What Are the Best Loblolly Pine Genotypes Worth to Landowners?

Steven E. McKeand, Robert C. Abt, H. Lee Allen, Bailian Li, and Glenn P. Catts

ABSTRACT

Forest landowners in the South can realize large financial benefits from planting the best loblolly pine (*Pinus taeda* L.) genotypes. Most of the productivity increases from genetics can be considered as increases in site index. We estimate that landowners can realize net present values of $50 to over $300/ac across a range of productivity and silvicultural management regimes simply by planting the best genotypes that are currently available from commercial and state forest nurseries. Landowners could pay more for the best genotypes, and the best seedlings would be well worth the additional costs.

Keywords: genetic gain, growth and yield, *Pinus taeda* L., tree improvement

Tree improvement has been a standard silvicultural tool in southern pine regeneration programs in the South for almost 50 years. Virtually all of the almost 1 billion loblolly pine seedlings planted annually come from tree improvement programs (McKeand et al. 2003) with the price for improved seedlings typically ranging from $40 to 60/thousand. Financial returns from tree improvement programs generally been high (e.g., Talbert et al. [1985]) because of both the modest price of improved seedling and the increased forest productivity and value realized from planting improved stock (Li et al. 1999).

Estimates of genetic gains from the second generation of seed orchards throughout the South have been about double the gains from the first generation. Estimated volume improvements over unimproved seed lots for rotations of 25 years ranged between an average of 13% in the Atlantic Coastal Plain and 21% in the Piedmont regions of North Carolina, South Carolina, and Georgia. If only the best open-pollinated (OP) families are planted from rogued seed orchards, the estimated genetic gains in volume growth are even higher, from 26 to 35% (Li et al. 1999). A recent analysis showed that potential genetic gains of full-sib (FS) families from the best second-cycle parents can produce volume gains over 50% (Jansson and Li 2004). If the improvements in stem form and disease resistance are added, stand value improvements may be twice the volume improvement.

Improved genotypes are increasingly being deployed as single family or clonal blocks to maximize genetic gains in growth, resistance to fusiform rust (caused by *Cronartium quercuum* [Berk] Miyabe ex Shirai f. sp. *fusiforme*), stem form, and wood quality traits (Duzan and Williams 1988, McKeand et al. 1997, McKeand et al. 2006). There are individual families that are substantially higher than the orchard mean, and many foresters are willing to plant a limited number of families on specific sites to increase genetic gain. As of 2002, 59% of all loblolly pine plantations in the South were established as single OP family blocks. For industrial lands, the percentage was even higher, with 80% of the loblolly stands being planted to individual families. In these more genetically homogeneous stands, problems associated with limiting the genetic variation in plantations by planting specific families to specific sites have not been observed. From our survey, there were no plantation failures reported because of planting a particular family on a particular site (McKeand et al. 2003).

Individual OP families, FS families, and selected clones of loblolly pine display remarkable stability and predictability of growth performance across sites in the southern United States. As long as genotypes are planted in climatic zones to which they are adapted (e.g., Schmidtling [2001]), there is little important genotype by environment interaction (rank change) for most traits (McKeand et al. 2006). This stability of performance is important when trying to predict genetic gains in growth across different sites. Across a wide range of sites, a family or clone will yield the same percentage of volume growth improvement on all sites (McKeand et al. 1997).

Although it has been valuable to analyze the average gains and profitability of tree breeding programs to assess the investments made in tree improvement (e.g., Talbert et al. [1985] and van Buijtenen [1984]), these general analyses are of little use to buyers and sellers of improved seedlings. Given that all loblolly pine seedlings come from tree improvement and nursery programs in the South, the appropriate questions are, “What is the best genetic material worth to a landowner?” and “What are the financial benefits of planting the best genetic material?” Over the past 10–20 years, most nurseries have not only sold mixtures of seedlings from various families, but also individual OP families or mixtures of only the best families. These families could range from the very best genotypes to average genotypes, but many industry nurseries have no extra seedlings for

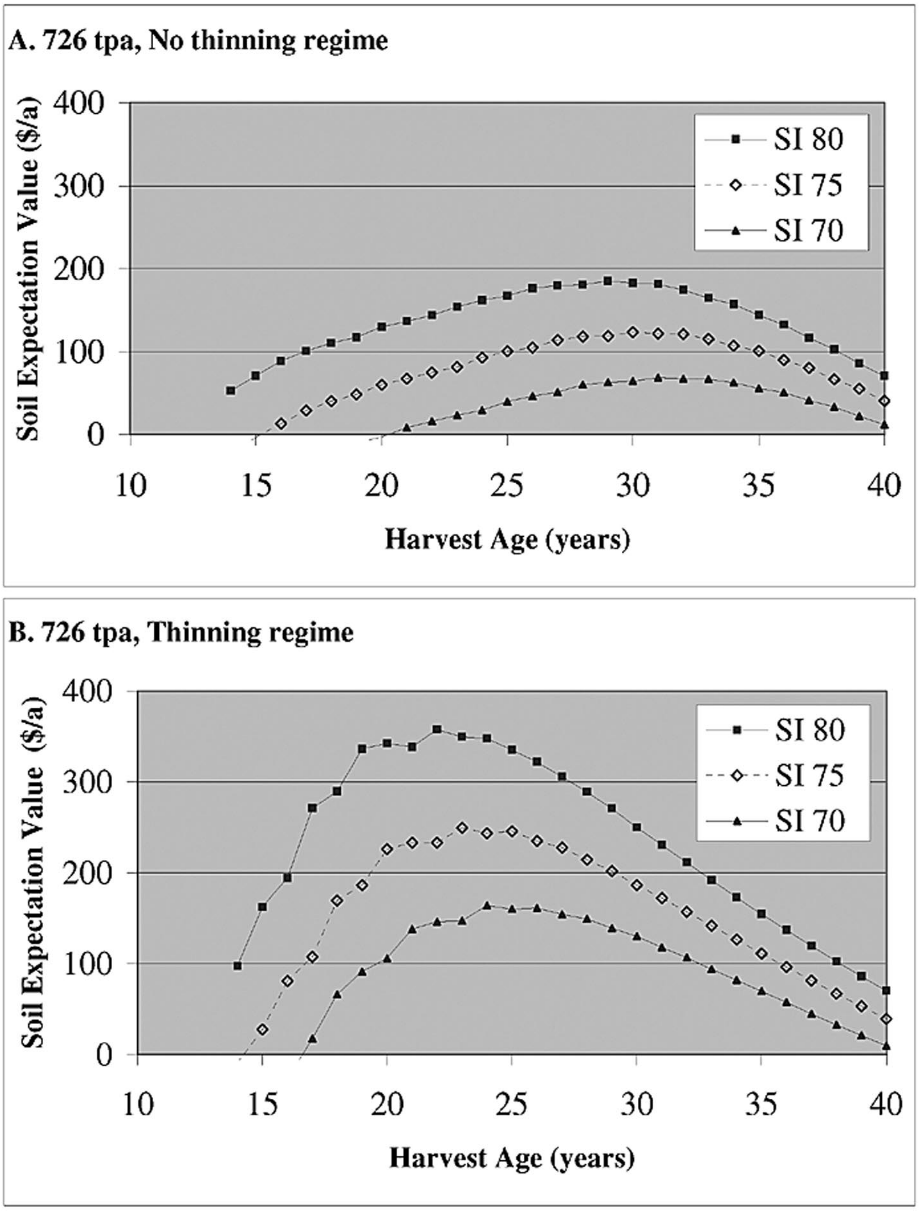

Figure 1. SEVs for projected yields for the 726-tpa regime at 8% interest rate with (A) no thinning and (B) thinning with SI_{25} = 70, 75, or 80 ft.

sale or want to keep the best seedlings for their own use on company lands. Industry foresters recognize the tremendous financial advantage that comes from planting the most productive families. State forestry agencies do have the full range of improved families available for landowners, but until recently, most states have only sold seedlings as mixtures of all families from their seed orchards. Many states now have "elite mixtures" of the very best families, and at least one state, North Carolina, has started selling individual OP families to landowners.

Unfortunately, most landowners often are not as knowledgeable as industry foresters and are not always able to purchase the best genetic quality seedlings except in mixtures with other families. If landowners were better informed of the benefits of using specific families for forest regeneration, then they should be willing to pay more for the best genetic quality seedlings to recognize the increase in the net present value (NPV) of their plantation investment. Likewise, if nursery managers received a better price for the best seedlings, then they might be willing to sell them on the open market and not use them exclusively on company lands.

In these analyses, we estimated the value of genetically improved seedlings from a range of improvement levels and site productivity levels using a growth-and-yield model. Our intention is to estimate the worth of genetically improved seedlings as opposed to the market price most buyers and sellers have used.

Methods

To estimate genetic gain in yields from the North Carolina State University Tree Improvement Cooperative's genetic testing program, we assumed that the primary response to genetic improvement was an increase in site index (SI; Talbert et al. [1985], Buford and Burkhart [1987], and Li et al. [1999]). Although other factors such as stem taper (Sherrill 2005), height-diameter relationships, and mortality functions probably influence yield differences among genotypes, it is difficult to quantify the difference among families.

We used a version of the FASTLOB growth-and-yield model developed by the Growth and Yield Cooperative at Virginia Tech University (Virginia Tech University–Growth and Yield Cooperative [2006]). The Silvicultural Decision Support System (DSS) of the North Carolina State–Virginia Tech Forest Nutrition Cooperative (North Carolina State–Virginia Tech Forest Nutrition Cooperative [2006]) is a modified version of FASTLOB (Montes 2001) that uses soils, SI (base age 25 years), amount of competing vegetation, stocking levels, and other stand characteristics to project pulpwood, chip and saw, and sawlog yields at different ages. Yields were estimated for planting densities of 726 and 436 trees/ac (tpa; 6′ × 10′ and 10′ × 10′ spacing, respectively) and for thinned and nonthinned stand management regimes. The nonthinned, 726-tpa regime would be typical of a low-intensity, pulpwood management scenario. The thinned, 436 tpa would typify a more-intensive, sawlog management regime. To standardize the different scenarios as much as possible under the thinning regime simulations, the stands were thinned when dominant and codominant trees reached 45 ft in height in the DSS runs. The stands were thinned to 65 ft^2/ac of basal area by taking out every fifth row and selectively thinning trees between the take rows. The age for thinning varied depending on the base SI.

To evaluate how the use of improved genetics varies by site quality, whether inherent site quality or management-induced site quality, we used different SI values in the growth-and-yield model. Allen et al. (2005) gave a more comprehensive presentation of how different silvicultural inputs and man-

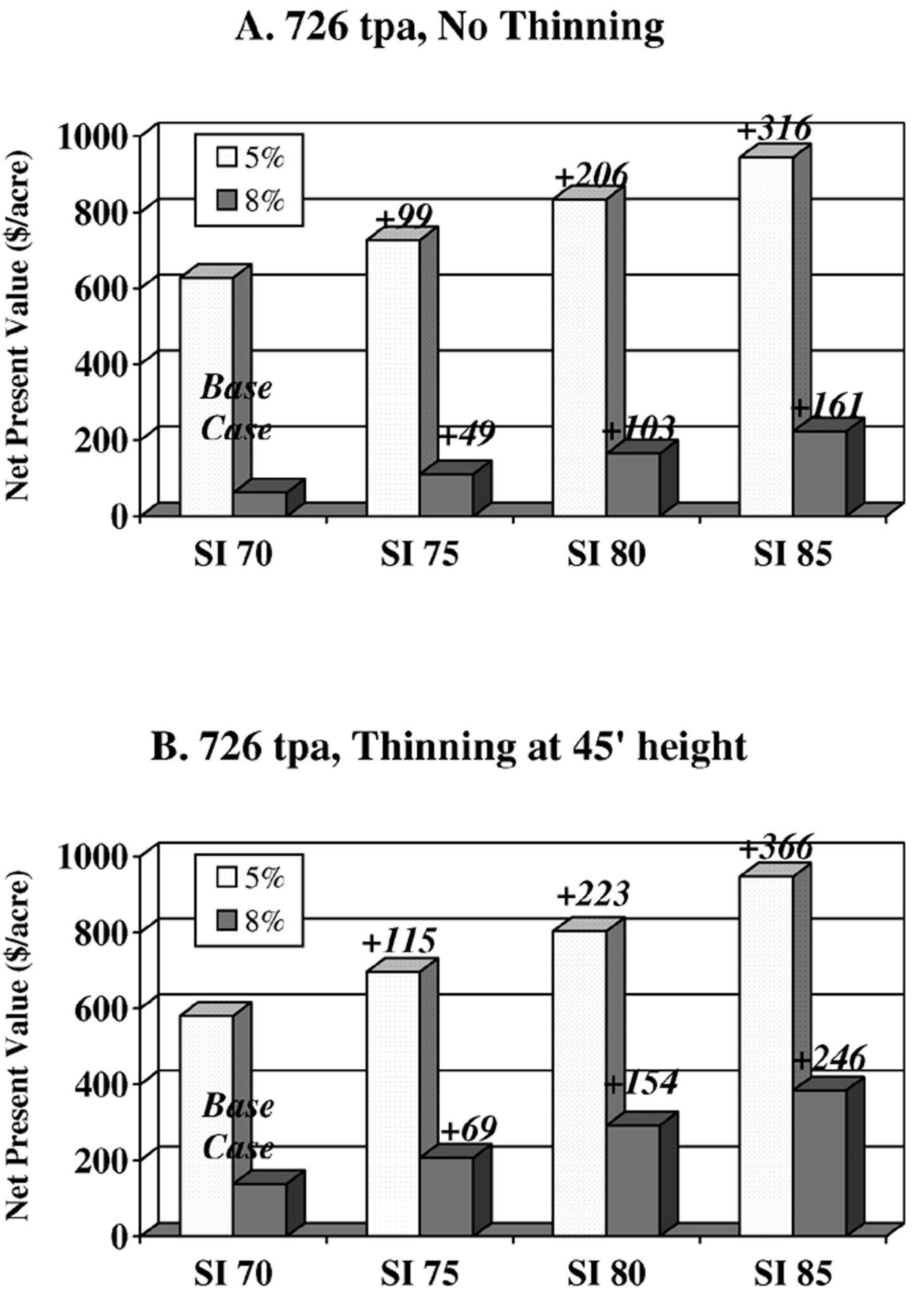

Figure 2. NPV at optimal SEV for productivity increases from different levels of genetic improvement (e.g., increases in SI). The base case examples are for SI_{25} = 70 ft, 726 tpa with (A) no thinning and (B) thinning when height of dominant and codominant trees reach 45 ft at age 13 years. The numbers at the top of each bar indicate the present value difference between the given SI class and the base case for a 5 and 8% internal rate of return.

agement options affect productivity in the DSS simulations. A given base case assumes that families of average genetic quality would be planted.

Yields from each DSS simulation run were used to calculate projected revenues and costs over time. These were used to calculate NPV and soil expectation values (SEV) for harvest ages up to 40 years (Gregory 1987). Stand establishment costs were set at $250/ac plus the costs of seedlings ($45/thousand). For 726 tpa, the stand establishment cost was $283/ac; for 436 tpa, the cost was $270/ac. Harvest income was generated based on simulated yields of pulpwood, chip and saw, and sawlogs that could be merchandized at various rotation ages (see North Carolina State University–Industry Cooperative Tree Improvement Program [2006] for examples of yield projections under various SI and silviculture management scenarios). We used stumpage prices of $7/green ton for pulpwood, $15/green ton for chip and saw, and $35/green ton for sawlogs. These stumpage prices are typical for eastern North Carolina and are low (especially for chip and saw and sawlogs) compared with other regions and for southwide averages (see Timber Mart-South [2006]). We chose to use conservative stumpage prices so as not to exaggerate differences caused by genetics. For the thinning regimes, we assumed that all the harvested wood was pulpwood, and the price per ton was reduced to $6 to reflect higher logging costs.

SEV is the NPV of an unending series of forest plantations (Gregory 1987) and was calculated using either a 5 or 8% rate of return:

$$\mathrm{SEV} = \frac{\sum_{t=0}^{r} R_t(1+i)^{r-t} - \sum_{t=0}^{r} C_t(1+i)^{r-t}}{(1+i)^r - 1},$$

where i is interest rate (5 or 8%), R_t is revenue from thinning or final harvest in year t, C_t is cost in year t, and r is rotation age.

Maximum SEV was used to determine the optimum rotation age for each regime. The differences in SEV would represent the value today of this and all future rotations' increased growth rate. The differences in NPV for one rotation at the optimal rotation age were used to determine the value of using better genetic quality seedlings for the first rotation. For example, the NPV for the optimal SEV at SI_{25} of 75 ft minus the NPV for the optimal SEV at SI_{25} of 70 ft would be the value of using improved families of loblolly pine that would increase the SI from 70 to 75 ft for this base case regime for one rotation. Although this is a proxy for the increase timberland value caused by improved management, the focus in this article is on the increased returns in the first rotation.

To evaluate the benefits of using different genetic entries that would result in increases in SI, SI values for the DSS runs for each combination of thinning and planting density scenarios varied from 60 to 95 ft in 5-ft increments. There are many OP families that grow 5–10% faster in height and should increase the base SI 5 ft. There are only a few OP families and some FS families that could be expected to grow 10–15% faster in height at age 25 years. To increase SI more than 15%, only the best FS families or intensively selected clones would have to be deployed.

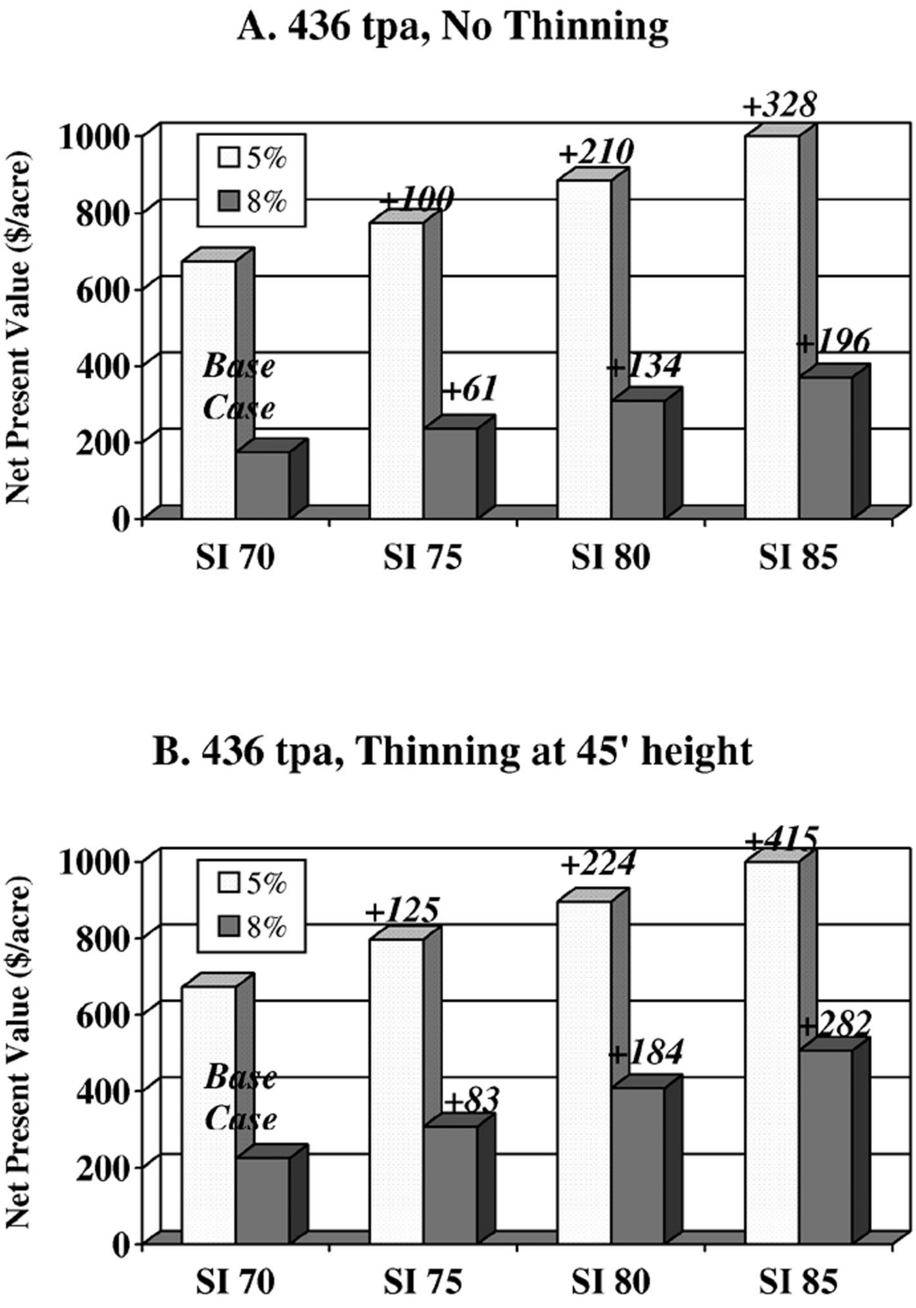

Figure 3. NPV at optimal SEV for productivity increases from different levels of genetic improvement (e.g., increases in SI). The base case examples are for SI_{25} = 70 ft, 436 tpa with (A) no thinning and (B) thinning when height of dominant and codominant trees reach 45 ft at age 13 years. The numbers at the top of each bar indicate the present value difference between the given SI class and the base case for a 5 and 8% internal rate of return.

Results and Discussion

For the no-thinning regime for 726 tpa at 8%, the maximum SEV for SI_{25} = 70 ft is \$68/ac (31-year optimal rotation), \$123/ac (30-year optimal rotation) for SI_{25} = 75 ft, and \$185/ac (29-year optimal rotation) for SI_{25} = 80 ft (Figure 1A). As expected, with increasing site quality, the projected value of the loblolly pine plantation increases. With the more-intensive silvicultural regime of thinning, when the dominant and codominant tree height reaches 45 ft, the value to the landowner is substantially higher at all SI values, ranging from \$164/ac for SI_{25} = 70 ft to \$358/ac for SI_{25} = 80 ft (Figure 1B).[1]

For each SI class, the NPV increase above the base case of SI 70 ft could be thought of as the maximum that can be spent per acre to purchase the faster-growing genetic material for one rotation and still improve the NPV (Figures 2 and 3). For instance, for the low-intensity, pulpwood management regime of 726 tpa and no thinning at an 8% rate of return, a loblolly pine family that increases the SI from 70 to 75 ft would be worth \$49/ac (Figure 2A). A better family that would increase the SI to 80 ft would be worth \$103/ac. When purchasing seedlings for planting densities of 726 tpa for a pulpwood regime, a landowner should be willing to pay up to an additional \$67–142/thousand seedlings for genotypes that could increase SI 5–10 ft, respectively.

Our estimate of the benefits to the landowner is very conservative. Increases in stem straightness and resistance to fusiform rust due to genetics (e.g., Li et al. [1999]) have not been factored into these analyses. Genetic variation in log quality is great, and the best quality stems are of greater economic value, and the stumpage prices paid for these better-formed trees should be greater. However, we have taken a conservative approach and have not included a price premium for better stem form.

For more productive sites, and for more-intensive management regimes such as incorporating thinning to increase sawlog production, a landowner benefits even more from better families. For the base case SI of 70 ft, 726 tpa, and thinning when dominant and codominant trees reach 45 ft, Figure 2B shows the benefits of using families that would increase SI to 75, 80, and 85 ft. At 8% interest, between \$69 and 246/ac could be justified to purchase seedlings that would grow faster and increase productivity to the different levels.

For the most-intensive scenarios evaluated (436 tpa, with one thinning, Figure 3), if the SI can be increased from 70 to 80 ft with genetics, the NPV would be \$184/ac at 8%. At 436 trees planted per acre, the landowner could justify purchasing these superior genotypes for up to an additional \$422/thousand.

The potential value of better loblolly pine genetics in other site management scenarios is summarized in Tables 1 and 2. For the 8% interest rate and across the numerous intensities of management and SI values, landowners can easily justify spending up to an additional \$40–140/ac on families that result in a 5-ft increase in SI. For families that would result in a 10-ft increase in SI, up

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[1] Only the 8% example is shown. The SEV and NPV values are higher for the 5% interest rate.

Table 1. Optimal rotation ages and NPV values at optimal SEV for productivity increases from different levels of SI (base age, 25 yr) for 726 tpa with no thinning and thinning at 45-ft dominant and codominant heights.

	5% Internal rate of return					8% Internal rate of return			
			Value of genetic improvement					Value of genetic improvement	
SI	Optimal rotation	NPV	5-ft SI gain	10-ft SI gain	SI	Optimal rotation	NPV	5-ft SI gain	10-ft SI gain
No thinning—726 tpa									
60	38	440	92	189	60	34	−26	42	88
65	37	532	96	196	65	33	16	46	95
70	36	628	99	206	70	31	62	49	103
75	35	727	107	217	75	30	111	54	112
80	34	834	110	229	80	29	165	58	123
85	33	944	119	247	85	28	223	65	130
90	32	1,064	127		90	27	288	66	
95	31	1,191			95	24	354		
Thinning at 45-ft height—726 tpa									
60	31	351	101	230	60	28	7	60	132
65	29	452	128	244	65	27	67	71	140
70	28	581	115	223	70	24	138	69	154
75	27	696	107	250	75	23	207	85	177
80	24	803	143	336	80	22	292	92	214
85	23	946	193	328	85	21	384	122	208
90	22	1,139	136		90	20	506	86	
95	20	1,275			95	17	592		

The value of genetic improvement (e.g., increases in SI of 5 or 10 ft) are shown for each base case SI.

Table 2. Optimal rotation ages and NPV values at optimal SEV for productivity increases from different levels of SI (base age, 25 yr) for 436 tpa with no thinning and thinning at 45-ft dominant and codominant heights.

	5% Internal rate of return					8% Internal rate of return			
			Value of genetic improvement					Value of genetic improvement	
SI	Optimal rotation	NPV	5-ft SI gain	10-ft SI gain	SI	Optimal rotation	NPV	5-ft SI gain	10-ft SI gain
No thinning—436 tpa									
60	32	509	97	166	60	26	66	52	109
65	31	606	69	169	65	24	118	57	118
70	27	674	100	210	70	23	175	61	133
75	26	775	110	227	75	22	236	72	134
80	25	884	117	247	80	22	308	62	149
85	24	1,002	130	216	85	19	371	87	190
90	23	1,132	86		90	18	457	104	
95	20	1,218			95	17	561		
Thinning at 45-ft height—436 tpa									
60	29	419	103	254	60	26	59	74	166
65	25	522	151	275	65	23	133	92	174
70	24	672	125	224	70	22	225	83	184
75	23	797	100	290	75	21	308	101	199
80	20	897	190	404	80	20	409	98	243
85	20	1,087	214	342	85	18	507	145	269
90	19	1,301	128		90	17	652	124	
95	17	1,429			95	16	775		

The value of genetic improvement (e.g., increases in SI of 5 or 10 ft) are shown for each base case SI.

to $85 to over $250/ac could be spent on these most elite families. The number of families that would increase SI by 10 ft is limited, but the extremely high value of these families is indicated. Of course, if a lower rate of return (e.g., 5%) is acceptable to a landowner, then the value of families that result in 5- and 10-ft increases in SI is even greater, up to $400/ac under the most optimistic scenario of a 10-ft SI increase with intensive culture (Tables 1 and 2).

Although we intentionally chose conservative stumpage prices for the analyses presented, we did conduct more analyses using prices in other southern markets. For example, the highest price region assessed was the Alabama coastal plain, where prices were pulpwood $7.64/tn, chip and saw $28.80/tn, and sawlogs $49.60/tn. The benefits from using better genetics were even higher when higher stumpage prices were used, resulting in a 50% increase in present value difference due to genetics (data not shown).

Because the greatest value from the most improved seedlings comes when they are used on the most productive sites and under the most-intensive forest management regimes, landowners should use them preferentially on these sites. If quantities of seedlings are limited or if a landowner is not willing to pay a premium for all the seedlings he or she will purchase, planting the best sites with the best genotypes makes the most financial sense.

One limitation to our analyses may be that landowners will not receive the stated

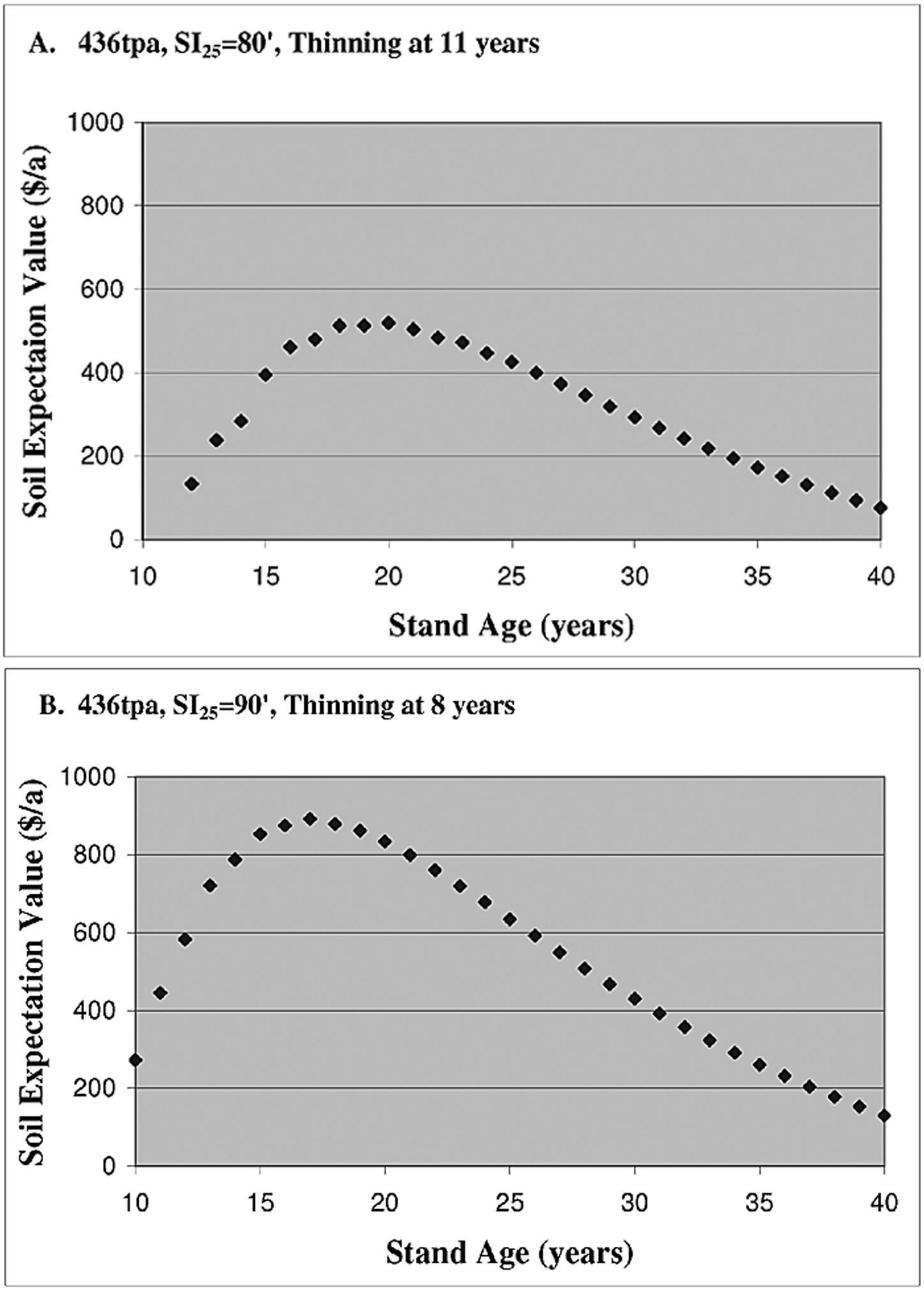

Figure 4. SEVs at an 8% interest rate. (A) SI_{25} = 80 ft, 436 tpa, and thinning when height of dominant and codominant trees reach 45 ft at the age of 11 years. The optimal rotation age is projected to be 20 years. (B) SEVs for the same site but using an extremely high-yielding family or clone that would increase the SI to SI_{25} = 90 ft (436 tpa, but thinning when height of dominant and codominant trees reach 45 ft at the age of 8 years). The optimal rotation age is projected to be 17 years.

stumpage prices for timber harvested at the shortened rotation ages for the intensive management regimes. For example, for the base case SI of 80 ft, 436 tpa, thinned, and 8% interest rate, the optimal rotation age is projected to be 20 years (Table 2; Figure 4). If an outstanding family or clone could increase the SI 10 ft, the present value to the landowner is projected to be $243 (Table 2) and the optimal rotation age would be 17 years (Figure 4). It is doubtful that a landowner would receive the $35/green ton stumpage for sawlogs at such a young age. Although fast-growing families of loblolly pine do not have poorer wood quality than slower-growing families under the same silvicultural systems, trees at 15–20 years of age have over 70% juvenile wood, which has much lower strength properties and higher moisture content (Zobel and Talbert 1984) and will not likely command the same price per ton as trees that are 25–30 years old. For instance, 17-year-old trees average 120+% moisture content, whereas 30-year-old trees have about 80% moisture content (Zobel and van Buijtenen 1989). Because stumpage price usually is based on green weight, a price penalty for harvesting young trees seems necessary, but it is not common. Sawmill managers would be ill advised to pay $35/green ton for the excess water in trees with a high proportion of juvenile wood.

Even if harvest is delayed under intensive silvicultural regimes and no price differential for harvesting young trees versus old trees is used, there would not be a severe loss in SEV by harvesting a few years past the maximum SEV. There is a gradual decline in SEV after the maximum (Figure 4), indicating that a high rate of return still will be realized from the plantation if the harvest is delayed a few years.

Fast growth per se is not a negative for wood quality in plantation-grown southern pines, but harvesting at young ages will result in poorer quality wood for most forest products. Silviculturists and tree breeders are studying ways to modify the properties of juvenile wood (e.g., Sykes et al. [2003] and Clark et al. [2004]), but tree age will continue to be important in determining wood quality and should be a driving factor in determining optimal rotation ages (e.g., Clark et al. [1996]). A challenge for forest product managers is to develop stumpage price structures for plantation-grown loblolly pine that recognize the strength, moisture content, and wood quality properties of trees with different amounts of juvenile and mature wood. Projected revenues can be appropriately adjusted and optimal rotation ages can be modified if price penalties are imposed for trees with a high percentage of juvenile wood.

Recommendations

Forest landowners should purchase the best genetic quality seedlings possible from nurseries that sell individual families that are adapted to their climatic zones. The benefits from planting the fastest-growing genotypes that have acceptable quality traits will result in tremendous financial benefits to landowners under most forest management regimes. Even with these conservative estimates of genetic gain and stumpage prices, our analyses suggest that landowners could pay more for the best genotypes, and the best seedlings would be well worth the additional costs. Rotation ages may not actually be as short as our model suggests for the most-intensive management regimes, but the economic benefits from planting the best genotypes still will be great.

When most of the intensively managed forestlands and nurseries were owned by wood processors, it may have been beneficial to provide improved seedlings at or below cost to all landowners in a wood procurement area to increase future supplies in the basin. In the future, where much of the productive timberland is no longer controlled by wood processors, genetically improved seedlings will have to generate a reasonable return for nurseries and research programs. These results show that financially motivated landowners should be willing to invest in the best genetic material possible for most plantations.

Landowners may not be able to purchase only the best seedlings from a nursery because of limited supplies. Additionally, tree improvement foresters do not deploy only the best few genotypes across a landscape because of potential risks with a limited genetic base. For any one nursery, tree breeders and nursery managers deploy an average of 13 OP families in a given geographic region (McKeand et al. 2003).

The potential benefits of investing in the best genetic material for all sites are great, and, to date, the costs are minimal, a "win-win" situation for all involved. Landowners should demand the best genetic material and should be willing to pay more for it.

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