SEED ORCHARD MANAGEMENT --
SUCCESSES, PROBLEMS AND CHALLENGES

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Abstract.--Managers of southern pine seed orchards have enjoyed major successes and encountered problems in the 40 years since the inception of the tree improvement program. They now face challenges for the future. The successes include the establishment of more than 10,000 acres of southern pine orchards, the development of protection procedures for cone and seed crops, the development of cultural practices to increase the production of flower crops and to maintain tree health, the development of indoor breeding of orchards, and the establishment of advanced generation orchards.

Problems include pollen contamination in orchards, environmental hazards and regulations associated with pest management, soil compaction and management, and clonal and annual variation in flower production.

Several challenges must be met if the quality and quantity of genetically improved seed are to continue to increase. We must devise alternative pest management procedures, develop an effective operational supplemental mass pollination procedure, and improve our methods of collecting, extracting, and storing pollen to insure high pollen viability and pollen vigor. We must increase our understanding of the basic reproductive biology of the southern pines, and must develop methods of increasing productivity of male and female flowers in young orchards.

INTRODUCTION

Until the southern pine tree improvement programs, seed for nurseries were collected from trees in natural stands, on logging sites, in fence-rows or along roads. Pine seed orchards were established under the tree improvement program. In these orchards, grafts or seedlings of selected phenotypes are planted in large blocks for the single purpose of producing genetically improved seeds to supply nurseries. (Zobel et al 1958). There have been a lot of changes in the management of seed orchards since the southern pine seed orchards were established in the early 1950's. In this paper I will discuss some of the successes, problems and challenges of seed orchard management.

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SUCCESSES

There is no question that the seed orchard program has been a big success and it is now taken for granted that the reforestation program in the South has an adequate supply of genetically improved seed. It has not always been this way. Many people have contributed to the overall success of the program. Five major successes have influenced the supply of seed for the South. These are:

- Establishment of over 10,000 acres of southern pine seed orchards
- Protection procedures that greatly increased cone and seed yields
- Development of cultural practices that increase flower production and tree health
- Development of technology for greenhouse breeding orchards
- Establishment of advanced generation orchards on improved sites

Establishment of 10,000 Acres

Certainly, the establishment of over 10,000 acres of southern pine seed orchards must be considered one of the tree improvement program's major successes. The fact that more than 1 billion southern pine seedlings are grown from genetically improved seed each year is testimony to the success of these seed orchards. Those who established these orchards had to overcome many problems. In the early years, grafting and planting required a major effort that involved many individuals. Then seed orchard maintenance, tree breeding, progeny testing, roguing, cone collection, and other procedures had to be carried out. These demanding tasks were completed by a group of dedicated individuals who had great confidence in the success of the program, and most companies and organizations had established first generation orchards by the 1960's.

Protection

As soon as the newly established seed orchards began to produce flowers, cones, and seeds, it became obvious that insect pests were going to be a major concern. The early work of Ed Merkle, Harry Yates, Gary DeBarr, Scott Cameron, Larry Barber, and others identified a host of insects that attacked cones and seeds. Although identification was important, protection procedures were desperately needed. The workers who devised the first protection procedures used modified agricultural or fruit crop sprayers and whatever chemicals were available. Later, intensive field tests identified specific pesticides for use in southern pine seed orchards. Gary DeBarr, Hans Van Buijtenen, and the tree improvement cooperatives deserve a lot of credit for carrying out the many large-scale tests that were required. Larry Barber made a significant contribution when he developed aerial application procedures that insure that pesticide coverage is correct.

Protection of seed orchards was unquestionably a major contribution to the production of seed from southern pine seed orchards. The seed crop produced by pines in unprotected natural stands is less than 10 percent as large as the biologically potential seed crop. Performance of unprotected pines in planted orchards is this bad or even worse. Godbee et al. (1977) reported that an unprotected slash pine seed orchard yielded only 6 percent of the potential seed crop. However, as the level of protection increases the production of seeds increases dramatically. For example, a 50-acre loblolly pine seed orchard with an average of 400 flowers per ramet and 50 trees per acre at age 14 could produce 10,000 pounds of seed (Bramlett 1987). At $80.00 per pound, the 10,000-pound crop would be worth $800,000. With no protection the actual harvest would be only 1,000 pounds, or enough seed to plant approximately 10,000 acres. Even with maximum protection the yield does not equal the biological potential, but we estimate that up to 54 percent of the potential seed can become plantable seedlings. This means that the same 50-acre orchard would yield seed worth $432,000, or enough seed to plant 54,000 acres of regeneration. Also, the protected orchard would produce as many seed on 10 acres as an unprotected orchard would produce on 50 acres.

Cultural Practices

Until the southern pine tree improvement program, no one had attempted to grow pine seeds in an orchard environment. Thus, it was necessary to identify cultural practices that would increase seed production and protect the health of orchard trees. Previous studies in natural stands led researchers to test fertilization, irrigation, and other cultural practices in seed orchards. Ron Schmidtling (1974) and J. B. Jett (1987) were especially diligent in identifying the nutritional requirements for good flower production in seed orchards. Their work indicated that additional nitrogen was beneficial even when the trees were receiving a balanced fertilizer application for tree health and vigor. To my knowledge, micronutrients have not been demonstrated as limiting in outdoor seed orchards in the SE United States.

Subsoiling has also been effective in promoting flower production in seed orchards. Subsoiling improves soil aeration by shattering compacted soils and by pruning lateral roots that are growing into the traffic area. The net effect is increased flower production. Subsoiling may have to be repeated periodically and in varying patterns (Jett 1987).

Irrigation has not consistently increased flower production. However, irrigation during the orchard establishment phase (ages 1-5) can promote the development of large vigorous crowns that have the capacity to support large flower and cone crops after irrigation has been discontinued.

Indoor Breeding Orchards

During the first generation of orchard establishment, most breeding of progeny to evaluate phenotypic selections was done in the production orchards. As trees produced flowers and pollen, they were crossed to provide seed for large-scale progeny tests. The procedure, however, was dependent on the initiation of adequate flowering under orchard conditions and subject to seed and cone losses from insects, diseases, and weather. To reduce the generation interval, Mike Greenwood and Claude O'Gwynn developed an innovative indoor breeding procedure. In this procedure, out-of-phase dormancy is induced by growing potted pines under moderate water stress in a greenhouse environment. These potted grafts of selected phenotypes are held for extended periods in a flower inductive state and initiate both male and female flowers earlier than is possible in outdoor breeding orchards or operational seed orchards. Viability of pollen from indoor grafts has also been adequate to complete necessary crosses for progeny testing. This very innovative approach has greatly accelerated the establishment and roguing of advanced generation orchards by reducing the pine generation interval. Future seed orchards will undoubtedly combine early genetic evaluation and indoor breeding technology to continue rapid progress in southern pine tree improvement.

Second Generation Orchards

The establishment of second generation orchards was an important achievement. This is because of the great improvement in the site selection, orchard management, and protection of the second generation orchards. First generation orchards were a learning experience for most organizations. The second generation orchards, however, represent the second cycle of recurrent selection and potentially a more valuable seed crop. Second generation orchard sites were established in geographic areas known for good flower and cone production. Some organizations located second generation orchards on productive sites far from their operational holdings. Careful attention to soil properties was part of the location selection process: many first generation orchards had been established on soils that were to wet or were otherwise unsuitable. In addition, grafting success and tree uniformity have been greater in second generation orchards, which have also had wider spacing, earlier roguing, and better maintenance and protection. The combination of these conditions has led to earlier cone and seed production. It is unlikely that as much improvement will be made in succeeding generations of orchards, but further fine tuning can be expected for to produce additional gains for several more breeding cycles.

PROBLEMS

Despite the overall success of the tree improvement program and the high level of production in seed orchards, problems arose that reduced the quantity and genetic quality of seed. The four major problems have been:

- Contamination by non-orchard pollen
- Environmental hazards and regulations associated pest management
- Soil compaction and management
- Clonal and annual variation in flower production

Contamination of Orchard Pollen

Right from the start of the tree improvement program, it has been recognized that pollen contamination is a problem for seed orchards. Isolation or dilution zones around the orchards were expected to reduce the inflow of outside pollen. The theory was that released pollen settles rather rapidly and that most of the pollen in an orchard surrounded by an isolation zone would be from the orchard's trees. Unfortunately, pollen is so buoyant that it is easily lifted in the atmosphere and may be transported for long distances. Lanner (1966) described the atmospheric conditions that could lead to long distance transport of pollen. In the southeastern US, pollen is first dispersed in the warmer southern latitudes. This pollen may be deposited locally but may also be transported by the prevailing wind. When the wind reaching an orchard is from a warmer climate, pollen is deposited in the orchard before the orchard pollen is released. Thus, as soon as female flowers are receptive in a given orchard, outside pollen will begin to contaminate the orchard selections. The problem of contamination increases as more and more local pollen is shed, and by the time of peak orchard pollen shedding, the whole atmoshpere contains very high concentrations of pine pollen. Estimates of pollen contamination for most seed orchards are in the 40-60 percent range. Furthermore, the consequences of pollen contamination will increase with each generation of improvement as the genetic value of the seed increases. Solutions will not be simple. The Australians have the good fortune to grow Pinus caribaea seed orchards far from the natural range of the species. It is also possible to isolate orchard trees reproductivity by altering or taking advantage of patterns of flowering phenology. Phenological isolation has been achieved for Douglas-fir in the Pacific Northwest and Canada El-Kassaby 1989). When the genetic value of orchard seed becomes high enough, other methods of avoiding pollen contamination may be justified. Orchards might be planted in clonal rows or clonal blocks, and supplemental or controlled pollinations and physical barriers to pollen might be employed to reduce the impact of unwanted pollen on the best genetic selections.

Environmental Hazards and Pesticide Regulations

The last decade has seen an increased awareness of environmental issues. These environmental concerns are important to each of us, yet growing pine seeds in a seed orchard without chemical protection would be extremely difficult. Bill Lowe and a SFTIC subcommittee are working to maintain the list of pesticides available for use in seed orchards, but there is a good possibility that the registration pesticides in current use could be withdrawn.

One of the problems is that the combined seed orchard acreage is only a very small market for a pesticide, compared to agricultural or horticultural use. Thus, we cannot expect that new compounds will be developed specifically for use in pine seed orchards. We will have to depend on existing pesticides. Fortunately, seed orchards have recently been classified as terrestrial non-food sites rather than forested areas. This means that horticultural or nursery products may be more readily available for orchard use.

The other problem is the public perception of aerial application of pesticides. Regardless of the low risk to human health or environmental safety of a pesticide, orchard neighbors and the public in general are opposed to aerial application. Even though aerial application may increase the efficacy of a pesticide, this technique may become unacceptable from a public opinion viewpoint.

Soil Compaction

Although the actual quantitative effect of soil compaction on seed production is not known, the continued use of aerial lift trucks, tractors, and other vehicle equipment is certainly detrimental to the physical properties of orchard soil. This problem can be partially alleviated by subsoiling as suggested by Jett (1987). Even so, orchard sites suffer from continued traffic over an extended period of time. Equipment that exerts less pressure on the soil surface is certainly more desirable as is minimization of traffic during periods of high soil moisture. Also orchard sites should be carefully selected for soils that are not easily damaged, and that have good surface and subsurface water drainage.

Clonal and Annual Variation

One of the problems of seed orchard management has always been the large amount of clonal and annual variation in fecundity. Clonal variation is a recognized fact of orchard management, yet its causes are little understood (Schmidtling 1983). Although it sometimes seems that the best genetic clones are the worst seed producers, there is little hard evidence that outstanding vegetative growth is negatively correlated with reproduction growth. The ideal seed orchard clone would produce abundant flowers and cones under seed orchard conditions yet give rise to progeny that would demonstrate only vegetative growth when grown in forest plantations.

Annual variation is also largely a mystery. The current theory is that good seed crops are favored when the inductive period (July and August) is relatively dry after a moist spring. The idea is that good shoot growth in the spring develops strong branches and that mild water stress causes buds to remain in the resting stage during the flower initiation period. Unfortunately, flowering is not strongly related to measurable weather variables such as monthly rainfall or temperature. Local conditions, microsite variability, tree age, and crown characteristics all influence the flower initiation process. It also appears that regional effects are important, because seed production is good in orchards throughout the South in some years and generally poor in other years.

There also appears to be an interaction between annual seed production and clonal production. In general, clones are consistently good or poor producers, but some clones change in rank between years. It would appear that a large cone crop would deplete a tree's carbohydrate reserves and that fewer cones would be initiated the following year. However, since crops of pine seeds require two years to develop, depletion of carbohydrates would favor production of cones every third years.

CHALLENGES

I see 5 challenges that must be met if southern pine seed orchards are to continue to yield large quantities of high quality seed. These are:

- Development of alternative pest management procedures
- Development of effective operational supplemental mass pollination procedures
- Development of better understanding of basic reproductive biology of southern pines
- Development of methods that will increase male and female flower production in young orchards
- Development of improved pollen collection, extraction, and storage methods that will insure high viability and vigor

Alternative Pest Management Procedures

Protection is vital to maintenance of high levels of seed production. DeBarr (1981) discusses different approaches to protection in seed orchards. Certainly safer and more effective chemical pesticides would be useful if they meet the increasingly stringent environmental requirements. Biological control offers exciting possibilities, but it is most unlikely that biological control will be as effective as the chemical methods now employed. Lack of a reliable arsenal of pesticides or effective biological control methods would drastically change the way that orchards are managed. Much greater orchard acreages would be required, and this could force organizations to look for other methods of producing the seedlings required for regeneration or for other locations in which to establish orchards.

Development of Supplemental Mass Pollination

An effective supplemental mass pollination (SMP) procedure would greatly reduce the detrimental effects of pollen contamination. Although SMP is a very simple concept, the actual yields of SMP seed on an operational level have been disappointing. The actual application of pollen to receptive female flowers has been relatively easy. Pollen is applied using a funnel on the end of a wand with an air delivery system (Bridgwater et al. 1987). The funnel is placed over the flower cluster and approximately 1 cc of pollen is dispersed over the flowers. As 1 cc of pollen has about 10,000,000 pollen grains, the probability is high that each ovule will have one or more SMP pollen grains attached to the micropylar arms. The problem is that there is a very narrow window of opportunity for applying the pollen to a particular flower. SMP appears to be most effective at a flower stage of late 4 (4.5-5.0). However, wind-borne pollen is being dispersed during the same time period and may also be found on the micropyle. If SMP occurs too soon, a lot of wind pollen will accumulate after SMP and will be transported to the pollen chamber in the pollination droplet. If SMP is too late (after the pollination droplet has emerged) it is almost certain that the SMP pollen will not be the male parent.

But even when the SMP is timed perfectly, the SMP pollen will have to compete with wind-borne pollen. Unfortunately, pollen tube growth of SMP pollen may be less vigorous than pollen tube growth of wind-borne pollen. Thus, the wind-borne pollen may be outnumbered by SMP pollen in the pine ovule, and yet be more competitive in completing fertilization and parenting the offspring from the seed orchard. The phenology of the female parent also contributes to the success of SMP. Clones with early female receptivity appear to be most adapted to SMP. Rates of SMP success for clones that flower late or in mid-season may be very low.

It will be a challenge to find methods for isolating receptive female flowers from wind-borne pollen long enough to complete SMP. Protective bagging, precise timing, or location of orchards in different geographic areas may be possibilities, but considerable work is needed to make SMP an operational success.

Reproductive Biology of Southern Pines

The reproductive biology of gymnosperms intrigued late 19th and early 20th century botanists, who conducted several outstanding studies of the pine life cycle. After this early work, however, little new information was added until recently, when the economic value of genetically improved seed justified additional research on the reproductive process. John Owens and his coworkers in Canada have produced outstanding descriptions of reproductive processes of western conifers, but current research on loblolly and other pines is sadly lacking. The time of fertilization of loblolly was observed by March et al. (1989). The life cycle process is apparently similar for all pines, but just how these processes are affected by orchard management practices is not known. For example, it is possible that levels of orchard fertilization change the number of archegonia formed per ovule. If heavy applications of fertilizer had this effect, the potential number of fertilization per ovule would be increased and the treated orchards "buffered" against relatively high levels of self pollination. This buffering could result in a reevaluation of orchard planting design or the use of clonal rows or clonal blocks to increase the efficiency of orchard management.

Additional work is also needed on pollen phenology and pollen dispersal within the orchard. Research by Boyer (1981) demonstrated that pine phenology was related to a cumulative heat sum. Other researchers have shown that dispersal patterns vary among seed orchard clones (Askew 1986, Blush et al. 1992, Bramlett and Bridgwater 1989).

Better understanding of pine phenology and pollen dispersal patterns will enable managers to increase the genetic quality of seed orchard seed through improved orchard design and improved pollination procedures.

Increase in Male and Female Flowering

Second generation orchards are producing clones and seeds sooner than did the original orchards. It would be better if trees began producing even earlier, because the most advanced selections will be in the youngest orchards and these trees will produce the most valuable seed. Much of the acceleration in production has resulted from better site selection and orchard management.

I do not think we have pushed the reproductive capacity of the trees far enough.

Recent results of stem girdling and $GA_{4/7}$ applications in a 10 years old loblolly pine seed orchard have been encouraging (Wheeler and Bramlett 1991). The combination of girdling and GA increased female flowering by approximately 300 percent. The treatment was effective for all test clones but the response was related to be flowering level of untreated controls.

Additional research is needed to determine the responses of young pines to flower stimulation treatments, the optimum timing of flower stimulation, and the rates of GA that produce the maximum response. Then the treatments must be incorporated into orchard management strategy.

Improved Pollen Processing and Storage

Extracted orchard pollen is used in SMP and is used in testing the genetic potential of selected phenotypes. When the vigor of orchard pollen is reduced by processing or storage, the background wind-borne pollen has an advantage. We now have evidence that the pollen vigor is reduced in extracted pollen stored in a refrigerated desiccator for more than 1 year (Bramlett and Matthews in press). Just how much pollen vigor is reduced by collection, extractions, and freezer storage is not known. We must evaluate the whole process of pollen processing and then develop a protocol that minimizes the reduction in pollen vigor. It also may be that pollen from some clones is more competitive than others in the fertilization process. Pollen competition could be an important factor in the success of SMP.

CONCLUSIONS

Without a doubt, the southern forest tree improvement program can be proud of its success in seed producing from pine seed orchards. The establishment and protection of the first generation orchards were major achievements. Furthermore, the cultural management practices developed have been transferred to second generation orchards. And second generation orchards have been very productive because of excellent site selection, good management, and high levels of protection.

The problems of contamination by outside pollen continues to plague the orchard managers, and its negative impact will increase with advancing generations of selections. Difficulties associated with pest management may well be the most serious threat to continued seed orchard productivity. The long-term effect of soil compaction is not known. If we understood the causes of annual and clonal variation in flower production we would be better able to manage for adequate annual production of seed.

Seed orchard managers will face many challenges over the next decade and in the 21st century. Certainly alternative pest management procedures must be developed. In addition, an effective operational SMP procedure is needed if we are to capture the high genetic gain of specific full-sib crosses. If we are to make further increases in seed production we need to have a better understanding of the reproductive process in pines and have ways to maintain high viability and vigor of processed and stored pollen. Finally, treatments that consistently increase female flower and pollen production in pines must be developed to provide management expanded opportunities to increase seed production.

The key to successful seed orchard management will be to intensively manage fewer ramets on smaller acreages. If production of flower and cone crops can be stimulated and high levels of protection maintained, the size of seed orchards could be reduced by 50 percent or more. If vegetative propogation becomes economically feasible the size of seed orchards may be further reduced. Even so, the seed production process will continue to be vital to the tree improvement program and will be necessary to provide the genetically improved seedlings for reforestation of the southern forests.

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