Growth of Loblolly Pine Planted at Low Densities

Research Report 135 **August 2017**

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Abstract
A study was installed at three locations on the Appomattox-Buckingham State Forest between 1990 and 1993 to compare the tree growth and stand-level productivity of plots planted with 200, 300 and 400 seedlings per acre (spa). After 22 years, all of the densities have resulted in well-stocked stands containing quality crop trees. Those planted at the lower density have slightly (four percent) taller trees with substantially (20 percent) larger diameters than those planted at the higher density. On a per-acre basis, the 400 spa plots contain significantly more basal area and fiber than the 300 or 200 spa areas. At present prices, the 400, 300 and 200 spa plots are estimated to be worth $1,949; $2,320, and $2,634 per acre, respectively.

Background
Planting density for loblolly pine is probably one of the most debated decisions affecting the long-term sustainability, productivity and value of a plantation. The number of planted seedlings per acre (spa) affects the timing of crown closure; the rate of individual tree diameter growth; the rate of fiber production (per acre), and the rate of natural branch pruning. Lower densities produce larger individual tree diameters while higher densities increase total per-acre fiber production.

Historically, planting densities have ranged from 400 to more than 1,000 spa, with recent decades favoring the lower end of that range. In the 1990s, relatively strong markets for larger diameter trees, combined with concerns over the future demand for the smaller trees that are removed in thinning operations, led to an interest in planting densities even lower than 400 spa.

In more recent years, better survival of planted seedlings (due to improved early competition control) and the emphasis on genetically improved (more expensive) seedlings have continued to support interest in lower-density plantings. In addition, there is growing interest in silviculture that creates light conditions favorable to more diverse and targeted understory flora (and fauna). All of these factors make the consideration of lower planting densities relevant.

Results from this study through age 15 were summarized by John Scrivani and Wayne Bowman in VDOF Occasional Report #124 (November 2004), and 20-year data were summarized in the August 2013 Forest Research Review.

Methods

In 1990, 1992 and 1993, genetically-improved first generation loblolly seedlings from the Virginia Department of Forestry nursery were planted on tracts located in the Appomattox-Buckingham State Forest in the Piedmont of Virginia. In each year, three replications were planted on a single tract. The 1990, 1992 and 1993 plots were on the Rinehart, Abbitt and Talbert units, respectively. The spacing and number of seedlings were varied in three plots per replication to obtain densities of 200, 300 and 400 spa.

Each tract was a recent cutover that had been site prepared by a prescribed burn. In the first two years after planting, each was released from hardwood competition using directed sprays of imazapyr (Arsenal) applied using a backpack sprayer. Volunteer pine seedlings were removed. In addition, the plots were mowed periodically to facilitate tree measurements. No other competition control was applied.

Soils on all of the locations are well-drained with a shallow silty loam surface and clay as the dominant subsurface texture. The parent material at Rinehart and Talbert is fine-grained metamorphic rock dominated by mica. The Abbitt soils, meanwhile, are derived from a slate belt parent material and have slightly elevated silt content.

The pines were measured at varying ages at each location until age 14. All locations were measured at age 15, 17, 20 and 22. The tract names and measurement intervals are summarized in Table 1. Total tree height was measured at each visit, and diameter at breast height (dbh – at 4.5 ft above ground line) was measured at age four and after. Those data were then used to calculate individual tree basal area (BA) and weights, which were consolidated into per-acre estimates. Financial values of pulpwood and chip-n-saw products were estimated assuming prices of $12 and $18 per green ton, respectively. Sawtimber values were derived using a price of $140 per thousand board feet (International 1/4 inch).

Table 1. Tract names and measurement schedule.

Tract Name	Year Planted	Measurement Ages
Rinehart	1990	1, 2, 7, 9, 12, 15, 17, 20, 22
Abbitt	1992	1, 2, 5, 7, 10, 13, 15, 17, 20, 22
Talbert	1993	1, 4, 6, 9, 12, 14, 15, 17, 20, 22

Results

Individual Tree Responses

Survival and individual tree height and dbh growth are summarized in Table 2.

Survival was not affected by planting density and averaged 91 percent – 97 percent at Abbitt; 92 percent – 93 percent at Rinehart, and 83 percent – 88 percent at Talbert after 22 years. Both tree height and dbh were affected by planting density, with the lower densities leading to small increases in total tree height and substantial gains in dbh. Statistical analysis proves the effect of planted spa to be significant; the chance of these differences being due to random chance is 0.029 for height and less than 0.001 for dbh. By age 22, total tree height averaged 64, 63 and 62 feet in plots planted at 200, 300 and 400 spa, respectively (Figure 1). DBH averages are 11.6, 10.5, and 9.7 inches (Figure 2). As Figures 1 and 2 demonstrate, heights seem to be affected more by locations than planting density, whereas diameters were more responsive to density.

Table 2. Average survival and individual tree metrics for all measurement ages on all three locations individually and for ages 15-22 at all locations combined.

	Survival (%)			Tree Height (ft)			Tree DBH (in)		
Abbitt Unit									
Age	200 spa	300 spa	400 spa	200 spa	300 spa	400 spa	200 spa	300 spa	400 spa
1	99%	94%	96%	1.3	1.3	1.3	-	-	-
2	99%	94%	95%	3.3	3.4	3.2	-	-	-
5	98%	92%	93%	13.3	13.4	13.3	2.6	2.6	2.6
7	97%	92%	92%	19.8	20.2	19.9	4.5	4.4	4.5
10	97%	92%	92%	31.0	31.8	31.4	6.8	6.5	6.4
13	97%	92%	92%	41.0	41.1	40.5	8.6	8.0	7.8
15	97%	92%	92%	47.6	47.3	46.6	9.6	8.9	8.5
17	97%	92%	92%	53.8	54.8	54.2	10.3	9.5	9.0
20	97%	91%	92%	60.2	60.1	59.4	11.4	10.4	9.9
22	97%	91%	92%	68.3	67.2	66.5	11.9	10.7	10.2
Rinehart Unit									
Age	200 spa	300 spa	400 spa	200 spa	300 spa	400 spa	200 spa	300 spa	400 spa
1	97%	98%	98%	1.1	1.3	1.2	-	-	-
2	95%	95%	95%	3.6	4.0	3.8	-	-	-
7	93%	94%	94%	20.4	21.2	20.7	4.3	4.4	4.2
9	93%	94%	93%	27.1	27.7	27.3	5.7	5.8	5.5
12	93%	94%	93%	37.7	38.6	37.8	7.4	7.3	6.8
15	93%	93%	93%	46.3	47.3	45.1	8.8	8.4	7.7
17	93%	93%	93%	51.3	51.6	49.8	9.5	8.9	8.2
20	93%	93%	93%	59.0	58.2	56.5	10.5	9.7	8.8
22	93%	92%	93%	63.3	62.7	60.2	11.2	10.3	9.3
Talbert Unit									
Age	200 spa	300 spa	400 spa	200 spa	300 spa	400 spa	200 spa	300 spa	400 spa
1	97%	96%	95%	1.0	1.0	1.0	-	-	-
4	91%	89%	90%	10.2	9.8	10.0	1.7	1.5	1.6
6	90%	87%	89%	17.0	16.2	16.5	3.6	3.3	3.4
9	89%	85%	88%	27.6	26.6	27.9	5.9	5.4	5.4
12	88%	83%	88%	36.8	35.7	37.3	7.8	7.1	6.9
14	88%	83%	88%	41.9	40.4	41.6	8.8	7.9	7.6
15	88%	83%	88%	45.9	44.4	45.6	9.1	8.3	7.8
17	88%	83%	88%	48.9	47.4	48.3	10.0	9.0	8.5
20	88%	83%	87%	56.3	54.1	54.1	11.1	9.9	9.2
22	88%	83%	87%	59.8	58.1	58.0	11.6	10.4	9.6
Combined Averages									
Age	200 spa	300 spa	400 spa	200 spa	300 spa	400 spa	200 spa	300 spa	400 spa
15	93%	89%	91%	46.6	46.4	45.8	9.2	8.5	8.0
17	93%	89%	91%	51.3	51.3	50.8	9.9	9.1	8.6
20	93%	89%	91%	58.5	57.5	56.7	11.0	10.0	9.3
22	92%	89%	91%	63.8	62.7	61.6	11.6	10.5	9.7

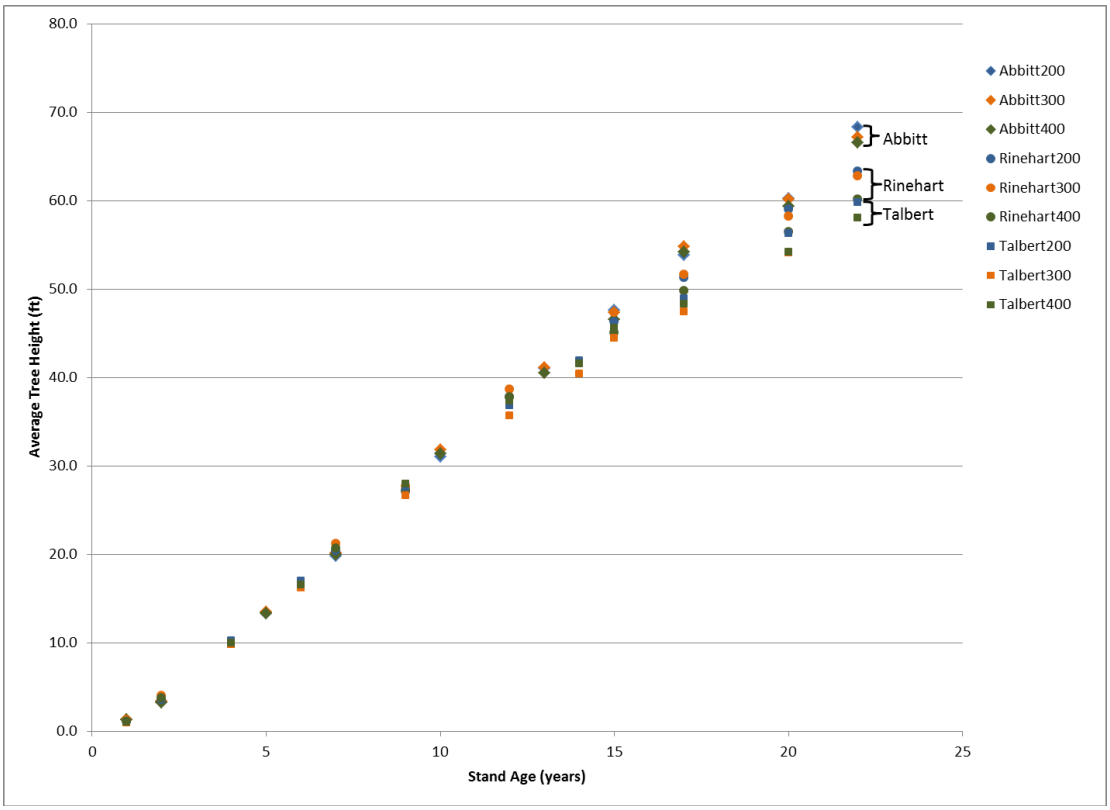

Figure 1. Average tree height through age 22.

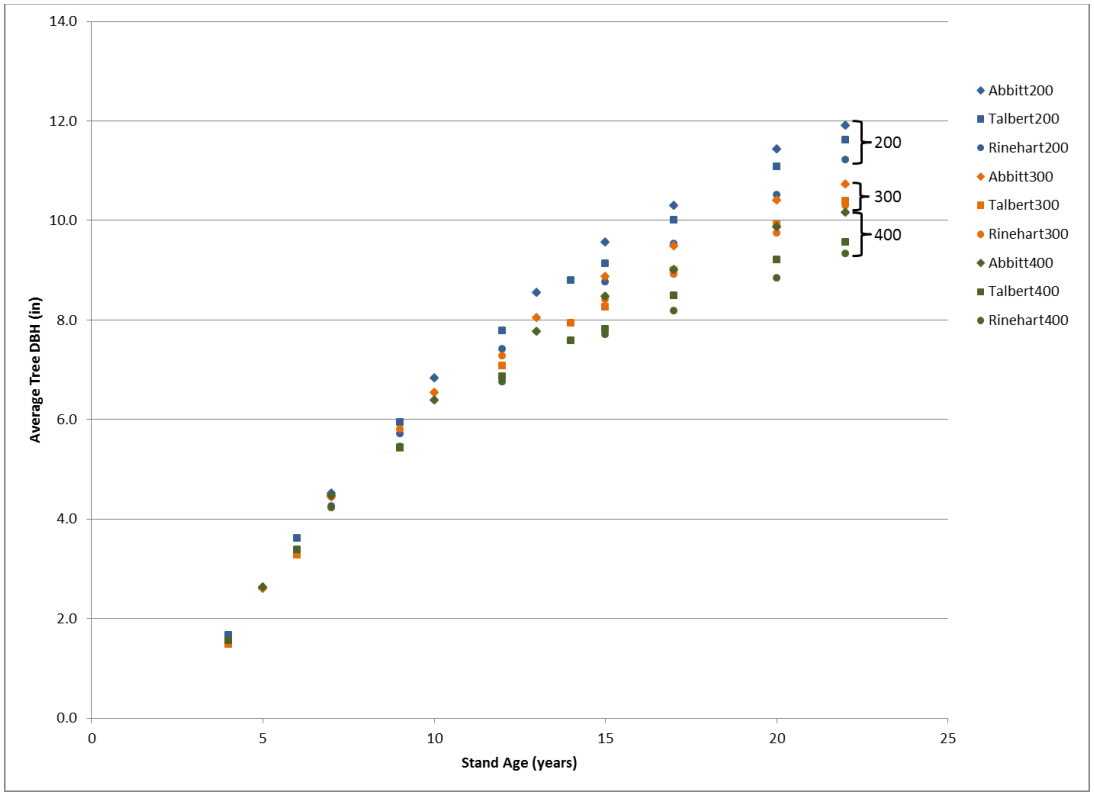

Figure 2. Average tree dbh through age 22.

Stand-Level Responses

At the stand level, both basal area and total fiber production are strongly affected by planting density. Statistically, the chances of the differences being due to random luck are less than 0.001 for both metrics.

Basal area (ba) at age 22 increases with increasing planting density; the 400 spa plots contain an average of 191 ft^2/ac – 42 percent and 16 percent more than the 200 and 300 spa plots, respectively. All of the 400 spa plots are approaching or exceeding a basal area of 200 ft^2/ac (Table 3), which is often cited as a maximum for loblolly pine. If we consider a ba of 140 ft^2/ac as a rough indicator of the stage at which a stand could benefit from thinning, the data show that all of the plots except 200 spa at Rinehart and Talbert could be thinned before age 22 (Figure 3). At Abbitt, this stage was exceeded as early as age 15 (on the 400 spa plots).

Table 3. Stand basal area at age 22.

	Basal Area (ft^2/ac)		
Tract Name	200 spa	300 spa	400 spa
Abbitt	148	177	214
Rinehart	126	165	182
Talbert	129	151	178
Combined Average	135	164	191

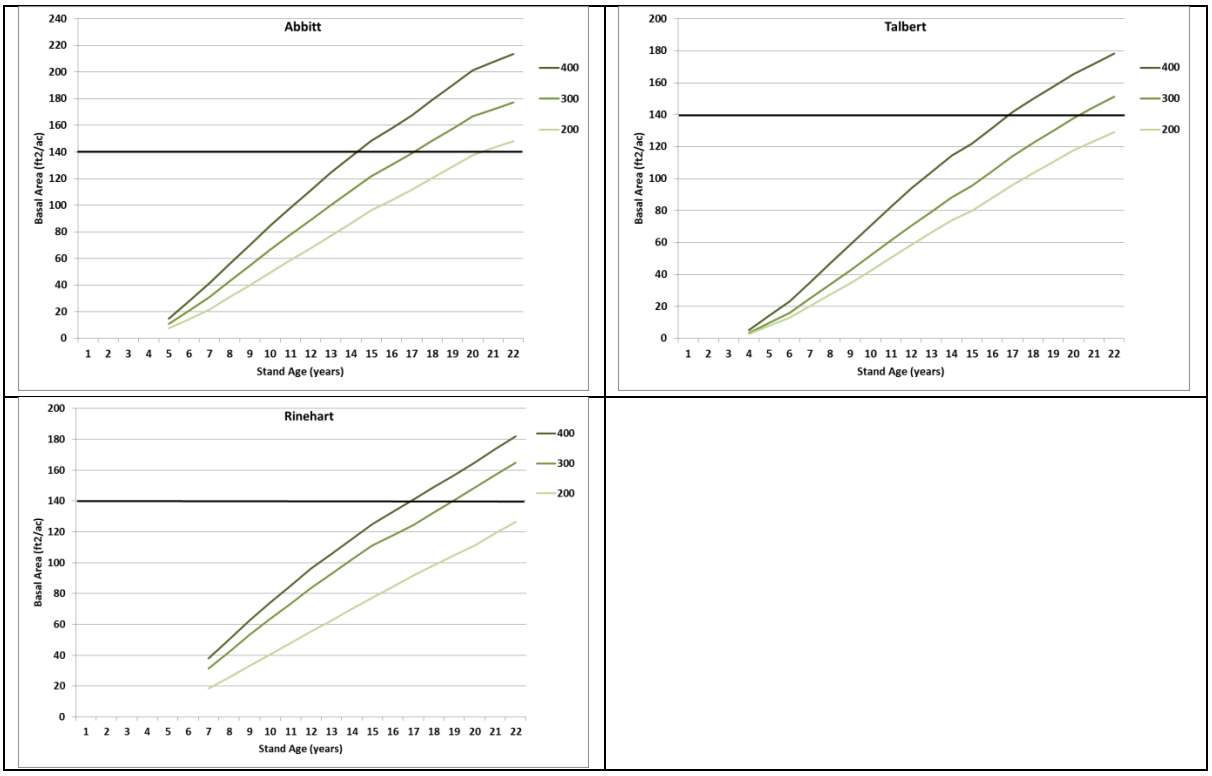

Figure 3. Average basal area through age 22 by location.

Fiber production per acre is also greater through age 22 on the more densely planted plots (Table 4). Averaged across locations, total green tons per acre ranges from 111 at 200 spa to 153 at 400 spa. Taking a closer look at the product classes reveals that the lower density (as expected) produces more larger diameter / sawtimber-sized material, whereas the higher density has yielded mostly chip-n-saw sized trees (Figure 4). Of course, for a landowner planning on a longer rotation, the chip-n-saw material on the 400 spa plots will ultimately progress into the sawtimber class.

Table 4. Stand fiber production by product class and location at age 22.

	Weight (tons/acre)											
	Abbitt			**Rinehart**			**Talbert**			**Combined Average**		
	200 spa	300 spa	400 spa	200 spa	300 spa	400 spa	200 spa	300 spa	400 spa	200 spa	300 spa	400 spa
Total	130	153	183	103	133	141	100	113	134	111	133	153
Pulpwood	0	1	2	0	1	4	0	1	4	0	1	3
Chip-n-Saw	29	91	138	43	100	124	32	73	105	35	88	122
Sawtimber	101	62	44	59	33	13	67	39	25	76	45	27
MAI (total)	6	7	8	5	6	6	5	5	6	5	6	7

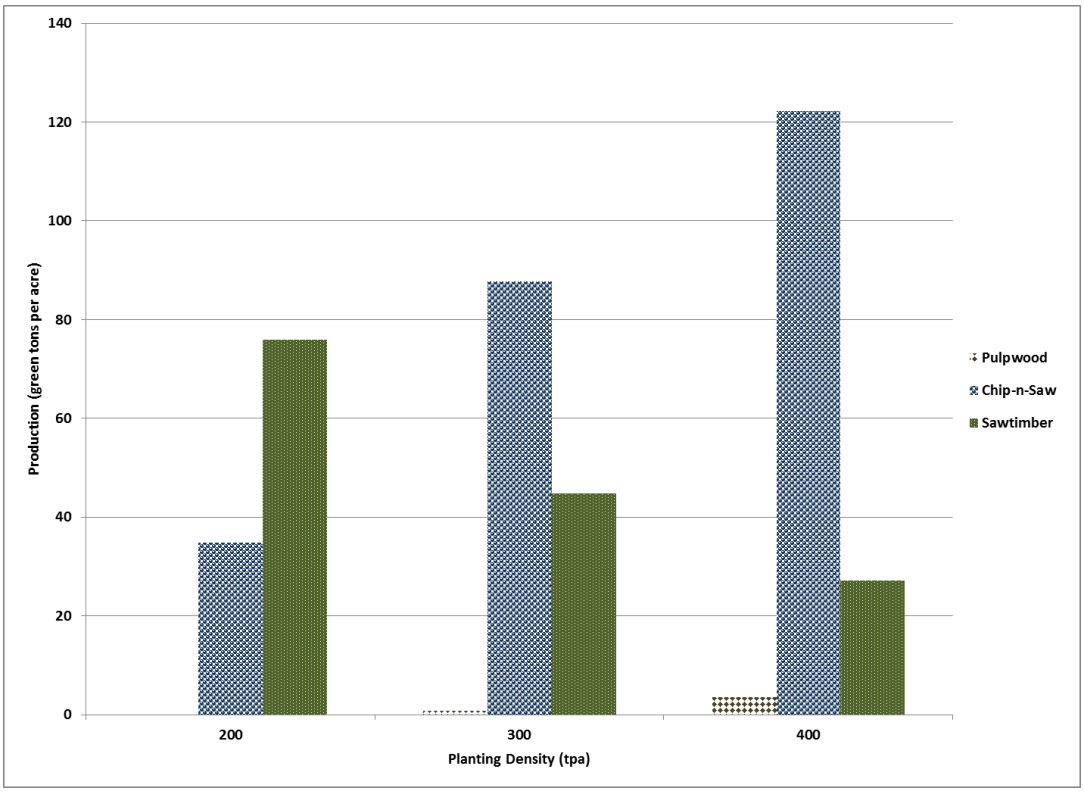

Figure 4. Average green tons per acre at age 22.

Location Effects

Throughout the preceding sections, it has become apparent that, in addition to the effect of initial planting density, tree growth varies by location. This is reasonable given the different soil characteristics (parent material) described on page two. To better characterize this difference, the formula developed by the Forest Modeling Cooperative (Amateis and Burkhart 1985) was used to project average tree height at age 22 to a Site Index at base age 25. The results are summarized in Table 5. Based on these estimates, the Abbitt (slate belt parent material) is

exhibiting a site index approximately five feet - nine feet greater than Rinehart and Talbert (metamorphic rock parent material). This may, in part, explain the greater individual tree and per-acre growth at Abbitt.

Table 5. Measured age 22 height and projected site index (base age 25).

	Age 22 Height			Projected SI_{25}			
Tract Name	200 spa	300 spa	400 spa	200 spa	300 spa	400 spa	Average
Abbitt	68.3	67.2	66.5	71.5	70.4	69.6	70.5
Rinehart	63.3	62.7	60.2	66.2	65.6	62.9	64.9
Talbert	59.8	58.1	58.0	62.5	60.7	60.6	61.3

Value

The age 22 values assuming prices of $12 and $18 per green ton, respectively, for pulpwood and chip-n-saw and $140 per thousand board feet (International 1/4 inch) for sawtimber are summarized in Table 6. The higher density carries more total financial value than the lower densities, and Abbitt has – on average – 37 percent more than the lowest value site (Talbert). Not surprisingly, a greater proportion of the value on the 200 spa plots is in sawtimber at age 22, whereas more of the 400 spa value is in the chip-n-saw trees.

Table 6. Per-acre value by product class and in total at age 22.

	Value ($/ac)											
	Abbitt			**Rinehart**			**Talbert**			**Combined Average**		
	200 spa	300 spa	400 spa	200 spa	300 spa	400 spa	200 spa	300 spa	400 spa	200 spa	300 spa	400 spa
Total	$2,307	$2,689	$3,198	$1,799	$2,325	$2,419	$1,740	$1,947	$2,285	$1,949	$2,320	$2,634
Pulpwood	$3	$6	$20	$3	$9	$51	$1	$11	$53	$2	$9	$41
Chip-n-Saw	$517	$1,630	$2,478	$779	$1,799	$2,235	$580	$1,311	$1,884	$625	$1,580	$2,199
Sawtimber	$1,787	$1,053	$700	$1,017	$518	$133	$1,159	$625	$349	$1,321	$732	$394

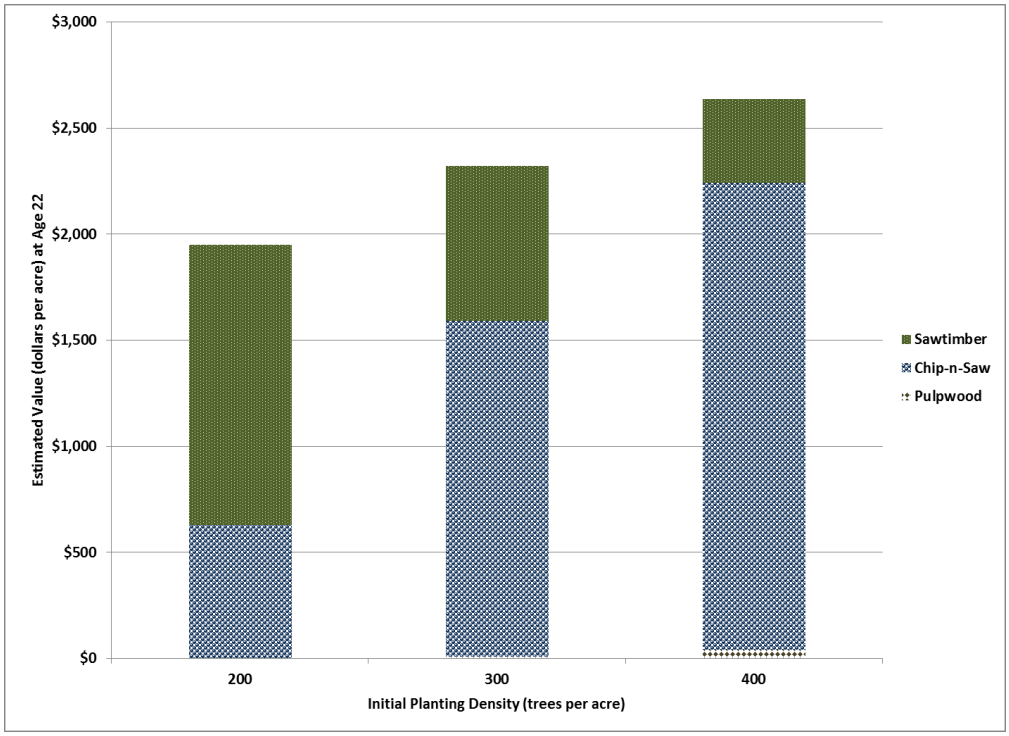

Figure 5. Product value per acre at age 22.

Discussion

In a paper published in 2006 in the Alabama NRCS Tech News, Dr. David South wrote that the answer to the question "How many loblolly pine seedlings should I plant?" is "It depends on your objective and who you ask" (South 2006). Simple as it may seem, this is an excellent summary of the debate on planting density. The choice can be affected by the assumed price ratio between sawtimber and pulpwood; expected survival rate; logging cost expectations; proximity of the stand to a mill or processing facility; perceived risk of insect or pathogen infestations, or concerns over wood-quality affects.

The Forest Modeling Research Cooperative conducted a study in Virginia and North Carolina comparing planting densities ranging from 300 spa to more than 2,700 spa (Amateis and Burkhart 2012). After 25 years, their important conclusions included:

1. No single planting density is optimal for the wide array of product objectives for which loblolly pine is managed in the South. Rather, managers must select an appropriate planting density in view of the products desired or anticipated at harvest.
2. Initial planting density profoundly impacts tree growth, stand development and product distribution.
3. Tree diameter is more sensitive to stand density than tree height.
4. Dominant stand height is relatively stable across a wide range of planting densities, but at the extremes site index is not a constant.
5. Trees at a rectangular spacing develop similarly to trees growing at a square spacing.
6. Trees growing at a rectangular spacing have branches with diameters that are not greatly different from trees growing at a square spacing.
7. Ice storms, hurricanes, beetle attacks and other anomalies can profoundly alter the development of loblolly pine plantations.

In this study, lower density plantings have resulted in well-stocked stands containing quality crop trees. By age 22, all of the stands contain harvestable crops either for thinning or final harvest, depending on market conditions and landowner objectives. Using a basal area of 140 ft^2/ac as an indicator of a stands readiness for thinning, all except the 200 spa plots on the Rinehart and Talbert locations reached a "thinable" stage of development between ages 15 and 21. Consistent with the findings and recommendations from past studies, these results suggest a wide range of flexibility in planting densities.

References

Amateis, R.L. and H.E. Burkhart. 1985. Site index curves for loblolly pine plantations on cutover site-prepared lands. South. J. Appl. For. 9: 166-169.

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