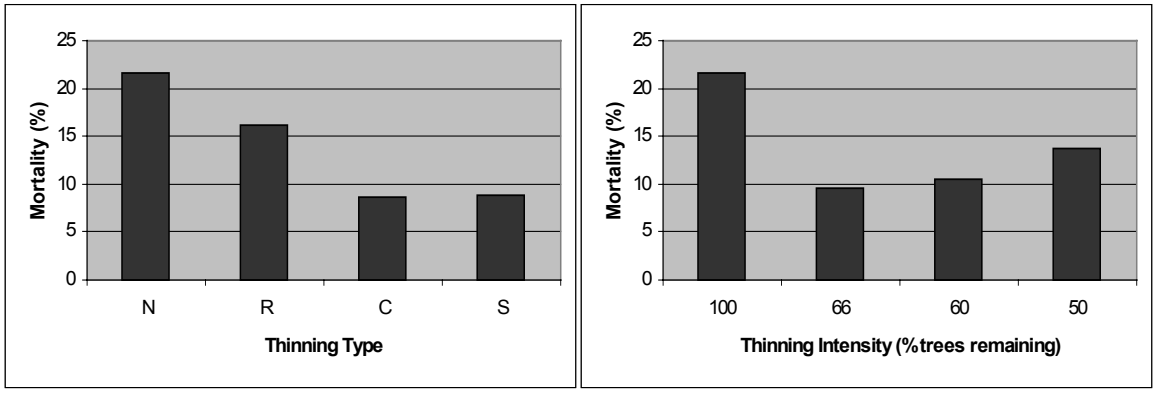

Figure 11. Nine-year mortality by thinning type and intensity on a percentage basis for loblolly pine.

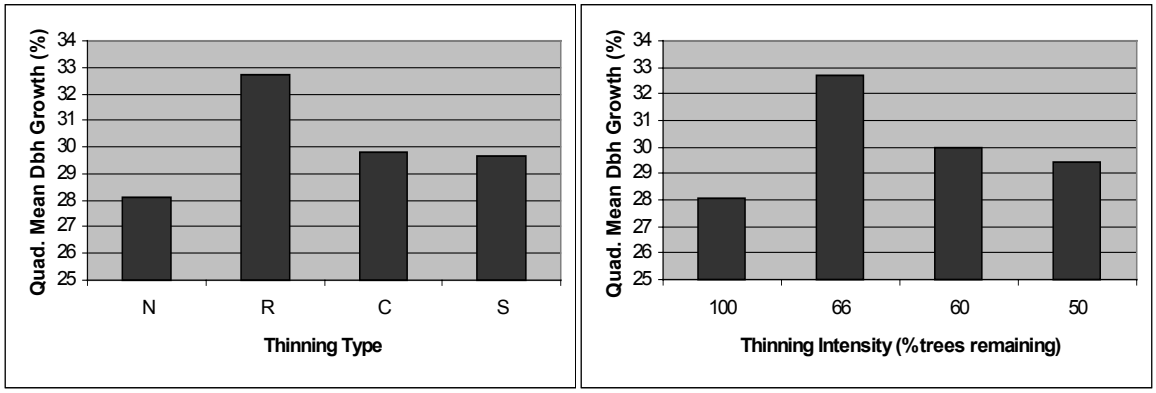

Figure 12. Nine-year quadratic mean Dbh growth by thinning type and intensity on a percentage basis for loblolly pine.

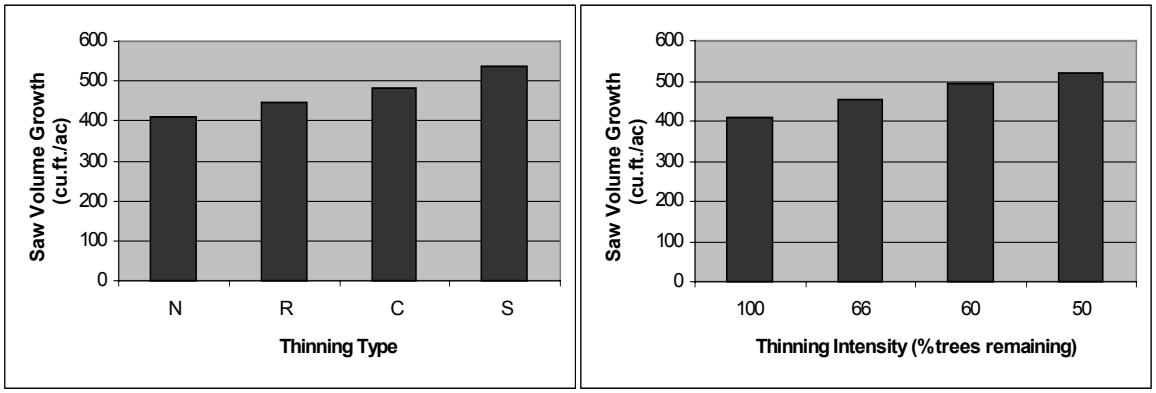

Figure 13. Nine-year sawtimber volume (trees identified as sawtimber to an 8" top o.b.) growth by thinning type and intensity for loblolly pine.

3.2 Slash Pine Results

For slash pine in the lower coastal plain, the thinning treatments had a significant effect on total and merchantable volume. The unthinned plots had significantly higher volumes than the average of the thinned plots and for the row, combination and select treatments, individually. The select thinning treatment had significantly higher volumes than the row and combination treatments. The least intensive thinning treatment (66% remaining) had significantly more total and merchantable volume than the most intensive thinning treatment (50% remaining).

The thinning treatments also had a significant effect on per-acre basal area. The unthinned treatment had significantly more basal area than the thinned treatments. The select thinning treatment had higher basal areas than the row and combination treatments. The least intensive thinning treatment (66% remaining) had a significantly higher basal area than each of the other two thinning intensities (60% and 50% remaining). Figures 14-20 show the means for all of the analysis variables by thinning type and intensity.

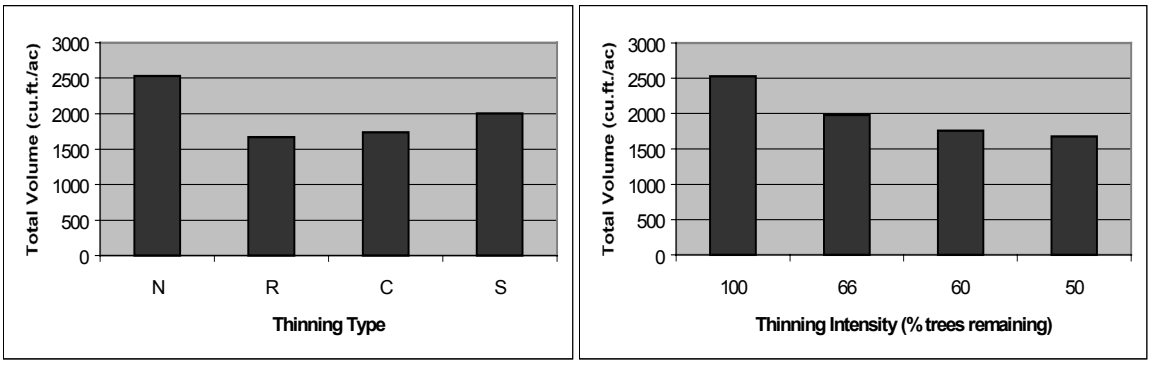

Figure 14. Per-acre total volume by thinning type and intensity nine years after thinning for slash pine.

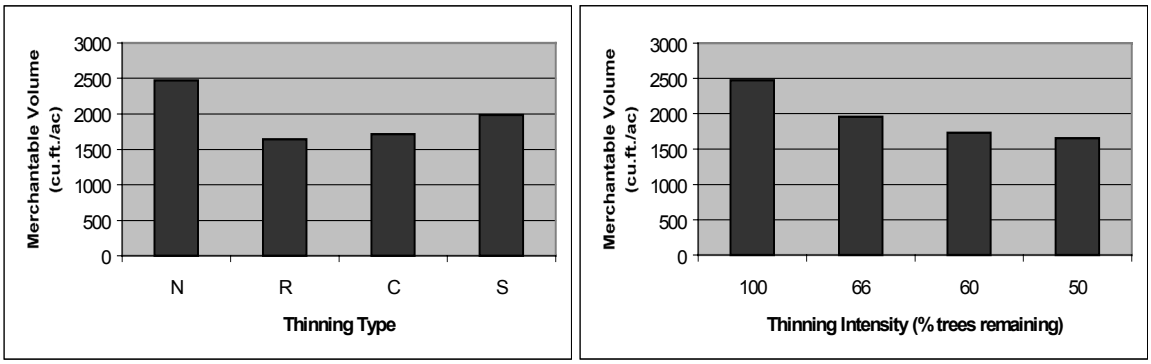

Figure 15. Per-acre merchantable volume (trees > 4.5" Dbh to a 2" top o.b.) by thinning type and intensity nine years after thinning for slash pine.

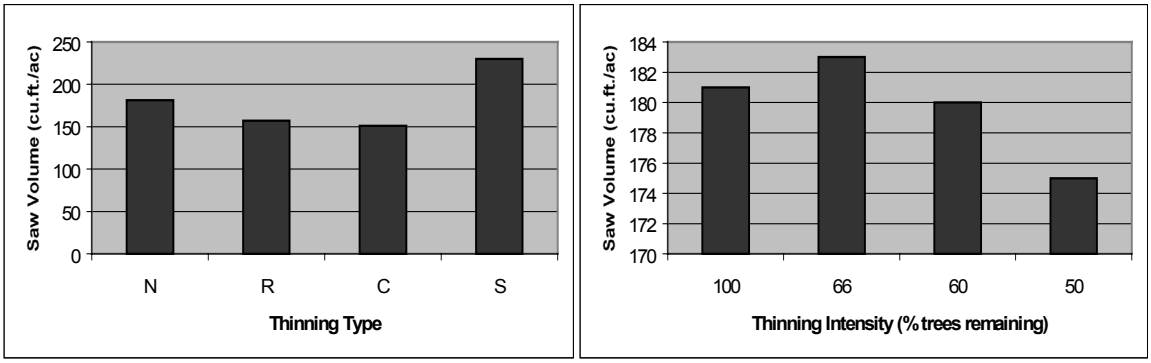

Figure 16. Per-acre sawtimber volume (trees identified as sawtimber to an 8" top o.b.) by thinning type and intensity nine years after thinning for slash pine.

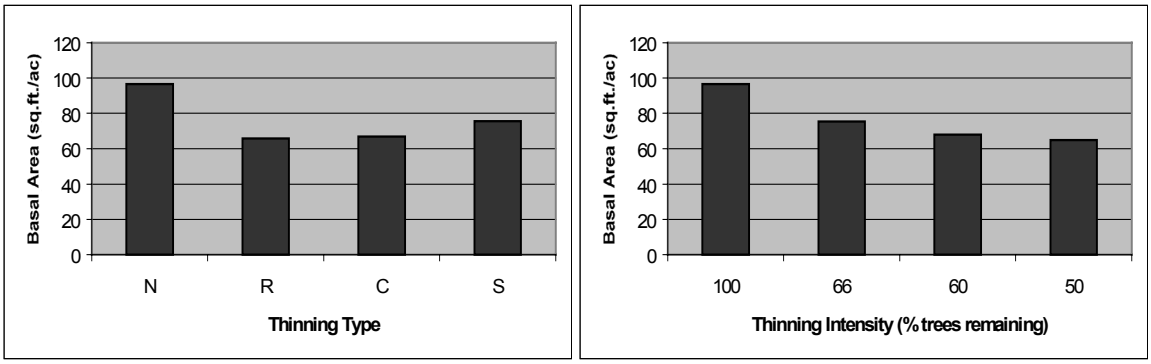

Figure 17. Per-acre basal area by thinning type and intensity nine years after thinning for slash pine.

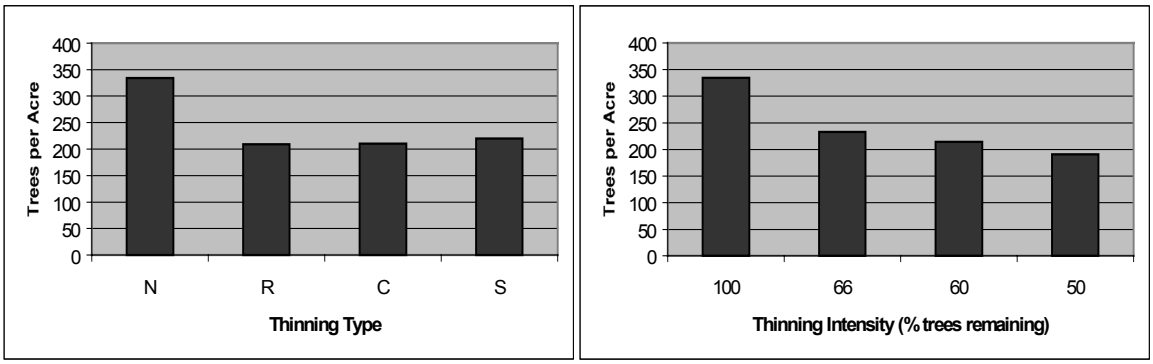

Figure 18. Number of trees per acre by thinning type and intensity nine years after thinning for slash pine.

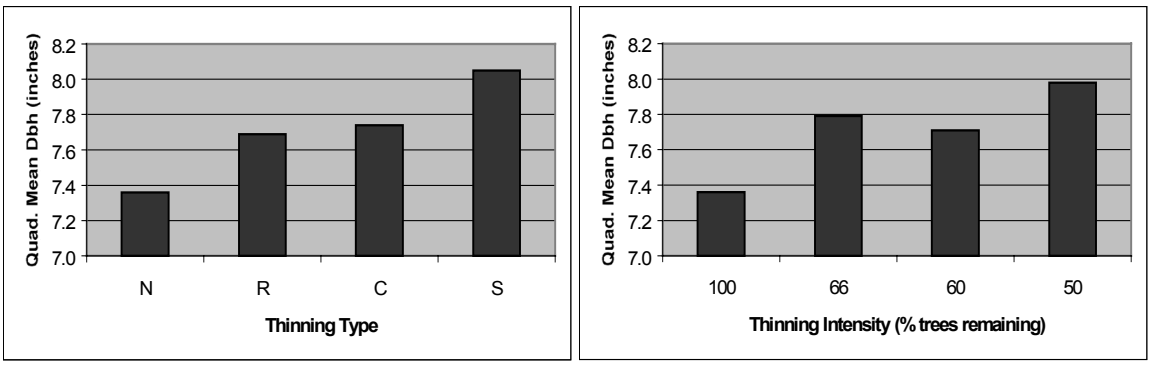

Figure 19. Quadratic mean Dbh by thinning type and intensity nine years after thinning for slash pine.

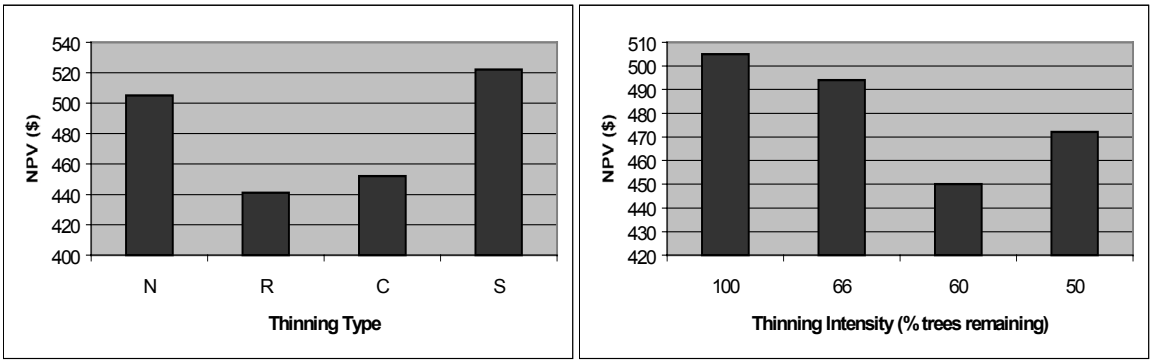

Figure 20. Per-acre net present value by thinning type and intensity nine years after thinning for slash pine.

Nine-year growth in total volume, merchantable volume, sawtimber volume, basal area, mortality and quadratic mean Dbh were analyzed with the analysis of variance and contrasts. The thinning treatments had a significant effect on mortality, only. The row thinning treatment had significantly more mortality than either of the combination and select treatments. The combination and select treatments had significantly less mortality than the unthinned treatment. The contrast analysis did not detect any differences among the thinning intensities. Figures 21-25 show the mean nine-

year growth data on a percentage basis. Figure 26 shows the growth in sawtimber volume on an absolute basis.

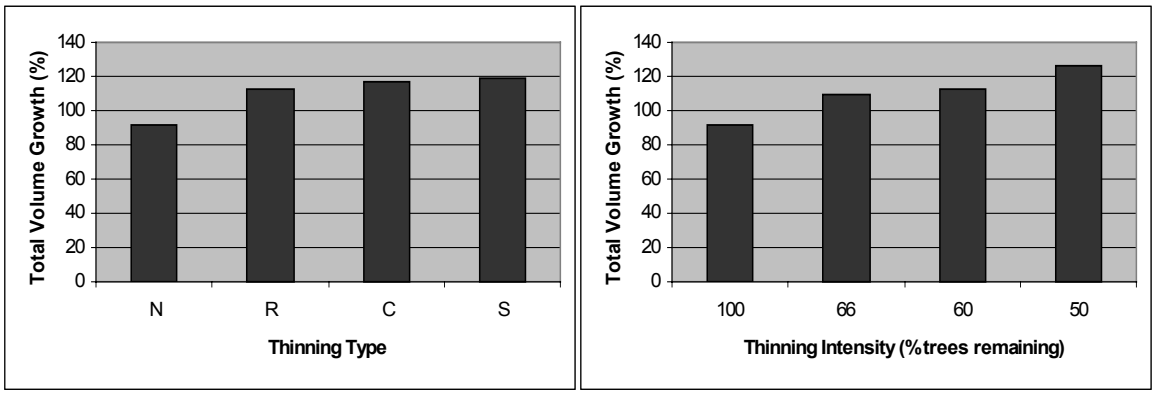

Figure 21. Nine-year per-acre total volume growth by thinning type and intensity on a percentage basis for slash pine.

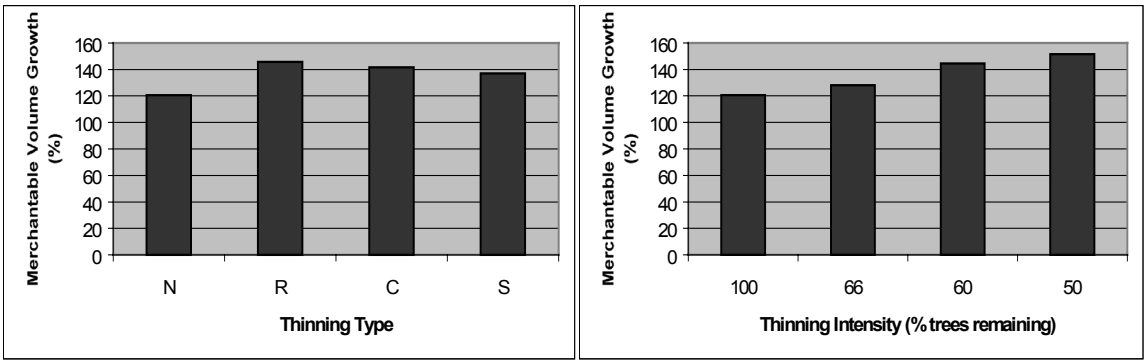

Figure 22. Nine-year per-acre merchantable volume growth by thinning type and intensity on a percentage basis for slash pine.

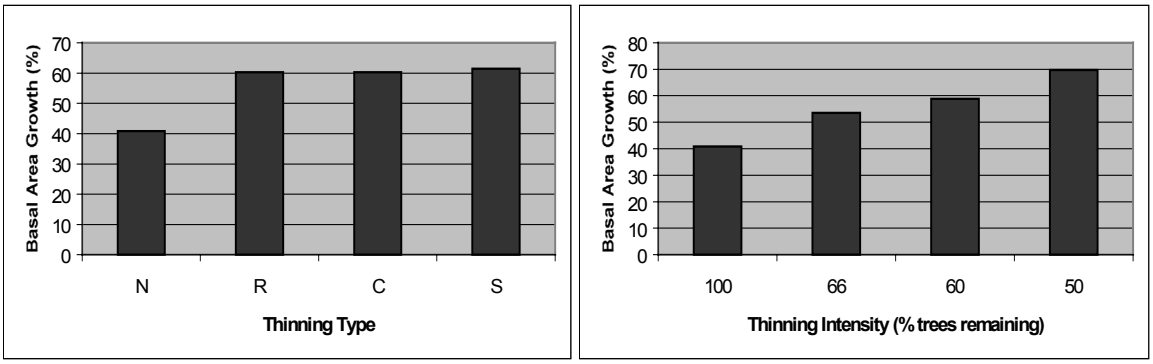

Figure 23. Nine-year per-acre basal area growth by thinning type and intensity on a percentage basis for slash pine.

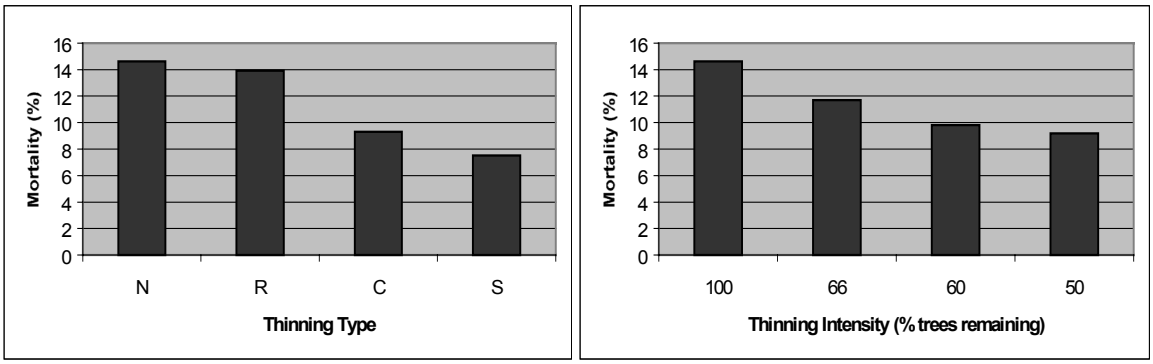

Figure 24. Nine-year mortality by thinning type and intensity on a percentage basis for slash pine.

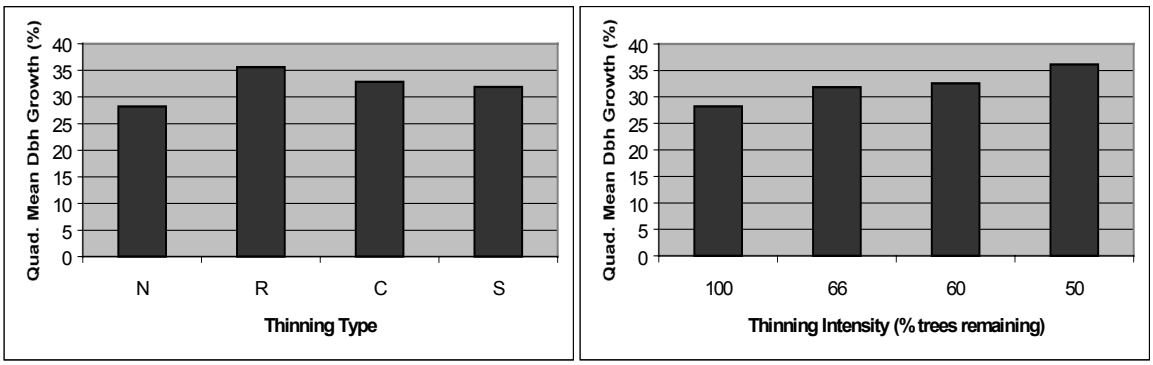

Figure 25. Nine-year quadratic mean Dbh growth by thinning type and intensity on a percentage basis for slash pine.

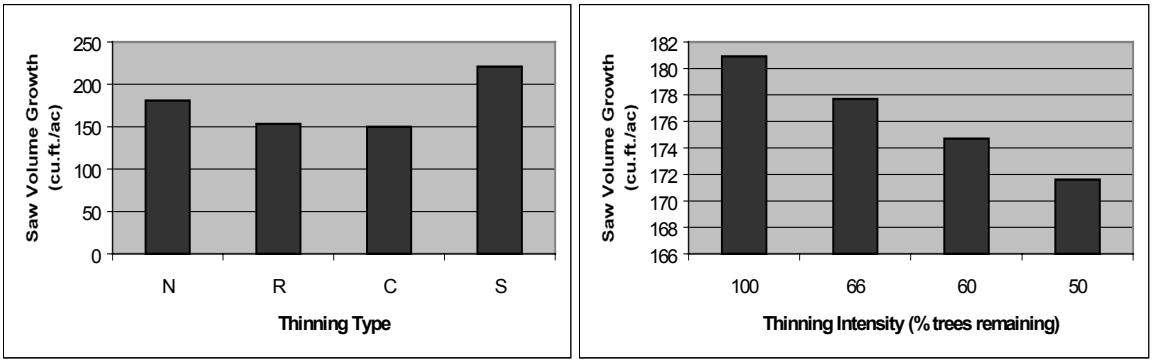

Figure 26. Nine-year per-acre sawtimber volume growth by thinning type and intensity for slash pine.

4 MODELLING CONSIDERATIONS

Many growth and yield projection systems employ the competition index to estimate the future per-acre basal area of thinned pine plantations. The system was applied locally by Harrison and Borders (1996) for loblolly pine and Pienaar et.al. (1996) for slash pine. Since some of the MS33 data were not available at the time of this work, it seems sensible to use these data to test the thinned stand projection systems. Residual analysis was carried out and percent variation explained was computed for Piedmont and upper coastal plain loblolly pine and for lower coastal plain slash pine.

Given that significant differences in survival patterns with respect to thinning treatments were found in the analysis of variance, it seems unlikely that current survival functions that do not account for thinning will perform satisfactorily.

The following system of equations is used to project the basal area of thinned loblolly and slash pine plantations. First, the basal area of the thinned plantation immediately after thinning must be known from inventory data or as a function of the number of trees per acre before thinning, the number of trees removed and the per-acre basal area prior to thinning as follows:

$$\frac{B_t}{B} = \frac{N_r}{N} + \left[1 - \frac{N_r}{N}\right]\left[\left\{\frac{N_s}{(N - N_r)}\right\}^b\right] \qquad \textbf{(1)}$$

where B_t = per-acre basal area removed in thinning (ft^2/ac),

B = per-acre basal area before thinning (ft^2/ac),

N = trees per acre before thinning,

N_r = trees per acre removed in row thinning,

N_s = trees per acre removed selectively from below,

b = 1.2345 for loblolly pine and 1.2248 for slash pine.

Equation **(1)** was tested against the select and combination treatment data. Table 7 shows residual and absolute residual statistics for loblolly and slash pine. Figures 27 and 28 show residuals plotted against predicted values. Equation **(1)** with the coefficients listed above explained 86.0% and 89.2% of the variation in basal area removed for loblolly and slash pine, respectively.

Table 7. Residual and absolute residual statistics for the thinned basal area prediction equation.

Species	Variable	N	Mean	Minimum	Maximum
Loblolly	Residual	168	-1.15	-14.37	12.39
	|Residual|	168	4.12	0.01	14.37
Slash	Residual	84	-0.64	-6.85	6.19
	|Residual|	84	2.19	0.02	6.85

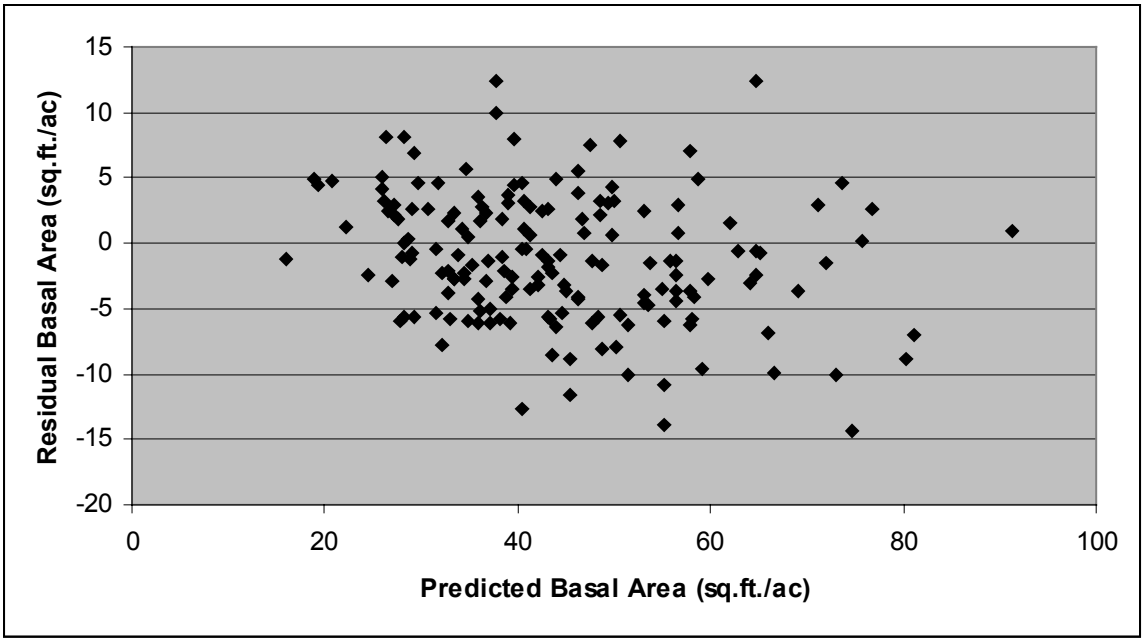

Figure 27. Residual vs. predicted thinned basal area for loblolly pine.

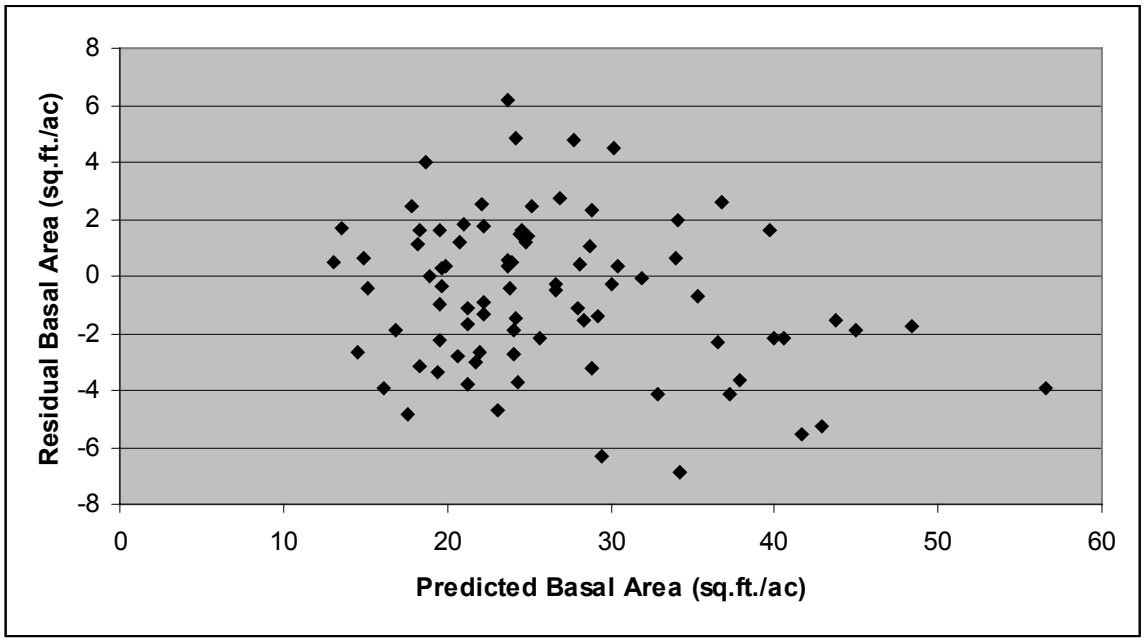

Figure 28. Residual vs. predicted thinned basal area for slash pine.

The next step in basal area projection for thinned stands is to estimate the per-acre basal area of an unthinned counterpart. That is, an unthinned stand on the same site as the thinned stand with the same age, same average dominant height and same number of trees per acre. Per-acre basal area prediction and projection equations for unthinned stands were tested against the unthinned MS33 treatments and the thinned plots prior to thinning. Table 8 shows the residual statistics for basal area prediction and projection for loblolly and slash pine. Figures 29 and 30 show the prediction residuals plotted against predicted basal area and figures 31 and 32 show projection residuals plotted against projected basal areas.

Table 8. Residual and absolute residual statistics for per-acre basal area prediction and projection.

Species	Type	Variable	N	Mean	Minimum	Maximum
Loblolly	Prediction	Residual	240	14.02	-18.55	49.70
		| Residual |	240	14.85	0.18	49.70
	Projection	Residual	108	-9.19	-67.78	7.98
		| Residual |	108	11.02	0.05	67.78
Slash	Prediction	Residual	198	2.75	-18.99	22.66
		| Residual |	198	7.20	0.01	22.66
	Projection	Residual	158	-2.82	-37.16	19.45
		| Residual |	158	6.94	0.07	37.16

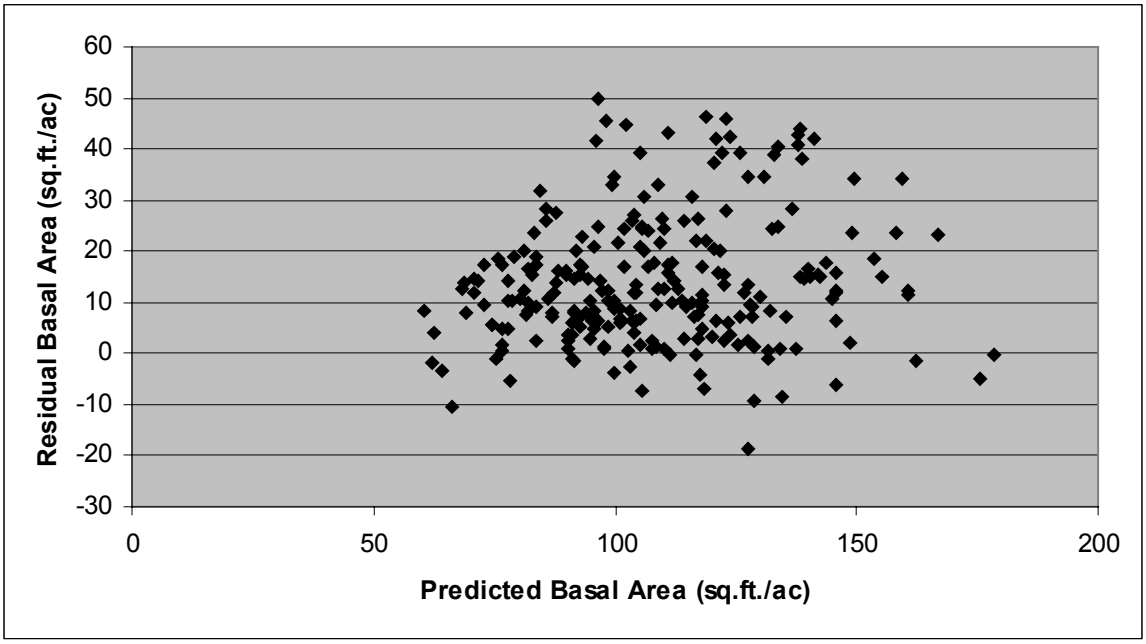

Figure 29. Residual versus predicted unthinned basal area for loblolly pine.

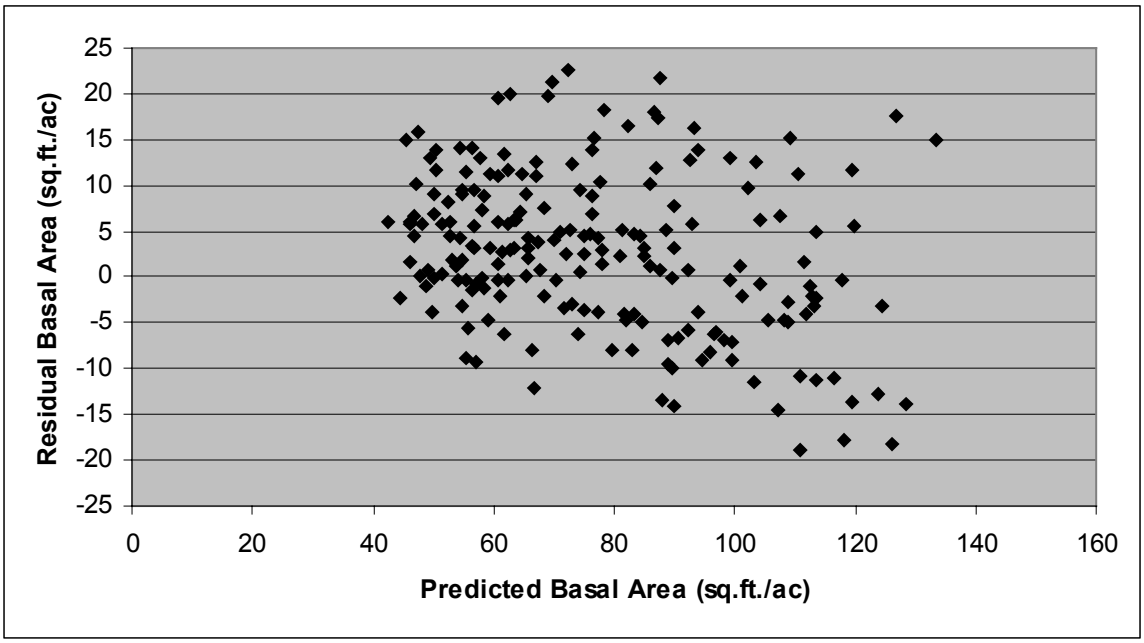

Figure 30. Residual versus predicted unthinned basal area for slash pine.

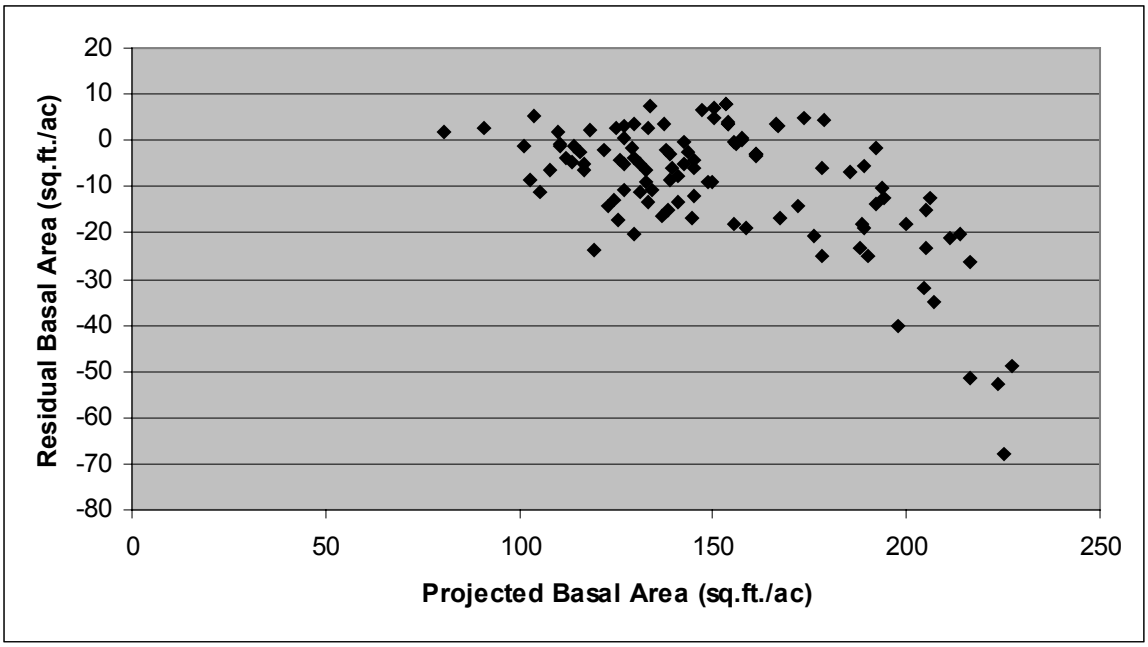

Figure 31. Residual versus projected unthinned basal area for loblolly pine.

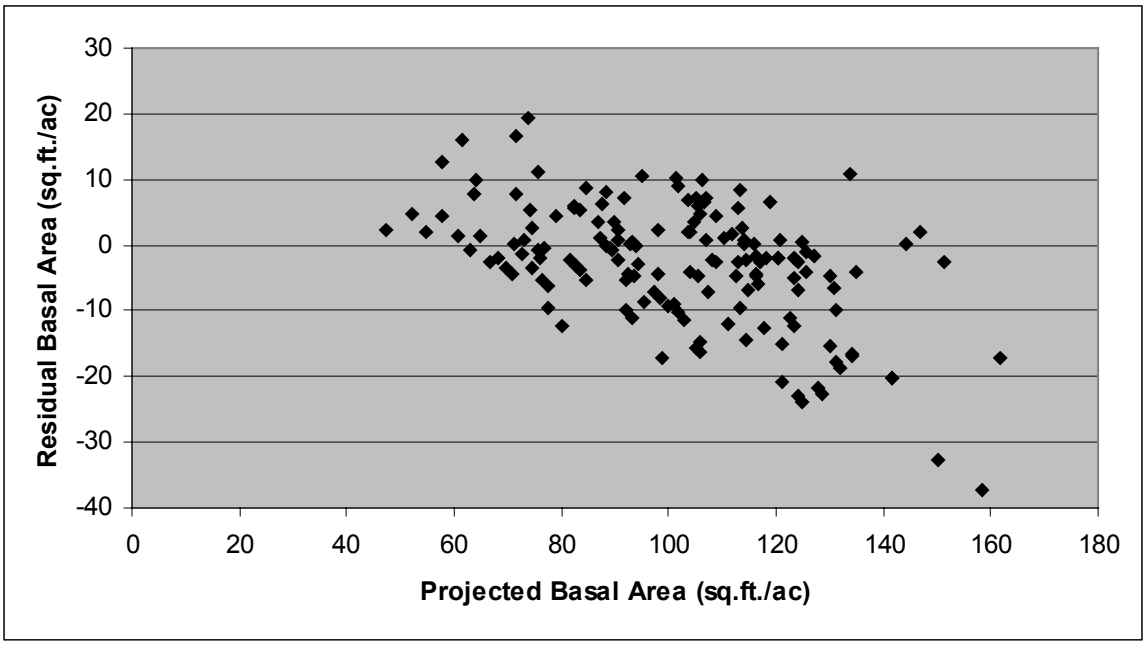

Figure 32. Residual versus projected unthinned basal area for slash pine.

The basal area prediction equation for slash pine performed reasonably well for the unthinned MS33 data. The average residual was 2.8 ft^2/ac and the model explained 82% of the variation in per-acre basal area. The loblolly pine model, however, did not perform satisfactorily. The average residual was 14 ft^2/ac and the model explained only 55% of the variation. Figure 29 shows that the predicted basal areas were generally biased. The model tended to underpredict per-acre basal area across the range of predictions.

The basal area projection models for unthinned stands explained 64% and 78% percent of the variation in per-acre basal area for loblolly and slash pine, respectively. The residual plots in Figures 31 and 32 show that the models for both species tend to over-project the higher basal areas.

The final step in the basal area prediction for thinned stands is to project the competition index and recover the basal area of the thinned stand as a function of the competition index and the basal area of the unthinned counterpart as follows:

$$CI_2 = CI_1 e^{-b(Age_2 - Age_1)} \quad \textbf{(2)}$$

where CI_1, CI_2 = competition indexes at Age_1 and Age_2, respectively,

b = 0.076 for loblolly pine and 0.093 for slash pine.

$$BA_{t2} = BA_{u2}(1 - CI_2) \quad \textbf{(3)}$$

where BA_{t2} = per-acre basal area of the thinned stand,

BA_{u2} = per-acre basal area of the unthinned counterpart.

These models were tested on the MS33 thinned plot data in terms of projected per-acre basal area. This method is not appropriate for row-thinned plantations so only the select and combination thinning treatment plot data were tested. The residual and absolute residual statistics for loblolly and slash pine are shown in Table 9 and are plotted in Figures 33 and 34. The competition index method did a reasonably good job projecting the basal area of the thinned MS33 plots. The average residuals were –3.52 ft^2/ac and 1.24 ft^2/ac for loblolly and slash pine, respectively. The system explained 91% of the variation in per-acre basal area for both species.

Table 9. Residual and absolute residual statistics for the thinned stand basal area projection using the competition index method.

Species	Variable	N	Mean	Minimum	Maximum
Loblolly	Residual	594	-3.52	-34.80	20.14
	|Residual|	594	6.00	0.01	34.80
Slash	Residual	708	1.24	-12.21	16.48
	|Residual|	708	3.67	0.003	16.48

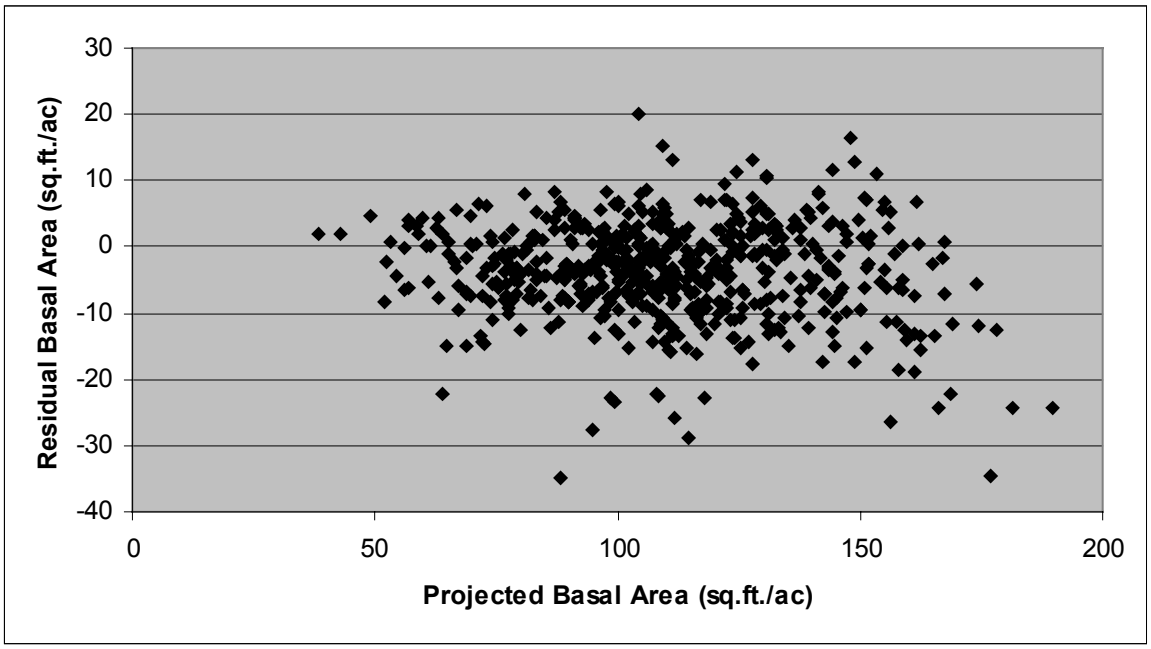

Figure 33. Residual versus projected thinned-stand basal area for loblolly pine.

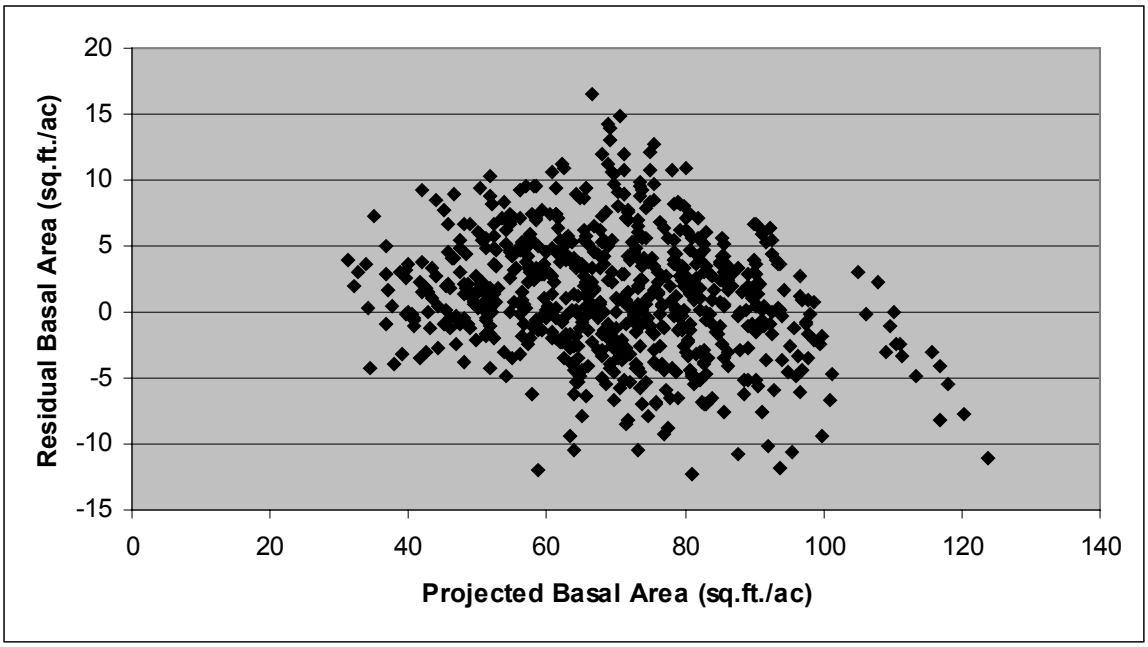

Figure 34. Residual versus projected thinned-stand basal area for slash pine.

5 SUMMARY AND CONCLUSIONS

The MS33 Thinning Study was initiated with the objective of examining the effects of thinning type, timing and intensity on the growth and yield of loblolly and slash pine plantations. The study was installed at 21 locations and 11 of these installations remain nine years after the first thinning. Many of these installations were thinned a second time, but this analysis deals only with the effects of the first thinning.

Analysis of variance and orthogonal contrasts were carried out to determine the significance of thinning type and intensity treatments. Analyses were done for total volume, merchantable volume, sawtimber volume, basal area, quadratic mean diameter and present value of simulated harvest incomes. With the exception of NPV, the nine-year changes in these variables, as well as mortality, were also analyzed.

For loblolly pine, the unthinned treatments had significantly more per-acre basal area than the thinned treatments nine years after thinning. The thinned plots, however, grew significantly more per-acre basal area over the same interval. The least intensive thinning treatment had more basal area and more basal area growth than the most intensive treatment. The unthinned plots

and the row-thinned plots had significantly more mortality than the combination and selectively-thinned treatments.

For slash pine, the unthinned treatments had significantly more total volume, merchantable volume and basal area than the unthinned treatments. The selectively thinned treatments had more volume and basal area than the other thinning treatments. The least intensive thinning treatment had significantly more volume and basal area than the most intensive treatment. The unthinned and row thinned slash pine plots had significantly more mortality than the combination and selectively thinned treatments.

Possibly the most meaningful and applicable result of this analysis concerns the differences in mortality patterns among the different treatments. For loblolly pine, Table 2 shows that, on the average, the combination and selectively thinned treatments lost 26.5 trees per acre in the nine years after thinning. The row-thinned plots lost 49 trees per acre and the unthinned plots lost 120 trees per acre to mortality over the same period. The slash pine results were significant but not of the same magnitude as for loblolly pine. The combination and select treatments lost an average of 20.5 trees per acre. The row thinned treatments lost an average of 34 trees per acre and an average of 58 trees per acre died on the unthinned plots.

The significant differences in volume and basal area for slash pine nine years after thinning may be due to the residual basal areas on the thinned plots. Basal area after thinning ranged from 39 to 50 ft^2/acre on the thinned slash pine plots. In contrast, after-thinning basal areas on the loblolly pine plots ranged from 68 to 88 ft^2/acre. With per-acre basal areas as low as 39 ft^2, the thinned slash pine plots were, most likely, understocked and were unable to sufficiently respond to the thinning.

The tests of growth and yield models on the MS33 data were revealing. In general, the basal area projections for thinned stands were acceptable, as shown in Figures 33 and 34. This is only because some of the MS33 data were used to develop the thinned-stand projection system, thereby compensating, somewhat, for the bias shown in basal area prediction and projection for the unthinned data (Figures 29-32). Given the differences in mortality patterns between thinned and unthinned stands and the poor performance demonstrated by the basal area models, future efforts will concentrate on incorporating all available data and developing more comprehensive growth and yield systems for slash and loblolly pine plantations.

6 LITERATURE CITED

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