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Realized Gains from Planting *Pinus taeda* in 6.1 Meter Rows in Alabama

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Abstract: *Pinus taeda* L. plantations in the United States are typically established using rows that are spaced 3 to 4 m apart. Although one company now plants pines in 6.1 m rows, reports on performance using this row spacing are rare. This paper provides a case study (established at the Solon Dixon Forestry Education Center) that compares two densities [672 *vs* 1344 seedlings per ha (SPH)] when fixing the between-row distance to 6.1 m and using either 2.44 m or 1.22 m within-row distances between the planted trees. At age 13-years, the aboveground biomass mean annual increment on this old-orchard site was 13.5 green Mg/ha/yr. Planting half as many pine seedlings as typical (for this region) did not reduce dominant height (P=0.22), basal area/ha (P=0.58) or total merchantable tonnes/ha (P=0.67). As expected, the higher density produced trees that were smaller in mean diameter at breast height DBH (25 *vs* 22 cm) and had more pulpwood than 672 SPH plots. However, planting pines 1.2 m apart within the row reduced survival, soon after two severe summer droughts. Apparently this stress increased the risk of attracting bark beetles. An economic analysis indicates that 672 SPH produced more valuable timber (at age 13 years) and had the highest Net Present Value (NPV). In contrast, the Ptaeda3 model indicated 1344 SPH would have the greater NPV. The conflicting results are related to Ptaeda3 predicting one sawtimber-sized tree while 156 were present in the 672 SPH plots. Although these findings should not be extrapolated to cutover sites, it appears there may be several advantages to planting pines in wider than traditional rows. The reluctance to plant *Pinus taeda* in 6.1 rows on flat, agricultural lands might be due to a lack of field data and/or a reliance on output from growth and yield programs that were developed using data from cutover sites.

Keywords: Rectangularity, loblolly pine, slash pine, economics, regeneration, stocking.

INTRODUCTION

Planting 740 to 1000 pine seedlings per ha (SPH) not only reduces planting costs (when compared to > 1300 SPH) but the lower stocking rates may also provide a quicker and greater return on investment [1-5]. Greater returns from these planting densities are likely when the demand for sawlogs is great. Even so, many pine plantations in the southern United States continue to be established with more than 1400 SPH. Although some foresters might establish hardwood plantations with fewer than 1300 SPH, it would be rare that similar planting rates would be recommended when the landowner's objective for planting pines was purely profit driven.

When planting less than 1300 SPH on relatively flat terrain, a rectangular spacing would make more sense than a square one. Typically, a rectangular configuration (within a certain range) has little or no effect on pine growth [6-10]. Lewis and others [6] found that basal area and volume yields for a 13-year-old stand were not reduced when the rectangularity ratio (i.e. long side divided by short side) was 6 (using a 1.2 m short side) or even 24 (using a 0.6 m short side). These ratios are greater than conventionally used for pines in the southern United States (e.g. < 2) but some plantations are now established using a ratio of 4. For example, the Weyerhaeuser Company currently uses 6.1 m rows with 1.5 m between adjacent trees [11]. However, there is little published literature regarding realized gains from using both wide rows and a 4 or 5 ratio.

When field data are not available, potential effects from planting less than 700 SPH may be simulated with certain growth and yield models. For example, Ptaeda 3 was used to vary the within and between-row spacing and the output was used in an economic analysis [12]. The simulations were used to examine the economic benefits of planting pines in wide rows. After measurements have been taken from actual studies, the simulated data can be compared to actual data.

In 1997, Rhett Johnson established a study that involved planting 6.1 m rows of either *Pinus taeda* L. or *Pinus elliottii* Engelm. A year later, container-grown *Pinus palustris* Mill. seedlings were planted in-between the rows established but growth of the interplanted pines was minimal. As a result, these plots were used to examine the growth of pines that were established using rectangularity ratios of 2.5 and 5. Measurements were made when the trees were 13 years old and data were compared with simulations made using the Ptaeda3 growth and yield model. The following questions were addressed: (1) was survival of *Pinus taeda* affected by planting configuration and was it similar to the predicted survival?; (2) does doubling planting density increase basal area and profits?; (3) do predicted and actual diameter

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distributions match?; and (4) were realized economic gains similar to expected economic gains?

MATERIALS AND METHODS

Site and Planting Methods

The site was located 4.8 km east of Dixie, AL on property managed by the Solon Dixon Forestry Education Center (31° 08' N, 86° 40' W; 87 m a.s.l.). The experimental area was previously a pecan (*Carya illinoinensis* (Wangenh.) K. Koch) orchard but in October 1995, Hurricane Opal damaged or toppled most of the trees. The trunks and limbs were removed from the site and the soil was ripped to a depth of 40 cm on 3.05 m centers using a slit trench planter, mounted on a farm tractor. Soils include a Dothan (fine-loamy, kaolinitic, thermic Plinthic Kandiudults) and a Malbis soil type (fine-loamy, siliceous, subactive, thermic Plinthic Paleudults). Vegetation consisted mainly of Bermudagrass (*Cynodon dactylon* L. Pers.), Bahiagrass (*Paspalum notatum* Flueggé) and crabgrass (*Digitaria* spp.).

Bareroot seedlings of *Pinus taeda* (open-pollinated seed from a rust-resistant seed orchard) were produced at the International Forest Seed Company Nursery in Buena Vista, Georgia. Seedlings were lifted on 1/22/1997 and were transplanted on 1/27/2007 to 2/4/2007. On 1/24/1997, bareroot *Pinus elliottii* (source unknown) were lifted at the Hauss Nursery at Atmore and these seedlings were transplanted 1/31/97 through 2/3/97. All seedlings were planted by machine (slit trench planter mounted to a farm tractor with a 3-point hitch) along the rip-lines. Row spacing was 6.1 m and within-row spacing was either 1.2 m or 2.4 m but for *Pinus elliottii*, all seedlings in the 2.4 m plots were removed a year after transplanting. The sizes of the experimental units were 0.24 ha or larger (Fig. **1**).

In January of 1998, *Pinus palustris* Mill. seedlings were hand-planted midway between adjacent rows of *Pinus taeda* (at a within row spacing of 1.8 m). Likewise, *Pinus palustris* was also planted between rows of *Pinus elliottii*. However, due to a year delay in interplanting, this species contributed little to the overall yields per ha. Therefore, limited amounts of data are presented for *Pinus palustris*.

Weed Control

In April of 1997, each row of pines was treated with banded herbicide application. The 1.8 m band treated 60% of the study area. The treatment contained 148 ml of Arsenal

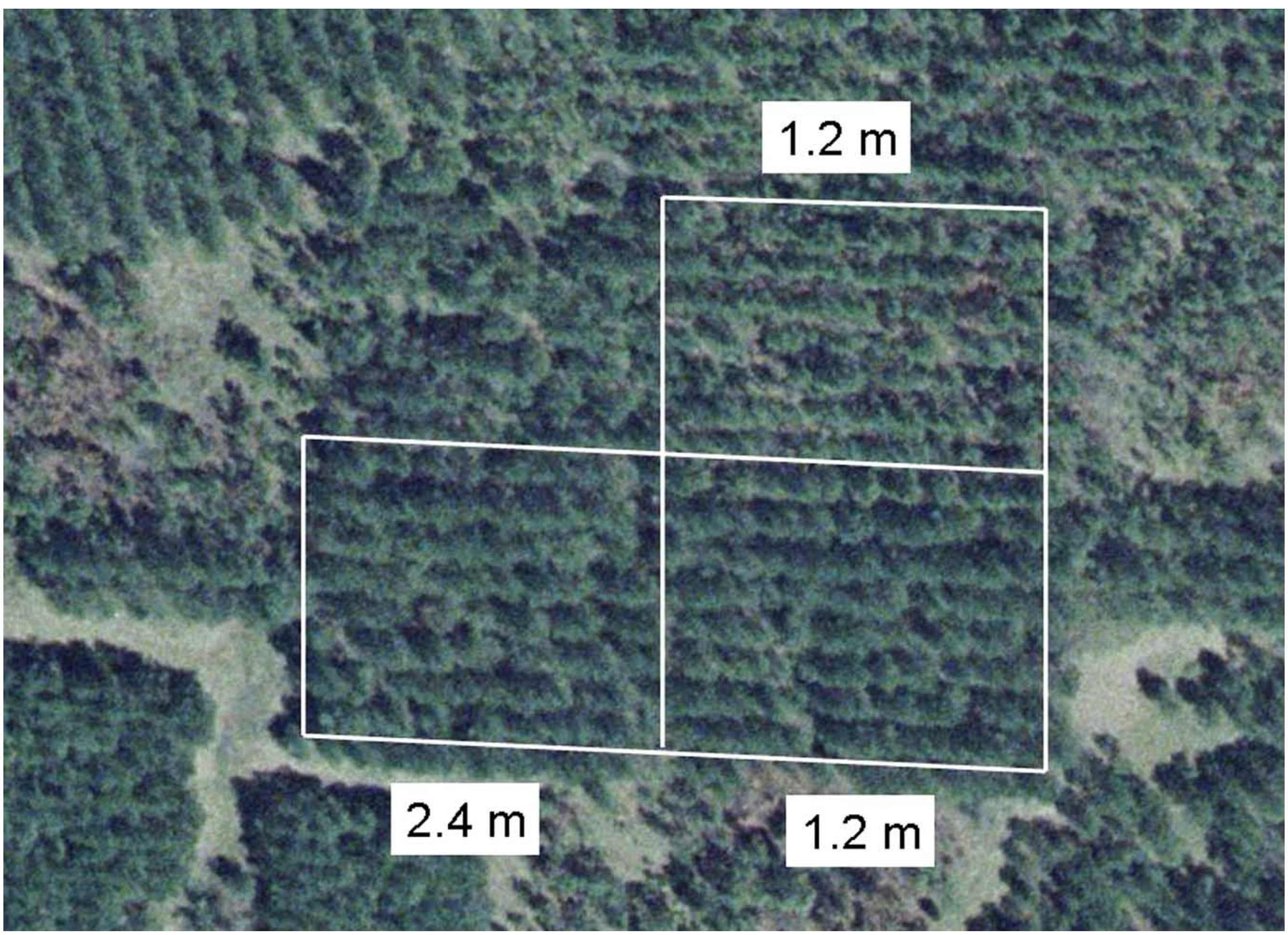

Fig. (1). Areal view illustrating the degree of canopy closure of three experimental units at age 11 years (March 9, 2008). *Pinus elliottii* was planted in the top square and *Pinus taeda* was planted in the bottom two squares. Row spacing was 6.1 meters and spacing within the row was either 1.2 m or 2.4 m. Each square represents approximately 0.24 ha (49 m x 49 m).

AC® (170 g acid equivalent of imazapyr) per ha. A second application (1.8 m band) containing 363 ml of Fusilade® (218 g active ingredient of fluazifop-P-butyl) per ha was made in July in an attempt to suppress the growth of grasses. Mowing grasses between the rows occurred twice after planting. A prescribed burn was conducted on 2/27/2008.

Rainfall

Precipitation recorded at Evergreen, Alabama (31° 25' N, 87° 03' W; 78 m a.s.l.) averages 1627 mm/year and from 1997 to 2010 it varied from a low of 952 mm (2006) to a high of 1942 mm (2009). Typically, October is the driest month (70 mm) with March as the wettest month (187 mm). Based on Palmer Drought Severity Index (PDSI) values for south Alabama, there was no drought in 1997 but severe droughts (PDSI <-3) occurred in 2000, 2006 and 2007. An extreme drought (PDSI<-4) occurred from July to October, 2000 (20, 71, 75, 10 mm/month). Severe droughts occurred from July to September 2006 (136, 38, 113 mm/month) and from August to September 2007 (3, 112 mm/month).

Measurements

In May of 2010, plots were sampled for DBH and two dominant trees from each plot were measured for height. Sampled areas varied with initial stocking; 0.04 ha measurement plots for 1.2 m spacing and 0.09 ha plots for 2.4 m spacing (thus resulting nearly equal numbers of planting locations). To determine stand values, the merchandizing limits for pulpwood involved DBH values ranging from 11.4 to 19.0 cm (assuming a 10 cm top). Chip-and-saw limits were 19.1 to 29.2 cm (assuming a 15 cm top) while sawtimber limits were >29.4 cm (assuming a 20 cm top). Green weights for each product (by diameter class) were based on the output of stand tables generated using the Ptaeda3 growth and yield model.

Analyses were conducted using the General Linear Model procedure in a SAS-PC program [13]. Each procedure utilized a completely randomized design with three treatments and four replications (12 experimental units). Contrast statements were used to test the following hypotheses: dependent variables were not affected by (1) pine species composition and (2) increasing planting density from 672 SPH to 1344 SPH.

Simulations

The Ptaeda 3 program [14] was used to estimate survival, growth and green mass of *Pinus taeda* when planted in rows 6.1 m apart (using the "new stand" option). The model simulated growth on a well-drained Coastal Plain site utilizing the "chop and burn" option. A site index of 26 m (base age 25 years) was selected in order to achieve similar height and basal area production for measured 1344 SPH plots. The simulated dominant heights reported here were determined by averaging the height of the 25 largest trees per ha. Merchandizing limits used in the model were identical to those described above.

RESULTS

Survival was not significantly affected by species (Table **1**). In contrast, the 1.2 m spacing reduced survival by 24 percentage points (57% *vs* 81%) (Table **2**). Survivals of the eight Pinus taeda plots were (57, 57, 54, 59 and 91, 67, 83, 82). As expected, doubling initial planting density reduced average DBH, in this case by 3 cm (Table **2**). In contrast, basal area was not affected by doubling the number of trees planted (average basal area for *Pinus taeda* was 29.8 m^2/ha (Table **2**)). In *Pinus taeda* stands, basal area of the interplanted *Pinus palustris* was less than 1.2 m^2/ha and this amounted to less than 4% of the total basal area. As expected, the lower stocking produced more trees in the higher diameter classes and this resulted in a greater amount of logs in the chip-and-saw category. In this trial, the within-row spacing had no significant effect on the estimated tonnes ($P=0.67$) or on the height of dominants and co-dominants ($P = 0.23$). However, planting density did affect the production of chip-and-saw and sawtimber (Tables **2** and **3**).

The Ptaeda3 scenarios suggested no effect on survival by age 13 years (Tables **2**). When considering both establishment costs and product mix, the computer simulation of the 1344 SPH treatment resulted in the highest NPV (Table **3**).

At this location, *Pinus elliottii* was not as productive as *Pinus taeda* (Table **4**). The average DBH for *Pinus taeda* was 4.6 cm larger than *Pinus elliottii* and heights of dominants and co-dominants were 1 m taller. At age 13 years, *Pinus taeda* produced twice the tonnage of merchantable logs (Table **3**).

DISCUSSION

Survival

Independent of planting density, one might expect 2 to 3 percent greater mortality when unthinned 20-year-old pines are 1.2 m apart instead of 2.4 m apart within the row (Table **5**). Therefore, we expected no large treatment induced difference in mortality at age 13 years. Simulations using Ptaeda3 and previous research in Florida [6], did not show additional mortality when 13-year-old pines were spaced 1.2 m apart within the row. Although predicted survival for plots planted at 672 SPH (81%) was very close to the estimated value (Table **3**), survival of plots planted at 1344 SPH (57%) was much lower than expected (81%). The reason for the lower survival of trees planted 1.2 m apart might be due to severe summer droughts when trees were 9 and 10-years old. The timing of the severe droughts likely induced stress on trees planted 1.2-m apart and this could have attracted bark beetles [15-17]. According to a Westvaco Stocking Chart, beetle induced mortality can occur when the stocking level is less than 100% and average DBH is greater than 20 cm [15]. A preliminary survey at age 5 years indicated excellent survival (i.e. 90%) for 1344 SPH plots, but in 2010 there were a number of standing dead trees with signs of egg galleries. Trees that were 2.4 m apart were likely under less stress than trees 1.2 m apart. A similar pattern was observed

Table 1. Probability of a Greater *F*-Statistic for Trees Per Ha (TPH), Percent Survival, Mean Diameter at Breast Height (DBH), Height of Dominants (DHt), Basal Area Per Ha (BA), Mass Estimate of Pulpwood (PULP), Chip-and-Saw (CNS), Sawtimber (SAW) and Total Green Mass Per Ha (TGW) in 2010

Species (within-Row Spacing)	d.f.	TPH	Survival	DBH	DHt	BA	PULP	CNS	SAW	TGW
Treatment	2	0.0019	0.0428	0.0005	0.0050	0.0587	0.0001	0.0050	0.0164	0.0074
P.taeda *vs* P.elliottii (1.2 m)	(1)	0.1198	0.1723	0.0049	0.0183	0.0258	0.0032	0.0029	0.1157	0.0039
P.taeda (1.2 m *vs* 2.4 m)	(1)	0.0079	0.1583	0.0349	0.2271	0.5876	0.0023	0.7642	0.0869	0.6737
Error	9									

Table 2. Effect of Species and Planting Density on Trees Per Ha (TPH), Percent Survival, Diameter at Breast Height (DBH), Height of Dominants (DHt), Basal Area Per Ha of Pines Planted in 1997 (BA) and Basal Area of interplanted *Pinus palustris* (PP-BA). Simulated Results for *Pinus taeda* are Listed as Ptaeda3

Pinus Species	Planting Density	Row Width	TPH	Survival	DBH	DHt	BA	PP-BA
	#/ha	M	#/ha	%	cm	m	m^2/ha	m^2/ha
P.taeda	672	6.1	546	81	25.1	16.8	28.3	1.1
P.taeda	1344	6.1	768	57	22.1	16.2	31.3	0.2
P.elliottii	1344	6.1	983	65	17.5	15.2	22.2	1.7
(L.S.D. α= 0.05)	--	--	(167)	(13)	(2.8)	(0.8)	(5.2)	-
Ptaeda3	672	6.1	549	82	22.6	18.6	22.8	-
Ptaeda3	1344	6.1	1112	83	18.3	17.8	30.3	-
Ptaeda3	1344	3.05	1112	82	18.8	17.7	31.9	-

Table 3. A Comparison of Green Mass of Merchantable Logs and Associated Economic Values with Simulated Values Using Ptaeda3. Prices for Pulpwood (Pulp), Chip-and-Saw (CNS) and Sawtimber (SAW) Size Logs are Assumed to be \$12, \$18 and \$28 Per Green Tonne, Respectively

Pinus Species	Planting Density	Row Width	Pulp	CNS	SAW	Total	Harvest Value	Seedling Cost	H+M	NPV
	#/ha	m	Mg/ha	Mg/ha	Mg/ha	Mg/ha	\$/ha	\$/ha	\$/ha	\$/ha
P.taeda	672	6.1	39	67	65	171	3494	33.6	133	1438
P.taeda	1344	6.1	49	102	26	177	3124	67.2	133	1264
P.elliottii	1344	6.1	46	42	0	88	1308	67.2	133	413
Ptaeda3	672	6.1	34	90	0.5	125	2048	33.6	133	793
Ptaeda3	1344	6.1	72	71	0	143	2140	67.2	133	803
Ptaeda3	1344	3.05	71	82	0	153	2324	67.2	266	756

H+M = cost of banded herbicide applications plus machine planting; Harvest value = revenue from wood harvested at age 13 years; NPV = net present value using a 6% interest rate.

with *Pinus elliottii* where survival of seedlings planted 1.2 m apart was 65% (Table **2**) but seedlings from a different nursery planted 2.4 m apart (the following year) had 83% survival (data not shown). These observations suggest that planting pines 1.2 m apart within the row may, on some sites, increase the risk of attracting beetles such as the Ips engraver beetles (Ips spp.).

DBH and Dominant Height

The data and the Ptaeda3 simulations were in agreement when considering the ranking of DBH and dominant height. The 672 SPH treatment produced the larger average DBH and dominant trees were taller (Table **2**). Ptaeda3 suggested denser plots would be 0.8 m shorter while the measurements were 0.6 m shorter. The difference is very similar, especially since a difference of 0.8 meter is required to detect a significant difference (Table **2**). Simulated heights were taller than measured heights which might be accounted for by differences in the pattern of height growth. The Ptaeda3 curve is a generalized pattern for a mix of genotypes planted on chopped and burned sites while a particular genotype was planted on the orchard site.

Growth

As expected, *Pinus taeda* growing on this Coastal-Plain site produced more merchantable green tonnes of wood than *Pinus elliottii*. The mean annual increment (MAI) for *Pinus elliottii* was 6.8 green tonnes/ha/yr while that for *Pinus taeda* was 13.5 green tonnes/ha/yr. The higher productivity may be due to a greater leaf area for *Pinus taeda* [18] (Fig. **1**).

Table 4. Distributions by Diameter Class at age 13-Years of Pines Planted in 6.1 m Rows at the Solon Dixon Educational Center, Alabama and Distributions Simulated for Pinus Taeda Using Ptaeda3

Species	P. elliottii	P. taeda	P. taeda	Ptaeda3	Ptaeda3
Seedlings per ha	1344	1344	672	1344	672
	Measured	Measured	Measured	Simulated	Simulated
DBH Class (cm)	#	#	#	#	#
5	13.5				
7.5	53.8		2.7		
10	78.0	26.9	16.1	30.1	
12.5	118.4	37.6	10.9	118.6	
15	183.0	43.0	8.2	170.3	5.4
17.5	142.6	107.5	40.3	288.6	67.0
20	169.5	91.4	64.5	312.3	102.5
22.5	67.3	182.6	96.9	155.2	191.0
25	35.0	134.4	78.1	36.6	143.6
27.5	5.4	86.0	72.6		41.0
30		32.1	91.4		1.0
32.5		26.9	48.4		
35			16.3		
Total (#/ha)	867	768	546	1112	551
Basal area (m^2/ha)	22.2	31.3	28.3	30.3	22.8
Survival (%)	65	57	81	83	82

Table 5. Effect of Row Spacing and Age on Predicted Survival of Unthinned, *Pinus taeda*. Predicted Values Determined Using the Ptaeda3 Growth and Yield Program (Site Index 26 m – Base Age 25 Years). The Simulated Survival Data Suggest an Interaction Between Planting Density and Rectangularity Ratio

Planting Density	Row Width	WITHIN ROW	Rectangularity	10 yr	20 yr	30 yr	40 yr	50 yr
#/ha	m	m	ratio	%	%	%	%	%
1122	7.3	1.2	6	83	80	67	52	38
1122	3.66	2.4	1.5	83	80	67	52	38
Difference				0	0	0	0	0
1346	6.1	1.2	5	83	77	62	48	36
1346	3.05	2.4	1.25	83	79	66	50	38
Difference				0	2	4	2	3
1683	4.8	1.2	4	83	74	57	42	31
1683	2.4	2.4	1	83	77	61	44	32
Difference				0	3	4	2	1

Others have also reported more volume growth when *Pinus taeda* and *Pinus elliottii* are growing in adjacent plots [19].

Simulations using Ptaeda3 produced a MAI of 11 tonnes/ha/yr which is slightly lower than the 13 green tonnes/ha/yr (Table **3**). This level of productivity was achieved with no fertilization of the site after 1995. The MAI achieved is less than that reported for intensively managed stands in adjacent states. For example, the MAI for fertilized plantations in Georgia (age 12 yr) was more than 27 green tonnes/ha/yr [20]. In Florida, fertilized Pinus taeda stands achieved a MAI at age 14 yrs of about 14.5 tonnes/ha/yr [19]. The relatively high MAI observed at the Solon Dixon Forestry Education Center is likely due, in part, to residual fertilization of the orchard and the long time period since pines last occupied the site.

In theory, doubling the number of seedlings planted should have increased merchantable biomass (Table **3**). According to Ptaeda3, planting 1344 SPH (instead of 672 SPH) might increase biomass by 100%, 18% and 8% at ages 4, 13 and 25 years, respectively. However, the increase in biomass observed at age 13 years was only 4% (Table **3**) which was not statistically different from zero (P=0.67). In a few cases, others have also reported no difference in merchantable green tonnes/ha (at year 21) when doubling planting density from 897 SPH to 1797 SPH [5]. The difference in merchantable tonnage on 1344 SPH plots may have been greater at this site had we included the standing, beetle killed trees as merchantable.

Diameter Distributions

The Ptaeda3 simulations produced seven DBH classes for both within-row spacings while actual distributions contained 10 or 12 DBH classes (Table **4**). DBH values in 672 SPH plots ranged from 7.3 to 37.1 cm while those in the 1344 SPH plots ranged from 9.4 to 34 cm. As a comparison, one intensively managed stand (site index = 8 m and 956 TPH) in Florida had 25-year-old trees that ranged from 12.7 to 35.3 cm [19]. Others have reported 14 DBH classes for a 21-year-old stand established with 746 SPH [5]. Since the range in diameters at this site was greater than predicted by Ptaeda 3, the 1344 SPH stand contained more sawlogs (even though estimated basal area was similar to observed basal area).

Economic Considerations

The realized economic gains were greater than those predicted using Ptaeda3. The harvest value of *Pinus taeda* planted at 672 SPH was almost $3,500 while the simulated stand was valued at less than $2,050 (Table **3**). For the 1344 SPH, the observed and simulated values were $3,124 and $2,140, respectively. The 50% disparity was not due to a difference in height or basal area/ha, but was due to variation in diameter distributions (Table **4**). For the 1344 SPH treatment, one ha had 59 sawtimber trees while none were predicted with Ptaeda3.

This brings out an important aspect about stand uniformity and stand value. In some cases, a perfectly uniform stand can have less standing value than a stand that contains a typical range of diameter classes [21-23]. For example, if we assume all trees in the 672 SPH stand were in a single diameter class (quadratic mean DBH = 23 cm), the stand would contain about 78% chip-and-saw and might have a standing value of $2,852/ha. Therefore, achieving this level of uniformity would lower stand value by about $642/ha. This is because the uniform stand would contain no sawtimber-sized trees.

Although some just ignore establishment costs when conducting an economic analysis, conclusions regarding the best treatment are on firmer ground when both costs and timber revenue are discounted to year zero. This is especially true when establishment costs vary with treatments. For example, in some situations the cost to establish a pine plantation might be cut in half by doubling the width between rows (Table **3**). This is, in part, because the costs of machine planting (and banded herbicide treatments) are directly related to the distance between rows [24]. In theory, the cost of hand-planting is also related to row spacing. This is because the time required to plant 1500 SPH in 6-m rows is half that required for 3-m rows. However, some landowners might not benefit from the savings when planting costs are charged on an area basis instead of a time basis. Since employing wider rows (and lower initial stocking) can decrease establishment costs and may increase sawtimber yields (Table **3**), this might help to explain why some company foresters now plant pines using a 6.1-m row spacing.

Over fifty years ago, Wakeley [25] recognized that wide rows could reduce establishment costs. Even so, many tree planting guides continued to recommend square planting designs, or sometimes rectangular ratios that are less than 1.7. For example, one planting guide on the internet lists six square designs and two with rectangular ratios less than 1.7. Rectangularity ratios of 2 are sometimes used in Europe because of decreased establishment costs and increased accessibility [26]. Intensively cultured, short-rotation hybrid poplar (*Populus* spp.) plantations are commonly planted in rectangular configurations to accommodate mechanized equipment [27].

There are two reasons why the stand values presented here are conservative in respect to favoring low planting densities. The main reason is a relatively low ratio of sawtimber price to pulpwood price (i.e. 2.3 ≈ $28/$12) that favors regimes that produce more pulpwood. A recent publication used a sawtimber/pulpwood ratio greater than 6 (i.e. $38/$6) and a recent timber auction at the Dixon Center obtained a ratio of 3.2 ($32/$10). The second reason involves logging costs, which are not included in this analysis. When two stands contain the same mass of logs, logging costs will be less for the stand that contains 30% fewer trees. For example, the feller in this study would have had to make 40% more cuts per ha when harvesting all the trees.

Ingrowth, Knots and Wildlife

Some foresters are concerned that wide spacings may reduce yields due to increased competition from non-pine species. A wider spacing allows extra light to reach the forest floor [28-29] and this would, in theory, increase ingrowth by hardwoods. However, at the Dixon Center site, there were few hardwoods present in the stand at age 13 years. This is because the previous crop was a pecan orchard and the area was prescribed burned in 2008.

Some foresters will not recommend planting pines in 5 or 6 m rows because they are concerned about the effects of wide rows on knot size. However, most *Pinus taeda* studies have shown a minimal (e.g. <3 mm) effect of density and rectangularity on average knot size. A rectangularity ratio of 8 produced no significant effect on the size of the largest branch in Georgia [10]. In Louisiana, researchers found when grown at 1075 SPH, a rectangularity ratio of 2.7 produced knots that averaged 1 mm larger (not significant) than did a ratio of 1.5 [30]. Knots measured from another study in Georgia at 748 SPH (square spacing) were 7.6 mm larger than at a 1497 SPH spacing [5]. In Virginia, a rectangularity of 3 had knots that were 0.7 to 1.6 mm larger than pines in plots with a rectangularity of 1.3 [8] but this small increase was neither biologically nor statistically significant. Therefore, for a given number of seedlings per ha, rectangular ratios up to 3 should not have much effect on lumber quality. In fact, when compared to a square spacing, *Pinus sylvestris* L trials in Finland [31] indicate a rectangular pattern (rectangularity ratio = 5) might reduce average knot size by 0.5 mm. The idea that, on post-agricultural sites, pines should be planted in squares is apparently based primarily on tradition and unjustified fears related to large knots.

Promoting wildlife habitat is an objective of many private landowners and some wildlife species benefit when trees are spaced far enough apart so that light reaches the understory. The amount of browse is related to tree stocking and, as a result, some wildlife professors recommend landowners plant trees 4 m apart or more.

CONCLUSIONS

When using a 6.1 x 1.2 m row spacing, it would be wise to conduct the first thinning when the average DBH is less than 20 cm. Otherwise, severe droughts may stress trees and increase mortality. Stands established using a 6.1 x 2.4 m spacing will be less susceptible to attack by pine beetles than a 6.1 x 1.2 m spacing (even though some growth and yield models suggest little or no effect on survival at age 13 years). When conducting an economic analysis based on expectations of future growth, stand uniformity will affect the analysis. In some cases, too much uniformity can lower NPV.

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