Value of production orchards based on two cycles of breeding and testing

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Abstract.--The net present values of two orchard alternatives were compared: 1) a production orchard per breeding-testing cycle (one-cycle orchard) and 2) a production orchard after two cycles of breeding and testing (two-cycle orchard). The specific question in current breeding programs is whether to install the third generation production orchard (one-cycle strategy) or delay orchard establishment until another breeding cycle can be completed (two-cycle orchard). Delaying orchard establishment and extending the service life of the second generation seed orchard (two-cycle orchard) was profitable if gains from progressive re-selection (roguing plus use of family-specific information) were 3.0 to 5.0%. The one-cycle orchard strategy was better if gains from orchard roguing were less than 5% and additional use of family-specific data had no value.

Additional keywords: Loblolly pine, one- and two-cycle production seed orchards, third generation orchard establishment.

There have two been classic alternatives to use of early selection technology. One is to establish a seed orchard after each shortened breeding cycle. The other is to delay orchard establishment until two or more breeding cycles have been completed. It has been suggested that it will not be possible to install seed orchards at very short generation intervals (van Buijtenen, 1981). The two-cycle production orchard may be profitable particularly if later years of an orchard's service life are highly valued.

The specific question as it pertains to the current cycle of loblolly pine tree improvement is as follows: should a third generation orchard be established or should establishment of the next orchard be delayed until one more cycle of accelerated breeding has been completed?

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BACKGROUND

The relative merit of the establishment of a third generation orchard and the alternative of using second generation seed longer is determined by service life of the third generation orchard and the value of seed from the added years of second generation orchards.

The third generation orchard's revenue depends on its seed's genetic value and its total production. The orchard's seed production is determined primarily by the length of time before its successor fulfills regeneration needs (orchard service life). The service life can be reduced to the point that the orchard is obsolete before it can yield an acceptable return on the establishment investment. If so, the two-cycle orchard is likely to more profitable.

The two-cycle strategy also has appeal because the seed from the later years of the orchard service life has greater genetic value than seed from the earlier years. Several years after a seed orchard reaches commercial harvest, information becomes available on the orchard clones' offspring (family) performance. This information may be used only to genetically rogue the orchard but it may be used to make additional production population gains.

Gains from additional re-selection (after roguing) are readily obtained. Cone harvest can be limited to the better maternal parents. Commercial-scale supplemental mass pollination or controlled-pollination can increase gains through re-selection on the maternal parents or through the exploitation of specific combining ability. Matching families to sites or the anticipated product demand may also boost gain (Gladstone, 1975; Duzan et al., in review). The additional use of family-specific information has a monetary value specific to each tree breeding organization. In general, the longer an orchard's service life, the greater the opportunity to identify and exploit these family-specific characteristics.

Our objective was to determine how high gains from re-selection within the second-generation production population must be to make the two-cycle orchard strategy at least as profitable as the one-cycle orchard strategy.

METHODS

The service life of the third generation orchard was determined by the generation interval which will hypothetically occur after the establishment of the third generation orchard. The generation interval was set at 20 years through a) use of selection for the fourth generation orchard at four years (rather than selection at six years) and b) the assumption that the fourth generation orchard reaches commercial harvest after six years rather than after eight years (e.g. Jett, 1983) (Table 1).

Table 1. Hypothetical generation interval after establishment of the third generation orchard. The service life of the orchard was 11 years.

Activity	Years	References
Breeding	5	Greenwood et al (1984)
Tests established over two consecutive years	1	Talbert et al (1981)
Selection	4	
Time from selection to outplant grafts	1	Byram et al (1986)
Time from outplant to commercial harvest	6	
Time required for orchard to fully meet demand	3	
Total	20	

The criterion for comparing the one- and two-cycle orchards was difference in net present value. We have used a marginal analysis where all costs identical to the mutually exclusive alternatives were eliminated. All costs and revenues were reported in constant 1987 dollars. We have assumed the third generation orchard would be installed on 1987 technology although projected establishment is for the mid- 1990's (McKeand and Bridgwater, 1986). Only its service life will be altered by the changes in accelerated breeding technology and orchard development.

Assumptions

1. Third-generation seed yield projections

   Each orchard was sized to meet the regeneration demands four years after the onset of flowering because the genetic quality improves in young orchards as more clones contribute pollen (Zobel and Talbert, 1983, page 443). The seed to seedling ratio was 1 lb. to 8000 (van Buijtenen and Saitta, 1971). Ten acres was added for roads, irrigation and storage. Orchard production was 50 lb. per acre at full production (Bey et al. 1986).

2. Establishment costs

Establishment costs used by van Buijtenen and Saitta (1971) were converted to 1987 dollars with the producer price index (Anonymous, 1987). Agricultural-quality land costs were estimated to be $1350.00 per acre assuming a 4% annual increase since 1979 (de Steiguer, 1982). A real discount rate (i.e. net after inflation) of 8% was used. Orchard establishment costs were considered fixed or variable as follows:

Fixed costs:	$54,520.00
Road construction	
Equipment storage	
Equipment purchase	
Irrigation system	
Variable costs for acres in production:	$ 749.33/acre
Survey and site preparation	
Rootstock	
Grafting and outplant	

Harvest costs have been deleted since harvest in older orchards is not necessarily more costly for all orchard mangement regimes (Ed Sossaman, Weyerhaeuser Company, pers. comm.). We assumed that the orchard would be installed adjacent to an existing orchard facility but that additional land purchase was required. The cost of a 26-acre orchard for an average forestry organization was conservatively estimated to be $101,609.

3. Prediction of genetic gains

Percentage genetic gains from breeding and testing were assumed to increase linearly across the second and third generation orchards. Genetic gains per cycle (G) for the second generation orchard were 4.4% and doubled for the third generation. Gain per cycle for the third generation was expressed as incremental over second generation gains from breeding and testing (i.e. an additional 4.4%). Gain was estimated for selection of top full-sib crosses plus the best individual within each of the selected crosses. The gain estimates for 24-clone orchards were based on a breeding region in the North Carolina State University-Industry Cooperative (McKeand and Bridgwater, 1986; Talbert et al. 1981). The prediction equation was as follows:

$$G = i_f \, Cov_{A,P} / \sigma_{\bar{P}_j} + i_i \, Cov_{A,P} / \sigma_{P_j} \qquad \text{(Equation 1)}$$

i_f = selection intensity for families
= 1.76 (24 out of 250 unrelated crosses)

i_i = selection intensity for individuals
= 2.62 (1 out of 144 full-sibs)

$Cov_{A,\bar{P}}$ = Covariance between breeding values of selection goal at age m and the family means of the orchard candidates at age j.
= 1/4 Cov

$Cov_{A,P}$ = Covariance between breeding values of selection goal at age m and the phenotypes of the orchard candidates at age m.
= 1/2 Cov

$\sigma_{\bar{P}_j}, \sigma_{P_j}$ = Phenotypic standard deviations of the family mean and the candidates, respectively. Dominance variance was set to zero.

$$\sigma_{\bar{P}_j} = \left\{1/2\sigma^2_a + 1/4\sigma^2_d + 1/rn(1/2\sigma^2_a + 3/4\sigma^2_d + r\sigma^2_{rf} + \sigma^2_e)\right\}^{1/2}$$

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where σ^2_a = additive genetic variance
σ^2_d = dominance variance
σ^2_{rf} = block by family interaction term
σ^2_e = experimental error
r,n = rep, plot number

4. Schedule for gains from re-selection in production orchard

Re-selection was based on offspring performance measured in open-pollinated progeny tests of all orchard clones. The seed was collected in the second year of commerical harvest then tested over two years. Measurement age was assumed to be the same as age of selection in the breeding population. Rogued seed was assumed available eleven years after the first harvest for the third generation orchard. Gains from the use of family block information were added only to the extra years of the two-cycle orchard's service life.

5. Revenue from genetic gain

Genetic gains in growth were projected with a loblolly pine plantation yield model (Smith and Hafley, 1984). The assumptions were a) rotation age of 30 years (genetic gain was realized through larger trees at a set rotation length) b) 800 trees per acre, 85% initial planting survival c) genetic gains in height increased site index d) value per acre per 1% increase in site index was $47.00 for multiple end-products (pulp, chip-n-saw, sawtimber).

The value of $47.00 was obtained from multiplying the merchantable volume for each product by Timber Mart South's February 1987 market values over the range of site indexes 65 to 78 (base 25). The market value is believed to be conservative since the amount of wood per acre was projected for unthinned stands and stumpage values are expected to increase (USDA-Forest Service, 1987).

RESULTS AND DISCUSSION

Extending the service life of the second-generation orchard (two-cycle orchard) was at least as profitable as the one-cycle strategy if a) either roguing gains were at least 5.0% or b) the combined value of roguing and additional use of family-specific information was 3.0 to 4.5% (Table 2). The latter estimates were lower because roguing was an option exercised in both alternatives (for different lengths of time) whereas the additional use of family-specifc information was restricted to the second-generation orchard only.

Table 2. The minimum genetic gains from re-selection in the second generation production orchard required to favor two-cycle orchard.

-----Gains from re-selection-----			
Roguing (%)	Additional use of family-specific data (%)	NPV one-cycle (k$)	NPV two-cycle (k$)
1	2.00	858.79	868.60
2	1.50	919.23	927.29
3	1.00	979.66	985.97
4	0.50	1040.09	1044.66
5	0.00	1100.52	1103.35

The values for gains from re-selection in the second generation production population (Table 2) constitute the minimum breeders can expect for two reasons. First, the requisite gain from re-selection will be higher than these estimates as long as the generation interval (i.e. the service life) in cooperative breeding programs continues to be longer than the biological minimum we used as our hypothetical generation interval.

Secondly, the required production population gains may be low also if there is additional cost incurred to obtain gains from additional use of family-specific information. For example, supplemental mass pollination and use of a family's site-specificity will incur costs not included in the comparision.

Sensitivity analysis

a) Gain for the third generation orchard

Genetic gain per cycle from selections in the breeding populations were considered to be 4.4% above selections in the second-generation orchard. If gain dropped to 3.7% then the two-cycle orchard strategy was optimal for generation interval of 20 years (Table 3). Genetic gain per cycle was the factor in the analysis most likely to be over-estimated in the current breeding program.

Table 3. Critical factors for the profitability of the third generation orchard after the third generation orchard and 3% gains from roguing the second generation seed orchard. Difference is between net present values of one- and two-cycle orchard strategies.

Genetic gain per cycle %	Discount rate %	Establishment costs ($)	Difference (k$)
4.4	8	101,609	111.06
3.7	8	101,609	- 6.84
4.4	9	152,413	- 1.83

The genetic gain estimate predicted for the third generation production orchard will be lower under one or more of the following conditions: a) dominance variance at the selection age is high so the phenotypic standard deviations in the gain prediction equation are underestimates (see Eq. 1) or b) the genetic value of the selections from the enrichment populations (plantation progeny) is lower than the mainline selections or c) the genetic covariances between selection and rotation ages are under-estimated by the use of age 15 genetic parameter estimates or d) if enough additional traits are included so that the selection intensity for height alone is substantially lowered.

b) Costs and annual regeneration demand

The costs reached a discount rate of 9% and an establishment cost overrun of 50% before the outcome was changed (Table 3). A reduction in the land base serviced by the third generation orchard also reduced the relative value of the one- over the two-cycle orchard (Table 4). The reduction in area serviced by the orchard slightly decreased the net profit but did not change its relative merit. This situation might be expected if vegetative propagules were used to regenerate areas previously regenerated with orchard seed. Conversely, a larger land base increases the net profit of the one-cycle orchard over the two-cycle orchard (Table 4).

Table 4. Effect of annual regeneration demand on the value of the one- and two-cycle orchard strategies for generation interval of 20 years. Difference (DIFF) is between the net present values of the one- versus two-cycle orchard strategies.

Annual regeneration (acres)	NPV one-cycle (k$)	NPV two-cycle (k$)	DIFF (k$)
16,000	2018.51	1737.13	281.38
8,000	979.66	868.60	111.06
4,000	460.23	434.30	25.93

Net profit from the traditional one-cycle orchard will continue to decline in the future if use of earlier selection continues because the orchards will have a shorter service life as well as less gain per cycle. The seed from these orchards will have less value and there will be less time to produce to seed to offset the costs of capital and establishment. The land base traditionally serviced by seed may also decrease as vegetative propagules are used to partially fulfill regeneration needs. The profitability of future one-cycle orchards will be lower than the value for third generation orchard as a result. The two-cycle orchard, by comparision, will gain appeal.

CONCLUSIONS

If the generation interval between the third and fourth generation orchard was reduced to 20 years with selection at age four years and a reduction of two years in development time then it was more profitable to bypass the third generation orchard if 1) genetic gain from selections made in the breeding population was 3.7% or lower or 2) gains from roguing the second generation orchard were 5.0% or higher or 3) gains from roguing and additional use of family-specific information were between 3.0 and 4.5%. There are other alternatives to the one-cycle orchards such as a pre-rogued orchard which may make better use of technological developments and of genetic gains from the breeding and production populations than the two-cycle orchard.

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