ABSTRACT

Two stock types of loblolly pine (*Pinus taeda* L. [Pinaceae]) were outplanted at 3 spacings: 749, 1122, and 1497 trees/ha (303, 454, and 605 trees/ac). Morphologically improved seedlings were grown at a density of 177/m^2 (16/ft^2) while standard seedlings were grown at a density of 277/m^2 (25/ft^2). Morphologically improved seedlings had an average root-collar diameter of 6.3 mm at time of outplanting and, after 3 y in the field, were taller and had more volume/ha than standard seedlings (4.5-mm root-collar at outplanting). An economic analysis was conducted based on 20-y volume estimates from a growth and yield program. If seedling cost is increased by 0.7 cent (due to growing at a low seedbed density) then outplanting cost per ha can be reduced by outplanting 750 morphologically improved seedlings instead of 1500 standard seedlings. Overall establishment costs might be reduced by US$ 108/ha ($44/ac) and the net present value of the stand might be increased by 10% or more (due to increasing the production of sawlogs). From this and other analyses, we determined that an important economic relationship exists between outplanting density and seedling quality.

KEY WORDS

Pinus taeda, bareroot, seedling quality, stocking, economics, loblolly pine

NOMENCLATURE

USDA NRCS (2004)

REFORESTATION CO$TS can be decreased by lowering initial stocking and outplanting morphologically improved seedlings

| David B South, Curtis L VanderSchaaf, and John R Britt

It is well-known that seedbed density affects early seedling performance of loblolly pine (*Pinus taeda* L. [Pinaceae]) nursery stock (Shoulders 1961; Switzer and Nelson 1963; Shipman 1964; Rowan 1986). Seedlings grown at densities less than 220 seedling/m² (20/ft²) typically outperform smaller seedlings grown at densities of 277/m² (25/ft²) (South 1993). In some cases, the gain in height at age 7 y can be 0.3 to 1 m (1 to 3.3 ft) (South and Rakestraw 2004). Because seedlings grown at densities less than 220/m² have more roots, a greater root-collar diameter (RCD), and a greater performance potential than standard seedlings, they are sometimes sold as "morphologically improved" seedlings (South 2000). A few forestry consultants and some forest companies plant morphologically improved seedlings because the benefit-to-cost ratio is attractive when long-term economics are considered (Caulfield and others 1987; South 1993).

Despite greater performance for morphologically improved seedlings, some foresters do not rely on economic analyses and instead recommend that landowners plant standard seedlings. They recommend standard stock because seedlings with 4-mm RCD are cheaper to purchase and are easier to plant by hand than morphologically improved seedlings (Blake and South 1991). As survival rates with standard seedlings are often lower under adverse conditions, however, these foresters often recommend outplanting more than 1000 per ha (400/ac). This combination (high outplanting rate and standard seedlings) often increases the overall cost of reforestation while reducing the production of large-diameter sawlogs.

Therefore, an important economic relationship exists between outplanting density and seedling quality. When valuable, high quality seedlings are used, the economic justification for outplanting more trees than needed is reduced (Maclaren 1993; South 1993). For example, at current prices, the cost of seedlings grown at 277/m² (25/ft²) could be 4 cents each and those grown at 177/m² (16/ft²) may be 4.7 cents each. Assuming machine planting in 3.7 m (12 ft) rows costs US$ 124/ha ($50/ac), then outplanting 1497 (600/ac) seedlings (average RCD = 4 mm) on a field previously used for farm crops might cost $183/ha ($74/ac) to establish while 749 seedlings (300/ac) (average RCD = 6 mm) might cost $159/ha ($64/ac). In this case, the landowner could reduce the cost of establishment 13% by outplanting fewer but higher quality seedlings. The question then becomes what are the long-term economic gains from outplanting fewer, high quality seedlings? To address this question, a study was installed by Mead Coated Board in Alabama. This is the first loblolly pine study to examine the effects of both seedling quality and outplanting density on the performance of loblolly pine.

MATERIALS AND METHODS

Seedlings were grown at the Buena Vista Forest Seedlings Nursery, Georgia. Seeds were obtained from a 1.5 generation Atlantic Coast seed orchard. Two bed densities (277 and 177 seedlings/m²

[25 and 16/ft²] were established in separate units at the nursery (that is, density was not replicated). At time of lifting, 60 seedlings from each bed were sampled and measured for heights and diameters. Shoots and roots were oven-dried for 72 h and roots were separated into laterals and taproots. The remaining seedlings were outplanted on a cutover site in Macon County, Alabama. The soil was a moderately well-drained Conecuh fine sandy loam (clayey, montmorillonitic, thermic, Aquic Hapludult) with 1% to 3% slopes. Three outplanting spacings were used: 749, 1122, and 1497 trees/ha (303, 454, and 605 trees/ac). The row spacing for each density was 3.7 m (12 ft). Site preparation consisted of shearing and raking in June 1999. In May 2000, the area was aerially sprayed with 840 g of imazapyr/ha (48 fl oz of Chopper®/ac) and 1120 g of glyphosate/ha (1 qt of Accord SP®/ac). Continuous mounds were formed on a 3.7-m spacing in July 2000. Seedlings were hand-planted on 11 January 2001.

An application of 575 g of hexazinone and 107 g of sulfometuron/ha (13 fl oz of Oustar®/ac) was applied in a band over the seedlings on 1 May 2001. This treatment was repeated on 25 April 2002. Diameter at breast-height (DBH) and total tree height were measured in March 2004. Individual tree volume was calculated using a formula developed by Van Dusen and others (1981).

Analyses were conducted using the General Linear Model procedure in a SAS-PC program (SAS Institute Inc 1989). The analysis involved a randomized block, factorial design with planting stock (that is, seedbed) as one factor and initial outplanting spacing as the other factor. Four blocks were established for a total of 24 measurement plots. There were 96 trees/plot with 72 interior measurement trees. To examine relationships between outplanting density and seedling performance, linear and lack-of-fit contrasts were conducted (Mize and Schultz 1985).

The NCSU Managed Pine Plantation Growth and Yield Simulator (Hafley and Buford 1985) was used to predict the effects of stocking and stock type on stand development to age 20 y. Seedlings grown at 177/m² were assumed to achieve a 6-mo advance in stand development (when compared to seedlings grown at high seedbed densities). A 6-mo advance for morphologically improved seedlings was obtained by averaging outputs for years 20 and 21. Mature wood formation is assumed to begin after 12 y (Clark and Saucier 1989). The percentage of basal area in juvenile wood was calculated by comparing the basal area of the average tree at age 12 with that at age 20.

RESULTS

At lifting, seedlings from the low-density bed were larger than seedlings grown at 277/m² (25/ft²) (Figure 1). The difference in average RCD between seedling groups was about 1.8 mm (Table 1). All measured seedling variables at time of outplanting were significantly different. After 3 y in the field, seedbed location affected loblolly pine growth (Table 2). Overall survival was high and therefore there were no significant treatment effects. Morphologically improved seedlings (those grown at 177/m² [16/ft²]) were on average taller and larger in DBH than the standard seedlings grown at 277/m² (Table 3). On average, morphologically improved seedlings (Figure 2) were taller than standard seedlings (Figure 3). An interaction, however, was present between seedbed location and field spacing. Morphologically improved seedlings had larger diameters and heights only when outplanted at densities greater than 1100 trees/ha (450/ac).

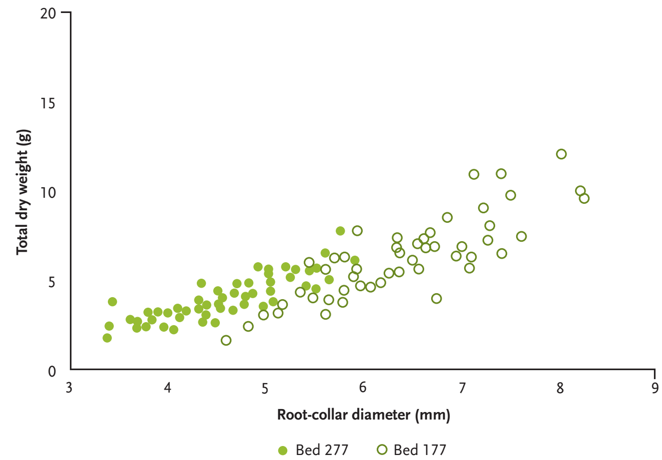

Figure 1. Relationship between root-collar diameter and total seedling dry weight for *Pinus taeda* seedlings (60 seedlings from each of 2 seedbeds).

Predicted merchantable volumes were compared for 2 spacing and stock type options (Table 4). In this example, doubling the number of seedlings outplanted increased the merchantable volume by only 15%. The increases in pulpwood and chip-n-saw volume resulted in a 78% decrease in sawtimber volume. As a result, the lower stocking of morphologically improved seedlings (along with a wider row spacing) increased net present value by US$ 258/ha ($104/ac). Regardless of establishment regime, the predicted basal area in juvenile wood (at age 20 y) was about 50%.

DISCUSSION

Recommendations regarding the "correct" outplanting density for pines are often based on traditional beliefs (Bennett 1969; South 2003). Rarely are stocking recommendations based on an economic analysis that involves outplanting morphologically improved seedlings (South and others 1995, 2001; South 2003). As a result, landowners in the southern US typically purchase 4-mm seedlings and outplant twice as many pines as do New Zealand farmers who usually plant 790 seedlings/ha (320/ac). In New Zealand, Maclaren (1993) says that "High initial stockings

(1200 to 2000 trees/ha) are expensive because of the cost of seedlings, outplanting, weed-control, etc., as well as the cost of thinning the surplus trees, if they are not to be extracted and sold." In the southern US, high initial stockings (1235 to 3200 seedlings/ha [500 to 1300/ac]) are expensive because of the cost of extra seedlings, added cost of outplanting (when time required to plant an area is increased), cost of extra chemicals (when banded treatments are used), extra cost associated with thinning (if employed), and reduced production of large logs at harvest (assuming a harvest age of 20 to 25 y). In some cases, outplanting more seedlings might increase the cost of establishment by US$ 108/ha ($43/ac) (Table 4). In addition, high stocking increases the risk of injury from southern pine beetle (*Dendroctonus frontalis* Zimmermann [Coleoptera: Scolytidae]).

It is not only less expensive to plant 750 seedlings/ha (300/ac) with a 6-mm RCD (Table 4) but also the projected production of 20-y-old sawlogs can be increased by 350% (when compared to outplanting twice as many seedlings/ha). Even greater increases in sawlog production have been reported from spacing trials (Clason 1989). Therefore, a win-win situation can be realized by lowering establishment costs and increasing the probability of producing 28 to 33 cm (11 to 13 in) diameter logs (Figure 4).

Some recommend precommercial thinning (PCT) of overstocked stands but the cost to the landowner can be US$ 170/ha ($69/ac) and might exceed $250/ha ($100/ac) (Moorhead and others 1998; Dubois and others 2003). At a 6% interest rate, the value of a 20-y-old stand would have to increase by at least $458/ha ($185/ac) for a PCT ($170/ha [$69/ac] at age 3 y) to "break-even." Waiting until after age 4 to perform a PCT might not justify this additional cost (assuming a 20-y rotation). On high-hazard sites for annonus root rot (*Heterobasidion annosum* (Fr) Bref. [Bondarzewiaceae]) thinning from September to May can increase the risk of disease (Nebeker and others 1985). Since pulpwood prices are now lower than in the past, commercial thinning at age 13 to 15 y usually returns little or no revenue to the landowner.

The economic incentives for outplanting morphologically improved seedlings are greater when outplanting 750 versus 1500 trees/ha (300 versus 600/ac) (South 1993). For example, when machine planting 1500 morphologically improved seedlings/ha, establishment costs could increase by at least US$ 11.50/ha ($4.65/ac). The associated gain from a 6-mo advance in stand development would only be $34.12/ha ($13.80/ac) (data not shown). Using this logic, some foresters do not believe the use of morphologically improved seedlings is warranted. When combining morphologically improved seedlings with low stocking, however, the economic gains can be substantial (Table 4). Therefore, instead of just considering the price of morphologically improved seedlings, we recommend a more holistic approach when comparing the costs and benefits of outplanting morphologically improved seedlings.

TABLE 1

Seedling morphological characteristics at time-of-outplanting for 2 seedbed densities.

Seedbed density (number/m²)	Height (cm)	RCD (mm)	Lateral root dry weight	Taproot dry weight	Shoot dry weight
			(g)		
177	32.1 (4.1)	6.34 (0.8)	0.59 (0.4)	0.55 (0.4)	5.11 (1.9)
277	27.6 (2.1)	4.55 (0.6)	0.27 (0.1)	0.39 (0.1)	3.25 (1.0)

Note: Variables within a column are significantly different (t-test; $\alpha = 0.01$). Values in parentheses represent standard deviations (n = 60 per bed).

Conversions: (number/m²) • 0.09 = number/ft²
cm/2.54 = in
mm/25.4 = in
g/28 = oz

TABLE 2

Probability of a greater F-statistic for third-year field survival, arithmetic mean second-year height (HT), quadratic mean diameter at breast height (QMD), basal area per ha (BA), volume per ha (VOL) of Pinus taeda.

Factor	df	Survival	HT	QMD	BA	VOL
Block	3	0.2123	0.0223	0.0457	0.0333	0.0145
Seedbed (S)	1	0.6162	0.0008	0.0080	0.0016	0.0011
Tree spacing (TS)	2	0.2463	0.1896	0.0698	0.0001	0.0001
Linear	(1)	0.1880	0.2599	0.0438	0.0001	0.0001
Lack of fit	(1)	0.2947	0.1459	0.2327	0.3253	0.2427
S x TS	2	0.2379	0.0256	0.0628	0.0244	0.0222
Error	15					

TABLE 3

Effect of seedbed location (177 or 277 seedlings/m² [16 or 25/ft²]) and outplanting stocking on third-year survival (TPH), quadratic mean diameter (QMD), arithmetic mean height (HT), basal area per ha (BA), and volume per ha (VOL).

Seed bed	Stocking (number/ha)	Survival (%)	TPH (number/ha)	QMD (cm)	HT (cm)	BA (m²/ha)	VOL (m³/ha)
177	749	98	736	4.32	302	1.10	2.3
	1122	97	1087	4.34	308	1.66	3.4
	1497	95	1417	4.31	315	2.17	4.5
	Mean	97	1080	4.32	308	1.64	3.4
277	749	97	728	4.39	304	1.14	2.4
	1122	94	1056	3.71	268	1.19	2.7
	1497	97	1448	3.74	274	1.65	3.8
	Mean	96	1077	3.94	282	1.33	3.0

Conversions: (number/ha) • 0.4 = number/ac
cm/2.54 = in
(m²/ha) • 4.4 = ft²/ac
(m³/ha) • 14.3 = ft³/ac

Figure 2. Morphologically improved loblolly pine seedlings outplanted at 749/ha (303/ac) average 3.0 m (9.9 ft) in height 3 y after transplanting.

Photos by David B South

Figure 3. Standard loblolly pine seedlings outplanted at 1497/ha (605/ac) average 2.7 m (9.0 ft) in height 3 y after transplanting.

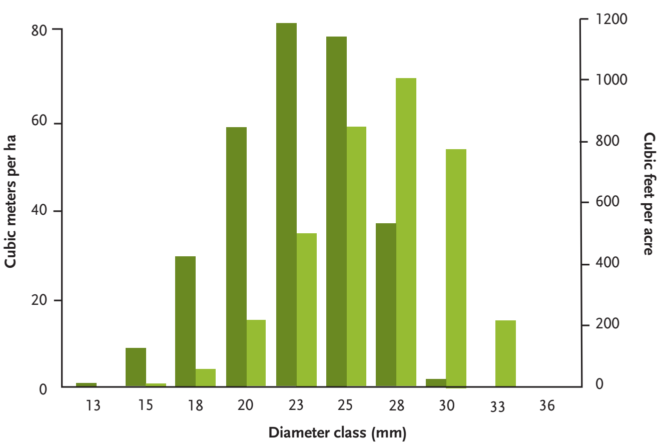

Figure 4. Simulated yield of 20-y-old loblolly pine from stands outplanted at 1500 standard seedlings/ha (600/ac; 4-mm root-collar diameter; dark green bars) and 750 morphologically improved seedlings seedlings/ha (300/ac; 6-mm root-collar diameter; light green bars).

When logs of the same age are compared, there is no relationship between growth rate and specific gravity for loblolly pine (Megraw 1985). As a result, the specific gravity of loblolly pine is about the same when outplanted at either 747 or 2990 seedlings/ha (300 or 1200/ac) (Clark and Saucier 1989). The NCSU model estimates about 50% of the basal area at DBH will be in juvenile wood, which is close to that reported for 20-y-old trees in the Atlantic Coastal Plain (Clark and Saucier 1989). In contrast, tree age does affect wood quality (Biblis and Carino 2002). A 28-y-old plantation might produce 5% more lumber that meets moderately high design values (that is No. 1 and No. 2 grade) than a 22-y-old stand (Clark and others 1996). The small increase in lumber value, however, would not keep up with the power of discounting (South 2003).

Future measurements of this study can provide insights into the realized age-shift gain attributed to outplanting morphologically improved seedlings. When growth rates are high, significant volume gains can be achieved by age 13 y (South and others 1985; South and Rakestraw 2002). It has been estimated that outplanting morphologically improved seedlings (with 6-mm RCD) can sometimes result in a 1-y "age-shift" when compared to standard seedlings with 4-mm RCD (South 1993). The Macon County study clearly shows an age-shift in stand development has occurred. When outplanting more than 1100 trees/ha (445/ac), morphologically improved seedlings increased average height by 0.4 m (1.3 ft). Future data will be useful in determining if the age-shift in this study is closer to 6 mo or 1 y.

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TABLE 4

Simulated effects of 2 management regimes on trees per ha; diameter at breast height (DBH); percent basal area in juvenile wood; pulpwood, chip-n-saw and sawtimber volumes; stumpage value, and net present value. For this example, morphologically improved seedlings are assumed to increase stand development by 6 months when compared to standard seedlings. All values in US$. Stumpage values are $10.00, $8.83, $31.78 and $44.14 per cubic meter for hardwood pulpwood, pine pulpwood, chip-n-saw, and sawlogs, respectively. Volumes calculated from the North Carolina State University Plantation Management Simulator for site index 24 m (base age 25) in the upper Coastal Plain.

VARIABLE		SEEDLING TYPE	
		Standard	**Morphologically improved**
Seedling root-collar diameter	mm	4	6
Outplanting rate	number/ha	1500	750
Row spacing	m	3	4
Mixed hardwoods at age 5 y	m^2/ha	1.4	1.4
Initial survival	%	97	98
Pine stocking at 20 y	number/ha	1129	670
Mixed hardwoods at age 20 y	m^2/ha	3	4
DBH (3.47 m) at harvest	cm	21.8	25.5
Average height at harvest	m	18.9	19.8
Percent basal area in juvenile wood (DBH)	%	50	50
Total merchantable volume	m^3/ha	258	225
Hardwood pulpwood	m^3/ha	2	4
Pine pulpwood	m^3/ha	161	121
Pine chip-n-saw	m^3/ha	80	32
Pine sawlogs	m^3/ha	15	68
Stumpage value at harvest	$/ha	4646	5127
Herbicide application (site preparation)	$/ha	225	225
Cost of shipping seedlings to planting site	$/ha	3	2
Seedling cost	$/ha	60	35.25
Hand planting cost	$/ha	125	75
Herbicide application (2 m band–after planting)	$/ha	133	100
Total establishment costs	$/ha	546	437.25
Net present value (6% discount rate)	$/ha	903.62	1161.35

Conversions:
mm/25.4 = in
(number/ha) • 0.4 = number/ac
m/3.3 = ft
(m2/ha) • 4.4 = ft^2/ac
cm/2.54 = in
(m^3/ha) • 14.3 = ft^3/ac
(US$/ha) • 0.4 = US$/ac

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