A TREE IMPROVEMENT PROGRAM FOR SOUTHERN HARDWOODS

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Abstract.--The hardwood genetics program started by the North Carolina State University-Industrial Cooperative Hardwood Research Program- has undergone changes which have produced groups of selected trees with different levels of improvement. The time has come to integrate the groups into a comprehensive improvement program. Only a few organizations are establishing greater than 800 hectares of hardwood plantations annually. The best option for an improvement program with limited interest is to rely upon an open-pollinated breeding scheme. The breeding population within each breeding region will be subdivided into 10 to 15 subgroups. Each subgroup's planting will be designed to improve the chances for cross-pollination between families within the subgroup. Open-pollinated progeny from the best individuals in these plantings will be used for the next generation's breeding population. Clonal seed orchards will be established, using the best trees from each subgroup within a region. Accompanying the seed orchard program will be an experimental vegetative propagation program with anticipation that vegetative popagules will eventually supplement or replace seedlings in reforestation.

INTRODUCTION

Hardwoods have been planted just as long as pines in the southern United States; however, most hardwoods planted before 1970 failed. The failure was largly due to misguided attempts to force the hardwoods to respond to silvicultural practices developed for the southern pines. Even during the 1960s when great interest existed in planting southern hardwoods, the silvicultural practices necessary for successful plantation establishment were poorly understood. Most successful commercial hardwood plantations were established after 1970, when intensive cultural practices became the standard. About 40,000 hectares of successful hardwood plantations exist in the southern United States,

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3/ The Hardwood Research Program consists of 18 industrial and 2 public organizations who own or control about 6 million hectares of land. Major emphasis of the cooperators is pine plantation establishment and management. About 10% of their effort is on regeneration and management of natural hardwood stands. Only 20% of the cooperators are planting hardwoods on a commercial scale.

and the area is increasing by approximately 4,000 hectares annually. With any plantation program it is imperative that each hectare be planted with the best genetically available stock and that a comprehensive improvement program be conducted to provide that stock.

Site specificity of most southern hardwood species dictates that four or five species must be used in an operational plantation program. As a result, the improvement program must to some degree genetically improve all the species needed in the plantation program. The degree of genetic improvement for a species will be determined by the economic value, unique inheritance patterns, and biological characteristics of the species. The decision could ostensibly be to establish intensive improvement programs for some species and less intensive improvement programs for other species. The improvement program outlined in this paper and adopted by the members of the N. C. State University-Industry Cooperative Research Program is sufficiently general so that it can be adapted to the needs and objectives for each species.

TREE IMPROVEMENT PROGRAM

Intensive Selection--Clonal Seed Orchard Programs

The hardwood tree improvement program has undergone some modifications since its initiation by the Hardwood Research Cooperative in 1963. The initial program emphasized selecting superior phenotypes ranging in age from 25 to 65 years old from natural stands, using a selection index. The index combined heritability and economic importance of selected traits into one score that was used to judge the relative quality of graded trees according to species and site. The traits used in the index were volume, pest resistance, crown conformation, leader dominance, bole straightness, bole pruning, freedom from epicormic branching, and branch angle. This system was used in lieu of a comparison tree or "check" tree selection system because most commercially important southern hardwoods occur in mixed stands where comparison selection systems are inappropriate.

A total of 709 trees representing 27 species were selected, using the index system. Many of the select trees were preserved in clone banks, while superior sweetgum (*Liquidambar styraciflua* L.), sycamore (*Platanus occidentals* L.), yellow-poplar (Liriodendron tulipifera L.), and green ash (Fraxinus penisylvanica Marsh.) were used to establish clonal seed orchards (Table 1). The progeny from these selected trees have been included in open-pollinated genetic tests.

Extensive Selection--Open-Pollinated Genetic Tests

The selection of phenotypically superior southern hardwood trees that were also genotypically superior was difficult because natural hardwood stands are composed of many species and have originated from both seedlings and sprouts. Trees from sprout origin are often selected at the expense of trees from seedling origin because sprouts have superior bole and crown characteristics which are features of vegetative propagules (Sweet and Wells, 1974). Phenotypic selection is also difficult in hardwood stands because many stands have suffered from dysgenic selection that has resulted from repeated, incomplete harvests.

Table 1.--Hardwood seed orchards established by members of the N. C. State Hardwood Research Program

Species	Orchards Established	Area (Hectares)	Clones Grafted (Number)
Sycamore	7	5.7	130
Sweetgum	5	13.0	70
Yellow-Poplar	1	2.4	22
Green Ash	1	1.6	17
Water-Willow Oak	2	2.4	a/

a/ Seedling seed orchards

The Hardwood Research Cooperative is circumventing these problems and limitations by selecting trees that have above-average phenotypic value for that site but not necessarily meeting the phenotypically superior standard required by the index selection. The genotypic value of the above-average trees is then determined in open-pollinated genetic (mother-tree) tests. Information from these tests will then be used to identify the best trees for grafting into clonal seed orchards. Using this extensive selection system, an additional 507 trees from six commercially important hardwood species are being tested in open-pollinated genetic tests (Table 2).

Table 2.--Number of above-average phenotypes being tested in open-pollinated genetic tests

Species	Trees Being Tested
Sycamore	231
Sweetgum	213
Water-Willow Oak	31
Black Walnut	38
European Alder (*Alnus glutinosa*)	32

THE FUTURE

The need exists to meld the trees selected and tested in the intensive and extensive selection programs into a cohesive improvement program. Despite the large number of species that are represented by selected trees, only sycamore, sweetgum, green ash, water oak (*Quercus nigra* L.) and willow oak (*Q. phellos* L.) have enough commercial importance across the southern United States to warrant a regional program. Other species that have great local commercial importance, such as yellow-poplar in the Southern Appalachians and cottonwood (*Populus deltoides* Bartr.) in the Mississippi Delta, could be genetically improved by the same type of breeding scheme on a smaller scale.

A large investment has been made for the improvement of southern hardwoods, but only a few organizations are establishing greater than 800 hectares of plantations annually. The best option for an improvement program of limited interest is to rely upon an open-pollinated breeding scheme. An open-pollinated breeding scheme offers the opportunity for some genetic gain at a cost that is generally lower than a control-pollinated program, especially for species where floral biology is poorly understood. However, increasing relatedness and accompanying inbreeding depression may require a shift to more control-pollinated breeding in the future.

For maximum efficiency and genetic gain, a tree improvement program has two distinct phases -- a breeding phase and a production phase. The breeding phase allows continuing genetic improvement into advanced generations and the production phase allows mass production of improved material in seeds or vegetative propagules. The individuals used in the production phase are a subset of the best individuals from the breeding population.

Breeding Phase

To maintain genetic diversity and integrity of geographic seed sources. the southeastern United States has been divided into breeding regions for each commercially important species. The breeding regions are zones that have genetically similar trees and similar physiographic and environmental conditions. For example, the range of sweetgum east of the Mississippi River, the working territory of the Hardwood Research Cooperative, has been divided into seven breeding zones (Figure 1). The selected trees will be utilized only within the region from which they originate, until tests reveal their suitability out side the breeding region.

The cooperating organizations within each breeding region will continue to select and evaluate trees from natural stands and unimproved plantations, using the extensive selection methods until each breeding region has selected at least 500 above-average trees per species. The open-pollinated genetic tests of the 500 above-average trees established with the extensive selection method will be used to select the superior trees for the breeding population, based on family and individual tree information. The two best trees from the best 50% of the families will be the parents of the second-generation breeding population_ The parents will be divided into groups of 50, and open-pollinated seed from each tree in the group will be kept together as a genetic test of the trees and as a subline of the second-generation population. Between 10 and 15 genetic tests will compose the breeding population for a breeding region and will be handled similarly to a sublined breeding population (McKeand and Beineke, 1980). Three commercial check lots common to each region will be included in all genetic tests of that region.

East genetic test will be planted at two locations, with each location hav ing ten replications with six trees per family per replication. The six trees from each family in a replication will be divided into three groups of two, and the three groups will be scattered throughout the replication so that a different set of families will surround each group (Figure 2). The groups will allow for a 50% thinning in the tests without losing any families and will also improve cross-pollination among families. Genetic tests will be computer-designe from N. C. State University. The cycle will then be repeated for subsequent generations, with individuals selected for the next breeding population being chosen from the previous breeding population on the basis of family and individual tree information (Figure 3). The level of coancestry within each subline will increase each generation, and the genetic quality between the subline

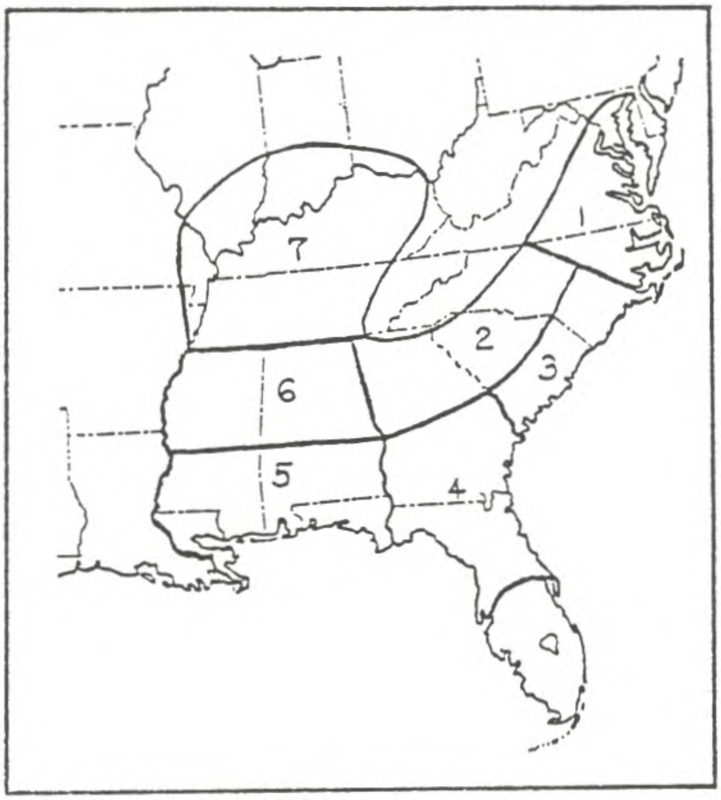
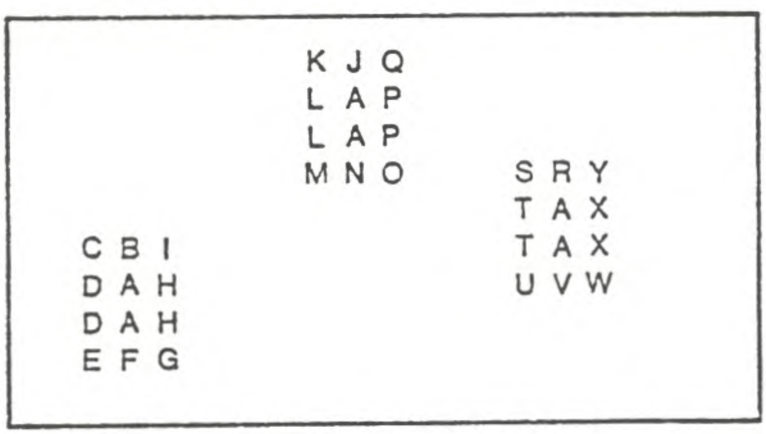


Figure 1.--Proposed breeding program for sweetgum.



i^{th} Replication

Figure 2.--Design of the 6-tree, partial-noncontiguous plots used in the second generation genetic tests.

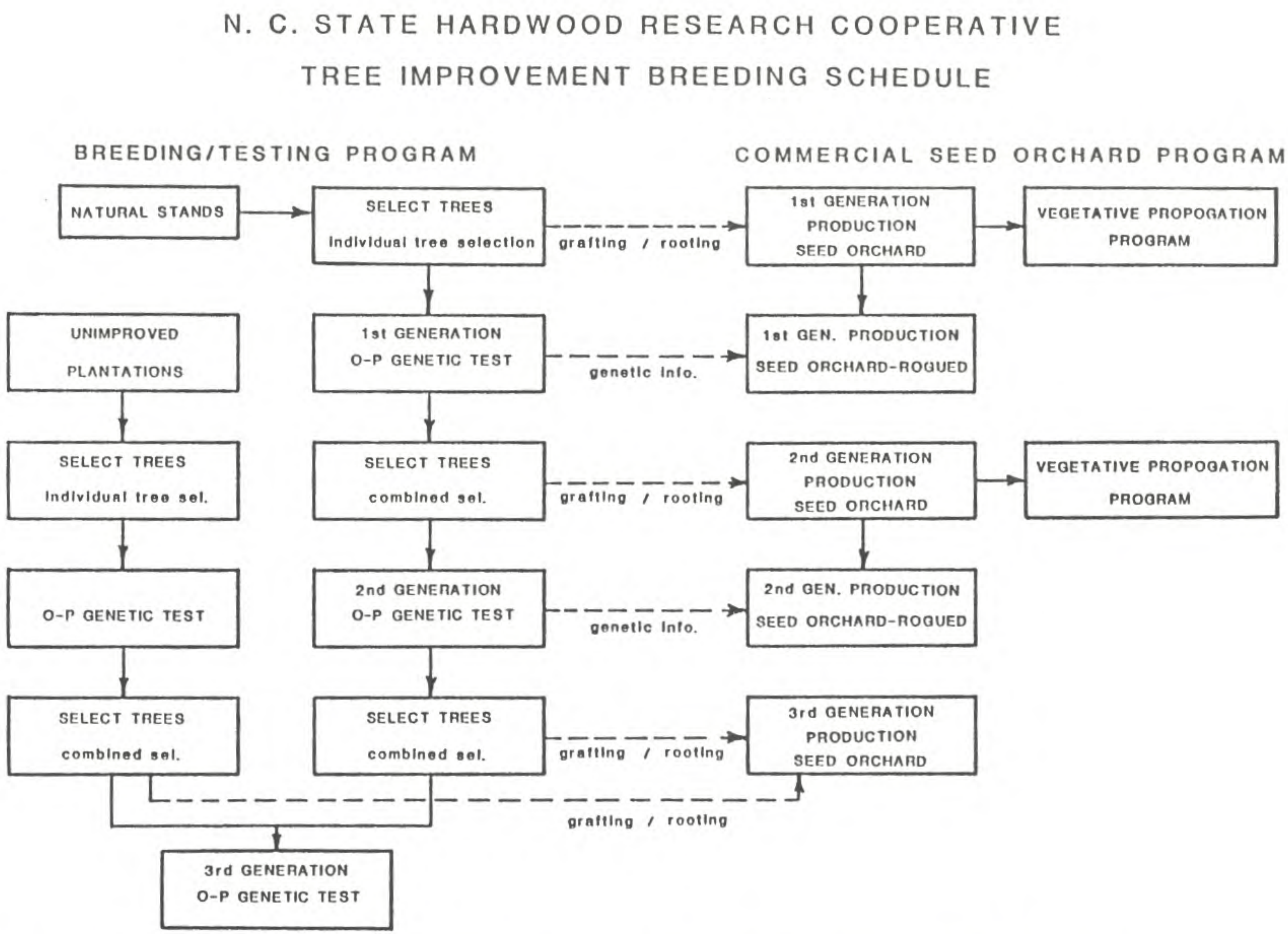


Figure 3.--N. C. State Hardwood Research Cooperative Tree Improvement Breeding Schedule

could become unequal; therefore, the breeding population and individual sublines may need to be supplemented with unrelated individuals to improve the genetic quality of the population. Plans have been made to infuse selections from unimproved plantations that have been shown through progeny testing to be superior genotypes at the third generation. It is important to select and test these supplemental individuals rigorously so that the levels of gain obtained by the third generation will not be diluted when the new selections are added to the breeding population.

The trees chosen from unimproved plantations should be fairly equivalent to selected trees from the third-generation breeding population, even though they have undergone one less cycle of selection, because a stronger selection pressure can be imposed in plantations than in natural stands, leading to a higher initial genetic gain.

Production Phase

The production phase of the improvement program involves the mass production of improved stock and will utilize the very best subset of trees from the breeding population. The improved material can be mass-produced either by seeds from seed orchards or by vegetative propagules. Vegetative propagation has a tremendous potential for the southern hardwoods; however, more research is needed before it is accepted for mass-producing the improved stock.

The cooperating organization's need for improved planting stock will determine when the production phase for that organization begins. Many of the organizations establishing hardwood plantations already have first-generation seed orchards. These seed orchards are being rogued, using genetic information obtained from the open-pollinated genetic tests. For organizations needing improved planting stock and not having a seed orchard, a clonal seed orchard can be established, using superior phenotypes from the open-pollinated genetic tests available in the breeding region or from the best selections from natural stands.

Clonal seed orchards are favored above seedling seed orchards within the Hardwood Cooperative because the design of the first-generation genetic tests is not conducive to conversion to a seed orchard. The second-generation genetic tests are more conducive for converting to seedling seed orchards because the individuals from a family are located in noncontiguous plots instead of row plots. However, the gains from these second-generation seedling seed orchards still would not exceed those of clonal orchards because the clonal orchard could utilize the best individuals from every genetic test in the breeding region, while the seedling seed orchard would be restricted to one test. For the second-generation seed orchard it would be best to utilize the very best individuals from each genetic test in the breeding region.

More improvement could possibly be obtained in advanced generation seed orchards by inserting selected trees from breeding populations from other breeding regions. The feasibility of seed source movement from one region to another will be investigated when breeding populations are established. Progeny from five superior trees from each genetic test within a region will be combined for test establishment in each of the other breeding regions. The design of this trial will be like that of the mother-tree study, comprising six replications of 10-tree row plots.

The design of the clonal seed orchards will be similar to existing hardwood seed orchards, with the size of the orchard depending upon the seed productivity of each species. Dioecious species like green ash pose special problems in production seed orchard design. Generally each planting spot in a seed orchard is both male and female; but for green ash, males and females will have to be positioned for maximum pollination efficiency. To keep seed production per hectare high in the orchard, there will be more female ramets than male ramets. The male clones in the orchard will be restricted to the best four or five clones in the breeding region and will not be rogued from the orchard. There will be many more female clones in the orchard and they will be rogued, using information from the open-pollinated genetic tests.

Accompanying the proposed seed orchard program, an experimental vegetative propagation program will be initiated with anticipation that vegetative propagules will eventually supplement or replace seedlings in reforestation. The best individuals from the breeding population in a given generation will be selected for the vegetative propagation program. Rooted cuttings from these trees will be tested in a number of environments with open-pollinated orchard seedlings of the same clones. These tests will provide information to determine the quality of trees produced from rooted cuttings as compared to seedlings and to better match genotypes to specific environments. By using rooted cuttings instead of seed orchard seedlings for commercial plantations, a greater genetic improvement can be realized because a greater portion of the genetic variance is captured, and the expected increased uniformity of the plantations will make stand management and harvesting easier. The long-term objective will be to replace seedlings and rooted cuttings with unrooted cuttings for plantation establishment.

For all hardwood species, selection of both parents in the breeding population will increase the gains achieved from the seed orchard. The most important reason for selecting both parents and maintaining the option to create control-pollinated families is to minimize inbreeding in the breeding population and production orchard. Inbreeding depression can seriously decrease the realized gain from the improvement program. Limited interest in hardwood breeding programs will dictate that open-pollinated breeding systems be initially used, but the option remains to adopt a control-pollinated breeding scheme after the second generation. A control-pollinated breeding scheme is particularly applicable to an operational planting program utilizing vegetative propagules.

SUMMARY

The area planted to hardwoods is increasing significantly and it is imperative that each additional hectare be planted with the best genetic stock available. The hardwood genetics program at North Carolina State University has undergone a number of changes since its initiation in the early 1960s. The changes have produced groups of selected trees with different levels of improvement. The time has come to integrate the groups into a comprehensive breeding program to provide for continued genetic improvement.

Initially, superior trees were selected and grafted into clone banks and clonal seed orchards with the intention of intermating these trees for the breeding program. It later became evident that genetically superior hardwoods could not be efficiently selected because of stand conditions and the silvics of the hardwood species. An extensive selection system was adopted in which above-average phenotypes were selected and progeny tested, using open-pollinated seed from the selected trees.

The clonal first-generation seed orchards are being rogued, using available genetic test data, and second generation clonal seed orchards are being established by selecting the best trees from the best families in the open-pollinated genetic tests. For the breeding phase, seeds are being collected from a larger set of selected trees from the genetic tests, to create the breeding population for the succeeding generations. Provisions have been made for continued selection of superior trees from unimproved plantations to increase the gene pool of the breeding population for future generations.

For the first generation an open-pollinated system for intermating the selected trees has been adopted, but in later generations control-pollination may be necessary to avoid inbreeding depression and reduce gains from the seed orchards. Along with clonal seed orchards, an experimental vegetative propagation program will be initiated in anticipation that propagules will supplement seedlings in reforestation.

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