SEED ORCHARD PRODUCTION: ITS POTENTIAL AND ITS LIMITATIONS[1]

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ABSTRACT-Over 8,000 acres of improved pine seed orchards in the South support annual regeneration programs of approximately 1.2 billion seedlings. These orchards are sufficient to meet the demand for improved seedlings if they are correctly allocated to the appropriate species and seed sources. However, because better clones are identified in the breeding and progeny testing programs of the tree improvement cooperatives every year, the most desirable seed will always be in short supply. Customer needs may also change rapidly, making it difficult to meet short-term demands.

Seed orchards supply seed to nursery programs very cheaply: seed costs generally range from $5 to $7 per thousand seedlings. Seed orchards are also the only technology that can currently supply the huge number of propagules needed for the large regeneration programs in the South. However, open-pollinated seed orchards have a number of limitations. Genetic potential is lost through pollen contamination and year to year variation in seed yields is highly unpredictable. In addition, the eight to ten-year delay between grafting a new orchard and the onset of commercial seed production makes it very difficult to respond to rapid increases in seed requirements. Sowing-by open-pollinated families has provided an incentive to design seed orchards only with heavy cone producers. Because there is no correlation between a family's cone production capability under orchard culture and the performance of its seedlings, clones with high genetic gains should not be automatically excluded from seed orchards because of low seed production. Their contribution to the overall genetic quality of the orchard through pollen production may be significant.

Short-term strategies for meeting increased demands using existing seed orchards include putting mothballed orchards back into production, substituting one seed source (or species) for another, and maintaining larger seed inventories. Each of these options has an associated cost, generally incurred by sowing lower genetic quality seed. Short-term strategies for increasing genetic gain from existing seed orchards include roguing, collecting by open-pollinated families, and controlled-mass pollination. Long-term strategies for increasing yields and improving the genetic quality of seed require regular establishment of new seed orchard blocks. Designing orchards with excess capacity provides increased flexibility to meet rapid increases in short-term seed demands and allows additional genetic gain to be captured by high-grading the seed crop in years with surplus production. Probability distributions for seed yields can assist in planning seed orchard expansion programs.

INTRODUCTION

One of the largest reforestation efforts in the world occurs each year in the Southeastern United States where approximately 1.2 billion pine seedlings are planted. This program is supported by over 8,000 acres of seed orchards supplying 120,000 pounds of seed. Orchard acreage in the South is currently less than the 9,600 acres reported six years ago (White 1992) because of the closure of 1,400 acres of orchard by the US Forest Service (T. Tibbs, personal communication). Seed orchard acreage managed by industry and the states appears to be steady as first-generation orchards are replaced with advanced-generation orchards (G. Powell and R. Weir, personal communication: Byram and others 1997).

Loblolly and slash pine seed orchards are sufficient to supply all the seed required for these species from genetically improved sources. Seed supply for some minor species, such as longleaf pine in the Western Gulf region, still rely on natural stand collections. However, seed orchards have been established for most of these species and genetically improved seed will soon be available. This does not mean that orchard establishment has been completed and that seed supplies are adequate. Because better families are identified in breeding and progeny testing programs annually, older seed orchards continually become genetically obsolete. The result is that the best seed sources will always be in short supply. This situation is aggravated when management makes rapid changes in favored seed sources, rotation ages, or planting densities.

While vegetative propagation techniques such as rooted cuttings or artificial seed will likely supplant some demand for seed in the near future, the large majority of the planting material in the South will continue to come from seed orchards. This is true because of scale and economics. Seed orchards are the only technology now available that can supply the large numbers of propagules needed and they do this very inexpensively. Seed costs generally range from 25 percent to 33 percent of total nursery production costs, or roughly less than $0.01 per seedling. Unfortunately, seed orchards have a number of drawbacks that affect the regeneration manager's ability to make long range plans. Major disadvantages are the inability of seed orchard managers to respond rapidly to increased seed requirements and the large year to year variation in seed yields. Genetic potential is also lost by dependence on open-pollinated seed.

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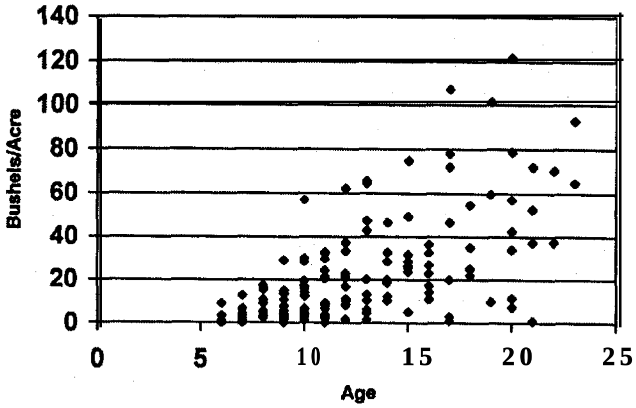

Figure I-Yield for WGFTIP loblolly pine seed orchards collected between 1976 and 1985.

SEED ORCHARD PRODUCTION

Seed Orchards Take Many Years to bring into Production

Designing a seed orchard program requires an extremely long planning horizon. Generally, a two-year period is required to prepare an orchard site, establish rootstock, and graft a new seed orchard. After grafting, there is an eight to ten-year delay before the production of seed in commercial quantities. At this point, seed production potential increases quite rapidly; however, annual production can still be extremely variable **(fig.1).** Top grafting for seed orchard conversion may shorten this period, but it is uncertain if this technique will be widely adopted.

There is very little that seed orchard managers can do to reduce large and unpredictable year-to-year variation in seed crops.

Factors that affect annual seed production include the amount of flowering and damage from weather and insects. Orchard managers practice fertilization and drought stressing to promote flowering, but there is very little that can be done to offset the effects of weather. For example, nearly all of the entire loblolly and slash pine flower crop was lost to a series of spring freezes in 1996 and some orchards in the Western Gulf Region experienced 30 percent losses again in 1998.

Crop losses to cone and seed insects can also be severe, exceeding 90 percent without insect protection. While these losses can currently be controlled, possible changes in pesticide regulations make for an uncertain future. Seed orchard mangers now depend on a limited number of products in only two classes of chemicals (organophosphates and synthetic pyretheroids), both of which are under review by the Environmental Protection Agency. Most chemical companies have only minimal interest in maintaining registration for seed orchard pesticides because such small amounts used. For the same reason, it is unlikely that any new chemicals will be introduced. If the industry looses a chemical or class of chemicals for cone and seed protection, average seed harvests could decline drastically and annual variations in seed crops will certainly increase.

The Best Genetic Quality Seed Will Always be in Short Supply

Older orchards become genetically obsolete as better families are identified in breeding and testing programs. For example, the average orchard currently in production in the Western Gulf Forest Tree Improvement Program (WGFTIP) produces seed with a 17 percent improvement in mean annual increment at age 20 (MA120) over unimproved sources (Byram and others 1997, p. 10). However, the newest orchards (which will begin production in about eight years) have a 30 percent improvement in MA120. In fact, new loblolly orchards have been increasing in gain at an annual rate of 1.4 percent genetic improvement for the last five years (Byram and others 1997, p. 7).

Short-Term Strategies to Supply More Seed Incur a Cost by Reducing Genetic Quality

Seed can be in short supply when managers change preferences for seed sources faster than the demand can be met by orchard establishment programs. For example, in the last eight years, one organization in the WGFTIP increased demand for one seed source by 400 percent while cutting demand for their previously preferred source by 90 percent. When shifts in demand occur, several short-term strategies can be used to address the resulting shortfalls. Unfortunately, all of these measures result in using seed with less genetic improvement.

Older, genetically obsolete seed orchards can be put back into production. There will be increased costs incurred due to managing additional orchard acres. Most importantly, lead-time is necessary to implement this option. Fertilization for flower stimulation must be done in the summer to affect the following spring's flower crop. The cone and seed insect control program should also be in place for at least two years to be fully effective. However, the biggest cost incurred is in using genetically inferior seed. This cost can be offset somewhat by collecting only the best families, but the poorer families in the orchard will still contribute to the genetic quality of the seed by their contribution to the pollen cloud.

Larger seed supplies can be stored in inventory by collecting more of the crop in years with surplus seed production. This is equivalent to collecting more genetically obsolete seed orchards, because this seed would not otherwise be used. Again, foresight is required and seed costs reflect additional collection and storage expenses.

One seed source (or species) can be substituted for another at an opportunity cost that depends on how closely the substitution meets the needs of the customer. This option can be justified only if it is better than other alternatives that might include waiting a year or substituting genetically unimproved seed.

Short-Term Strategies for Improving Genetic Gain can Reduce Seed Production

Short-term strategies for improving genetic gain from existing orchards include roguing, collecting by family or gain groups, and controlled-mass pollination (CMP). All of these options lower seed production potential, at least temporarily, and may raise seed costs. Whether or not these options are economically desirable, depend upon the availability of surplus seed and on the value of genetic gain. According to Bridgwater and others **(1998),** 1 percent improvement in MA120 has a present value of $0.01375 per seedling ($13.75 per thousand seedlings). Assuming 80 percent nursery efficiency, this value translates to $0.011 per seed.

Roguing reduces the number of trees per acre and has a short-term affect on seed yields. Long-term affects are negligible as expanding crowns on the remaining trees increase production. In fact, thinning is an integral component in maintaining the health and seed production potential of seed orchards.

Controlled-Mass Pollination has Implications for Nursery Production Systems

CMP seed is produced by isolating the female flowers before they are receptive and using selected male parents to perform controlled pollination. This technique captures genetic gain by avoiding pollen contamination. As little as 30 percent pollen contamination will result in losses averaging 2.5 percent in MAI20 for the current production orchards in the WGFTIP (Bridgwater and others 1998). Pollen contamination rates may be much higher (Lowe and Wheeler 1993) and the losses in absolute value will increase in higher gain, advanced-generation orchards. Gain is also captured by using selected male parents. Using the best six parents in a breeding region will provide an average improvement of 13.8 percent gain in MAI20 in addition to the 2.5 percent improvement achieved by preventing pollen contamination. Therefore, CMP seedlings with 16.3 percent gain in MAI20 over average orchard seed have a marginal present value of $224.12 per thousand ignoring the cost of seed production.

Unfortunately, CMP seed is expensive to produce. Current estimates from pilot scale projects indicate that isolation bags, pollination, labor, equipment rental, and processing will cost approximately $0.05 per seed, or assuming an 80 percent nursery efficiency, $62.50 per thousand seedlings. This expensive seed may justify an extra effort to improve nursery efficiency. Furthermore, to maximize the benefits of these additional genetic gains, these seedlings may need to be used in intensive silvicultural systems that include growing larger seedlings at lower nursery bed densities.

Long-Term Strategies for Improving Seed Yields and Genetic Gains Require Regular Orchard Establishment

The potential to capture more genetic gain than is available from using seed makes vegetative propagation attractive. However, to be economical, vegetative propagules must have a marginal value sufficient to offset production costs when compared to alternative sources. Except for high value products in specialty markets or the development of transgenic plants with novel attributes, this is not likely to occur for southern pines in the near future. In the meantime, we will continue to depend on orchard seed and the only way to ensure continued genetic improvement is the regular establishment of new seed orchard blocks. Orchard establishment should be timed to coincide with the identification of better genetic material in the tree improvement program. In the WGFTIP, as well as in many other regional tree improvement programs, the breeding and progeny testing program is distributed across members and generations are indistinct. This results in new and better families being identified almost every year.

One strategy for rapidly incorporating new clones into the production population is the advancing-front orchard. The advancing-front orchard is a fully regulated seed orchard complex where new orchard blocks are established at regular intervals with the best available genetic material. At any given time, there are multiple orchard blocks of different ages, different genetic gains, different seed production capacities, and under different management regimes. Because some of these orchards are too young to produce seed, they add to management costs without adding to seed production capabilities. However, these blocks contain the best genetic material and the overall quality of the collected seed improves as they mature and contribute a larger portion of the harvest.

Genetic Gain is Evaluated by Progeny Testing not Generation Number

Generation refers to the number of breeding and selection cycles that separate an individual from the base population. More advanced generations are expected to be better than previous generations. However, it is important to realize that there are exceptions. Some excellent parents in one generation may be better than their progeny in the next generation simply because they were crossed with inferior partners. Furthermore, selections from a cross between two good parents may have disappointing performances (table 1). This occurs because a tremendous amount of genetic variation exists within families and selection between siblings is inexact. The only way to accurately evaluate the genetic quality of a seed orchard is to field test progeny from the parents.

Poor Cone Producers Should not be Automatically Excluded from Orchards

The strategy of sowing open-pollinated families is an incentive to design seed orchards with many ramets of a few clones and to ensure that all of these clones are abundant cone producers. There is no correlation between seed production capability of a clone managed for cone production in an orchard and its progeny's performance in

Table l-Predicted performance based on parental mid-parent values for two sets of half-sib second-generation selections compared to actual progeny test performance

Selection	Predicted perfomance	Actual perfomance
Family one		
A	104	99
B	104	130
Family two		
A	106	92
B	106	116

growth tests (Byram and others 1986). Some clones with poor cone production have very high genetic values and should not be automatically excluded from orchard designs. These clones contribute significantly to the overall quality of the orchard through their pollen production. They may also be good candidates for use in CMP programs.

Over Capacity is not a Mistake, it's a Strategy

Deliberately designing seed orchard programs with surplus seed production capacity permits increased flexibility to meet rapid increases in short-term demands. This flexibility is extremely important as seed demands can change much more rapidly than seed orchard managers can respond with orchard establishment programs. Excess capacity also allows additional genetic gain to be captured by high-grading the seed crop in years with surplus production. Unfortunately, these benefits come at the cost of managing more orchard acres than strictly needed in most years. This extra cost is an insurance premium against unexpected disasters or rapid changes in demands.

Determining the size of a seed orchard program requires knowledge of average seed production and the variation around this value. Cumulative probabilities for seed production developed for specific management scenarios can be used to plan seed orchard expansions with known levels of risk. For example, under the production parameters represented in figure 2, average seed production for an advancing-front orchard is 20.2 pounds per acre over a twenty-year life span. In other words, 50 percent of the orchards will meet or exceed this production level and 50 percent of the orchards will not. However, there is an expectation that 80 percent of the orchards will exceed seed yields of 17.2 pounds per acre over a twenty-year life span. A regeneration program requiring a 1,000 pounds of seed per year could on average, be supported by an orchard complex of approximately 50 acres (1,000 pounds/ 20.2= 49.5 acres). However, increasing the overall size of the orchard by only 8 acres (1,000 pounds/17.2=58.1 acres) improves the likelihood that seed demands will be met or exceeded to 80 percent.

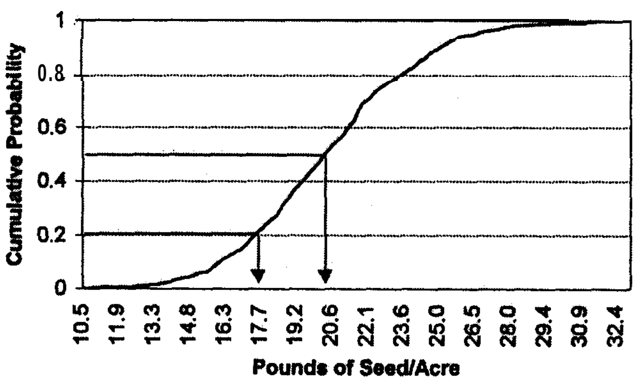

Figure 2—Cumulative probability curve for pounds of seed per acre averaged over a twenty-year life span of a hypothetical loblolly pine seed orchard.The probability on the y-axis is the likelihood that production will be less than the seed production value on the X-axis.

SUMMARY

Regeneration programs in the South will continue to depend on seed orchards for the foreseeable future. Seed orchards have the advantage of being able to inexpensively supply the large numbers of propagules needed for southern regeneration programs. However, seed orchards require many years to reach full production, year to year variation in seed yield is large and unpredictable, and genetic gain is lost to pollen contamination and the dependence on sexually reproduced seed. Furthermore, seed demands can change much more rapidly than seed orchard expansion programs can respond to them. Continued improvement from the tree breeding programs also ensures that desirable seed sources will always be in short supply. Unfortunately, short-term strategies for increasing seed supply reduce genetic quality; conversely, all short-term strategies to improve genetic quality lower seed production capability, at least in the short-term.

Controlled-mass pollinated seed offers one of the best options for capturing substantial quantities of additional genetic gain for use in operational regeneration programs. This seed will be much more expensive than the seed currently grown by nursery managers. Maximizing the return on CMP seedlings may require that their use be incorporated into intensive silvicultural systems that include growing larger seedlings at lower nursery bed densities. Attempts to improve nursery efficiency for these seed lots will certainly be warranted.

Long-term strategies for improving genetic quality while ensuring adequate seed supplies require regular establishment of new seed orchard blocks. Designing these blocks with excess production capacity provides important flexibility to meet changing demands and allows additional gain to be captured by high-grading the seed crop in years with surplus production.

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