LOBLOLLY PINE TREE IMPROVEMENT
AN ATTRACTION FORESTRY INVESTMENT

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ABSTRACT

First generation tree improvement programs with loblolly pine (Pinus taeda L.) are now reaching maturity. Yields from first generation seed orchards in the N. C. State University-Industry Tree Improvement Cooperative are now such that most members are able to meet all of their regeneration needs with improved stock. Progeny test measurement is a major Cooperative activity, with the final first-generation progeny test being established in 1982. Gains in stand value from one generation of loblolly pine tree improvement are estimated to be as high as 32% when planting stock is derived from fully rogued seed orchards. Tree improvement continues to be regarded as an attractive investment opportunity. Rates of return for investments in loblolly pine tree improvement depend on seed orchard yields, but appear to be on the order of 14-19% after taxes.
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INTRODUCTION

During the past forty years, the genetic improvement of southern pines has evolved from being an idea in the minds of far-sighted foresters and scientists to a point where it is now an integral part of forest management activities. Programs with loblolly pine (Pinus taeda L.) and slash pine (P. elliottii Engelm.) have reached a stage where members of the three largest cooperative improvement programs are able to meet most or all of their annual planting needs with improved stock. Activities in tree improvement are intensifying each year as the cooperatives turn to the second-generation of selection and breeding (Talbert, 1979; van Buijtenen and Lowe, 1979).

There have been numerous economic analyses of tree improvement programs. Results have shown that in general the most profitable programs involve species that have high product values, are widely planted, can be grown on relatively short rotations, are genetically variable in important economic characteristics, have the potential to produce large quantities of seed in a reasonable period of time, and which can be easily control-pollinated for progeny testing purposes.

1/The authors are Liaison Geneticist, Director, and Research Assistant, respectively, N. C. State University-Industry Pine Tree Improvement Cooperative, Raleigh.

2/The three cooperatives are the Western Gulf Tree Improvement Program, Texas A & M University, The Cooperative Forest Genetics Research Program, University of Florida, and the N. C. State University-Industry Pine Tree Improvement Cooperative.
Loblolly pine, the species with which the authors are most closely associated, has high product values and is extensively planted. Compared to most temperate zone tree species, rotation lengths are short. The species is extremely variable genetically (Stonecypher et al. 1973; Zobel, 1982). Yields from seed orchards have been beyond expectations (Table 1) and some organizations now have enough seed in storage to meet their planting needs for several years. Several second-generation orchards are beginning to produce meaningful quantities of seed. Breeding efforts for first-generation selections were complete as of 1982, and for many orchards, we have considered progeny test information sufficiently complete (most tests 8 years or older) to rogue them to their final genetic composition.

As expected, economic analyses of loblolly pine tree improvement efforts have shown them to be attractive investments. For example, an early assessment by Davis (1967) showed that a 2.5% to 4% improvement in volume gain (about 1 cord per rotation) over unimproved stock would be sufficient to

<table>
<thead>
<tr>
<th>Harvest Year</th>
<th>Bushels of Cones</th>
<th>Tons of Seed</th>
<th>Millions of Seedlings</th>
<th>Millions of Acres Regenerated</th>
</tr>
</thead>
<tbody>
<tr>
<td>1977</td>
<td>32,152</td>
<td>24.8</td>
<td>396</td>
<td>0.66</td>
</tr>
<tr>
<td>1978</td>
<td>37,977</td>
<td>23.5</td>
<td>376</td>
<td>0.63</td>
</tr>
<tr>
<td>1979</td>
<td>38,693</td>
<td>27.7</td>
<td>443</td>
<td>0.74</td>
</tr>
<tr>
<td>1980</td>
<td>15,296</td>
<td>7.9</td>
<td>127</td>
<td>0.22</td>
</tr>
<tr>
<td>1981</td>
<td>64,811</td>
<td>50.5</td>
<td>808</td>
<td>1.35</td>
</tr>
<tr>
<td>Total</td>
<td>188,811</td>
<td>134.4</td>
<td>2,150</td>
<td>3.60</td>
</tr>
</tbody>
</table>
justify a tree improvement program. An important result of Davis's analysis was that profitability was closely tied to production levels in seed orchards. Row (1967) showed a 12.4% rate of return from improvement activities with southern pines. Similar results were obtained by Porterfield et al. (1975) utilizing goal programming techniques. The latter analysis indicated that maximum profits could be obtained with intensive initial selection efforts, followed by progeny testing and heavy orchard roguing.

Most economic assessments of tree improvement have been based upon genetic gain information obtained from young progeny tests and from relatively young seed orchards. The N. C. State Cooperative now has a number of progeny tests at least 12 years old, and considerable information is available as to trends in performance of improved and unimproved stock through about half-rotation age. Additionally, costs associated with seed orchard programs have risen as orchards have matured and management intensity has increased. It is the purpose of this paper to discuss the gains being observed in the Cooperative's first generation loblolly pine tree improvement program and to show that despite increases in the costs of producing improved seed, tree improvement remains an extremely attractive forestry investment.

GAINS FROM TREE IMPROVEMENT

Growth Rate

Gains in growth rate in progeny from first-generation orchards are proving to be greater than anticipated at the outset of the program. When tree improvement activities were initiated with loblolly pine, it was felt that environmental variability associated with selection in natural stands would limit first-generation improvements in growth, and that greatest
improvements would be made in quality characteristics. Test results show that
significant gains have been obtained in both types of characteristics.

The N. C. State Cooperative's first generation genetic tests were
established primarily for assessing the genetic value of selected parents
(progeny testing) and for selection purposes. Row plots were utilized, and
these do not permit direct comparisons of yield among families or between
improved stock and unimproved check lots. However, many tests have now been
measured at four, eight, and twelve years of age, and trends are evident in
the relative growth performance of improved and unimproved stock over time.

Average percentage gains in height growth for first generation loblolly
pine progeny compared to unimproved checks are shown in Table 2. Gain figures

Table 2. Average percentage height gains for first generation loblolly
pine seed orchard stock at different assessment ages (from
Talbert, 1982). 1/

<table>
<thead>
<tr>
<th>Age</th>
<th>4</th>
<th>8</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage Gain</td>
<td>3.14</td>
<td>4.06</td>
<td>2.84</td>
</tr>
<tr>
<td>Standard Error</td>
<td>.45</td>
<td>.52</td>
<td>.65</td>
</tr>
<tr>
<td>Range</td>
<td>-2.18 to 7.54</td>
<td>-.79 to 8.00</td>
<td>-3.49 to 6.89</td>
</tr>
<tr>
<td>No. Orchards</td>
<td>33</td>
<td>30</td>
<td>16</td>
</tr>
</tbody>
</table>

1/Gains are calculated as average performance of progeny test
seedlings in comparison to unimproved check lots.

2/Percentage gains at all ages are significantly greater than
0 (p < .01). Gains at different ages are not significantly
different from each other.
Projected improvements in stand value may be as high as 32% under similar conditions, depending on whether planting stock is derived from unrogued or rogued seed orchards (Table 3). The large increment of gain in value results from the harvest of larger, more valuable trees in stands where improved stock was used.

Increases in stumpage values shown in Table 3 are probably conservative. Growth rate was the only trait considered, and improvements in quality characteristics have been ignored. Test data shows that genetic improvements in quality have been large, especially in stem straightness. The improvements in quality undoubtedly have an impact, especially in stands harvested at young ages where quality characteristics play a large role in determining whether a log is of pulpwood quality or whether it could be used for solid wood products. Research is currently underway to more fully elucidate the relationship between the crown and straightness scores used in N. C. State Cooperative and product yield.

<table>
<thead>
<tr>
<th>Type Stock</th>
<th>Value (Dollars/acre)</th>
<th>% Gain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unimproved</td>
<td>1887</td>
<td>--</td>
</tr>
<tr>
<td>Unrogued</td>
<td>2223</td>
<td>18%</td>
</tr>
<tr>
<td>Rogued</td>
<td>2489</td>
<td>32%</td>
</tr>
</tbody>
</table>

Assumptions:

- Value of trees < 9 in. dbh = $12/cord
- Value of trees 9-12 in. dbh = $40/cord
- Value of trees 12+ in. dbh = $60/cord
Quality Traits

Genetic gains have also been made in other characteristics. Wood specific gravity is a highly heritable trait in many species, including loblolly pine (Otegbye and Kellison, 1980; Dadswell et al., 1961; van Buijtenen, 1965; Zobel et al., 1972). Based upon parent-offspring correlations, we have estimated that with one generation of light selection for increased wood specific gravity (1 in 2 individuals saved), improvement has been on the order of .75 lbs/cubic foot of dry wood in 12 year-old trees (Jett and Talbert, 1982).

Improvements in fusiform rust resistance appear to be resulting largely from progeny testing and orchard roguing. There is considerable genetic variation in fusiform rust resistance in loblolly pine (Kinloch and Stonecypher, 1969). In progeny tests, however, unimproved check lots have performed nearly as well, on the average, as progeny of selected trees. This has happened even though a requirement for first generation selections was that they be free of rust. Many selections were made in stands with low to intermediate rust infection, so there was a low selection intensity for disease-free trees. Substantial gain can be made in rust resistance in slash pine (*Pinus elliottii* Engelm.) by selecting rust-free trees in heavily infected stands (Goddard and Schmidt, 1979). Where fusiform rust resistance is of over-riding importance, specialty loblolly pine seed orchards composed of proven rust-resistant parents have been established (Zobel et al., 1971) which are now producing commercial quantities of seed.

Perhaps the most noticable quality improvement has been in stem straightness. In nearly all orchard testing programs, the unimproved check lot ranks at or near the bottom in the straightness score used by the
N. C. State Cooperative (Table 4). Studies have shown that this characteristic can have a marked impact on yield and quality of solid wood and pulpwood products (Blair et al., 1974). Similar but less dramatic improvements in crown form are also evident in genetic tests.

<table>
<thead>
<tr>
<th>Company</th>
<th>Location</th>
<th>Unimproved Check Performance Level 2/</th>
<th>Rank</th>
<th>Out of</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catawba Timber Company</td>
<td>Piedmont, S. C.</td>
<td>17</td>
<td>41</td>
<td>41</td>
</tr>
<tr>
<td>Continental Forest Industries</td>
<td>Piedmont, Ga.-S.C.</td>
<td>26</td>
<td>23</td>
<td>23</td>
</tr>
<tr>
<td>Virginia Division of Forstry</td>
<td>Coastal, Va.</td>
<td>12</td>
<td>31</td>
<td>32</td>
</tr>
<tr>
<td>American Can Company</td>
<td>Lower Gulf, Ala.</td>
<td>20</td>
<td>36</td>
<td>36</td>
</tr>
</tbody>
</table>

1/ The Cooperative uses a 1-6 subjective scale to assess progeny stem straightness, with 1 = excellent and 6 = poor.

2/ Performance levels are calculated on a 0-100 basis, 50 is approximately average, 100 is the best (Hatcher et al., 1981).

COSTS AND OTHER ECONOMIC CONSIDERATIONS

Investments in loblolly pine tree improvement have risen almost annually as first-generation programs have matured. Inflation has been one cause of increased expenditures, but a major factor has been increased management intensity of seed orchards and progeny tests as the value of tree improvement in forestry operations became widely recognized. For example, application of insecticides in seed orchards for protection of seed crops was a rarity until about 1970. As the economic impact of losses of improved seed to cone and
were computed by determining average gain for each loblolly pine seed orchard in the Cooperative, and then averaging across all orchards. Each orchard was treated as an independent estimate of gain. Percentage gains for any individual orchard may be biased to the extent that the tester mating system used does not represent what would be obtained with random mating in the seed orchard\(^1\), and to the extent that the unimproved check does not accurately represent unimproved planting stock\(^2\). However, when averaged across a number of orchards, these effects should average out.

Percentage gain estimates for height appear to be remaining constant at 3-4\% regardless of test measurement age (Table 2). Individual orchards differ widely in their performance, but combined gain figures are all significantly greater than 0 (p < .01) and are not significantly different from each other. With intensive orchard roguing (removing poor parents) based on progeny test information, estimated percentage gains in height growth increase to approximately 7\% in the average orchard.

We have recently used an early version of the growth and yield model developed by Hafley (1982) to project from these data the volume and stand value increases expected for an unthinned plantation on site index 60 (base age 25) land at a rotation age of 25 years. Cubic foot volume increases are approximately 7\% and 12\%, respectively, for unrogued and rogued seed orchards.

\(^1\)With the tester mating system, four to five selections are chosen as male parents (testers) and mated to all other selections in the orchard. The genetic quality of the testers will have a disproportionate influence on the performance of the progeny test population.

\(^2\)In the first generation, each Cooperator was responsible for furnishing his own unimproved check. We know that unimproved checks of Cooperators in the same area differ in their performance.
Tree improvement programs in general are hampered by long generation intervals caused by the perennial nature of forest trees. For example, correlation of performance of young trees with their subsequent performance at rotation age is far less than perfect. This has posed a major stumbling block to selection of very young trees in genetic tests for establishment in advanced-generation seed orchards. Loblolly pine presents an added complication because a rather long period of time elapses from when trees are selected to when they produce sufficient "flowers" for breeding. These two factors combine to create generation intervals that are very long.

Only limited success has been obtained in selection experiments involving very young trees. Use of specific artificial environments in greenhouses and growth chamber facilities (Cannell et al., 1978) or use of close spacings to accelerate the onset of tree to tree competition (Franklin, 1979) show promise. However, results to date have not been sufficient to employ these techniques in operational programs. We currently make advanced-generation selections at about 6-8 years of age in Cooperative genetic tests.

Recently, excellent progress has been made in developing accelerated breeding techniques which promote flowers on very young trees (Greenwood, 1978; Greenwood et al., 1979). Techniques include growing trees in pots in greenhouses, use of plant hormones in conjunction with water stress to promote female flowering, and wire girdling of limbs and forced dormancy out-of-phase with the normal winter period to produce pollen.

While effective, these techniques do increase the costs associated with breeding. An analysis by McKeand and Weir (1983) showed that the extra sums of money being spent for accelerated breeding can be justified because they
shorten the time until seed from orchards representing the next generation of improvement can be obtained. Money that could be spent depends on the number of acres reforested annually, the desired rate of return, stumpage prices, and the number of years saved. For $15 per cord stumpage, a 7% rate of return and an annual regeneration program of 10,000 acres, the net present value of saving 2 years per generation for two generations was shown to be over $228,000. The extra costs associated with accelerated breeding appear to be well justified.

Delays in flowering also impact established seed orchard programs. A rule of thumb for loblolly pine is that 8-12 years usually elapse before orchards reach meaningful production levels. This delay has a negative influence on the profitability of tree improvement. Judicious choice of seed orchard sites and expenditures in orchard management practices which will enhance vigorous tree growth and promote early flowering will almost certainly be good investments. Use of full season irrigation in young orchards, which can promote tree growth and increase the potential number of flowering sites on each tree (Jett, 1982), is one such seed orchard practice. Adherence to standard recommended practices for seed orchards, such as full orchard stocking, weed control, fertilization, and insect control are mandatory if tree improvement programs are to show greatest profit.

Mass production of selected material through vegetative propagation would allow production seed orchards to be bypassed entirely and would also hasten the deployment of superior stock. Mass vegetative propagation of loblolly pine by any means is not now feasible, either biologically or economically, but it is likely to become a reality in the next decade. Conceivably,
techniques such as tissue culture could be used to produce large quantities of propagules 1-2 years after selection. This is an often overlooked but extremely important potential benefit of vegetative propagation.

SUMMARY

Tree improvement activities with loblolly pine are having a major impact on southern forestry. Gains in stand value in excess of 30% may result from using stock from rogued first-generation orchards, depending on such factors as site index, rotation age, and stand management practices. Since the above figures were calculated for growth improvement alone, aggregate gain figures including improvements made in both growth and quality traits will likely be even larger. Improvements in quality characteristics have been at least as dramatic as those for growth, but their impact on value is more difficult to quantify.

Substantial sums of money are invested in loblolly pine tree improvement. Despite this fact, real rates of return appear to be as high as 19% for production seed orchards, after taxes. Tree improvement remains an extremely attractive forestry investment.

The figures given for gains and costs in this paper represent averages for the N. C. State University-Industry Tree Improvement Program and do not necessarily apply to individual seed orchards or to results obtained from other breeding programs. As shown in Table 2, estimated gains vary considerably from orchard to orchard in the Cooperative. Costs will also vary. Application of our results to individual orchard programs should be done with considerable caution. However, tree improvement can be one of the most cost-effective alternatives available to forest managers to improve forest productivity.
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LITERATURE CITED


