Proceedings of the SEVENTH Southern Conference on Forest Tree Improvement

Gulfport, Mississippi June 26-27, 1963

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Contents

Papers are in the order of their presentation at the Conference. Titles and moderators of the five sessions were: How intensive will forestry practices become? *J. W. Johnson;* How much can genetics help the forest manager? *B. J. Zobel;* What do we know about inheritance patterns—how can we get improvement through genetics? *C. H. Driver;* Mass production of improved seed, *R. E. Goddard;* Value and speed of the genetics approach, *J. P. van Buijtenen.*

"Tree Improvement in Modern Forest Management" was the theme of the Conference, which was sponsored by the Committee on Southern Forest Tree Improvement. Officers of the Committee then were: *Chairman,* J. W. Johnson, Woodlands Research Dept., Union Bag-Camp Paper Corp.; *Vice-Chairman,* B. W. Henry, Institute of Forest Genetics, Southern Forest Experiment Station, U. S. Forest Service; *Secretary,* R. A. Bonninghausen, Forest Management, Florida Forest Service. Officers now are: *Chairman,* B. W. Henry; *Vice-Chairman,* R. A. Bonninghausen; *Secretary,* Donald E. Cole, Continental Can Co., Inc.

Impact of the Pulp and Paper Industry Upon Forestry in the Southern United States

Gunnar W. E. Nicholson

Tennessee River Pulp & Paper Co., New York

The pulp and paper industry in the 12 Southern States has developed from its beginning about 40 years ago into a giant industry, producing more than 60 percent of the total pulp production in the United States. The present annual consumption of pulpwood in the South is 25 million cords, with a market value of over $500 million. Approximately 100,000 employees, men and women, are directly engaged in the southern pulp and paper industry, and the annual value of pulp, paper, and board shipped from the 73 pulp and paper mills is over $2 billion. The capital investment is over $4 billion.

The industry is an ideal combination of natural resources together with people, progressive management, and technological and scientific know-how. The industry has brought about a better balance between agriculture and industry with a higher standard of living. The pulp and paper companies own only 12 percent of the total 200 million acres of commercial forest land located in the 12 Southern States, whereas 1½ million private small landowners own about 74 percent, and the balance of 14 percent is owned by large landowners and the State and Federal government.

During the early years, before modern forestry management was practiced, the timber inventory was being reduced year by year to such an extent that the consensus of opinion was that timber eventually would have to be shipped in from other sections of the country. This trend has been changed entirely, and during the last 25 years a surplus of inventory has been built up, and at the same time the annual amount of pulpwood produced has been increased from year to year. This tremendous improvement in increase in productivity of the timberland has been brought about by a cooperative effort by the forest industries together with the U. S. Forest Service, the various State forestry departments, various forestry organizations such as the Forest Farmers Association, the Southern Pulpwood Conservation Association, the American Forestry Association, the American Forest Products Industries, Inc., and several others, together with research and educational facilities of the forestry schools and universities.

One of the most important and effective actions taken has been better fire protection, reducing the annual acreage losses by fire from 5 percent or higher to the present 1 percent or lower. These losses will undoubtedly be reduced still further in the years to come.

Other very important developments are: the employment of more than 1,600 graduate foresters by forest industries, the organization of school forests and pilot forests, the establishment of training camps for thousands of 4H clubs and FFA members. In general, a very effective public relations campaign for publicizing the tremendous importance of better forestry land management on the whole economy of the Southern States has been taking place over the years.

A much greater utilization of the whole tree has also been brought about by the introduction of modern log barkers in the sawmills, making it possible to convert slabs and edgings into chips shipped to the pulpmills. This has added about 15 percent of the total pulpwood required.

The usage of hardwood in pulp manufacture has been continuously increasing, to the extent that 20 percent of the total pulpwood used is now hardwood. This will, of course, increase still further in the years to come.

Other developments of improved forest management practices have been selective cutting with seed trees left for natural reseeding, a tremendous increase in plantings of seedlings amounting to about one million acres per year during the last few years, seeding by airplane, cultivation of land for planting or seeding, research on combating insects and tree diseases.

All such activities have been essential in order to bring about the great step-up and increase of the timberland productivity which has been experienced during the last 30 years or so. These efforts will continue to an even greater extent in the years to come.

I believe, however, that you scientists and foresters who have been and who are creating new strains of pedigreed trees will effect by far the greatest progress in the increase of financial return for the timberland owners as well as for the forest industries in the years to come.

The fundamental research which has been carried on during the last 40 to 50 years in the Scandinavian countries and Western Europe, as well as during the last 30 years or so in this country, very clearly indicates the tremendous possibilities ahead of you. The application will work in two ways:

1. The development of new strains resistant to insects and tree diseases, as well as faster growth in volume and weight in pounds of fiber per acre will give the landowner a much greater financial return.

2. The development of new strains will also bring about a new specified type of fiber which will allow the pulp and paper industry to produce new, superior grades of paper products with new applications and usages. Encouraging results have already been achieved, and I believe we can predict that long before the end of this century we will produce, in planted seed orchards, all of the seed of known and specified parentage that will be required for all seeding of forestry land, and the requirements of the nurseries for growing of seedlings.

Progress in other phases of timberland management will also take place, and it is not impossible to think that most forests will eventually be planted like any other agricultural crop, and harvested in a mass-production way by very highly developed machinery in a manner similar to our present method of cutting the wheat fields with harvester combines.

The loading and hauling of pulpwood will be mechanized entirely, and roads will be built for regular tractor-trainloads. Pallet loading will be carried out by the small landowner, leaving pallet loads at the country roads to be picked up by hauling contractors in the same manner as milk cans are now being picked up and delivered to the creameries.

In some instances, barking and chipping will be carried out in the forests, and chips transported through movable light metal or plastic pipelines to the pulp mill.

It is quite possible that the average annual yield of pulpwood produced per acre can be increased to between 1 and 2 cords.

The preceding outline will, in a general way, forecast the possibilities of improved forest management which will bring about a very great effect upon the financial return to the landowner. It should also be of utmost importance from the national economy viewpoint as the increase in the demand for wood will be very great.

We are today using 25 million cords of pulpwood per year in the Southern States, and the forecast is that this will be increased to between 75 and 100 million cords per year by the end of this century. This is based upon increased usage per capita, increase in population, and a very great growth in export of pulp and paper products to the Free World.

The byproducts from the pulpmills, such as tall oil, turpentine, and others, are playing an important role today in the profitability of the industry. Such development will undoubtedly expand very greatly in the years to come.

There are enough indications and results from research carried out so far over the years that eventually a method of using the lignin in the wood as raw material for the production of various valuable organic chemicals will be discovered. As the lignin amounts to nearly half of the total dry weight of the wood, the quantities involved are very great.

Whenever this is accomplished, the total byproducts made in the pulp mills could become of greater value than the cellulose fiber made, and this certainly will increase still further the demand for additional wood, giving still greater value to the timberland.

There is indeed a very great need for greatly improved efficiency of forestry operation, harvesting, and transportation when we realize that the cost of pulpwood used as raw material in making chemical pulp makes up more than half of the total cost of the finished product.

The present low efficiency in growing, harvesting, and delivering pulpwood to the pulpmill, compared with the present highly developed method of conversion of pulpwood into finished product, chemical pulp in the plant, can be compared with the driving of a Model T Ford versus the driving of a Cadillac.

The opportunities to bring about a change in this relationship are enormous, and this should bring about a still brighter future for the paper industry in the Southern States. This would also mean a brighter future for the landowners, and greater accomplishments to be achieved by you forest managers, scientists, and forest geneticists.

The past is only a prologue to the accomplishments to come.

Site Preparation, Fertilization, Other Cultural Practices

Donald D. Stevenson

Buckeye Cellulose Corp., Foley, Florida

The prediction of future developments in almost any field of human endeavor is a chancy matter. Such predictions are uncertain because man is endowed with the intelligence not only to reach great heights of achievement but also to make colossal blunders. Few would have believed 40 years ago that we could reach the type of affluent society in which we now live or would have predicted on the other hand a second World War, more terrible than the one through which that generation had just passed. Now we see the possibilities for material and cultural progress menaced by forces which could wipe out most of the human race.

In spite, however, of such great uncertainties and the fears of a biologist like Dr. Ernst Mayr of Harvard that the human race may already have reached its peak in development of brain size and intelligence and the trend may be in a downward direction, I am optimistic that man can solve his problems and will continue to produce startlingly new methods of accomplishing constructive goals.

My optimism carries over into the field of forest management in which here in the South we have made notable progress. Favorable economic factors have enabled us to introduce forest practices which paralleled in intensity many of those developed in agriculture. Mechanized tree farming is no longer something to dream about but is here. In pine management we prepare sites with harrows and choppers, or by chemicals. To improve drainage some are throwing up ridges like the celery beds of south Florida, and digging canals in deep swamps. Fertilizing tree crops may be a practice just around the corner. Timber stand improvement with tractor-mounted mist blowers or by aerial spraying with silvicides has been carried out on extensive areas. All this is apart from forest genetics programs from which we anticipate sizable dividends.

The degree to which cultural practices will be intensified is dependent on demand and supply and a host of other economic factors of a national and international nature. Time does not permit a detailed discussion of these questions, but we cannot forget that wood is grown by the forest industries as a raw material for products and those products must be sold at a profit in order to continue in business.

The current over-abundance of available pine timber in many areas of the South is a matter of concern to private forest owners with wood to sell. Nor does this situation put any pressure on the forest industries to intensify cultural practices.

On the other hand, long-range forecasts indicate a tightening of wood supply against demand. In fact, the authors of the recent book, "Resources in America's Future" (Landsberg et al. 1963), in their interpretation of the Timber Resource Review (U. S. Forest Service 1958) and other source material, see some serious deficits by the year 2000. They suggest that the median demand, as projected in their report, is not likely to be satisfied without serious depletion of forest stands.

The pressures on timber supply will be of two kinds: increased demands for forest products, and a diminishing forest land area. Timber deficits, they believe, will have to be met by more intensive forest management, use of substitutes, and possibly more imports.

It is the judgment of the authors of this report that the land resource in the United States overall will be adequate only if yield and efficiency levels, as projected, will be reached.

I am not prepared to evaluate critically the assumptions and projections in this very comprehensive study. It could be, however, that a population of 330 million by the year 2000 will place demands on the forest resource which will force a high degree of intensity in forest practices joined with careful allocation of forest land to various uses.

However we may predict the future of forestry, intensification of forest practices by the wood-using industries on their own land will continue to be dependent as much on business considerations as on economists' projections to the year 2000. Management has to decide how much can be invested in the growing of the tree crop in relation to rate of return on its investment. On the more intensively managed forest lands I assume that present programs to build up growing stock to levels which will meet anticipated requirements will be continued.

This is not to say that the industries will disregard the results of research by the forest experiment stations, forestry schools, and their own research staffs where analysis shows that modest investments in new cultural practices will pay off. I simply want to emphasize the fact that the forest industries are spending more time and effort on cost analysis than ever before and must show a good economic justification for additional investments in forest management.

In this connection it is instructive to take note of a statement made by Yoho and Muench (1962) in considering the fact that labor productivity in the woods must be increased in the South in order for the forest industries to remain competitive. I quote: "the only likely way of achieving this in forestry and logging would be through the means by which it has been accomplished in other sectors of our economy—namely, through increasing the ratio of capital to labor . . . . In this regard, perhaps the greatest contribution which the industrial forest manager could make would be to cast off many of the shackles of the classical concepts in forestry and to concentrate upon growing a uniform product. In this way he could increase the feasibility of substituting capital for labor all along the forest production line."

Will more intensive forestry cultural practices be adopted by the thousands of small forest landowners and farmers who produce the bulk of the timber in the South? One obvious answer is that they may find it profitable to do so if they have markets for their wood products at a profitable price. I am afraid, however, that the answer is not as simple as that.

W. B. Lord (1963) may have brought out the best answer to this question. He suggests that more important investments are open to farmers in the farming enterprise and forestry investments must take second place. Changes, therefore, are necessary in farm organization to form larger accumulations of capital before farm forestry becomes more attractive as a business undertaking.

Realizing all the economic uncertainties in the forestry enterprise, I shall make a few modest predictions about forestry cultural practices in the South with some data to back them up.

1. *Site preparation* of wild land for pine plantations will be intensified. Subsoiling on some sites may be practical. Bedding to improve drainage shows real promise. An analysis by my company of slash pine plantations growing on unbedded and bedded flatwoods land shows that bedding has increased present plantation value by $11.60 per acre. This discounted present value is based on the assumptions that 400 trees per acre will be harvested at age 30 and that bedded plantations will accumulate their current growth advantage to that age.

A company owning a 30,000-acre property in south-central Florida reports that it has obtained per-acre yields of pine by bedding, as contrasted with burning only and chopping, as follows:

Burning only	5 cords at 18 years
Chopping	5 cords at 15 years
Bedding	8 cords at 12 years

2. *Fertilization* of trees on sites where soil deficiencies exist will be widely practiced. Better knowledge of forest soils, including the part played by mycorrhizae and other micro-organisms, and the physiology of trees may well enable us to increase yields economically with fertilizers even on average and good sites.

On the basis of experiments with first-year applications of phosphorus to 1-year-old slash pine plantations on bedded sites, we have found that discounted present value is increased through fertilization by about $14 per acre. This, of course, assumes that the present growth advantage will be maintained.

We have fertilized 630 acres of young pine plantations this spring, applying 200 pounds of triple superphosphate per acre by airplane. This is wet "pitcher plant" land near Carrabelle, Fla.

If this pilot project proves successful in terms of increased growth, we shall assume a shortened rotation advantage and probably fertilize additional acreage. Fertilizer and application cost came to $7.25 per acre. The job was contracted to Christopher Dusting Service of Okeechobee, Fla. This firm used Grumman Ag-Cat planes carrying 1,200 pounds per load.

3. *Thinnings in natural stands will have to be highly mechanized* to be economical in the slash pine belt where stagnation occurs at such an early age. Mechanization of woods operations, however, has still so far to go that we cannot predict what economies there will influence stand treatments.

4. *Plantations will be grown at wide spacings without thinnings and clearcut.* Uniformity of growth will result in a more uniform product to the industries.

5. *Plantations will be cultivated* as well as fertilized.

6. *Timber stand improvement, widely practiced today, will be intensified* as new, more effective chemicals come on the market. Phil Briegleb, in reporting to the SAF meeting at Atlanta last fall on progress in technical forestry in the South, said that research has shown that an investment of $5 per acre for release work can raise the value of timber growth over the following decade by as much as $50.

7. *Insect and disease control will have to be intensified.* We are looking to the research organizations to find the answers. It is a serious question as to whether enough is being done now, or is being planned in the immediate future, to meet the many unsolved problems in entomology and pathology. I believe that a larger percentage of the research dollar should be going into basic and applied work in these fields.

These are a few of the cultural means, along with genetic improvement, that we shall probably employ to grow more wood and a more uniform product per acre. And I have little doubt that those of you who are on hand by the year 2000 will have seen other developments in forestry practice that will dwarf anything yet attempted in the sixties.

Future Management of the Southern Pines

L. E. Chaiken

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The only rational basis for this discussion must be within the framework of Don Stevenson's observation that the intensity of our future forest management will depend only little upon our technical prowess, and, indeed, only partially upon future supply and demand, but will be affected largely by the complexities of the world, national, and regional economies, and especially those peculiar to each forest operating organization.

But if we will presume that these relationships will be favorable for additional investments in forestry, which will in turn yield additional economic benefits, we might spend a few minutes in speculating how we might intensify these investments, and hence our forest practices.

Several years ago I had the assignment of trying to find out what the research needs were for the management of the southern pines. It seemed to me at the time that the best way to approach this was to find out what the future management practices were likely to be, and that the best way to do this was to hit the road and talk with forest managers.

I finally cornered about 50 professional foresters of many faiths and persuasions. They represented pulp and paper companies, lumber companies, State forestry commissions, National forests, schools of forestry, as well as research foresters, both public and industrial. They were a diverse group, but they had one thing in common: each held a responsible position, roughly equivalent to woodlands manager (or assistant or staff forester) or was recognized as qualified in some segment of forest management or research.

To these, the following questions were put: (1) What do you think the future forest practices will be in the southern pine region? (2) In connection with these practices, what are the problems needing solution?

As might be expected, the answers to the first question varied by objectives of management and locality, and, of course, there was considerable discussion of what products were to be produced. But everyone agreed that practices will become more intensified, with greater investments in cultural measures resulting in lower unit production costs. Further, with the exceptions to be noted later, there were strong opinions that future practices, particularly on the larger ownerships, would be intensive culture for the mass production of *wood fiber* of high quality especially in woodlands in proximity to the mills. This will be done by:

a. Complete ground preparation, not only for type conversion but for many pine sites.
b. Artificial regeneration, by planting and direct seeding.
c. Such cultural measures as may be profitable: fertilization, cultivation, protection from pests, etc.
d. The shortest possible rotations, consistent with the production of the desired size, quality, and uniformity of the fiber-package.
e. Efficient extraction and conversion into a marketable and competitive product.

Divergent opinions were expressed by a small group of foresters whose product objective is sawtimber, and especially those whose timberlands are located in areas of high site quality. In such areas, natural regeneration of the pine types is relatively easy, given a modest investment in the control of competitors. Seed supply is consistently high, and moisture for germination and survival is seldom limiting. Natural reproduction is considered to be more suited to the production of saw logs, poles, and piling, where rate of wood increment is secondary to quality increment. Nor is the longer regeneration period as vital a factor as it is in short rotations.

There are trends and countertrends, yet it is the consensus that the relative production of sawtimber will decline in the future, and that the management of the forest will be geared to the production of wood fiber on essentially an assembly line basis. These notions could easily come from a sampling heavily weighted with pulp company foresters. But the fact remains that intensive forestry will be practiced by foresters—and large holdings by lumber companies in the region are declining.

This is no place to toll the bells or mourn the passing of a vital segment of the forest products industry. The production of lumber still absorbs the largest share of the production of the forest. And yet if we are to discuss future practices we must inevitably do so with the view of future products.

Perhaps this is an irresponsible and sweeping generality, but we are told that the processing of lumber would frequently be an unprofitable venture if it were not for the sale of chips from mill residues. We are further informed that the current market is more favorable to the lower grades of lumber than the better grades. We see the increase in lamination and the rapid rise in the production of particle-board. One can reasonably question the advisability of choosing to grow high-quality saw logs, on a purposeful investment basis with rotations in excess of 50 years.

But whether you agree or not as to whether the lumber industry will decline or not, the most significant point remains: the advanced practices of the region will be directed toward the production of wood fiber for conversion products.

It appears, then, that these advanced techniques, whatever they may be, are likely to be applicable mainly to the large industrial ownerships. The problems peculiar to the small owner, and those of the National forests too, will call for somewhat different approaches. But let no one suggest that the forester is not aware of the many problems associated with these practices. He knows full well, for example, that if the 30 million acres of large ownerships are to be managed on a 30-year rotation, 1 million acres must be regenerated each year—and if planted, almost *1 billion* seedlings must be planted *each year*. He is also aware that much is still to be learned about planting and direct seeding, and of the management of plantations. He knows, too, that insects and disease will have a greater impact upon his intensively cultured stands. But he looks hopefully for answers, through organized research and through his own mass empiricisms and those of his colleagues.

What are the specific practices and what are some of the main problems associated with them? Briefly, they break down into:

1. *Seed and seedling production.*—If artificial regeneration becomes common practice, it is evident that large quantities of seed and seedlings will be required. As for quantity of either, there seems to be no great concern, although some adjustments will certainly be needed. With rotations being shorter, seed production areas will become even more necessary, with the collection and storage of seed in good seed years to meet anticipated demands.

As for quality, everyone seems confident that the programs in tree improvement will produce seed and seedlings with superior qualities. This, they point out, is one of the most compelling reasons for shifting over to artificial regeneration.

Those who propose planting programs believe that more efficient nursery practice will provide seedlings of better vigor and improved field survival and growth. They are counting on improved culture in the nursery and better methods of lifting, handling, packaging, transportation, and storage of seedlings.

2. *Site preparation.*—This has been thoroughly covered by Don Stevenson, but I should mention one matter of concern to the foresters in the northern part of the region. They wonder whether the techniques, mainly mechanical, but also fire, will cause deterioration of the heavier soils, as in the Piedmont and parts of the upper Coastal Plain. Although bulldozing or any method of topsoil movement is no longer advocated, they are alert to the possibility of soil compaction through the use of heavy equipment, and of erosion through disturbance.

3. *Techniques of artificial regeneration.*—The regeneration period—that most vulnerable point in the rotation—will come more frequently. It is here that losses are most likely to occur, and costs to soar. We need to know how to insure successful regeneration, with our blooded stock, and how to do this with the least cost. It may be surprising that so many organizations have proceeded with large-scale programs of artificial regeneration with so little actual experience and background in woods planting. It is presumed that the planting techniques are the same as those of the extensive old-field plantings of the past 20 to 30 years. Yet those who have observed the misshapen roots of planted trees, as reported by Trousdell and others, are wondering now if trees are currently being planted less carefully than back in the days of the Civilian Conservation Corps and whether it makes much difference if the roots are "balled-up" anyway.

Since there should be little difference in root development between plantings in old fields as opposed to well-prepared woods sites, they feel that if root arrangement proves significantly to affect survival and growth, then more care can be exercised in planting, and if this cannot be done efficiently, then there is always the alternative of direct seeding.

As a matter of fact, the success of direct seeding during the past few years has given the forester considerable confidence. Its advantages are well known, as are the disadvantages. The forester feels that broadcast seeding has adequately served the purpose of quick regeneration of large areas, but future seeding will be mainly by spots or rows.

So it appears that the forester has several alternative techniques for artificial regeneration. One bothersome point, for which he has no ready answer, is the invasion of volunteer seedlings into the neatly spaced plantation; if heavy, this could be quite annoying.

4. *Growing stock levels.*—The forester presently has only scant information on which to base his decisions as to spacing in his plantations. He knows, for example, that close spacing generally yields more total volume of fiber for the first 15 or 20 years or so than the wider spacings—but the wider spacings produce more usable wood more efficiently extracted. And he also knows that it is cheaper to plant 500 trees per acre than 1,000. So the trend is toward 8 by 8, 8 by 10, 10 by 10, and wider. But how should this vary by site quality? Or by intensity of ground preparation? How does spacing affect wood quality and fiber yield? Or its effect upon competing species? What are the growth responses to thinning? How might spacing be varied

with the use of intensive cultural practices, such as fertilization, cultivation, and pest control?

At present, and for some time to come, the forester will be managing three distinct populations: the natural stands, old-field plantations, and forest-origin plantations. How different are these populations in their growth responses to different levels of growing stock?

It is well to note that few foresters have precisely similar objectives and resources for timber management. Some are more concerned with wood quality than others; some have limited and consolidated holdings, while others may have scattered lands distant from the mills. Financial structures and objectives may differ; one may choose to produce greater yields per acre at lower returns on invested capital, while another may be vitally concerned with generating the highest rate of return. So it seems futile to search for regional "optimum stocking." These foresters are quite capable of choosing their own optima, given the biological responses of any array of stocking levels and treatments.

5. *Site improvements.*—As one forester in Virginia put it: "We can't buy reasonably good forest land any more; in fact, because of population pressures and all sorts of progress, we're being pushed off our better lands now. We are going to have to learn how to grow crops of trees on the dry deep sands, the organic wetlands, and the heavily eroded soils." So we see sizable programs of scrub-oak clearing in the sandhills and ditching for water control in the wetlands. How will the pines perform? And in between the drylands and the wetlands there are a lot of shallow soils, sites 50 to 70, where pine trees are growing slowly.

What can be expected in site improvement? The addition of nutrients through fertilization, the control of moisture both excess and deficient, modification of organic hardpans—are all possible. Another approach would be some modification of the trees instead of the soil: perhaps, the development of drought-resistant and flood-resistant strains, or the adaptation of species to site, such as the current trials with sand pine on the dry sites.

6. *Control of insects and diseases.*—As recently as 15 years ago the average forester in the region dismissed as minor nuisances the few forest insects and diseases he encountered. He had been aware, of course, of the threat of the southern pine beetle and others, but as the years went by without major depredations, this too was dismissed. He took comfort in the knowledge, for example, that littleleaf disease was restricted to stands on depleted soils. He learned that the frequently extensive damage caused by tip moth in young old-field plantations became less important as the plantations became older. He dutifully salvaged his *Ips*-killed trees, or absorbed the loss, with the view that this was one of the hazards to be expected in growing timber, especially in the dry years.

As long as the forester was busily engaged with the many household chores needed before the truly professional job of management could begin, and as long as he was dealing with (and frequently liquidating) naturally grown, second-growth timber, such things as insects and diseases were of minor concern. More pressing jobs needed to be done. Land acquisition, boundary surveys, fire protection, road construction, inventories, etc., took all available time. Following these came the job of large-scale rehabilitation of understocked, depleted, and idle lands.

But during the course of all this, the forester began to take a closer look at his trees because he is determined to let nothing upset his carefully planned program of management, and certainly not his "forester-grown" timber stands. He discovered *Pales* weevil, the cone insects and diseases, *Fomes annosus*, and tip moths on the tops of 80-foot trees where they were not supposed to be. When he plants 600 trees to the acre he wants 600 to survive, and if any thinning needs to be done he wants to control it.

With all his enthusiasm for the intensive production of trees, the forester seems a bit uneasy, for he knows that his forest will be vulnerable to the common insects and diseases. He is aware that even if no new pest arises to plague him, there will be a greater impact upon his intensively cultured stands than ever before. Even so, he is quite optimistic about his ability to cope with this problem. He hopes that research will provide him with effective control techniques, particularly with the use of systemics. He is counting on the development of genetic strains resistant to all pests. But most of all he feels that he is flexible enough to change his practices if and when the pests become dominant.

7. *Methods of harvesting.*—Another point of agreement among almost all foresters in the region is that along with our intensive culture of the forest we must streamline our methods of extraction of products, and this will strongly influence our management practices. The need for more efficient extraction techniques is evident. Decreasing supply of woods labor, the drudgery of it and inefficiency, increasing minimum wage standards, increasing taxation, and the tremendous rise in paperwork connected with it all surely indicate that improvements must be made.

In speaking of pulpwood logging, one of our foresters commented, "The tree itself, free of limbs, forms a nice package, but we proceed to sail into it, cutting it up into confetti at the stump—and then struggle to re-assemble these pieces on a truck or railroad car."

But whether we leave the tree as confetti or whether we go into long-length logging, it is certain that mechanization will necessitate large-scale operations. For one thing, we will have to change some of our notions about thinnings—although I am not so sure that we will be thinning in our short rotations. But if we do thin our stands, spacings must be such as to permit access of the mechanized equipment, and volumes must be high enough to justify its use.

And at the same time we must accept systematic selection of trees to be removed as thinnings: whole rows or some such. But no longer will we spend time making judicious professional decisions as to which tree to cut and which to leave. Because of the anticipated advances in tree improvement, all our trees will be alike as peas in a pod, and the only decision to make is how much to cut.

Trend Toward a Monotype

What will the intensively cultured forest be like? If the forester has his way, there will be sizable areas of pure, even-aged stands with a minimum of competing species. No one conceives of vast areas, for the land-use pattern in the region is such, as are the sites, that it is unlikely that there will be many stands in excess of a thousand acres homogeneous as to species and age.

The forester doesn't seem to be impressed by the several classic examples of failure of tree monotypes. He points out that pure even-aged stands of the southern pines have existed in the region for many years, without untoward losses. He also knows that any forest management will increase the risk of economic loss, and that although the unmanaged wild and mixed-species forest may be the "safest," it is certainly not the most productive.

He further argues that even though risks can be scattered, and perhaps minimized, by scattering his stands and age classes, these will be more complex and costlier to manage. And yet, paradoxically, if he achieves success in his search for improved strains of trees, he may incur even greater risks, for how vulnerable will be the monotype, especially if founded upon an increasingly narrow genetic base?

Just a few words in conclusion. I don't suppose that what I have said is really new, for many of these practices are currently being applied. But I would like to insert a word of caution. The streamlining of our forest operations is inevitable as we strive toward greater efficiency, for to remain competitive in this free enterprise system we must increase production with decreased unit cost. And here may be the trap; may we not be led into what might be called forestry by the average? To streamline, we must smooth out the bumps and depressions. Yet these bumps and depressions represent the biological variations inherent in forestry, many of which may be profitably ignored because they would be too costly to recognize. To ignore others, however, could lead to substantial losses of production opportunity.

No one advocates the tree-by-tree forestry typical of the Europeans. But let us beware of the sausage grinder.

Hardwood Silviculture in Tomorrow's Southern Forest

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Some 101 million acres, comprising half the southern forest, are currently dominated by hardwoods. Seventy million of these acres are capable of growing high-quality timber rapidly, and are likely to continue in forest indefinitely (Briegleb and McKnight 1960). The Forest Service's Timber Resource Review (1958) estimated that the Nation's total wood requirements will double in the next decade. For the past half-century, these 70 million acres have been supplying more than half the Nation's needs for factory lumber and veneer logs, and they will have to meet at least an equal portion of the increased demand for these products in the future. In addition, they will have to grow vast amounts of pulpwood. Southern pulp mills sextupled their consumption of hardwoods in the last decade, and the end of this expansion is nowhere in sight.

These facts make it plain that we must intensify our forestry in good hardwood stands as well as in our wonderful pine forests. To what extent silviculture may be practiced in southern hardwoods is the question to be dealt with in this paper.

Some recent results with cottonwood show off the possibilities. In a plantation established by the Missouri Conservation Commission on a good Mississippi River bottom site near Hannibal, dominant trees averaged 6 feet per year in height growth during the first 14 years. Diameter growth over the same period averaged about one-half inch annually. This was achieved with little or no weed control (Wylie 1961).

By carefully cultivating to control weeds during the first year, Chapman and Dewey Lumber Company of Memphis, Tenn., established a cottonwood plantation on a favorable old-field site in the bottoms of the Coldwater River. The trees, which are now 9 years old, have annually grown 7 feet in height and 1 inch in diameter (McKnight 1963).

Intensive cultivation for the first 2 years rewarded another plantation owner, near Vicksburg, Miss., with an average annual growth of 15 feet in height and almost one and three-fourths inches in diameter the first 3 years, according to Virginia McKnight (1962). Considering the values inherent in species such as walnut and cherry and the technical qualities of oak and hickory coupled with their reasonable growth rates, there is no reason to doubt that comparable opportunities exist in species other than the poplars.

Achievement of intensive silviculture will depend a great deal on recognition of appropriate sites for the culture of hardwoods. Good hardwoods can be grown on sites of four physiographic classes: bottom lands of major rivers, uplands with rich soils, bottom lands of creeks and small streams, and some swamps. Within these classes, the growth rate and quality of major timber species are greatly influenced by soils and local drainage.

In several recent reports (Broadfoot 1960, 1961, 1963; Broadfoot and Krinard 1959) the growth capabilities of particular hardwood species are related to the series and phase of soils on which they occur. Growth relationships of white oak to soils of northeast Mississippi have been reported (McClurkin 1963). These are but examples of the classification work that is sure to become more exact and to form the basis for intensified silviculture. Already the soils on some important forest areas have been fully classified and mapped by experts. With accurate soil maps and corresponding capability ratings for hardwood species, the silviculturist can reliably choose the single or several species best adapted to each of his sites.

The intensity of silviculture that can be justified will be measured, partially at least, by soil productivity. On a site that will without amendment produce 400 cubic feet per acre annually, very intensive stand culture is likely to be well repaid. On a site capable of only 80 cubic feet, less intensive measures may be justified.

Hardwood silviculture of the future will recognize the demands for other use of land on which the forests grow. Our hardwood forests are the ideal habitat for game. Some bottom land sites may be inundated by new dams and by waterways. Others may always be in demand for agricultural purposes. The intensity of silviculture must be guided by the interrelationship of timber production with other uses of the forest or the site. Unbalanced multiple use may deter intensive silviculture. For instance, this past spring deer browsing severely damaged hardwoods in a plantation-spacing study of the Southern Hardwoods Laboratory. Some is both expectable and tolerable, but an overpopulation of deer (one deer per 7 acres) seeking food in the forepart of the growing season has

[1] Maintained by the Southern Forest Experiment Station in cooperation with the Mississippi Agricultural Experiment Station and the Southern Hardwood Forest Research Group.

kept new growth nipped back almost to the ground and very likely ruined a 220-acre study.

Thus, the application of silviculture to both natural and seeded or planted stands will be guided by site-species relationships and take into consideration the multiple uses of the forest or possible alternative use of the land.

A Silviculture For Natural Stands

Within the next decade there will be a marked increase in the effort to eliminate weed-species and culls from stands of hardwoods on qualified sites. But stand improvement is only preliminary silviculture. For mixed hardwoods on good sites, some form of partial cutting will always be necessary to avoid premature harvesting of trees capable of making premium products. The hardwood silviculture of the future will result in a mosaic of even-aged stands and will amount to group selection guided by the growth capability and potential value of the individual trees within the group (Putnam et al. 1960). Thinnings will not only promote good growth but will aid in quality control for specific products. Obviously they will be made practical by the expanding markets for pulpwood from southern hardwood forests.

Intermediate cuts will be made with an eye to favoring species and trees that have the least likelihood of producing epicormic branches and that have little sign of diseases or insects. Some crop trees of potentially superlative value may be protected from boring insects through the periodic spraying of the tree boles with long-lasting insecticides or repellents. In preliminary tests by R. C. Morris of the Southern Hardwoods Laboratory, annual spraying of boles in June with a 0.25 percent water emulsion of BHC has prevented attack by borers for the past 4 years.

In many cases, some site treatment will be required to obtain adequate regeneration of the desired species. Possibilities of such treatment are suggested by recent pilot-scale tests along the banks of the Mississippi River, where considerable acreages of high-quality site were taken over by the tolerant but undesirable boxelder after most of the pioneer cottonwood was logged. In a cooperative effort the Southern Hardwoods Laboratory and the Anderson-Tully Company logged or deadened all overstory trees except cottonwood and then plowed trenches to a depth of 8 inches and a width of 7 feet—the purpose being to prepare a bare, moist seedbed for cottonwood. So far, this site treatment has been very successful when applied in the spring on silty and sandy loam soils (Johnson 1962). Results on clay soils or when plowing was done in the fall have been erratic.

How about nutrition? Will fertilizers be used in hardwood silviculture? In natural stands near Tallulah, La., applications of nitrogen have significantly increased both diameter and height growth of 20-year-old sweetgum, willow oak, and water oak. It is too early to predict the economic significance of fertilizers, but these early results indicate a likely place for their use.

Of several soil amendments tested, supplemental watering has proved most helpful. Broadfoot (1958) found that where clay soils were kept covered with water during the winter, trees grew twice as fast the next growing season as they did on sites where no water had been impounded. These temporary lakes also attract waterfowl into hardwood forests. Particularly on broad slack-water sites, this multiple use management to aid both game and timber is being employed by a number of landowners. To avoid killing of timber, water is trapped only during the winter months and drained off early in spring.

Plantation Possibilities

Plantability of hardwoods has until recently been low, but certain species are now emerging as good candidates for particular sites—cottonwood, yellow-poplar, sweetgum, sycamore, green ash, and some of the oaks. Also, the possibilities of direct seeding are unlimited for open sites or situations where the forest needs to be converted to more desirable species. Discovery of appropriate techniques for repelling rodents from acorns will advance the reforestation of good hardwood sites. Physical properties of the soil as well as the nutrient condition may need to be amended to assure survival and successful growth of future hardwood plantations.

Of course, site will dictate to a certain extent what can be planted or which species should be favored, but Charles A. Heavrin of the Anderson-Tully Company has calculated a Species Value Index to compare the most important species in growth, form, and market value in west Tennessee. The Index is in terms of the dollar value of the annual growth per tree. Using an arbitrary 24-inch diameter for maturity and taking into consideration the average height and form of each species, he divided the volume of the average tree of each species by age to get the average annual growth per tree.

Then he converted the average annual growth per tree into dollars, using the Hardwood Market Report. The resulting Index appears below:

Species	*Value Index*
Black walnut	$1.61
Yellow-poplar	.72
Cottonwood	.70
Willow	.56
Cherrybark oak	.42
Green ash	.40
White ash	.36
Nuttall oak	.35
Sycamore	.34
Sweetgum	.31
Red maple	.30
Pecan	.26
Cypress	.25
American elm	.22
Hackberry	.20
Overcup oak	.19
Hickory	.11
Honeylocust	.10

It can be seen that a yellow-poplar can increase in value at the rate of $0.72 per year, while hickory is only increasing $0.11 annually—a species differential of 6 to 1. But cottonwood, with a lower market value than cherrybark oak, has a greater index because of its fast growth.

Of course relative values may change over the years. For instance, pecan has very recently become an extremely popular furniture wood, and veneer and lumber companies are competing for logs. Pecan is a fast grower on suitable sites and in addition provides food for deer, squirrels, and turkey. These considerations might well raise its position in the desirability index. Change is inevitable, but such an index, if carefully conceived and coupled with site-species evaluations, can provide an admirable guide to choice of species to plant.

Equally important will be site preparation and cultivation appropriate to the value index assigned and to the species to be planted. Illustrating the effects of differences in preparation is a cottonwood plantation on riverfront soils near Greenville, Miss. When it was established 5 years ago, it was given minimum site preparation, cultivation, and weed control. Another planting was made 2 years later on a well-prepared adjacent site where weed control was absolute and cultivation was intensive. Now the younger stand averages 42 feet tall and 6.5 inches d.b.h., while the older is the same height and has an average diameter of 6.7 inches.

In another place sycamore planted in trenches made by a fireplow was killed by excessive competition, whereas in cultivated plantations it performed well.

Rundown sites on alluvial soils may be rejuvenated by extremely deep plowing. Trials with a pan plow indicate that old pastures can be turned over to a depth of 16 inches for a cost of $15 per acre. Full benefits have yet to be determined, and so does the value of deep ditching to aid moisture retention next to planted trees on droughty sites. However, site preparation and maintenance are sure to be part of hardwood plantation management of the future.

When the development of superior planting stock assures us of uniformly good growth and survival, most of the guesswork will disappear from plantation spacing. We will be able to space pretty strictly on the growth requirements of the trees and the need for cultivation. With present-day variation in growth and survival, the conservative course is to space close within the rows, so as to provide against possible heavy mortality and also to allow some choice between survivors of differing form and vigor.

As a hedge against high risks of planting one species, plantations may be of two or more species. For instance, sycamore, sweetgum, and ash are likely to be planted with cottonwood on riverfront sites. Nuttall oak and green ash may be planted in alternating rows on slackwater sites. The degree of intermingling will be determined by factors such as shade tolerance, requirements for growing space, and machine plantability.

Until effective and economic methods of repelling rabbits and deer are developed, special food plants for such game may have to be established to entice the animals away from seedlings or seed and allow for maximum development of the trees.

Eventually these plantations will be started with stock developed or selected for good tree form, fast growth, resistance to insects and disease, and heavy yield of high-value wood products. In the South such planting stock may first be achieved with cottonwood, which is exceptionally suitable for genetics and tree improvement research. Breeding techniques are relatively simple with *Populus*, and improvement once expressed in a single genotype can be maintained indefinitely on a commercial basis by way of vegetative propagation.

It should be clear from the foregoing that genetic improvement of the important plantable species would greatly enhance the returns from money spent on cultural techniques. It is almost a password phrase for the geneticist but it is worth emphasizing that we shall more and more realize that genetic improvement, once established, results in long-term profits without further costs.

Better Forest Management Through Better Adaptation

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Adaptation, in the forest genetics context, is a process of evolutionary adjustments that fit individual trees or stands to better survive, grow, and reproduce in their environments. The idea and the principle are scarcely new. In history and literature we find evidence that primitive forest dwellers already recognized and understood the importance of adaptation, of putting the right tree in the right place. Perhaps the earliest record of adaptation of forest trees is found in the beginning stanzas of the Finnish epic poem Kalevala, dating back to 900 B.C. In this poem the bard recounts a project undertaken by the hero Pellervoinen (possibly a precursor of Paul Bunyan) who set out to perform a direct seeding operation with a keener awareness of species adaptation than perhaps is exhibited by many highly trained foresters of our times. To quote in part from Kalevala:

> " . . . On the firm soil he plants acorns,
> Spreads the spruce seeds on the mountains,
> And the pine seeds on the hill-tops,
> In the lowlands he sows birches,
> On the quaking marshes alders,
> And the basswood in the valleys,
> In the moist earth sows the willows,
> Mountain ash in virgin places, . . .
> Junipers on knolls and highlands,
> Thus his work did Pellervoinen."

In the intervening centuries since Pellervoinen's heroic direct seeding operation, many silviculturists have, by trial and error, acquired a considerable degree of sophistication and awareness concerning adaptation and its significance in forest management, at least as regards a few major species. For example, in the South today, in fewer and fewer instances are loblolly pines being recommended or planted on deep sand sites, and possibly only a very few million slash pines annually are being set out much above latitude 34° N. These signs of restraint indicate the beginning of real progress in an area of primary importance to sound forest management.

Adaptation in forest trees involves adjustment to two major environmental factors, climate and site. Climate includes such variables as range, level, and duration of temperatures, length of frost-free growing season, amount, intensity, distribution, and character of precipitation, and hours of sunlight. Site is construed to include such variables as soil moisture, depth and texture of surface soil, total soil depth, chemical and physical characteristics of surface and subsoil, topography and hydro-geology, depth to water table, and drainage.

Progress toward fuller understanding of adaptation, and especially of its significance and practical employment in forest management, has not been spectacular or rapid. Research in this area represents the efforts of many investigators in many lands over a long period of time. No attempt will be made here to review the very large number of studies that have been published on this subject, but it may be of interest to mention a few; also it may be relevant to note that a rather large number of past investigations have dealt mainly with provenance in relation to climatic factors.

Some Lessons from Study of Provenance

Species occupying a wide geographic range or wide variety of habitats have been the main objects of provenance studies in the past, and, in general, have been the ones exhibiting the most pronounced racial diversity. The Frenchman Vilmorin is generally credited as the first to prove the heritability of racial characteristics of pines. During the years from 1820 to 1830 he conducted extensive experiments in the Loiret Department of France, using seeds from French, Scottish, German, and Russian (Riga) sources of Scotch pine. Interestingly enough, the seed source from the Riga region produced the finest trees, which he described as having straight, beautiful cylindrical stem and "slight boughs" (Engler 1905). Moreover, he noted that the second generation of the Scotch pines from the Riga source grown from seed harvested from the Loiret plantings possessed the same fine qualities as the first generation.

In the United States one of the earliest studies of adaptation was a ponderosa pine provenance experiment begun in the fall of 1911 in Idaho (Weidman 1939). In the 22 progenies under investigation, marked differences in both height and diameter growth were observed, along with differences in several foliage characteristics. One of the more important findings from this study was the observation that a source making the best growth at first was later overtaken by a source showing a steadily sustained growth rate and greater resistance to extremes of climate at the planting location.

In the South, the pioneering study of loblolly pine provenances established in 1926 in Bogalusa, La., has served to dramatize the enormous influence that geographic source of seed may exert on the success of planting this species (Wakeley 1944). Subsequently, striking differences among provenances of loblolly pine in survival, growth, or drought hardiness have been demonstrated by such studies as that of Zobel and Goddard (1955), and similar results have been reported for shortleaf pine, for example, by Auganbaugh (1950).

In a recent study of 188 origins of Scotch pine, Wright and Bull (1963) recognized 14 ecotypes, basing differentiation on such characteristics as seed size, height growth, summer foliage color, autumnal coloration, first-year bud formation, second-year growth initiation, second-year leaf length, and type of root system. However, these differences were observed only on 1- to 3-year-old seedlings in uniform nursery beds, hence judgment of their importance needs to be deferred until outplantings have been observed over a sufficiently long time.

At this point I want to emphasize and punctuate the dangers inherent in early decisions based on short-run provenance tests. Many seed origins may appear fully adapted to a new environment at the start, and continue to show promise even for 2 or 3 decades, and then succumb to, for example, a single sudden drop in temperature, particularly if the change is unseasonal. A good example of this was observed in some slash pine plantings in North Carolina during the past year. A one-night freeze when temperatures dropped to approximately 20° F. in October 1962 killed over ninety percent of the slash pine seedlings on an organic loam site situated approximately at latitude 34°30′ N. and longitude 77°30′ W. In an older planting of slash pine on a deep sand site at about the same latitude, the same freeze killed or damaged most of the saplings (already 8 to 10 feet tall) in depressions and basins throughout the plantation. These instances are minor, but they point to the real possibility of similar occurrences on a large enough scale to knock management plans into "a cocked hat." No introduction of exotics or extension of existing range of native species should be made without careful study of probable adaptability. It is not the average values of temperature, rainfall, frost-free season, etc., that are necessarily important, but the extremes of high and low and the probable duration of such extremes.

Other Ecotypes

Most of the provenance studies of the type mentioned above have been concerned wholly or chiefly with discovery and evaluation of climatic ecotypes. But other adaptations are also important. One of the most vital considerations is that a species or strain must be adapted to the soil as successfully as it must be to the climate of that site. Unfortunately past investigations that have taken account of the interrelationships with quality of site and soil are meager indeed, and the price for this lack or oversight or failure has been high. As one example near home to most of us, we may readily recall that in the middle thirties tremendous quantities of black locust seedlings were planted, hopefully for soil stabilization purposes, on eroding Piedmont upland fields. Today the ragged, riddled remnants, still persisting in places, dismally attest to the failure of foresters to adequately assess the edaphic requirements of this species. Even the heroic Southwide study of pine seed sources (Wakeley 1952) was limited in its major emphasis to latitude and longitude of origin, with soil-site aspects included only in a secondary and incidental way. Considering the size of that study it is understandable enough why the decision to limit variables was made, but it is unfortunate that an assessment of edaphic ecotypes could not be made at the same time on the same heroic scale. This lack in this instance is certainly not unique. More often than not the worth of an ecotype or strain is assessed with only one environmental factor as a criterion. This limitation is dangerous; frequently the interaction of two or more factors may be the decisive one, a point not to be overlooked in the progeny testing programs that are burgeoning in the South right now.

Perhaps the first study in North America that made any attempt to include site quality along with altitudinal and latitudinal influence was undertaken in 1912 on Douglas-fir in the Pacific Northwest (Munger and Morris 1936). This study was not designed to evaluate soil-site effects in a critical way, and at age 17 no differences, indeed, were observed. Other studies have, however, demonstrated that there are such things as edaphic ecotypes, meaning that some species do maintain, among other characteristics, a definite root form or habit, and that such ecotypes may not adapt readily to other environments. For example, in Wisconsin the failure of several red pine plantings on sandy soil was thought attributable to the origin of planting stock raised from seed collected from trees on rich lacustrine clays (Wilde 1954). Extensive deterioration of red pine plantations in Pennsylvania also attests to the hazards of ignoring site quality in assigning species to planting chances.

In longleaf pine rather marked differences in root systems have been observed that seem to be related to origin of seed, the more fibrous root systems being associated with moister habitats. In jack and red pine Youngberg (1952) found that seedlings from sand dune sites grew at a much slower rate than those originating from parentage on granitic outwash and other fertile soils. The cited studies and observations, and many others, clearly indicate the necessity of paying heed to soil and site factors wherever and whenever the management situation involves species assignment, racial diversity, or ecotypic variation of any kind.

Beyond Provenance and Site

The problems of adaptation in forestry are not restricted to reactions and susceptibilities that may be encountered in new environments associated with large changes in geography and climate, or in site and soil. In a very real sense, adaptation is also involved when it comes to taking advantage of individual tree variation within restricted local environments.

Fecundity and precocity are two characteristics that are of vital concern in tree improvement, and they are inherent at least to some degree within otherwise apparently uniform populations. But under a different photoperiod or a different thermoperiod, a given source may turn out to be neither fecund nor precocious, or vice versa.

Differences among species in the capacity to tolerate intra-stand competition are so well known as to be taken for granted. But this capacity extends also to strains within species, and to individuals within strains. The rigidity of control in this characteristic has not been adequately determined but its importance in forest management can be appreciated easily enough; it concerns spacing directly in relation to maximum production of fiber, volume, or both per unit area of land.

Variation also occurs among trees, at least in loblolly pine, with respect to their capacity to respond to fertilizer applications affecting wood properties; that is, some trees may show a marked growth response without a concomitant drop in specific gravity or some other properties (Zobel et al. 1961). Some individual trees apparently have greater tolerance to changes in fertility levels of the site, insofar as effects on anatomical characteristics are concerned.

Phenological variations, relating to active periods of shoot elongation and diameter increment, are also observable not only among species and different environments, but within species in the same environment; they may, in fact, account for a very significant portion of dry matter production differences among trees. Variation of this type can also determine how successfully a species can become established in a new environment, particularly one involving higher altitudes or greater latitudes where killing frosts may decapitate, decimate, or destroy the early starters or the late season growers. By the same token, these variations may also be closely associated with *apparent* resistance to pests; a strain that appears resistant to an infestation, such as tip moth, on average or better sites, may prove to be essentially nonresistant on sites of poor quality. These variations, and similar ones, provide a basis for selection among species and among strains within them for improved adaptation. But to capture the full potential and to make intelligent use of such superior specimens or strains will require rigorous assessment of their adaptation to the environments in which they are to be grown to specified sizes.

What About Hardwoods?

From foregoing examples and observations an impression may have been created that adaptation phenomena are confined to softwood or coniferous forestry. Nothing could be farther from a true picture. Hardwoods in general are even more likely than conifers to exhibit greater sensitivity to large changes in geography and soils, climate and site. (For example, a freezing temperature on the night of May 1, 1963, killed back all new shoot growth on most of the native strains of yellow-poplars in sapling-size plantations on the Hill Forest in Durham County, N. C., but in local sources of loblolly, Virginia, and shortleaf pine plantings of the same age, it appeared to cause no damage.) Local climate, indeed, is likely to have a greater bearing on the outcome of various silvicultural practices in hardwoods than in pines, as is suggested in the studies by Hough (1945) and others. Because many hardwoods regenerate from old root stocks and stump sprouts more readily than from seed, the opportunity for perpetuating given traits or characteristics through hardwood silviculture is greater than in pines, at least in our existing populations. Conversely, the problem of getting rid of undesirable strains may prove more difficult.

Most hardwood species lack the capacity for successful invasion of situations involving primary succession; hence, where hardwood establishment is attempted on open land, extra help in the form of cultivation and fertilization may be almost invariably necessary to assure a successful start. Even on existing forest soils on cutover lands some form of relatively drastic site preparation may be necessary. For example, our studies on yellow-poplar planting have shown that this species when planted into spots where logging slash has been burned will attain an average total height of 18 feet in 6 years, but outside these severely burned spots on otherwise identical soil it will attain a height of only about 9 feet in the same length of time.

Although knowledge about hardwood silviculture and hardwood adaptation problems is meager, particularly for species in the South, we are in a better position with this group of species than we were with pines to draw on the considerable backlog of research and experience accumulated over the centuries in the field of horticulture.

What About Breeding and Hybridization?

In striving for better adaptation, we are not limited to selections from superior phenotypes in existing populations. Much improvement may also be achieved from breeding and crossing for specific purposes, as indeed has already been done and is being done, for example, in projects of the Industry-North Carolina State Cooperative Tree Improvement Program. Through such work we may ultimately achieve crosses or strains with greater photosynthetic efficiency, drought hardiness, or other characteristics that make for better utilization of existing resources of soil, water, and air. It is a foregone conclusion, however, that no miraculous outcome is in the offing, just solid, and perhaps sometimes annoyingly gradual, improvement. As an illustration, our study of loblolly pine has indicated a high degree of correlation between certain foliage constituents and usable volume in individual trees. One might loosely assume that some trees are much more efficient than others in extracting the available nitrates, phosphates, and other molecules or elements from the soil. What is more likely is that certain apparently rapid-growing trees have had access to greater amounts of the constituents that appear in greater concentration and amount in the foliage of the larger specimens. It seems very likely also that new strains or new hybrids selected or developed for rapid growth will not attain their full hereditary potential, if at all, unless given an environment of high native fertility, or one made high through intensive culture.

In Peroration

In a general, rambling discourse of this sort, indulging in peroration seems pardonable, justified, and maybe even necessary. I have attempted to show how adaptation in forestry from a genetic viewpoint is vital to sound forest management. Many aspects involving other facets of interactions and susceptibilities of genotypes to their environments have been passed over or mentioned only in passing because others on this program will treat them in detail. But lessons from the past stand out clearly enough even in a general exposition to point out where we have operated stupidly in the past and to suggest how and where we might operate more cleverly in the future. A few specific areas relevant to this southern forest region bear reiteration now.

We have replaced longleaf pine with slash and loblolly on deep sands and other droughty sites.

We have introduced slash pine on loblolly sites on much too large a scale.

We have planted loblolly on "poop-out" spots all over the Piedmont, spots so poor that a demanding species like loblolly will die before reaching marketable size, whereas other species without cultural measures or loblolly with intensive cultural measures would have made the grade.

We have tended largely to ignore or to malign such species as Virginia pine and pond pine, overlooking their splendid qualities such as tolerance, respectively, of infertile sites or wet pocosins; their vegetative vigor, sure-fire regeneration capacities, and the tremendous capacity of pond pine to survive or to recover from severe damage by fire.

We have attempted planting hardwood species on eroding old fields without even the minimum of cultural assistance.

We have brought slash pine too far up from its native botanical range.

We have assumed that shortleaf pine is more drought resistant than loblolly, confusing its capacity to sprout at early ages with its persistance on dry ridges.

We have made many species-site studies using sources of seed or seedlings often with no knowledge of their edaphic or geographic home site.

Additional examples of ignoring or failing to understand the importance of adaptation might be cited, but let this suffice. These past mistakes will haunt us for some time to come, but the experience should be worthwhile, if we learn something solid about adaptation from it. We may even need to *un*learn some things from our past mainly of the empirical and frequently uncritical studies. As Sir Thomas Browne said over 300 years ago: "To purchase a clear and warrantable body of truth, we must forget and part with much we already know."

But I should not want to close on so negative a note. We surely know enough about adaptation already to avoid making big mistakes. The first and perhaps the greatest benefit from application of the genetic viewpoint in forest management stems from rigorous use of the growing knowledge about adaptation. The beauty of it is that we need not wait to start reaping the benefits; they accrue from the day we employ that knowledge in forest renewal.

How Much Is Forest Genetics Helping the Forester by Increasing Growth, Form, and Yield?

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Today we are beginning to measure the increased yields from forest genetics, and we now have a basis for estimating the gains expected in the future. Until recently the principles of forest genetics had been consciously practiced very little, but good silvicultural practices incorporate many of the basic principles. Thinning from below, seed tree cutting, and shelterwood management are examples of practices that should leave the best formed, fastest growing trees for the regeneration of future stands. The recent developments in forest tree improvement have served to make foresters consciously aware of the importance of considering the individual tree in addition to species and race with the future in mind. We realize that we have to maintain a positive selection pressure to avoid retrograde. We have also become much more aware of the importance of individual traits in the ultimate use of the tree and recognize the intrinsic characteristics of the wood itself. We are learning how important characteristics like straightness can affect pulp quality and how small differences in specific gravity can mean important differences in pulp yield and in yield per acre.

Wakeley (1954) has shown that the choice of the wrong geographic source of seed can be disastrous in terms of growth and disease resistance. Perry and Wang (1958) have translated these volume differences into monetary values to demonstrate that we can afford to make large investments in controlling our seed to prevent the use of wrong sources. There are numerous similar references covering various species, but let us leave geographic origin with the assumption that good land managers are going to use the best geographic source available; they will be using local seed when they do not have reliable data on which to base their selection of geographic source of seed. For the remainder of this paper, I will be speaking with reference to individual trees and local stands.

We haven't begun to realize many of the gains from our tree improvement work, but the material we are now planting and using from seed production areas and, on a limited scale, from seed orchards is earning its way in added growth and quality that will be havested in the not-too-distant future. In fact, the Ida Cason Callaway Foundation sold for pulpwood last winter the rogues from a seedling seed orchard established in 1955. This is probably exceptional, but it does show that we don't have to wait a lifetime to see some of the fruits of our labors.

The available data on growth, form, and quality of individual trees and progenies are limited to rather young age classes. Charlie Webb will tell you how confident we can be in projecting our juvenile data and using them as a basis for selecting our best trees and progenies. With some degree of conservatism, here is some current information and what I think we might realize based upon it.

Growth

Squillace and Bengtson (1961) reported heritabilities of 8 to 16 percent for height and 29 to 58 percent for diameter in 14-year-old slash pine. I have calculated [1] heritabilities of 20 to 30 percent for height and 6 to 34 percent for diameter in 7- and 8-year-old slash pine progenies.

There are numerous reports in the literature of significant differences among open and control-pollinated progenies of our southern pines. Considering only the older of this material, we see differences of 10 to 20 percent among means for both diameter and height. If we use a selection differential of the top 5 percent of a stand (2.06 standard deviations) and apply a heritability of about 30 percent for height and diameter, we can expect our future crop to exceed the present stand average by about 10 percent. So you see, we can translate our present knowledge into a rough figure to show what we might expect in the future by immediate control of seed source. Gain = heritability × selection differential, thus *both* are of great importance. As you realize, our selection level for seed orchard clones is much higher than mentioned and though the heritabilities may be slightly lower when applied to selections in natural stands, we can expect greater increases in growth—

[1] Barber, John Clark. An evaluation of the slash pine progeny tests of the Ida Cason Callaway Foundation (Pinus elliottii Engelm.). Ph.D. Diss., Univ. Minn. 206 pp., illus. 1961.

possibly up to 12 or 15 percent in height and diameter.

In the first selection cycle from natural stands, the selection differential can be at a maximum for all traits because we have the entire population to choose from. In subsequent cycles of selection, we will be selecting from progenies of only a few hundred trees at most and will be limited in the selection differential that we may use.

Our data on the southern pines is supported by studies in several other species. Callaham and Hasel (1961) have estimated heritability of height growth from 15-year-old ponderosa progenies of about 39 percent. These progenies averaged about 26 feet in height. Toda (1958) has reported broad-sense heritabilities of 68 percent for height and 58 percent for girth in *Cryptomeria* from seedling (42 years old) and vegetatively propagated (39 years old) trees. He concluded that where vegetative propagation could be used, selection of the top 1 percent of the stand would show gains of 17 percent in height and 28 percent in girth. In another study, Toda et al. (1959) worked with 20-year-old progenies of *Cryptomeria* averaging 26 feet in height and found narrow-sense heritabilities of about 26 percent for both height and diameter. He also worked with some data from Europe on Scots pine and found a narrow-sense heritability of 24 percent for height.

Form

One very interesting aspect of form is the proportion of the wood produced by a tree that is in the stem where it can be harvested. Fielding (1953) determined the volumes of several Monterey pines by trunks and branches. Two of his trees were almost identical in total volume (9.59 and 9.75 cubic feet), but one had 48.9 percent of its total volume in the trunk and the other 62.6 percent—a difference of about 1.5 cubic feet or 28 percent more stem wood in one tree than the other. As we select for smaller, shorter limbs we may also select for a higher proportion of total wood in the stem.

Bob McElwee will give you the details of wood quality, but I want to mention the part that some aspects of form play in the production of compression wood. Zobel and Haught (1962) reported a study made of loblolly pine compression wood. There are two important aspects to their work, the effect of stem straightness on the production of compression wood and the compression wood associated with knots. Their "straight" trees had about 6 percent compression wood, the "average" trees had 9 percent, and their "crooked" trees about 16 percent. These differences are not only statistically significant—they are meaningful. Mergen (1955) reported on the inheritance of crook in controlled crosses of slash pine where he found 76 percent of the offspring from one parent were crooked. Perry (1960) has reported similar data on loblolly pine resulting from crosses made among crooked parents. He obtained 88.5 percent crooked trees when both parents were crooked and 51.8 percent when both trees were straight. Reversing these figures, we see that the straight trees produced more than four times as many straight progeny.

McWilliam and Florence (1955) discussed stem form of slash pine in Australian plantations. Using "routine seed" from the best 160 crop trees per acre as their control, they found that open-pollinated progenies of selected trees contained twice as many acceptable trees. Controlled crosses among selected trees produced four times as many as "routine seed." The best open-pollinated progenies produced 7 to 10 times as many plus trees per acre. The best control-pollinated progenies produced 20 to 25 times as many plus trees. These trees were picked at a lower level of selection than we are using in our seed orchard programs; consequently, we can expect substantial improvement in stem form.

Open-pollinated slash pine progenies at the Callaway Foundation varied from 30 to 90 percent crooked stems at 7 and 8 years of age.[2] These were subjective ratings but very critical. Many of the stem deviations considered as crook or sweep will probably be masked by eccentric stem growth with its associated compression wood before the trees reach harvest age.

From these few studies we can see the opportunity for improving stem form to produce straight logs, poles, and other products. The accompanying reduction in compression wood will improve pulp quality and reduce problems in drying lumber.

As mentioned earlier, Zobel and Haught (1962) reported on the compression wood surrounding knots. They found that each knot was surrounded by an approximately equal volume of compression wood. Here we have the opportunity to reduce not only the size and amount of knots but at the same time to reap the benefits of a parallel reduction in compression wood.

Many foresters are inclined to think that stand conditions are of primary importance in determining branch size and limb retention. Undoubtedly, stand conditions are very important in controlling crown length, but sampling of natural stands or plantations of our southern pines will show great variation in branch size and number in trees of the same crown length. Our data on the inheritance of branching characteristics is limited because most of our progeny test are relatively young and have not had an opportunity to exhibit these traits under closed stand conditions. I have already mentioned Fielding's (1953) work on the relative volumes of stem and branches which emphasizes the importance of branching habits.

Kiellander (1957) showed that branching and quality in spruce could not be controlled entirely by plantation spacing. Finely branched trees planted at 4.9 feet retained their good branching and quality while a course source planted at 3.9 feet

[2] Ibid.

remained course branched and of poor quality. Fielding (1960) has described the number of whorls as highly heritable in Monterey pine, and they appear not much influenced by site.

Detailed crown examinations of seven 25-year-old slash pine trees in a plantation in Georgia showed that the average basal area of branches varied more than 100 percent from the finest to the coarsest.[3] A similar range was found among their open-pollinated progenies, but data were too limited to establish a reliable parent-progeny regression. Differences in crown width from 39 to 51 percent and heritabilities of 16 to 19 percent have been reported in slash pine (Barber 1961). Squillace and Bengtson (1961) reported heritabilities of crown width in slash pine of 12 to 48 percent. Trousdell et al. (1963) have recently published data on crown differeneces in 7-year-old loblolly pine open-pollinated progenies with heritability estimates of 17 to 34 percent. Although we cannot translate these differences into dollars or quantities harvestable at maturity, we can expect the gain in form to represent appreciable value not only to the manufacturer of primary products but also to the landowner in increased volume and value and to the harvesting crew in reduced labor for limbing.

Yield

These differences in growth and form add up to increased yield in quantity and quality. Also, improvement in wood quality and disease and insect resistance will add further increases in forest productivity.

Let's translate some of our height and diameter values into volume. In Queensland (1962) the best crosses among slash pine gave 30 percent more volume at 10 years and showed a "substantial superiority in stem straightness." Squillace and Bengtson (1961) reported volumes among 14-year-old progenies of 6.0 to 8.4 cubic feet; the fastest growing contained about 40 percent more volume than the slowest. From these data they estimated heritabilities of 31 percent from control-pollinated material and 18 to 35 percent from open-pollinated progenies.

Peters and Goddard (1961) arrived at an estimate of heritability of "vigor" in slash pine. This was the ratio of progeny superiority in height to parental superiority in volume. Based on controlled crosses and open-pollinated progenies, they arrived at a heritability of 15 percent.

Fielding and Brown's (1961) report on tree-to-tree variations in health of Monterey pine and response to fertilizers showed very sharp contrasts in growth and response. They worked with both seedling and clonal material. At 15 years they had clones varying in height from 20 to 50 feet and with foliage color differences; each clone was characterized by its own vigor state and set of systems. These sharp differences in site adaptability certainly reflect important selection criteria and point the way to greater gains where site extremes are encountered.

Working with 7- and 8-year-old slash pine data (Barber 1961) and using an approximation of cubic-foot-volume [cubic foot volume = $(d.b.h.)^2$ (ht.) (0.002315)], I have found that the faster growing progenies average about 2 times the volume (0.41 to 1.21 cubic feet; 0.87 to 1.59 cubic feet) of the slower growing ones. If calculated on total plot volume, the range would have been greater because the faster growing progenies had the better survival, resulting in more trees per plot.

Toda (1958) has been very optimistic about the values to be achieved with selections of *Cryptomeria*. He calculated that selection of the top 5 percent of seedling trees, when propagated vegetatively, would increase volume by 43 percent. This was based on increases of 8 percent in height and 15 percent in diameter.

I will mention specific gravity only briefly. There are numerous references on variation and inheritance of specific gravity (Dadswell et al. 1961, Goggans 1961, Van Buijtenen 1962, Thorbjornsen 1961, Zobel 1961). Heritabilities are quoted from about 20 to 70 percent, depending upon material examined and methods used. Squillace et al. (1962) calculated values of 21 to 42 percent among open-pollinated material and 56 percent for controlled crosses. Let us assume a heritability of 30 percent—this means that we can expect yield increases of 4 to 6 percent simply by confining selection to the top 20 percent of our stands.[4]

Now let us add to this the increase in yield and quality associated with the reduction in compression wood. By appropriate selection, we might improve the straightness of our trees to achieve a reduction in average compression wood of as much as 25 percent. I am sure we would be hard-pressed to place a value on this, but if compression wood is important, then such a reduction should be meaningful.

Oleoresin yield is another factor I've not previously mentioned. This is the trait about which we have the best data arrived at from breeding. Squillace and Dorman (1961) summarized this work recently and reported heritabilities of 45 to 90 percent for the trait. They used an average heritability of 55 percent to calculate estimated gains with various methods and levels of selection. If a selection level of 200 percent average yield was taken, then their open-pollinated progenies would be expected to yield a gain of 27 percent. In a clonal seed orchard, proven 200-percent yielders should give progenies with a yield 100 percent above average. In the case of a seedling seed orchard based on 9 F_1 clones from crosses among 200 percent proven high yielders, the expected increase would be 152 percent or 2½ times present yields. They also projected yields for a seed production area using the top 10 percent from a stand

[3] Ibid.

[4] Data of the Southeast. Forest Expt. Sta. on file at Macon, Ga.

of 300 trees per acre. These seedlings should reflect an increase of about 30 percent for this one trait.

Toda (1956) has introduced the possibility of increasing total yields by increasing the number of trees per acre. He calculated that a 17-percent decrease in crown diameter would permit 50 percent more trees per acre, and though they may grow slower as individuals, the gross yield would be higher.

Discussion

Now how can you use this information? There are several ways, depending on the management programs for your forest holdings and whether you have or contemplate having an active tree improvement program as such. No matter what your situation, you can put certain principles of forest genetics into action.

Let's consider the situation of the landowner who uses natural regeneration. He can begin by paying particular attention to the trees that will produce the seed for his new stand. He should remember that his new stand may be established several years before he makes his final cut and adjust his marking rules to insure the elimination of all undesirable parents before regeneration becomes established. This landowner can expect to make appreciable improvement in only those traits that can be readily evaluated by ocular estimate. He can select for straightness, growth rate, form, and possibly disease resistance. In some situations he may be able to make a crude selection for oleoresin yield. It is not now practical to make quick screenings for the various wood quality traits. If he uses the shelterwood method, he may be selecting at a level equivalent to the top 5 to 10 percent of the stand. Of course, he is limited to the particular stand on the site, but gains can be appreciable.

The first step for those land managers who use some form of artificial regeneration is the establishment of seed production areas in the best stands they have. This will provide seed requirements for the immediate future and will serve on a continuing basis or until seed orchards have been placed into production.

The availability of stands for conversion to seed production areas determines how effective the program may be. Those of you who have tried to find suitable stands with sufficient trees meeting requirements such as those of the Georgia or South Carolina Certification Standards know that these stands are rare and difficult to locate. Where these top quality stands are not available we must still take the best we have and work with them. We would probably all agree that our "best" stands are much above those from which the majority of State and commercial seed are usually obtained when purchasing cones from unrestricted collectors. We have here a real opportunity to upgrade the genetic quality of our seed by converting our best stands to seed production areas and realizing the gains from limiting the parentage to the top 5 to 10 percent of the stand. Easley (1963) in a first report on growth of trees from loblolly seed production areas, has found a height superiority of 17 percent above controls at 5 years on a sandy site and 27 percent on a clay site.

We must realize that the amount of gain for any single trait is going to depend upon its heritability and the selection differential used. As we add additional traits to our selection criteria, the selection level at which we work for each trait must be reduced sharply if we are to retain sufficient trees for seed production. As an example, if we wish to retain only trees that are within the top 10 percent of the population for one trait, we could keep an average of 1 out of 10. When we go to the second trait and select at the same intensity, we could keep 1 out of 100, assuming traits are independent. The third trait drops it to 1:1,000 and the fourth to 1:10,000. This means that where more than two traits are involved we must reduce our standards or have too few trees remaining for practical use. If we lower our standards of selection to maintain sufficient trees for efficient seed production, then we sacrifice some of the gain we might have achieved from a single trait. To many people, the standards for individual trees on seed production areas seem rather liberal, but when you consider height, diameter, straightness, branching, natural pruning, and pest resistance, you find a reason to remove most trees.

For single traits we might expect appreciable gains from seed production areas, such as the 30-percent increase in oleoresin yield calculated by Squillace and Dorman (1961) for selection of the top 10 percent. Other individual traits, such as height and diameter, might produce gains of 5 to 10 percent, but when several traits are considered we must sacrifice part of the gains possible for each because of the limited population and area concerned.

With immediate seed needs stop-gapped by seed production areas, and recognizing their limitations, the next step for a land manager is the seed orchard. He must project his needs to determine what characteristics are important to his goals and then draw up selection criteria to evaluate plus-tree selections. The same rules of probability apply here where many traits are rated, but the individual tree may be found anywhere without regard for frequency per unit area. Clonal establishment of an orchard means that a broad spectrum of selections may be assembled to interbreed freely—each parent possibly representing the best among many thousands of trees. Each parent *must* be tested to insure that it will transmit the desirable traits for which it was selected and that it does not transmit any undesirable trait.

When these clones have been tested and the poor ones rogued, we will be producing seed that should eventually yield appreciable gains in several traits simultaneously. I believe we can conservatively think in terms of increased volumes of 10 to 15 percent, gains in specific gravity of 4 to 6 percent, and reduction in compression wood of several percent. Add to this increased quality value for straightness, form, and pruning, further increased yield achieved by disease resistance and improvement of other wood quality traits, and you can recognize the worth of an aggressive tree improvement program.

I expect someone to raise the question of which type of orchard to use—clonal or seedling? Both have merits—I do not believe there is any single answer. We have recommended both. Quickly, I might say that seedling orchards are somewhat cheaper to establish, but remember that parent selection costs the same and control pollinations on widely scattered trees are expensive and time consuming; at least 3 years are needed after selection to get seedlings in the field and by then you could have 2- or 3-year-old grafts. My observations are that clonal orchards will "flower" earlier and more abundantly than seedlings of slash and loblolly pines. Seedling slash pine orchards planted in 1955 by the Callaway Foundation have produced no "flowers." Clonal orchards established by the Georgia Forestry Commission since then have been "flowering" well for several years.

Possible inbreeding (selfing) in clonal orchards has been raised in objection, but the effects may be low. In seedling orchards, we have the risk of mating the full-sibs and half-sibs, but less risk of selfing. The effect of this is unknown. Where the usual 6 to 10 traits are rated, we have the problem of probabilities in seedling orchards. How many trees per acre will we have left if we keep only the top 10 percent for each of six or more traits—hardly enough to recognize the area as a seed orchard. In clonal orchards we select the parents at whatever level we wish without particular concern for the probabilities or frequency of occurrence per unit area or per unit of population.

Theoretically, the idea of seedling orchards is good when considering a limited number of traits and when juvenile-mature correlations are high. Practically, the idea is sound under similar restrictions and it has a place—but when time is of essence, I personally prefer to place the added investment in clonal orchards. However, until we have seedling orchards established on at least a pilot-plant scale, we will not be able to make a sound comparison with the extensive clonal orchards now beginning to produce seed.

In closing, let us look at the values Perry and Wang (1958) placed on seed of varying yield potentials. A meager 2-percent increase in yield over a 25-year pulpwood rotation is equivalent to $18.93 per pound of seed when used in the nursery for seedling production. A 10-percent yield increase would amount to $90.63 in value per pound of seed; a per acre per year yield increase of $1.05. These values are what we can afford to spend to improve our seed. We cannot afford to lag any longer. We should be aggressively pursuing our tree improvement programs now.

Genetics in Wood Quality Improvement

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The incorporation of genetic principles into a forest management program can be, and has been, justified for one or a combination of several different reasons. The papers already presented on this panel have developed ideas which show that genetic principles applied to management of forest lands will produce tangible gains in the form of increased growth and yields. By the application of tree improvement principles, including use of properly adapted seed sources, additional benefits can be gained by increasing volume and improving form of trees. The speaker immediately following me will show how increased benefits can be derived through reduction of losses to diseases and insects.

In this paper I shall attempt to emphasize benefits derived from a genetically oriented forest management program through improving the quality of wood produced. Other speakers have stressed improvement of yields of wood per acre but have not been primarily concerned with the anatomical characteristics of the wood or the overall benefits that can be gained from the control of the wood quality.

Benefits gained through improvement of wood quality are not of a type that can be credited back to forest management in the same manner as can an increase in yield. Evaluation of benefits to be gained from wood quality improvement is based on higher value of the end product. Final evaluation of benefits must be made by mill technologists and chemists rather than by foresters; thus, the responsibility of determining the direction and kind of wood quality improvement must be shared both by those who grow the trees and by those who convert them into the final product.

Methods of Achieving Improvement

Tree improvement practices for use on commercial forests have varied from judicious marking rules on areas to be restocked naturally, through seed production areas to seed orchards. For significant improvement in wood quality, very little can be accomplished below the level of seed orchards; this method is the only one through which sufficient control of the wood quality of parents and progeny can be feasibly determined and maintained. Selective marking for natural regeneration or seed production areas does not afford the opportunity to find desired qualities in large enough percentages of stems to achieve significant improvement.

This shortcoming can perhaps best be illustrated by a hypothetical situation in which it is desired to improve one wood characteristic, specific gravity, through the use of seed production areas. For simplicity, assume that it is desired to increase specific gravity in the next generation of trees obtained from the seed production area. It has been found that specific gravity is distributed normally among the individuals of the stands from which the seed production area has been established; thus, about 50 percent of the trees in the stand would have less than average specific gravity. Experience has shown that few of the remainder will have suitable form and growth, leaving too few trees with both desired wood and desired form to make an adequate seed production area. The difficulties of achieving desired goals in improvement of wood characteristics through seed production areas are thus limited. This example concerns only one property; if a second criterion is added the rigor of selection is increased several fold, and significant improvement of wood quality tnrough means less intensive than a seed orchard becomes much more difficult.

Seed orchards, the most commonly applied breeding method, contain only individuals having the desired wood properties; however, this is always within the framework of the features of fast growth and good form. Each additional wood characteristic included results in a manifold increase of the difficulties of locating seed orchard material. However, the benefits to be gained outweigh these difficulties if wood quality is of any importance to manufacturing operations and quality control of the final product.

Measurement of Improvement

Wood properties, as other characteristics, vary in their expression among individuals. This variation is the result of the genetic makeup of the individual and the action of the environment on the genotype.

The genotype is defined by Johannsen (1911) as the reaction norm and is the modification of expression set within the limits of the genotype. This simply means that most characteristics of the individual, including wood characteristics, are controlled to some degree by the genetic makeup of the individual. Additionally, all environmental modifications influencing expression of the characteristic operate within the framework of this genetic makeup.

The magnitude of the genetically determined limits can be expressed mathematically by use of the term *heritability*, which is a numerical expression falling between 0 and 1. The exact value for any characteristic indicates the degree to which variation is received from the parents; thus, a heritability of 1.0 means that the expression of the characteristic is determined entirely from the parents, the environment playing no part in the expression. A heritability of 0 connotes that the characteristic is governed entirely by the environment, inheritance having no influence.

Heritability is but one part of the "equation" necessary to determine genetic gain, the other being the selection differential. Genetic gain in the final analysis is the factor which expresses the amount of improvement possible. Care must be exercised in discussions involving heritabilities; some of the points to be considered have been pointed out by Zobel (1961) as:

1. What type of heritability is being referred to? Broad sense heritabilities are those which include all of the genetic variances (additive, dominant, and epistatic) normally present in biological material. It is impossible to take advantage of all three types of heritability in forest trees unless working with clonally propagated trees such as the hybrid poplars.

Narrow sense heritabilities are derived using only additive genetic variances. Most wood properties in which we are interested are inherited quantitatively (several genes are conditioning the inheritance of a particular characteristic). Trees having the type of wood in which we are interested demonstrate the possibility of having the capability of producing the wood quality sought. By allowing many such individuals having this capability to interbreed in the seed orchard, we enhance the opportunity to produce trees having the desired wood quality. The amount of improvement in wood quality is partially determined by the narrow sense heritability for the particular wood property.

2. To what age material does the heritability apply? Heritabilities change as plants get older. A characteristic may have high heritability at a young age and be lower nearer maturity of the tree, or the converse.

3. Under what environmental conditions were the heritabilities estimated? Heritabilities will differ for the same plant material under different environmental situations in which it might be planted.

4. How was the heritability estimated? Several methods of estimating heritability are available, which may give considerably different estimates.

Statistical procedures for determining heritabilities are complicated and beyond the scope of this paper, but results (i.e., the heritability figures) will be cited as indication of genetic control. In general, the characteristics considered to be of importance to wood quality improvement have heritabilities within the range of 0.2 to 0.7.

Heritabilities are not the same for each wood property in which we are interested, and improvement possible in one character will be different from another character using the same breeding procedure in a given period of time. In an improvement program for wood quality, it behooves the forester to work with production technologists to decide which characters are most important to the finished product, as well as develop a system of priorities allowing most rapid progress toward achieving improvement.

Amounts of Improvement Possible

The following discussion will emphasize heritability estimates in pines, principally the southern pines; these estimates will be used as indicative of possible genetic gain.

Specific gravity.—Much interest has centered on improvement of wood qualities by varying specific gravity. Such improvement has been approached in three ways: (1) increase in average specific gravity, (2) decrease in average specific gravity, and (3) no change in the average out elimination of the extremely high and extremely low gravities. Such manipulation of specific gravity is needed to increase quality of pulp, such as tearing strength, bonding strength, or burst, or to provide a more uniform raw material for production of a more uniform end product. Table 1, based upon the

TABLE 1.—*Heritabilities of specific gravity of certain species of pines*

Species and progeny	Broad sense heritability	Narrow sense heritability	Source
Slash pine:			
14-year open-pollinated seedlings		0.2	Squillace et al. (1962)
14-year control-pollinated seedlings		.5	Do.
12- to 14-year grafts	0.7		Do.
Monterey pine:			
20-year grafts	.5		Fielding and Brown (1960)
6-year open-pollinated seedlings		.2	Do.
8-year grafts	.7		Dadswell and Wardrop (1960)
Grafts (rings 7 and 8)	.7		Do.
Loblolly pine:			
1-year grafts	.2-.6		van Buijtenen (1962)
5-year grafts	.6-.8		Do.
2-year control-pollinated seedlings		.4- .5	Do.
6-year open-pollinated seedlings		.6-1.0	Do.
Core wood—open-pollinated seedlings 5 years old		.8	Goggans (1962)
Core wood—open-pollinated seedlings 2 and 3 years old		.7	Stonecypher [1]

[1] R. W. Stonecypher, personal communication.

results of several different workers, emphasizes the high degree of heritability of this complex character.

The average for all of the above heritabilities is around 0.7 for broad sense and 0.5 for narrow sense. The heritabilities are for young trees, and indications are that they may increase in older material so that narrow sense heritabilities are approaching the broad sense values. Assuming a differential in paper yield of 25 pounds per cord for each increase of 0.01 in specific gravity, 90 pounds green weight (Taras 1956), selection for higher specific gravity can increase paper yields from 25 to 80 pounds per cord of wood cut, the amount of the increase depending upon the selection differential employed in the selection. Assuming the moderate increase of 40 pounds of paper per cord for all the wood used, a 400-ton-per-day paper mill would realize an annual increase of 4,200 tons of paper using no greater volume of wood.

Increase in specific gravity is attained principally by an increase in the percent summerwood growth of the annual ring and an increase in the cell wall thickness of the individual tracheids. Such properties are not consistent with an increase in certain qualities; for example, increasing specific gravity will increase tearing strength but reduce bursting, tensile, and folding strength (Watson and Dadswell 1962).

It is unfortunate that certain factors of cell and tree anatomy which contribute to higher weight yields may also contribute to a reduction in quality of the paper produced. It is in this realm of determining where the balance will be made between gross fiber yield per cord and quality of product that mill technologists must aid in decisions influencing tree improvement programs.

Tracheid length.—A second important wood property for products which is under strong genetic control is that of tracheid of fiber length. This characteristic is important in the areas of strength properties of both pulp and paper.

Many authors have reported tracheid length of progenies to be intermediate between those of the parents; these include Chowdhury (1931), Jackson and Greene (1958), and Echols (1955). However, there are few reports of actual heritabilities for this characteristic. Dadswell et al. (1961) found gross heritabilities for tracheid length to be about 0.75 in *Pinus radiata* and Goggans (1962) obtained an even greater value in the narrow sense for *Pinus taeda.* High heritability for tracheids will produce rapid progress from selection resulting in an increase of the mean fiber length. By including only long-fibered parents in the seed orchards, it is possible to obtain an increase up to one-half millimeter in the first generation of selection.

There is little reason to believe that short fibers per se will ever be desirable, since bonding strength is an asset to any product. It is possible to produce short tracheids in the mill—thus, it would appear that in the future longer fibers and tracheids will be sought. For fiber length, as well as for specific gravity, the objective is to improve the average for the characteristics. Inherent within tree variations in wood properties and between-tree variation will always dictate variability in the wood coming into the mill.

Cell wall thickness.—This characteristic of fibers and tracheids affects specific gravity as well as being important in influencing bonding properties. Thin-walled cells collapse, become ribbon-like, and provide a strong bond with adjacent fibers. Thick-walled fibers, on the other hand, tend to retain a round shape, do not collapse, and provide a poorer bonding surface, reducing the bonding strengths of pulp.

Inheritance of wall thickness was found by Goggans (1962) to be 0.84 in summerwood and only 0.13 in springwood. Improvement in wall thickness will go hand-in-hand with improvement in specific gravity.

Percent summerwood.—Percent summerwood, like cell wall thickness, influences pulp properties much as does specific gravity. According to Dadswell and Wardrop (1959), tearing strength and bulk density increase with higher percentage late wood; but bursting strength, tensile strength, and fold endurance decrease with increase in late wood percent.

Narrow sense heritability of summerwood in the entire core in young stems was found to be around 0.8 by Goggans (1962). This value is somewhat higher than the broad sense value of 0.5 found by Dadswell et al. (1961). Progress toward improvement of percent summerwood is tied very closely with progress in specific gravity, just as is cell wall thickness.

Percent reaction wood.—Reaction wood such as compression wood in conifers reduces quality in all types of products. Poor yields and strength properties result in paper produced from such wood while lumber cut through zones of compression wood is subject to a high degree of shrinkage, warp, and crook.

The type of material produced in reaction wood is inferior in both softwoods and hardwoods. Quality of compression wood is such that low yielding, short-fibered wood, unsatisfactory for high-grade products, is produced.

Reaction wood is produced whenever a tree stem grows out of the vertical plane. Auxin balances are upset, the result being the "abnormal" type wood. Extent of such wood, therefore, is closely tied to straightness of stem. Amount of compression wood in 50-year-old loblolly pine has been found by Zobel and Haught (1962) to vary from 6 percent in essentially straight trees to 16 percent in a crooked tree, with one exceptionally crooked tree having 67 percent of its bole volume in compression wood.

The actual heritabilities of straightness are unknown; however, Perry (1960) believes straightness to be under the control of several genes. Evidence that straightness is strongly inherited has also been shown by Mergen (1955) and McWilliam and Florence (1955). Even though straightness of stem and consequently percentage of reaction wood is subject to many environmental influences, it is apparent that heriditary influences are also important, offering the opportunity to reduce amount of this inferior material through producing more straight trees. It is because of the phenomena of compression wood production that straightness of stem is given so much weight in selecting material to be used in tree improvement programs.

Other characters.—Several other wood characteristics have been studied by Goggans (1962) to determine heritabilities in loblolly pine. Several of the characteristics Goggans worked with are of practical importance to wood users; economic importance of others is not recognized at present, principally because their influence on end products is not known. Table 2 is a modified ranking, taken from Goggans' paper, listing the ease with which improvement can be made in wood characteristics in an improvement program.

Table 2.—*Relative ranking of wood characteristics according to the ease with which progress may be made in a selection program.*

Numerical rank	Characteristic
1	Summerwood tracheid length
2	Percent summerwood
3	Specific gravity
4	Springwood tracheid width
5	Springwood tracheid length
6	Summerwood tracheid width
7	Summerwood tracheid wall thickness
8	Springwood tracheid wall thickness

Several of the characteristics listed above are interrelated, and any work toward changing one will result in change of another, i.e., increasing or decreasing the percent summerwood will have a similar effect on specific gravity.

Summary

Most tree improvement programs, in addition to bettering form, growth rate, insect and disease resistance, etc., have as one of their major objectives the improvement of wood quality. These wood quality objectives are directed toward the production of trees containing types of wood most beneficial to maintenance of yield and quality of the final product.

That such objectives are possible is shown by the results of several workers on the variation, inheritance, and heritabilities of wood properties. Studies on heritabilities are not numerous but enough have been reported to indicate that progress toward improvement of wood quality is possible. Many other studies are now under way and more concrete evidence of the amount of improvement that can be achieved will be available soon.

Information to date indicates that in seed orchards of loblolly pine it is possible to produce "strains" having one or more of the following characteristics, except where two characteristics are diametrically opposed:

Increased pulp yields of 40 or more pounds per cord.

Increased average fiber or tracheid length up to 0.5 mm.

Improved tearing strength.

Improved bonding strength.

Increased bulk density.

Improved bursting strength.

Improved folding ability.

Improved tensile strength.

How Can Genetic Control of Diseases Aid the Forest Manager?

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Forest diseases caused mortality and growth losses during 1952 of more than 5 billion cubic feet of growing stock and almost 20 million board feet of sawtimber in the continental United States, according to the Forest Service's Timber Resource Review (1958). Diseases were responsible for 45 percent of the losses from all causes, including fire and insects. In the South, fusiform rust alone accounted for 97 million cubic feet of growing stock and 281 million board feet of sawtimber. The situation is probably not any better today. Obviously, we must improve our control of forest diseases if we are to obtain maximum production on our forest lands.

The control of tree diseases in the forest by chemical or cultural means has been historically difficult, usually being temporary, expensive, and generally unsatisfactory. The application of chemicals, even antibiotics (Lemin et al.), gives at best short-term and expensive protection. The one cultural method in general use in southern forests, i.e., burning for the control of the brown spot needle disease of longleaf pine, is a drastic treatment that often has questionable results. An important avenue of attack on the overall control problem is through genetics and tree breeding. Develop a resistant tree and you will have built-in control with no further manipulation required.

With agricultural crops, the geneticists and plant breeders have been able, through selection, progeny testing, and use of plant hybrids, to produce disease-resistant varieties that have been a major force in revolutionizing agricultural production in this country. For example, of 90 new crop varieties released by the U. S. Department of Agriculture and the State experiment stations in 1959, more than half were developed with specific disease resistance in mind (U. S. Agr. Res. Serv. 1960). Some of the findings in disease-resistance research have virtually saved valuable crops from becoming lost to commercial production.

So the principles of disease control through resistance have been proven and are available for application to forest trees. We have begun that application at the Institute of Forest Genetics in our attack on the fusiform rust of slash and loblolly pines. Our first efforts were aimed at determining if resistance could be incorporated into the susceptible slash pine by crossing it with the naturally resistant shortleaf pine. Selection, breeding, and progeny tests under conditions of both artificial and natural infection have shown that this hybrid does indeed carry a considerable amount of resistance to fusiform rust (Jewell 1961; Jewell and Henry 1961).

Our next efforts were to find whether or not resistance to this rust exists naturally in individual trees of the susceptible species, slash pine. Open- and control-pollinated progenies of selected rust-free parents were artificially inoculated with the rust along with progenies from check parents. The open-pollinated progenies of certain of the selected parents exhibited significantly fewer galled individuals than the progenies from check parents. When the selected rust-free parents were crossed with one another, the progenies showed still greater resistance (Jewell 1961). So resistance does exist in individuals within the susceptible slash species.

Therefore, there are two sources of resistance to fusiform rust. Resistance can be bred into slash pine by crossing it with shortleaf, or resistant strains of slash itself can be developed by crossing individual trees whose progenies have been shown to be resistant. Both these methods appear promising.

The concept of individual-tree resistance to fusiform rust is actually already in practice in the South, thanks to the foresight of many early workers in tree improvement programs. By their insistence that slash and loblolly pine selections be free of fusiform rust, an appreciable amount of resistance is apparently already incorporated into the clonal seed orchards (N.C. State Col. School Forestry 1963). Future progeny tests for rust reaction and subsequent roguing should result in a still higher percentage of resistant material in these orchards.

The discussion so far has dealt with resistance to only one forest disease. However, we have evidence that the same principles of control by resistance can be applied to others as well. The crossing of western white pine trees selected for resistance to blister rust yields a high percentage of resistant progenies (Bingham 1963). The first-generation, F_1, progenies are put into seed orchards and the next generation, F_2, will be used as planting stock.

Another disease that possibly will be susceptible to genetic control is the brown spot of longleaf pine. Under field conditions the open-pollinated progeny from a selected longleaf has consistently shown less infection than control progenies (Derr 1963). Progeny from a cross of this selected parent and nonresistant longleaf were far less susceptible than the open-pollinated progenies from the nonresistant parents. He concludes that resistance to brown spot is genetically controlled and that there are distinct possibilities for developing and producing resistant longleaf pines.

The three examples just mentioned illustrate the prospects of controlling forest tree diseases through resistance. The prospects appear good: not only does it seem likely that research will be able to find and produce resistant trees, but control of diseases may well be among the earliest practical results of genetics programs.

Now for the question that forms the title of this paper, "How can genetic control of diseases aid the forest manager?" In essence, it can eliminate one of his most plaguing problems—having to plan a management program in the face of disease losses that must be expected, but in unknown quantity. It can enable him to establish the species he wants on the site he wants without regard to disease hazard; it can free him from having to establish and maintain heavy stocking to compensate for disease losses. With genetic control he can have the thinning regime he wants, rather than one dictated to him by the necessity of removing trees made infirm by disease. And he can carry his stand on to maturity without fear of disease loss, because resistance lasts for the life of the tree.

Breeding Methods in Tree Improvement

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The two previous papers have presented a very thorough account of current information on heritabilities for wood and morphological characteristics. A primary purpose for determining heritability figures is to better orient breeding methods. How, then, can this information be used in the current tree improvement programs and how will it affect silviculture in the long run?

Ten years ago the descriptive words "phenotype" and "genotype," commonly used in genetics, had very little meaning to management foresters. These terms are relatively common today and are employed freely in discussions of tree improvement programs. They exemplify the new set of terms used in advancing techniques in genetics and breeding procedures. It will be necessary to define and develop some other new terms as they are used throughout this paper.

Heritability, a term so freely used in previous papers, is defined in the tree improvement glossary (Snyder 1959) as a "measure of the relative degree to which a character (or characteristic) is influenced by heredity as compared to environment." Variation among trees can be expressed by formula as follows:

Total Variation = Hereditary Variation + Environmental Variation

A properly designed heritability experiment can separate variation due to heredity from the variation due to environment. Heritability is usually expressed as a decimal or percent figure. For example, if a broad sense heritability of 0.7 or 70 percent is found for a characteristic such as specific gravity, it means that 70 percent of the total variation in specific gravity is due to heredity and 30 percent is due to environmental influences.

What elements are included in the heritability portion of the estimate and what do they mean? The term "broad sense heritability," or the total hereditary variation, refers to a numerical estimate including three values: namely, additive variance, dominance variance, and variation due to epistasis. Additive variance is due to the average or additive effect of a gene or genes. Each gene contributes a small addition to the overall effect. Dominance variance is due to the interaction of alleles. Epistatic variance is due to the interaction between non-alleles. The term "narrow sense heritability" refers to ratio of additive to phenotypic variation.

Broad sense heritability is determined by dividing total genetic variance (V_G) by phenotypic variance (V_p) and is expressed mathematically by the equation $h^2_{\text{broad sense}} = \frac{V_G}{V_p}$. Narrow sense heritability is obtained by dividing additive variance (V_A) by phenotypic variance (V_p) and can be expressed by the formula $h^2_{\text{narrow sense}} = \frac{V_a}{V_p}$.

If the narrow sense heritability figure is high, then the mass selection method of breeding will be most productive. On the other hand, if the dominance or epistatic variation is very high, the greatest gain can be accomplished by an intraspecific hybridization approach.

Figures on inheritance, represented by heritability values, are essential to the development of any tree breeding program. If, for example, specific gravity were controlled to a considerable extent by environment, the field forester would be the one who could most easily increase or decrease the specific gravity of stands by silvicultural manipulations. The tree breeder would be able to add very little by genetic or breeding techniques. If, on the other hand, as Mr. McElwee has shown, specific gravity is controlled to a considerable extent by heredity, the silviculturist can do less to affect it, and management techniques must be quite drastic to bring about major changes. However, the tree breeder can accomplish a great deal.

Initiation of a Tree Improvement Program

Assuming that a tree improvement program is about to be initiated, the ideal procedure is to make a thorough study of the species to be improved. Detailed information concerning variation between and within individuals must be gathered and a complete study made of this species, with an assessment of causes of variation over the entire range. Heritability of important characteristics and the mode of inheritance must be determined. Controlled crosses with related species should be made and their progenies studied. Armed with this information the tree breeder could then devise a breeding scheme and proceed with improving the species.

Since one rarely approaches ideal conditions, chances are that a tree breeder will find himself with the situation that confronted forest geneticists approximately 10 years ago, when the first southern pine tree improvement programs were initiated. Little of the necessary information was available as a base for an efficient breeding design. There was not time to make the required surveys and conduct experiments that would provide knowledge needed to choose among the several immediate avenues of approach available. These had already been explored, developed, and exploited in various crop improvement activities with other plant species. The problem in forestry in the Southeast was to determine which breeding method would result in the greatest improvement in the shortest time so as to provide improved seed for the very large and expanding planting program then underway.

Methods to Produce "New Creations"

Polyploidy.—The "go for broke" approach was characterized by polyploidy adherents. In this breeding system, the fundamental structure of the cell is manipulated to change its genetic constitution. Each cell in every species has two sets of a fixed number of heredity units or chromosomes. Pine species have 12; aspen, 19; human beings, 23. Normally this number is characteristic to the species, but occasionally something occurs that upsets the normal condition and then the resulting progeny have an abnormal number of chromosomes. There are certain plants which are improved by such a change in chromosome number; some persons have suggested that this might be true for forest trees.

Probably the most intensive search for polyploid trees has been made in the aspen improvement program, where individuals were located that were extremely vigorous and had exceptionally large leaves. A microscopic examination of cells from these selections demonstrated that they had 3 sets of 19 chromosomes instead of the normal 2 sets. Since these trees were so very vigorous, it was hoped that such triploids might be especially desirable.

Geneticists artificially recreated triploid individuals with colchicine, a chemical that interrupts the natural processes of cell division (Inst. Paper Chem. 1955). When a seed is placed in a solution of colchicine at the time of germination, a few individuals with twice the normal number of chromosomes develop. An aspen seed with 2 sets of 19 chromosomes can be forced to develop twice this number. This individual is partly fertile and, when crossed to a normal aspen, develops seed which grow into very vigorous seedlings with 3 sets of 19 chromosomes. These triploids are normally sterile or have very low fertility so could not be reproduced by seed. However, it might be possible to produce triploids in sufficient number by establishing seed orchards of alternating rows of normal diploid and tetraploid individuals. If so, triploid individuals could be used in practical forest management if desired.

Although examples of polyploidy in pines have been reported, (Hyun 1954; Mergen 1958, 1959) in every case the seedlings are malformed and grow poorly, with undesirable form; thus polyploid seedlings in the pines are of little value. Polyploidy as a breeding method in pines must be relegated to the laboratory, at least for the foreseeable future.

Induced chromosomal changes.—Another means for producing artificial genetic variation is to subject seed or plants to X-ray (Snyder et al. 1961) or other radiation (Beers 1962). This causes actual physical disturbances in one or several chromosomes. These can be large changes involving whole sections of chromosomes or minute "gene changes" which are reflected in changes in the developing seedlings; such seedlings with artificially induced changes or mutations have up to now been very difficult to keep alive, and this technique can also be considered in the laboratory stage as a practical breeding tool.

Interspecific hybridization.—Crossing two species of pine is another method that sometimes produces seedlings with spectacular characteristics. The resulting progeny are compared to each parent to determine what improvement, if any, has been gained. This phase of forest genetics has been extensively pursued at the Institute of Forest Genetics at Placerville, Calif. Control crossing techniques were developed here in the early 1930's, and the major effort of this station has been directed into the methodology and usefulness of interspecific hybridization. Such crosses between species have produced some remarkable hybrids (Callaham 1957), but for one reason or another very few of them have been of practical use. Two of the hybrids, the Jeffrey × Coulter and the knobcone × Monterey, have been quite successful. Jeffrey × Coulter hybrids are now being planted in California forest plantations and the Jeffrey × Coulter hybrid backcrossed to Jeffrey is also being planted in the Jeffrey pine range where it is resistant to the pine reproduction weevil (Righter 1960).

The most impressive practical use of the hybridization technique has been developed in Korea (Hyun 1961) where in 1 year over 1 million control-pollinated seedlings of a pitch pine × loblolly pine hybrid were produced. This hybrid has much of the growth habit of loblolly pine and some of the frost resistance of the pitch pine parent. The labor cost of such hand-produced hybrids would be prohibitive in this country, but a few have been produced to be used on an experimental basis. Hybridization, as a completely practical method, cannot be used until some inexpensive system of control pollination is developed.

Some research has been done to develop practical means of mass producing hybrids. Wakeley and Campbell (personal communication) have tested a method of applying slash pine pollen to unbagged longleaf strobili, but with indifferent success. Brown and Greene (1961) and Hyun (1961) are working with chemicals that will cause male sterility.

If Wakeley's or some other simple method can be developed so that successful hybrids are produced consistently it would be relatively simple to make a mass collection of pollen and dust a large number of trees in the seed orchard inexpensively. On the other hand, if male sterility can be induced, orchards could be so designed that the species to be crossed would be planted in alternating rows.

The pollen of the seed parents would be rendered sterile so that all of the seed would be hybrid. These techniques are still in the experimental stages but may hold some promise.

Improving Existing Species

Intraspecific hybridization.—The technique of making controlled crosses between members of the same species may be used to combine desirable characteristics from different individuals. It always must be remembered that some selection is implied regardless of the breeding scheme used. However, the difficulty of making selections varies considerably with the type of breeding method in use, and the size of the population that must be examined. As the size of the population available for selection and the number of characteristics being considered increases, selection difficulties are compounded.

The problem of selecting usable breeding stock is minimized with the intraspecific hybridization method of plant improvement. Usually in this system individuals with one particular outstanding trait are selected. The original selections are crossed in an attempt to combine the outstanding features of each into one hybrid. The system is time-consuming, though, especially with species that have considerable time lapse between seed germination and the development of reproductive organs. After the original crosses are made, progeny must be grown and new selections made which contain the desirable characteristics. These are then cross bred to fix the characteristics in a high proportion of the progeny and to establish a seed source. In order to prevent inbreeding depression, several selections must be made and carried on concurrently. The seed source is eventually developed from these selections.

Mass selection.—This is a system of breeding for improvement that promises slow steady gains. Normally, the increase one can expect is limited by the genetic capability of the most outstanding individual in the population. With a large amount of natural variation of the additive type, large increases can be expected; conversely, with little natural variation, there can be little improvement by this method.

As the number of characteristics to be improved increases, selection difficulty increases. In order to make the greatest possible gain a high intensity of selection must be practiced—and suitable individuals are difficult to locate. On the other hand, once the selections are made, seed production problems are simplified as a continuous supply of large quantities of seed can be produced from vegetatively propagated ramets of the original selections.

Practical Tree Improvement

With these methods available, the pioneer southern pine tree breeders took a long, hard look at their species. Little or no information was available from previous data to guide them. A few preliminary surveys indicated that variation was present and seed source important. Interspecific hybridization had not been particularly promising. The problem at hand was to develop a genetically improved source of seed as soon as possible. The decision was: mass selection.

The data now available testify to the validity of this choice for most characteristics. It must be remembered that many of the experiments from which these data have been drawn were designed for other purposes and that much is from relatively young material, but the significance cannot be denied. Heritability values made from measurements of immature material can be expected to increase as the plantings come closer to maturity, at least for some species. Let us now, as the politicians say, examine the record.

Barber and McElwee have quoted heritabilities for many characteristics and indicated the amount of improvement that can be expected based on these figures. They have urged the immediate pursuit of an aggressive tree improvement program based on the mass selection method of breeding, or some variation thereof.

A brief review of some of the heritability figures quoted will emphasize the soundness of the recommendation.

Some of the oldest plantations which can be used for estimating heritabilities were established by personnel of the Southeastern Forest Experiment Station at Lake City, Fla. Planting consisting of grafted clones, open pollinated progeny, and control pollinated progenies are available for estimating the genetic improvement possible. Squillace and Bengtson (1961) have reported heritability figures for several characteristics from these 10- to 14-year-old plantations. Narrow sense heritabilities of 56 percent for specific gravity were obtained with control pollinated progeny while the broad sense or total heritability was estimated to be 73 percent from clonal data. Fairly high heritabilities for diameter growth (25 to 58 percent), stem volume (18 to 35 percent), crown width (24 to 48 percent), and bark thickness (33 to 67 percent) were obtained. A fairly low heritability for height growth of 5 to 10 percent was obtained. A tentative hypothesis advanced by Squillace indicates that this is probably due to the wide spacing (20 by 20 feet) of the plantation and the attendant lack of competition. This is somewhat substantiated by Barber's [1] figure of 27 to 37 percent for material planted at a spacing of 10 by 10 feet, van Buijtenen's figure of 20 percent for material planted at an 8 by 8 foot spacing (personal communication), and by recent results obtained by Stonecypher (personal communication) from seedlings planted also at an 8 by 8 foot spacing. It is interesting to note that the broad sense heritability of oleoresin yield is estimated at 90 percent while the narrow sense estimates vary from 45 to 90 percent depending on the methods used.

[1] Barber, John Clark. An evaluation of the slash pine progeny tests of the Ida Cason Callaway Foundation (Pinus elliottii Engelm.). Ph.D. Diss., Univ. Minn. 206 pp., illus. 1961.

van Buijtenen (1962) estimated broad sense heritability of 64 percent and 84 percent from 5-year-old grafts for specific gravity, and narrow sense values of 37 and 49 percent for 2-year-old control pollinated material. He also reported diameter heritability of 20 percent for 6-year-old loblolly pine progenies. He estimated that an improvement of 10 percent for each of these characteristics may be expective from one cycle of selection and that an increase of 25 percent in total wood production for the several factors combined would not be out of reason (personal communication).

Stonecypher (personal communication) found a low narrow sense heritability for first year height growth, which increased with second year measurements. He noted that narrow sense specific gravity heritability estimates for 1- and 2-year-old progenies approach the actual values given by van Buijtenen and that they remain constant for the 2 years.

Selection severity can be varied from slight to intense, with selection of low to medium intensity. Forestry practices can be guided so that any landowner can achieve a moderate amount of genetic improvement in his forest stands. Some gain will be achieved, if, in a seed tree cutting, selection of seed trees from which cones will be collected is made as the first step in harvesting. Improvement here is controlled by the nature and number of trees in the stand being cut. There is no doubt that a minimum amount of improvement can be expected when the selections represent only 10 to 20 percent of the stand, which is normally the case. As soon as the area is sufficiently stocked, the seed trees are harvested during a year of heavy cone production. Such areas are designated as seed collection areas. Careful planning is necessary as harvesting of the seed trees must be scheduled to coincide with the optimum period for cone collection. Cost of cone collection from trees which have been cut is relatively inexpensive, especially when large crops are present.

The next highest level of selection severity is represented by the seed production area, where better than average stands are selected, carefully rogued of undesirable individuals, and managed for a continuing supply of genetically improved seed. Since mature trees must be climbed for cone collection it would seem at first that the expense would be prohibitive, but collection costs as low as $3 to $5 per bushel have been attained as compared to an average cost of $2.50 per bushel when cones are purchased on the open market (Goddard 1958; Cole 1962). According to Easley (1963), seedlings from one seed production area had a height advantage of 24 percent at the age of 8 years on sandy soil as compared to nursery run seed; this same seed production area produced seedlings with a height advantage of 7 percent on heavy clay soil. He concludes that the collection of seed from a local source of selected parent stock is advantageous.

The most severe selection that can be commercially applied is through seed orchards. Individual elite selections are made only after the examination of thousands of acres of forest land. These selections are rigidly graded in comparison to a number of surrounding dominant specimens, and included in the orchard only after they indicate a maximum amount of advantage. The selections are vegetatively propagated and planted in a central orchard location, or a seed orchard of seedlings from the selected parents is established. The orchard is designed to insure a minimum amount of inbreeding. Here the trees are cultivated as intensely as in fruit orchards and will serve as a source of high quality seed for the future.

Based upon the figures quoted today and if we take into consideration improvement due to increased vigor, finer limbs, straighter boles, and less disease, it seems probable that the yield increase of 10 percent suggested by Barber can be obtained with ease and the suggested figure of 25 percent advanced by van Buijtenen is within reach. Assuming no change in pulpwood stumpage values from the figure advanced by Perry and Wang (1958) and figuring a 20 percent increase in yield due to tree improvement efforts, we can realize a gross increased profit of some $600 per pound of seed at a 25-year rotation, or an extra $2.10 per acre per year. This profit, they say, justifies the expenditure of $181.27 per pound of seed, allowing 5-percent interest on the invested money.

Perry's figures are based on yield alone, and no attempt was made to include other advantages which cannot be represented easily by monetary values—for example, the morphological characteristics of bole straightness. It is difficult to determine how much more solid wood content would be delivered per cord by minimizing the amount of crook, spiral, and sweep. It is difficult to learn how much more cellulose is in each cord and how much less cooking liquor will be needed at the mill. One can only estimate the increase in usable fiber contained in the straight pulpwood stick. Add to these figures a decrease in knot wood volume, a concomitant decrease in compression wood associated with knots, and an increase in the number of seedlings growing to maturity by virtue of increased disease resistance. Consider also the pulp increase reported earlier by McElwee due to increases in specific gravity and the probable improvement in paper sheet formation due to having wood with more uniform fibers. All these advantages, nebulous as they may be, are to be gained as a result of the activities now taking place. Estimates of possible improvements made several years ago covered the entire scale from a minimum 1, 2, and 5 percent made by the conservative members of this group to a maximum 100 percent by the most optimistic. Actual values today indicate an intermediate expected increase of 15 to 25 percent based on yield, plus the additive increment due to quality. Perry's figures, which seemed so unobtainable 5 years ago, are becoming more realistic as we gain additional knowledge of the inheritance patterns in the species we are using.

How Can We Improve Southern Hardwoods Through Genetics?

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Before discussing the genetic potential of hardwoods we must define the objectives in hardwood tree improvement. We can safely generalize and say that any tree-improvement program is going to have as its major goal the increase in genetic potential for rapid growth and superior tree quality. Rapid growth is an easily understood characteristic, but tree quality is a more complicated concept.

The quality of a hardwood log is determined by its size and shape, and particularly by degree to which it is free from defects like knots, holes, bark pockets, stain, and rot (Lockard, Putnam, and Carpenter 1950). In general, freedom from defects is more important than species in determining the value of an individual tree. Increasing the proportion of high-grade material within the tree therefore will be an important facet of tree improvement, and will require evaluation for tree form, branching characteristics, and resistance to insects and diseases.

When hardwoods of improved strains have been developed, they will probably be grown in plantations. We don't know how most species will respond to this kind of culture. The performance of cottonwood has generally been good, but unexpected problems may arise such as the stem disease which is attacking cottonwood plantings along the Mississippi River. Undoubtedly, hardwoods grown in plantations are going to require different management procedures from those for natural stands, and tree breeders and silviculturists will have to work in full cooperation to develop such procedures. Among other things, the possibility of plantings of mixed species as well as single species should be explored.

Beyond general concepts we must cease speaking of hardwoods as a group and concentrate on individual species. Some 140 hardwood species are native to the South. Of these, between 60 and 70 are of some commercial importance (Putnam, Furnival, and McKnight 1960). These 60 to 70 species represent 25 genera that differ in morphology, site requirements, and utilization. Are we considering a species of oak or ash? These species commonly grow in mixed stands, a fact which complicates comparisons among individual trees. Or are we considering cottonwood, which usually occurs in pure, even-aged stands in which comparisons of individual trees with their neighbors are quite easy? Some species, such as sweetgum, occur in both mixed and pure stands. How should this affect our criteria of individual tree selection?

In discussing seed production, we must again relate our comments to individual species, for they differ in floral morphology and pollinating agent. Cottonwood is a dioecious species; yellow-poplar has perfect flowers. Yellow-poplar is insect-pollinated while many other hardwoods are wind-pollinated. Differences such as these will influence the development of techniques for controlled pollination and eventual methods of producing commercial quantities of seed of improved stock.

Finally, characters to be improved and their relative importance will vary from one species to another, depending upon species characteristics and utilization practices.

When we have designated the species we want to work with and defined our objectives for that species, we can begin systematic research to attain these objectives. You have heard the various steps in tree improvement discussed in detail at previous meetings. The initial step is to assess the variation present in the species for characters of interest. The next job is to estimate heritability for these characters, i.e., determine how much of the variation is under genetic control and how much is due to environmental effects. The modification of that portion of the variation which is under genetic control is the final phase of the improvement program.

Considering these steps in tree improvement, where do we stand now with some of the major commercial hardwoods of the South? I would like to review what has been done to date on five representative southern hardwood species, or genera, as applicable to the South. These include sweetgum, yellow-poplar, cottonwood, several oaks, and green ash.

Sweetgum and yellow-poplar occur throughout much of the Eastern United States. Their wood is used for a variety of products including lumber, veneer, cabinetwork, and, especially in sweetgum, pulpwood. Cottonwood reaches its maximum development on the bottomlands adjacent to the lower Mississippi River. At the present time the greatest quantity of cottonwood goes into veneer and saw logs, with pulpwood a promising outlet for the future. This species is planted in greater quantities than any other hardwood in the South today. Several species of oak grow rapidly, generally develop good form, and have a variety of uses including lumber, veneer, cooperage, and pulpwood. Ash is a high-value species used primarily in the manufacture of handles, sporting goods, and furniture.

Sweetgum

The literature on variation in sweetgum is limited to variation in leaf morphology (Holm 1930; Duncan 1959). There is no information on inheritance patterns for any characteristics. Studies on patterns of variation in wood quality characteristics are under way at North Carolina State College. Other work there and at the Institute of Forest Genetics, Southern Forest Experiment Station, includes studies of flowering habits and pollination techniques, and progeny tests from individual parent trees. This research will provide information on geographic variation as well as on inheritance patterns for economically important characters.

Characters which are receiving major attention include resistance to epicormic sprouting and, since sweetgum is the leading hardwood pulp species in the South, wood quality. Epicormic sprouting frequently occurs along the upper and middle portions of the bole in response to environmental disturbances such as extreme release from competition. Although careful management can reduce the extent of sprouting, there is an immediate need for some method of evaluating individual-tree variation in this character during the juvenile stage. Otherwise it will not be possible to evaluate progenies for resistance until they have attained considerable size, and improvement for this characteristic will be an extremely slow process.

Wood quality is a complex characteristic involving density, fiber length, and cellulose content. Since hardwood pulps are commonly used in blends with longer fibered pulps, increasing fiber length should increase the proportion of hardwood pulps in these blends. Sweetgum is particularly important in the manufacture of dissolving pulps and, since cellulose is the desired product, high cellulose content would be a desirable feature of improved strains. Any speculation on the improvement potential for these and other characters will have to await results of the research mentioned previously.

Yellow-Poplar

Seed source studies with yellow-poplar show a general north-to-south trend in resistance to cold (Funk 1958; Sluder 1960). Sluder (1960) reported better survival of the local source than of sources from several other geographic locations. Height growth of local yellow-poplar has been reported to be as good as or better than that of seedlings from other locations (Sluder 1960; Lotti 1955). In one study (Limstrom and Finn 1956) significant differences (0.05 level) appeared among six geographic sources in average height of 1-year seedlings. Variation in height of progenies from different trees was equally significant (0.05 level). Often the variation in height among seedlings from a single tree exceeded the mean difference in progeny height among trees and seed sources.

The data just mentioned are from young stands, 5 years or less in age. Whether the patterns will persist to maturity and be evident for additional characters is problematical.

Thorbjornsen (1961) reported variations in wood quality characteristics in natural stands. He found that wood density varied considerably among individual trees within stands but discovered no differences among stands. He concluded that relatively rapid improvement could probably be made by selecting and breeding for high density. In fiber length, the variation within trees exceeded both the variation among trees and among stands, an indication that selection for long fibers would probably not result in a marked increase in fiber length.

Several studies on variation in seed quality and effects of pollination are well worth mentioning, since they will probably influence the methods and techniques used in improvement programs. Limstrom (1959), comparing seed quality from five trees in each of six stands over a 3-year period, found as much variation among individual seed trees within a stand as among stands. Seed quality varied considerably from year to year.

There is general agreement that self-pollination results in markedly reduced seed set as compared to cross-pollination. Self-pollinations yield up to 11 percent filled seed while cross-pollinations yield up to 60 percent filled seed (Boyce and Kaeiser 1961b; Carpenter and Guard 1950; Guard 1943; Wright 1953).

Efficient control-pollination techniques have been developed for the species (Taft 1962). Seedlings from cross-pollinations tend to be more vigorous than seedlings from wind pollinations. Pollen from distant trees tends to produce the greatest increase in vigor (Carpenter and Guard 1950).

Boyce and Kaeiser (1961b) concluded that yellow-poplar trees are not freely interbreeding under natural conditions and that there is a low rate of gene interchange among stands. Self- and cross-incompatibilities are important, as adjacent trees are likely to be closely related and less compatible than trees a mile or more apart.

The results cited indicate that yellow-poplar has a high potential for improvement in growth rate as well as in wood density. The most immediate gains will probably result from interpollinations among stands within broad geographic areas rather than from the use of open-pollinated seed from selected trees. Orchards of outstanding trees from several stands should produce seed of good viability and subsequent stands with good vigor.

Cottonwood

Several studies have been made on wood quality variation in eastern cottonwood. Kaeiser (1956) reported that fiber length within trees increased as number of rings from the pith increased.

In one study stem diameter and number of annual rings accounted for an estimated 50 percent of the fiber-length variation within and among cottonwoods. The genetic variance was estimated to be about 30 percent. High correlation coefficients were reported for mean fiber length among rings of the same tree. The twentieth ring from the pith had the highest correlation with all other rings and was the best ring for comparing fiber length among trees (Boyce and Kaeiser 1961a).

Statistically significant differences in specific gravity and fiber length have been reported between clones of cottonwood (Gabriel 1956).

In studies being carried on by the Southern Hardwoods Laboratory in cooperation with the Institute of Forest Genetics, progenies from individual parent trees have differed significantly (0.05 level) in growth rate, branching, and resistance to *Melampsora* rust. When the progenies are clonally propagated under commercial planting conditions, they are expected to yield much valuable information on inheritance patterns of these and other characters.

Probably the bulk of the cottonwood planted in the South will be from unrooted cuttings. This asexual method of propagation will undoubtedly influence the kind of breeding program followed and the final product of any improvement program. Once favorable genotypes are developed they can be multiplied with no genetic change, and selected clones can be planted together over extensive acreages for maximum production with no danger of diluting the superior genetic stock.

Cottonwood is very sensitive to apparently minor site differences, and one improvement problem will be the isolation of genotypes that will perform consistently well throughout plantations.

Cottonwood shows a high potential for improvement in growth rate and wood quality characteristics. Its rapid growth on good sites combined with the relatively short rotation age will mean that progenies can be evaluated for economically important characteristics sooner than most other hardwood species. Hence improvement should be more rapid than with other hardwoods.

Oaks

As with the species already discussed, much of the data on variation is from reports of juvenile characteristics manifested in seed-source studies. Genetic differences among seedlings of four seed collections of Shumard oak have been reported (Gabriel 1958). Seed sources ranged from Illinois to Florida. In plantations in Pennsylvania, seedlings of northern origin suffered less dieback and grew more rapidly during the early part of the growing season than seedlings of southern origin.

Two-year data on seed-source studies with Shumard oak, bur oak, and water oak indicated that these species should be classed as geographically variable (Wright 1957). All three species exhibited variation in growth rate and autumn coloring associated with seed sources.

Single-tree progenies of five white oak and five red oak species from several locations were evaluated for earliness of germination, 1-year and 3-year height, and survival (Santamour and Schreiner 1961; Schreiner and Santamour 1961). From these studies the authors concluded that individual-tree selection appears to offer more promise for genetic improvement than ecotypic or racial selection in these species.

Variation in wood properties within and among trees of southern red oak have been reported (Hamilton 1961). Specific gravity, percentage of latewood, and toughness were inversely related to both height in the bole and age from the center. Fiber length was directly related to height and age. Some among-tree variation existed, but in most instances more variation was observed within individual trees.

A statistical comparison of the distribution of forkedness and straightness among the two largest stems of 132 sprout oak clumps indicated that the tendency to fork may be hereditary (Downs 1949).

An improvement program with any species of oak will have to overcome a number of technical problems. Especially needed are techniques for making controlled pollinations. The oaks are notoriously difficult to control-pollinate, and the most informative genetic studies as well as the accumulation of favorable genes into a superior genotype are dependent upon such pollinations.

The limited data cited indicate that early improvement should be possible in tree form as well as growth rate. Bringing together superior individuals within broad geographic areas would be the initial step. Wind pollinations among these individuals should result in progeny with good seedling vigor and good tree form.

Green Ash

Wright (1959) has summarized much of the information on the genetic variation of green ash. He differentiated (1944) a northern ecotype and a Coastal Plain ecotype on the basis of growth rate, petiole color, and winter hardiness. Meuli and Shirley (1937) distinguished three ecotypes on the Great Plans on the basis of drought-resistance.

Information on individual-tree variation is very limited. Wright (1959) demonstrated clonal differences in hardiness of leaves to growing-season frosts among the open-pollinated offspring of a single female parent. He surmised that randomly distributed variation in pubescence and samara shape is under genetic control.

The extremely limited information on this species does not permit an estimate of progress to be made in tree improvement.

Summary

Beyond these few species, or genera, data on variation and patterns of inheritance in important southern hardwoods are either extremely limited or completely lacking. For example, there is no information on the extent of variation or on patterns of inheritance for important characteristics of sycamore, willow, black cherry, and the tupelos.

In summary, then, just what answers do we have to the questions, "What do we know about inheritance patterns of southern hardwoods and how can we get improvement through genetics?"

We actually have very little information about inheritance patterns of southern hardwoods. We have good evidence from seed-source studies that several juvenile characteristics, including survival and early growth, are under genetic control. The information at this stage is limited, but the studies will yield more data as they mature. Research on wood quality of yellow-poplar, cottonwood, and oak indicates that enough of the variability is under genetic control to make selection profitable in these species.

In spite of the limited information on inheritance patterns, we know we can get improvement through genetics. The genetic principles that apply to other plant and animal species apply to southern hardwoods as well. Selection of individuals with desirable characteristics and their propagation, clonally or from seed, should result in timber stands that are better than the average forest of today. As results of current and future research become known, optimum ways of combining germ plasm from selected individuals will bring further benefits. The genetic potential is available to us. The development and application of breeding techniques can improve southern hardwoods to their full potential.

Physiology of Trees as Related to Forest Genetics

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After defining some terms, I shall present some specific examples which I hope will illustrate the relationship between genetics and physiology and show that an understanding of the physiological processes of forest trees is important to forest geneticists. It is also important to progress in the everyday task of forest management, but that is not my subject. In this discussion I have borrowed heavily from ideas introduced to me by Dr. Paul J. Kramer at Duke University, and from the book "Physiology of Trees" (Kramer and Kozlowski 1960).

What is forest tree physiology, and are there any unusual attributes of trees that make tree physiology a special area in the general field of plant physiology? Webster's Third New International Dictionary defines physiology as "a branch of biology dealing with the processes, activities, and phenomena incidental to and characteristic of life or of living organisms." B. M. Duggar (1911, p. 3) made this somewhat more specific: "Plant physiology . . . concerns itself with plant responses and plant behavior under all conditions; that is, with relations and processes readily evident or obscure, simple or complex, which have to do with maintenance, growth and reproduction of plants."

This seems to cover all angles, but are trees any different from other plants in their physiology? Kramer and Kozlowski (1960) describe clearly the differences that make trees distinctive:

> "The peculiar characteristics of trees are a matter of degree rather than of kind, however. They go through the same stages of growth and carry on the same processes as other plants, but their larger size, slower maturity, and longer life accentuate certain problems as compared with smaller plants with a shorter life span. The most obvious difference between trees and herbaceous plants is the great distance over which water, minerals, and food must be translocated in the former. Also, because of their longer life span, they usually are exposed to greater variations and extremes of temperature and other climatic and soil conditions than annuals or biennials. Thus, just as trees are notable for their large size, they are also notable for their special physiological development."

The only thing I would add to this is that in forestry we are primarily interested in the stem of the plant, rather than in the fruit, which is the object of main interest to scientists interested in field crops. This different emphasis may change somewhat the direction of physiological research on the part of those interested in forest tree physiology.

Keeping in mind these definitions of forest tree physiology, how then is it related to forest genetics or species improvement? To illustrate the association I would like to refer to the concept which, according to Kramer and Kozlowski (1960), was developed by the German physiologist Klebs and refined by others in this country. This concept emphasizes the principle that hereditary or environmental factors can affect the growth of a living organism—be it an alga, cotton plant, or tree—only by affecting the plant's internal processes and conditions; in other words, its physiology. These relationships are illustrated by the accompanying diagram.

HEREDITARY POTENTIALITIES OF TREES
forest genetics
and tree breeding

ENVIRONMENTAL FACTORS
forest ecology
and forest soils

PHYSIOLOGICAL PROCESSES AND CONDITIONS
tree physiology

TREE GROWTH
forestry and horticulture

(After Kramer 1956)

Thus, in order to understand how genetic factors may affect tree growth, wood quality, or other important features, we must learn how the factors affect the physiological processes involved.

Now I hope that this concept does not offend the geneticists present, since I seem to be saying that they cannot get anywhere without knocking on the physiologist's door. I do not intend to imply that physiology is more important than genetics.

In reality you can bypass physiology temporarily and, for example, develop a hybrid which grows faster than either parent species, without knowing why or how this growth increase occurs. For the greatest progress and for the widest application of our results, however, we eventually would have to try and determine what processes or conditions in the tree were changed to bring about an increase in growth. Rather than to attempt a comprehensive literature review of physiology-genetics work under way, let us just illustrate the relationship with some specific examples in several areas of forest genetics.

Selection

The phase of forest species improvement with which most of us are somewhat familiar here in the Southeast is selection. To illustrate how selection for a desired trait is related to tree physiology, let us use the example of selection for high oleoresin yield which has been conducted by the U. S. Forest Service at Olustee, Fla., since 1941 (Squillace and Dorman 1961; Squillace and Bengtson 1961).

The first step in this work was the selection of 12 slash pine trees for high gum-yielding potential from natural stands in north Florida and south Georgia. The yield of these trees was about double that of comparable non-selected trees. Subsequently, crosses were made among nine of these selected trees, and between the selected trees and average and low-yielding trees. By using a micro-chipping technique on young trees stemming from these crosses, it was shown that oleoresin yield is inherited, with a heritability of about 55 percent. These studies also showed that of the original nine rigid selections used, only three were outstanding in passing on their high gum-yield qualities to their progeny.

Now, how does physiology enter this picture? Schopmeyer et al. (1954) suggested that gum yield should be related to certain anatomical and physiological characteristics, namely, number and size of resin ducts, gum exudation pressure, and gum viscosity. Mergen et al. (1955) demonstrated that gum yield was inversely related to gum viscosity, and Bourdeau and Schopmeyer (1958) were able to prove that oleoresin exudation pressure was directly correlated with oleoresin yield. They concluded that the ratio of pressure to viscosity could be used for predicting yield potential of young trees.

So, what has happened here? The geneticist has selected high-yielding trees and proven that some of them pass to their progeny this high-yielding trait. The physiologist, working hand-in-hand with the geneticist (indeed, often they have been the same individual), has discovered why some trees yield more oleoresin than others. Now they have a tool which is available to improve selection techniques and to improve progeny testing. If techniques can be developed so that exudation pressure and gum viscosity can be measured on a seedling, the testing program can be speeded up considerably.

This research has revealed some physiological differences, but has raised many new problems for the physiologist to consider. Why do some trees have a higher exudation pressure? Why do some produce low-viscosity oleoresin? These questions will carry the researcher back toward more fundamental processes, e.g., photosynthesis, cell metabolism, gum synthesis. When you answer one "Why?" you generate a dozen new "Whys?".

Before we leave the subject of selection, let me just mention the physiologically complex problem of selection for fast growth rate. What are we really selecting for? Efficient photosynthesis, efficient utilization of water or minerals, some difference in cell metabolism that allows one plant to convert to cellulose more of the products of photosynthesis.

Breeding

Now let us move on from selection and consider for a few minutes the subject of breeding for desired traits and multiplication of genetically identical individuals once a desired strain is available.

One major deterrent to rapid progress in forest genetics is the flowering habit of most commercial tree species. They do not normally begin producing the organs for sexual reproduction in appreciable numbers until they are 10 or more years old, so breeding and progeny testing are delayed. Compare this with, say, corn breeding, where four crops of a 90-day maturing variety can be raised in one year by using a greenhouse during cold weather. The forest geneticist knows or can work out the techniques of breeding in the various species, but he cannot do breeding without flowers or strobili.

Some treatments, such as fertilizing, strangling, and root pruning, have been successful in stimulating precocious flowering, but there remains abundant opportunity for further advancement. Here again the physiologist can perhaps help. The U. S. Forest Service's Dr. R. L. Barnes and associates at the Research Triangle near Durham, N. C., are trying to determine internal physiological factors governing flowering. They are studying the biochemical changes which bring about "readiness to flower," and are attempting to identify the basic processes which initiate the changes. This work is far from finished, but when the controlling physiological processes have been identified and the biochemical steps determined, one can then make some logical "guesses" about methods of manipulating flowering with more hope of success in producing flowers or strobili on young saplings or even seedlings.

In this same area of genetics, it is desirable to have some reliable means of clonal reproduction of individuals with desirable traits. This requires grafting or some form of rooting, and raises many problems of a physiological nature. For example, with loblolly pine and many other species, root-ability declines with age (McAlpine and Jackson 1959). What is the basic cause of this decline? Can rooting potential be restored? Also, cuttings from one part of a tree may root better than those from another (Grace 1939), and the resulting ramets may even have different growth characteristics (Libby and Jund 1962). What physiological processes of a cutting are affected by age of parent tree, or by its original position in the crown?

As for grafting, several techniques have been used successfully to establish the initial graft union, but in many instances a large number of the grafts later die. Some physiological difference between stock and scion causes an incompatibility which prevents normal functioning of some essential process. What causes the incompatibility, and can it be overcome? When the physiologist can answer some of these questions, the geneticist can make more rapid progress in species improvement and will be able to assess more precisely true genetic differences.

Application

As a final example, let us turn to the essential step of utilizing superior strains once they have been tested and proven. Let us suppose that selection, breeding, and testing at the University of Georgia have produced a strain of shortleaf pine highly resistant to littleleaf disease (Zak 1955). Now disease resistance is not of much benefit unless the tree also makes satisfactory growth. Can we expect good growth from this new strain throughout the natural range of shortleaf pine from New Jersey to Texas and in areas where it has been planted outside its natural range? We know that geographic races exist within species, and so we would assume that this new strain would be limited in the geographic range over which it could be expected to make good growth. We could make trial plantings of the new strain throughout the range of shortleaf pine and wait 20 to 40 years to assess the pertinent growth results. But as our knowledge of physiology of trees increases, perhaps we can arrive at some valid estimates of potential range by making certain physiological tests. For example, drought resistance of some species has been found to be related to stomatal control and rate of transpiration (Polster and Reichenbach 1957). Could we make estimates of soil moisture or rainfall limits of the new strain by measuring these characteristics on seedlings in the laboratory? Cold hardiness has been associated with the concentrations of certain cell constituents (Parker 1962). Could temperature limits for the new strain be determined by measuring cell sugars? The optimum temperature for maximum net photosynthesis has been established for some species (Decker 1944) and could be established for the new strain. Some species and races within species can tolerate shorter daylengths than others and still make satisfactory growth (Pauley and Perry 1954; McGregor et al. 1961; Allen and McGregor 1962; Watt and McGregor 1963). These limits also could be established for the resistant shortleaf pine strain.

By measuring the rates of the various physiological processes and determining the limits of optimum operation of these processes under various conditions, perhaps we could predict how well our new strain would perform in a certain locality in competition with other tree species. With continued research, this will be possible.

I seem to have raised many questions and given very few answers. However, I hope that I have contributed to your better understanding of physiology and of its relation to forest genetics. Let me summarize by saying that physiologists are interested primarily in how trees grow, while forest geneticists are interested in changing the way in which trees grow. The greatest progress will be made when the two work together to solve the many remaining problems.

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How Far Can Seed Be Moved?

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How far it pays to move forest tree seed has been a serious question for nearly two centuries. Baldwin (1942) traces discussion of it back to an anonymous Swedish author writing in 1769.

Use of seed from the wrong source can eliminate any chance of profit from a plantation. Weidman (1939), for example, reports a northern Idaho test of 20 races of ponderosa pine, one of which, after 9 years of successful growth, suffered 100 percent mortality in a colder-than-average winter. Leon Minckler (personal communication) reports extensive to complete killing of North and South Carolina races of loblolly pine in the Central States by winter temperatures that did negligible harm to Maryland loblolly of comparable ages. At 35 years, the mean annual increments of three loblolly stocks originating 350 to 450 miles from a planting site at Bogalusa, La., were from 47 percent to as little as 20 percent of the mean annual increment of local Louisiana stock (fig. 1).

In extreme cases like these, when stock of distant geographic origin produces only a fifth as much wood as local stock, or no wood whatever, it is easy to name specific sources from which seed should *not* be obtained.

Most of the evidence from studies of racial variation is, however, less clear and more difficult to interpret. The immediately practical questions

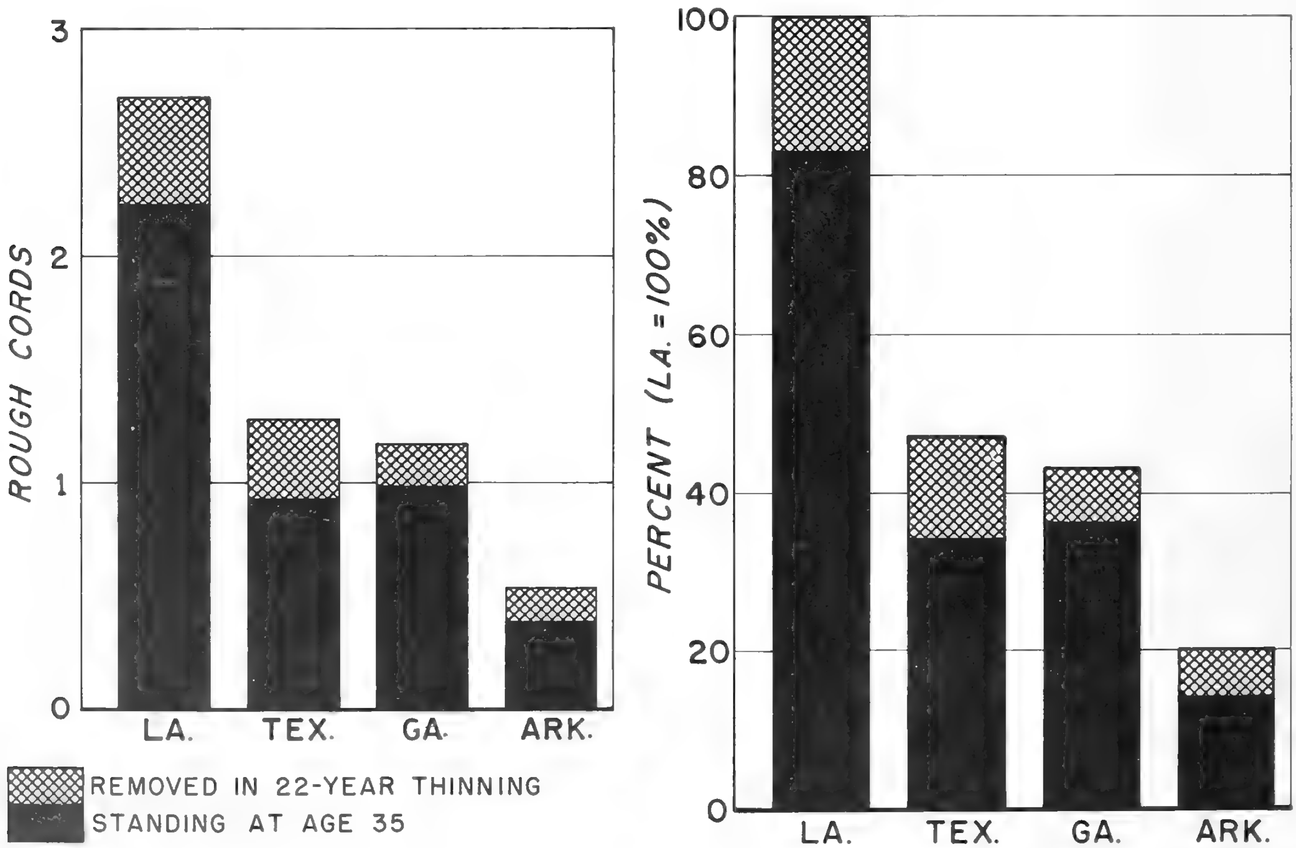

FIGURE 1.—Absolute and relative mean annual increments per acre, at 35 years, of loblolly pines of four geographic origins, planted at Bogalusa, La. The four sources, from left to right, were 50, 350, 450, and 350 miles from the planting site.

of how far one may venture from the planting locality to get seed when the local seed crop is inadequate, and of which of several moderately distant sources to choose, are hard to answer. Furthermore, the best answers we can give today cannot be considered final. They will require revision and amendment as new studies are established and reported and as trends in existing studies change with the passage of time.

Surveys of variation in the morphological characters or wood specific gravity of native stands, such as those Thor (Thorbjornsen 1961) and Wheeler and Mitchell (1959) reported at the Sixth and Fifth Southern Conferences, are of little practical help in choosing a source of seed for a planting program. Often such surveys deal with characters (like shape of seeds or size of pollen grains) that, while important in basic research, have no direct bearing on the survival, growth, or form of planted trees. In any event they fail to distinguish between the effects of the genetic makeup of a race and the effects of the environment in which the race occurs. Growth-chamber and laboratory studies are sometimes more helpful guides. Characteristically, though, growth-chamber and similar studies cover such a brief portion of a tree's life cycle that they supply only a fraction of the information needed. With few exceptions, therefore, the practical guides to choice of seed source have been conventional provenance tests, in which stocks representing several different geographic origins have been planted together in one place and observed for a number of years under field conditions.

Provenance tests are not all equally reliable or useful, however.

To justify generalization about racial variation within a species, a provenance test must include stocks representing a considerable portion of the species' range—preferably all of it. To distinguish races clearly and to indicate their geographical distributions, the test must include stocks representing numerous sources not too widely or irregularly spaced.

To yield dependable information, the stocks representing the various sources must be replicated in the plantation and planted in random arrangement within replications; the planting site must be relatively uniform; all stocks must be planted at essentially the same time; and the nursery treatment, lifting, packing, and shipping of all stocks must be as nearly identical as possible. A provenance test is a specialized form of progeny test and should adhere to the same exacting standards as other progeny tests (Wakeley et al. 1960). Close scrutiny of the records, however, will show that very few provenance tests, and practically none of the older ones, have done so.

Finally, conclusions must be drawn cautiously, if at all, from the earliest remeasurements of a provenance test, lest later developments show them to have been both premature and misleading. Let me illustrate briefly what I mean.

In the ponderosa pine study reported by Weidman (1939), the stock of Coconino origin grew fastest the first few years, and at 10 years excelled all other stocks but one in height, and equalled that one. At 10 years it might easily have been selected as best for planting in northern Idaho. By the 20th year, however, its average height was less than that of 12 of the 18 other stocks still surviving in the study.

Similar reversals have occurred in southern pine provenance tests. In the study established at Bogalusa, La., with four loblolly pine stocks from the 1925 seed crop, the Texas stock was very significantly taller than the Georgia stock at 15 and 22 years, and taller even at 28 years. By the 35th year, however, the Georgia stock had overtopped the Texas stock (fig. 2).

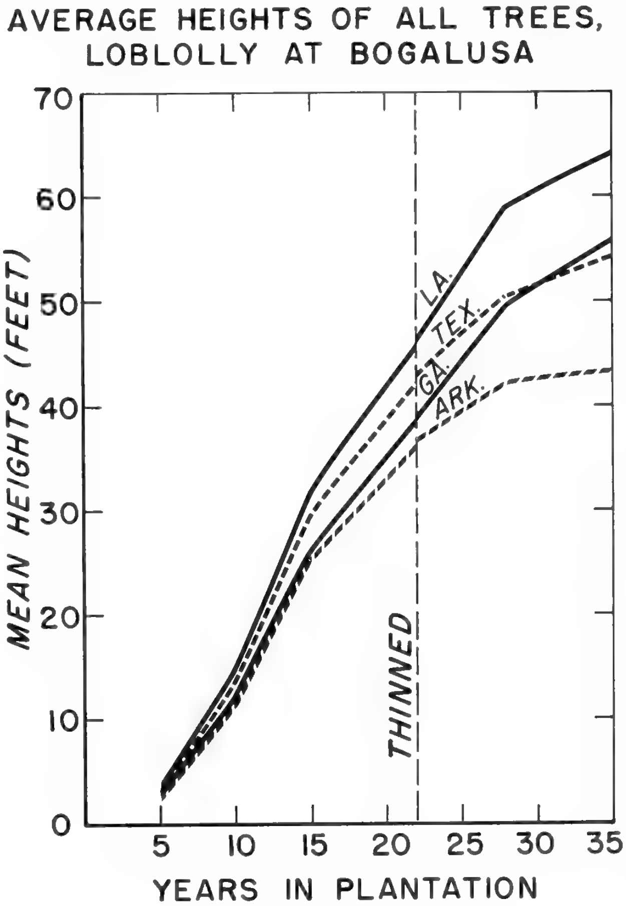

FIGURE 2.—Mean heights of all trees of stocks representing four sources of loblolly pine seed from the 1925 crop, planted at Bogalusa, La.

Through the 15th year of this same study at Bogalusa, the Texas and Arkansas stocks survived better than the local Louisiana stock. By the 35th year, the survival of the Texas stock had fallen slightly below, and the survival of the Arkansas stock had fallen significantly below, that of the Louisiana stock (fig. 3).

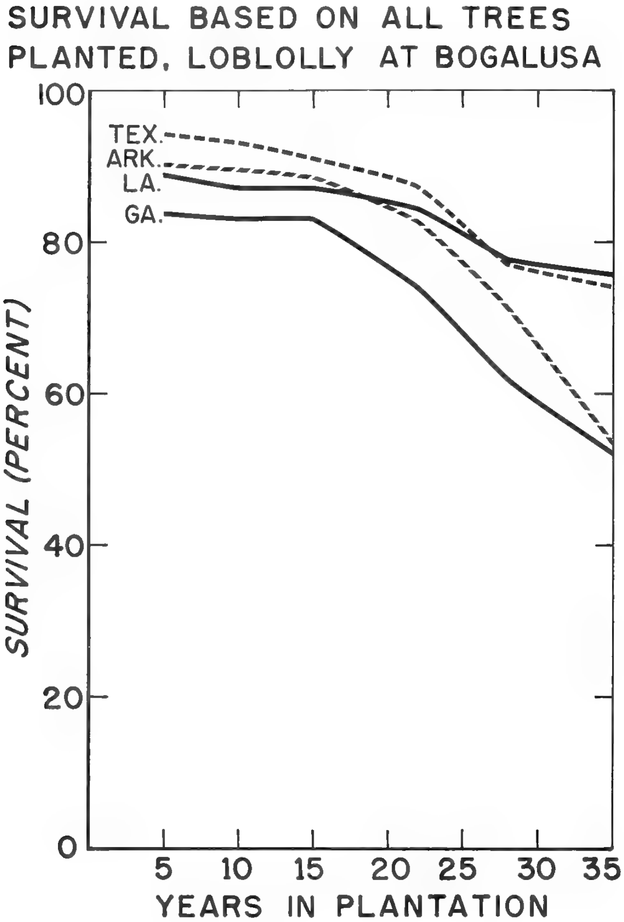

FIGURE 3.—Mean survival percents of stocks representing four sources of loblolly pine seed from the 1925 crop, planted at Bogalusa, La.

Only four southern-pine provenance tests of major importance were installed before the Southwide Pine Seed Source Study (Wakeley 1959; 1961), and of these only the loblolly study established at Bogalusa, La., with seed from the 1925 crop, has gone through a full pulpwood rotation—35 years. All four of these earlier provenance tests suffered from various defects of design, execution, or both. In the study of loblolly from the 1925 crop, the extreme contrast between the Louisiana and Arkansas stocks from age 15 onward must be discounted somewhat because of the nonrandom arrangement of sources in the replicated rows. Except for the results obtained with seed sent to the Union of South Africa (Sherry 1947), an ambitious study established with seed from the generally abundant 1935 crop was practically a total loss.

Ten or more conventional southern-pine provenance tests of potentially major importance have been established since the Southwide Study, and reports on them are appearing with increasing frequency. Several are superior to the Southwide Study in design, sampling, or execution, but none is as broad in scope, and it is not beyond possibility that some of the first conclusions drawn from them will have to be revised.

We have, in short, an insufficient basis on which to lay down any final rules for the movement of the forest tree seed principally used for reforestation in the South.

I feel, however, that we are in far better position to lay down tentative rules than we were 10 or even 5 years ago. The 10th year analyses of the Southwide Study, plus forthcoming publications on other studies, may enable us to improve such tentative rules even within the next 12 months.

Personally, I have no doubt whatever that economically important racial variation associated with geographic location exists in all four principal species of southern pine.

Such variation is clearly very great in loblolly and shortleaf. Stocks from opposite extremes of the ranges of these two species differ conspicuously in their requirements for optimum survival and growth. There is good evidence that, even within individual States, loblolly pine varies in susceptibility to fusiform rust, and, toward the western limit of its range, in drought resistance.

Racial variation, though present, seems to me to be least in slash pine, particularly in those portions of the species' range in which seed is collected commercially.

The picture of racial variation in longleaf pine is still somewhat obscure. The species is difficult to plant successfully, slow to commence height growth, and prone to brown-spot infection. For these reasons, results of provenance tests take longer to obtain than with other species, and tend to be erratic. My personal impression is that longleaf exhibits less racial variation than loblolly and shortleaf, but considerably more than slash pine.

Certain extremely long movements of seed have had catastrophic results. They obviously should be avoided in practice, especially when they have been tried several times. Longleaf from seed collected in Hillsborough County, Fla., has twice made a very poor showing in States north and west of Florida. Shortleaf seed from the central and southern Atlantic States and the Gulfcoast States has been tried three times in Pennsylvania without success. North and South Carolina loblolly stocks have succumbed to cold in Central States locations in which Maryland loblolly has survived.

Noncatastrophic but still economically serious setbacks have occurred when longleaf, loblolly, and shortleaf stocks have been tested at shorter but still considerable distances from their points of origin. In a majority of instances in the Southwide Pine Seed Source Study and other studies, the setbacks have taken one of two forms. Either the stock from a distant source has survived well but grown poorly, or the survivors, although fairly rapid in growth, have been few in number.

There are indications, though there is hardly as yet conclusive proof, that a few geographic races of southern pines are capable of both good survival and good growth, even at very great distances from their points of origin. Longleaf pine from Baldwin County, Ala., and loblolly pine from Onslow County, N. C., have exhibited such wide adaptability to varied conditions, each in two sets of plantations established with different seed lots collected from different stands in different years.

For the first 3 to 5 years, shortleaf and loblolly stocks of northern origin have generally outgrown stocks of southern origin when planted with them in the northern portions of the species' ranges, while in the southern parts of the ranges southern stocks have generally outgrown northern stocks (figs. 4 and 5). In some cases, though not in all, the tendency has persisted through the 10th year (figs. 6 and 7). There seems to me to be good evidence that variations in both temperature and day length, each of which is strongly correlated with latitude, are involved in this pattern of growth behavior.

As a rule, though again with some exceptions, an east-and-west movement of southern pines in the same general latitude seems to affect growth less than does movement for an equal distance north and south.

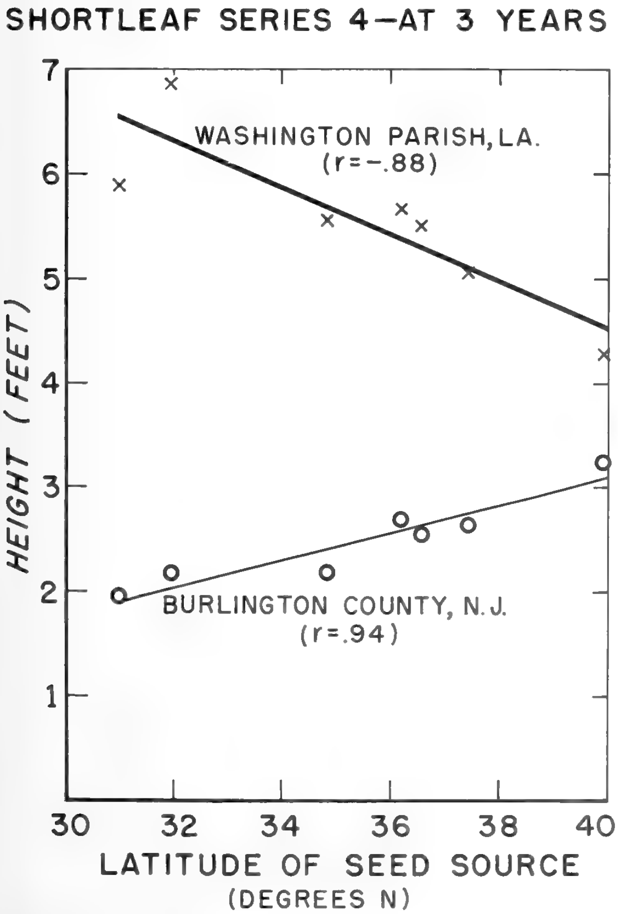

Figure 4.—Mean heights of shortleaf stocks at 3 years, over latitudes of seed sources, in northern and southern plantations.

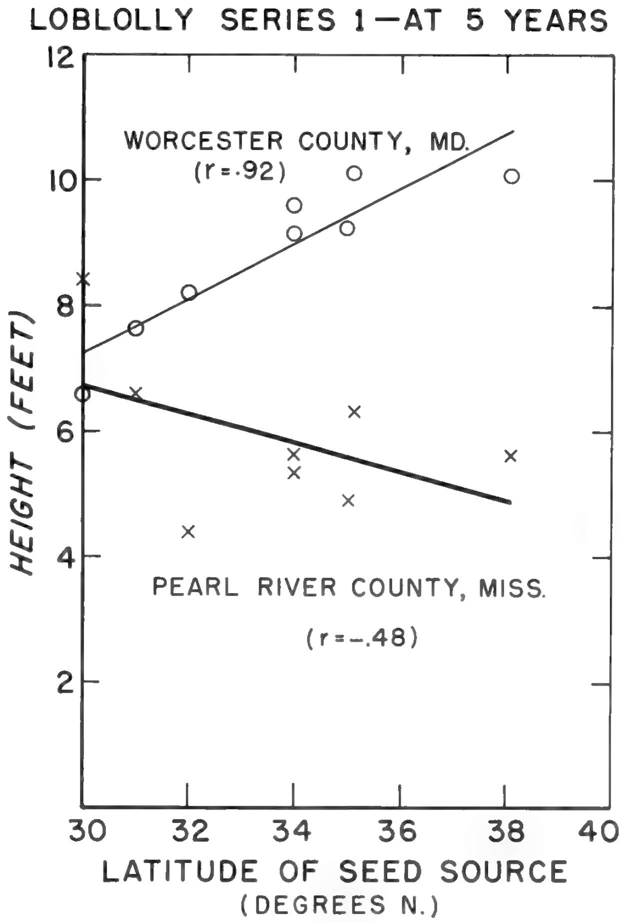

Figure 5.—Mean heights of loblolly stocks at 5 years, over latitudes of seed sources, in northern and southern plantations.

The susceptibility of loblolly pine to fusiform rust does, however, vary conspicuously with longitude of seed source. While variations in susceptibility occur even within individual States, they seem to be overshadowed by a general tendency for susceptibility to decrease from east to west. The lower susceptibility of western stocks has been dramatically illustrated by a Southeastern Station study in Georgia, in which, at 5 years after planting, the percent trunk-infected in each of 14 Georgia and 3 north Florida stocks was from 4 to 10 times the percent trunk-infected in a single Arkansas stock planted among them.

If I were a land manager or company executive and had to decide in favor of one as against some other nonlocal source of seed, I would follow these 10 guides in making my choice.

1. I would assume that the farther I moved seed in any direction, the greater would be the risk of its being poorly adapted to the planting locality,

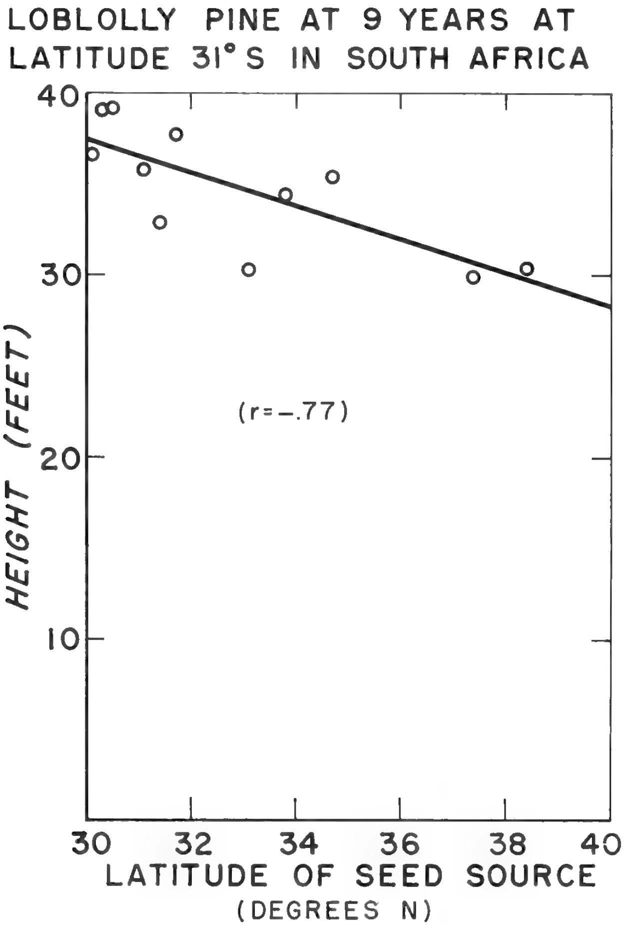

Figure 6.—Mean heights of loblolly stocks at 9 years, over latitudes of seed sources, in a plantation at a low latitude in South Africa (data from Sherry 1947).

and the more serious the maladaptation might be. The evidence to date does not justify saying it is always safe to move seed of a certain origin thus far and never safe to move it any farther.

2. I would avoid moving seed of any of the southern pines, even slash pine, over extreme distances, lest I duplicate one of several catastrophes already demonstrated. To avoid such extreme moves, I would go to considerable lengths to store seed of suitable origin in years of abundant production. As a last resort, I would suspend planting or seeding till seed of a suitable source became available.

3. I would be more cautious about moving seed of any of the southern pines a given distance north or south than about moving it an equal distance east or west. Going north or south involves a greater change in temperature, to which racial variation evidently is strongly related, and also a greater change in day length, to which loblolly and shortleaf races seem delicately adjusted and to which races of the other species may be adjusted also.

4. Other things being equal, I should prefer to move seed east rather than west, and would consider moving it farther to the east than to the west, especially if I were planting on droughty sites. Longleaf, loblolly, and shortleaf pines from western sources may be somewhat slower growing than those from eastern sources, but do seem to be more drought resistant and hence to be capable of better survival in dry years and on dry sites.

5. I should be particularly cautious about moving loblolly very much to the west. Maryland loblolly has incurred relatively light rust infection wherever planted, but other eastern provenances, from North Carolina south to Florida, have generally proved markedly more rust susceptible than more westerly provenances from corresponding latitudes.

6. Even within these limitations, I would try to get seed from a source (such as Baldwin County, Ala., for longleaf or Onslow County, N. C., for loblolly) that had proved widely adaptable in at least two tests.

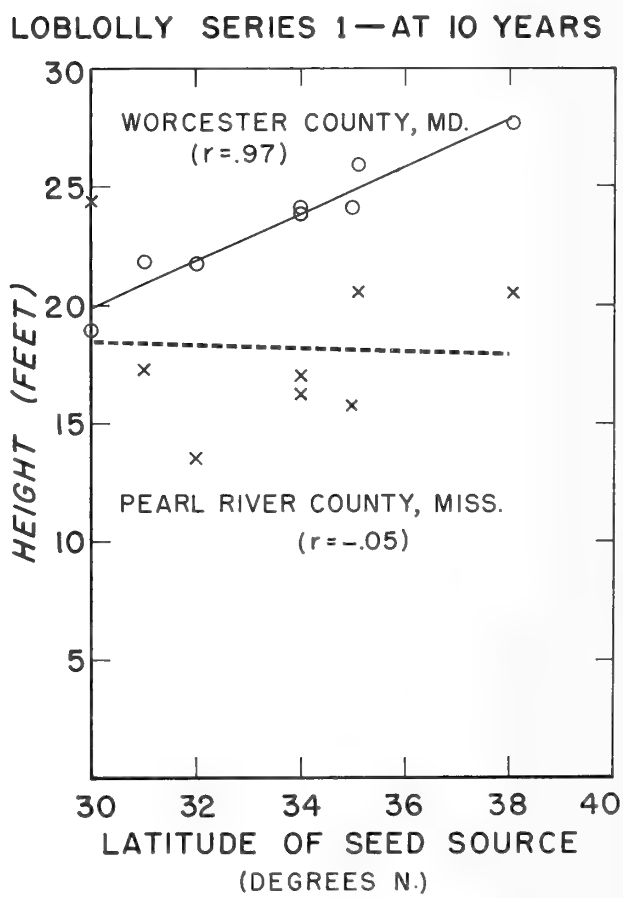

Figure 7.—Mean heights of loblolly stocks at 10 years in the same plantations as those shown in fig. 5. The relation of growth to latitude of seed source has become intensified in the northern plantation but dissipated in the southern one.

7. Although supporting evidence is not yet conclusive, I should be strongly inclined to limit planting of longleaf on the Carolina or Florida sandhills to stock grown from seed from the corresponding sandhill areas.

8. Within the range from the central Florida peninsula north to southern South Carolina and west to eastern Louisiana, I should be less apprehensive about unrestricted movement of slash pine seed than about similar movement of seed of the other three principal species. Even here, however, I should feel less free to move slash seed north or south than to move it east or west, and I should avoid getting seed from coastal-strip slash pine of a typical form for the species.

9. I should by no means depend upon correct provenance alone to insure good growth in my plantation, but should take care also to avoid getting seed from high-graded, inbred, or otherwise minus stands within the provenance chosen.

10. Though there is as yet no experimental evidence to support me, I believe I should risk moving genetically superior seed from plus stands, elite trees, or tested seed orchards slightly farther than I would move "run-of-the-woods" seed. Loss in growth resulting from the movement might be offset, at least in part, by a gain in growth resulting from selection. Under no circumstances, however, would I move seed-orchard or other improved seed over extreme distances. It is questionable, for example, whether any degree of selection and breeding would enable Maryland loblolly to equal the growth of ordinary Texas loblolly if both were planted in Texas. The same would be true of any other genetically improved southern pine seed moved an excessive distance from its geographic origin.

Management of Pine Seed Production Areas

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A great deal of planting and direct seeding is being done with the southern pines and there is every indication that this will be the case for a long time to come. Since the seed used has such a profound effect on the harvest and since we are planting and seeding on such a grand scale, it is vital that we use the best seed available as long as its cost is not excessive.

The fastest way of mass-producing southern pine seed is by means of seed production areas. Where suitable stands are available, substantial quantities of seed may be produced in from two to five years from the time a seed production area is established. This is much quicker production than is possible from grafted or seedling seed orchards and although the degree of improvement from seed production area seed is not as great as may be expected with seed orchard seed, we feel that the combination of rapid seed production and a modest improvement in quality is sufficient to make the establishment of seed production areas worthwhile.

Having thus stated our basic premise, let us consider in more detail what is involved in the establishment and management of seed production areas.

A seed production area is a stand managed specifically for the production of seed; its purpose is to provide, in quantity, seed of known origin from the best phenotypes available. The establishment of seed production areas is a stop-gap measure designed to produce seed of the best possible quality until our seed orchards begin to bear.

The most important single factor in the establishment of a seed production area is the quality of the stand; there is no method by which fertilization, spraying, etc., can produce first class seed from second class trees. Therefore, it is essential that the stand chosen be of the best possible quality (quality being used here primarily with reference to vigor, freedom from fusiform cankers, and form —good bole and crown characteristics—not site). Site quality isn't too important as long as it will permit fair growth and cone production (Thorbjornsen 1960) and the site is fairly representative of the area where the seedlings are to be planted.

The next point to consider is stocking; the larger the number of trees per acre, the more selective you can be regarding the trees you leave and this again has an effect on quality. Therefore, only well-stocked stands are suitable for conversion to seed production areas; 100 trees 10 inches in diameter or 50 feet of basal area per acre should be the minimum acceptable stocking.

The size, in area, of the stand has a bearing on the practicability of the operation; as the size of the area increases, management costs per acre are reduced and the proportion of the total area tied up in the isolation zone decreases. For instance, a 5-acre seed production area will have about 21 acres in its isolation zone; a 20-acre seed production area will have about 48 acres in its isolation zone. In addition, the number of trees on the area has an effect on the frequency with which the area can be harvested economically (if the number of trees is 100, and 20 percent have a crop of harvestable size, it is almost sure to be more expensive to collect them than it would be on an area where the total number of trees is 500, and 20 percent have a crop of harvestable size). We now feel that 10 acres in the seed production area proper is the least that is worth developing and we prefer larger areas.

Tree size has a strong influence on cone production, of course; we try to choose stands where the average diameter of the leave trees will be at least 12 inches. Stands of smaller trees can be used but they will take longer to produce cone crops of harvestable size.

Having selected a stand that meets our requirements for quality, stocking, acreage, and average diameter, the leave trees are marked and everything else is cut. We follow the Georgia Crop Improvement Association's Standards for the Certification of Forest Tree Seed in selecting leave trees even in States which have no provision for the certification of the seed. These give rather stiff specifications for bole and crown characteristics, freedom from fusiform cankers, width of the isolation zone, etc. We have found that these standards give us a good set of reference points to follow in establishing the areas. And the examination of the areas by the Association inspectors, with the attendant culling of sub-standard trees, puts the areas in very good shape. Generally about 10-15 trees are left per acre. This often seems like a very sparse stand, but heavy culling is necessary if much improvement in quality is to be attained.

Matthews (1963) cites research by Florence and McWilliams which showed that the density giving maximum cone production per tree is much lower than the density giving maximum cone production per acre; this has an important effect on the economics of seed-production area management since the size of the cone crop per tree is so closely correlated with cost of cone collection. Pollen production is also greater at wider spacing and is reflected in a higher number of viable seeds per cone. It is possible to have too few trees, of course; eight fair-sized trees per acre is probably close to the lower limit for good cone production and seed-set.

The release furnished by such heavy cut has a stimulating effect on the remaining trees (Allen and Trousdell 1961; Allen 1953; Bilan 1960; Easley 1954; Phares and Rogers 1962). The third season after release they usually will begin producing larger cone crops. This may continue for two or three seasons or longer, depending on the density of the stand on the seed production area.

We do not yet have sufficient data or experience to estimate accurately the number of trees needed to produce a given volume of cones. I am less optimistic in this regard than I once was, however. I now feel that about five trees are needed for each bushel of cones that is required annually. This is necessary because of the irregularity of good cone crops, because many trees do not produce cones in harvestable quantities, and because a buffer is needed against the loss of trees to insects, storms, lightning, etc.

Once a seed production area has been established, we have found that additional cultural practices are beneficial.

Fertilization has been found to be an effective method for increasing cone and seed production by a number of workers (Allen 1953; Hoekstra and Mergen 1957; Timofeev 1959). B. F. Malac, Union Bag-Camp Paper Corporation, is experimenting with the effect of different amounts of a complete fertilizer on cone production on a seed production area. He reported in a personal communication that (1) fertilized trees produced approximately twice as many cones as unfertilized trees in the same seed production area, and (2) approximately 50 percent of the cones were lost between the time of pollination and the time of harvest with no difference in the rate of loss between fertilized and unfertilized trees. However, it has been reported by Asher (1963) that squirrels prefer cones from fertilized trees, that cone losses from all causes were significantly greater on fertilized plots, and that this suggests insects also may prefer cones from fertilized trees. And Hughes and Jackson (1962) say that fertilization, especially with phosphorous, markedly increased damage from *Dioryctria* and *Cronartium* in young slash plantations. Fertilization may have other effects; Mergen and Voigt (1960) found that seed from fertilized slash pines produced larger and more vigorous seedlings than did seeds produced on unfertilized control trees.

The cost of fertilizing 1,665 trees on our seed production areas was 63 cents per tree per application of 20 pounds of 8-8-8 (NPK, with sulfate of potash-magnesia) at $47.75 a ton. Of this, 15 cents was for labor, at a rate of $1.50 per hour. It took almost exactly 1 man hour, including loading, unloading, and travel, to fertilize 10 trees. The only seed production areas fertilized are those prepared according to the Georgia Crop Improvement Association Standards where we feel that the extra cost is justified by the quality of the seed to be harvested. The fertilizer is applied in the spring, no later than mid-May.

Root pruning, girdling, and strangulation have been used to increase seed production (Bilan 1960; Grano 1960; Hoekstra and Mergen 1957; Timofeev 1959) but the results have been erratic and have even been reported to give fewer cones, in the long run, than no treatment (Bergman 1955; Girgidov 1960; Klir et al. 1956). Speaking of these practices, Matthews (1963) says "The girdling of stems of fruit trees was in common use one hundred years ago as also was root pruning; both techniques have been superceded in general practice by the use of fertilizers, shoot pruning, and clonal rootstocks. It appears certain that similar treatments will be of greater benefit than root pruning and stem girdling or strangulation in increasing seed production in forest trees."

The control of seed and cone insects is very important to the continued successful management of seed production areas. Thrips, *Laspeyresia* seedworms and *Dioryctria* coneworms seem to be the worst offenders; they can cause drastic losses of cones and seed from the time of pollination right on up to the time of harvest. And it is in this phase of seed production management, the economical control of cone and seed insects, that I believe the greatest opportunity lies for increasing the yield of our seed production areas.

Edward P. Merkel, located at the Olustee, Fla., unit of the Southeastern Forest Experiment Station, in a personal communication recommends the following formulations for the control of coneworms (*Dioryctria* spp.): BHC (gamma isomer) at 4 pounds of active toxicant per 100 gallons of water or Guthion at 1½ pounds of active toxicant per 100 gallons of water. Applications should be made during each of these periods: March 15-31, May 1-15, June 1-15, July 10-20. To lower costs the July application can be omitted with very little loss in cone protection. At these concentrations the cost of the chemicals is about the same for both BHC and Guthion and since the May application of Guthion alone gives good control of seedworm (*Laspeyresia*) it would seem to be the preferred material at least for the May application; it is more toxic to humans than BHC, however. His work was done with a hydraulic sprayer which would reach trees 50 feet tall; about 8.5 gallons of spray was used per tree at a cost of 80 cents per tree for chemicals alone.

More recently Merkel has compared the relative effectiveness of hydraulic sprayers and mist blowers for applying insecticides. In a personal communication he reports that he made applications on April 10, May 5, and June 8 of the following formulations: (1) 0.5 percent BHC hydraulic spray, (2) 2.5 percent BHC mist blower application, and (3) 1 percent Guthion mist blower application. Treatment 1 gave 93 and 85 percent control of *Dioryctria* on first and second-year cones. Treatment 2 gave only 50 and 69 percent control of *Dioryctria* on first and second-year cones. Treatment 3 gave 88 and 69 percent control of *Dioryctria* on first and second-year cones and 70 percent control of *Laspeyresia* (slash pine seedworm). BHC has no effect on *Laspeyresia*. The cost for both the BHC and Guthion mist treatments was 48 cents per tree per application for the chemicals alone. About 1 gallon of spray was applied per tree with the mist blower.

John F. Coyne, of the Institute of Forest Genetics, Gulfport, Miss., in a personal communication reports a cost of $1.72 per tree per application where he was treating individual parent trees with a 0.5 percent BHC water emulsion. He used a Buffalo turbine mist blower mounted on a two-wheel tractor; his cost figures include chemicals, labor, and depreciation of equipment. Three applications were made each season for a total cost of $5.16 per tree per season. Cone survival was 70-80 percent in treated trees and about 30 percent in untreated trees. It is quite likely that these costs could be reduced where similar work was being done on a seed production area or seed orchard where the trees are closer together.

Cone rust can cause heavy losses of slash and longleaf pine conelets on the Gulf Coast and in North Florida. If it is not possible to locate seed production areas outside of the areas where cone rust losses are likely to be heavy, the rust may be controlled by spraying at 5-day intervals during the time of pollination with Ferbam at the rate of 2 pounds per 100 gallons of water plus a Du Pont spreader-sticker (Matthews and Maloy 1960). Adding heptachlor (1½ pints of a 2-pound-per-gallon emulsifiable concentrate of heptachlor per 100 gallons of ferbam suspension) gave significant control of both cone rust and thrips (Southeastern Forest Expt. Sta. Ann. Rpt. 1961, p. 30).

Regardless of the original condition of the stand, control of understory vegetation sooner or later becomes necessary because the release and fertilization stimulates the understory vegetation as well as the pines. Such control reduces competition and makes harvesting and other operations on the area much easier. The method chosen may be a control burn herbicidal spray, mowing, or a combination of these. But it should be suited to conditions in a given stand and the ideal result would be the lightest vegetative cover that would keep the soil in place.

But in spite of all we do, cone crops are extremely variable. They are not always produced on schedule the third season after release and they do not occur consistently on the same areas even when we fertilize, control competing vegetation, etc. Apparently the number of flowers produced is fairly consistent from year to year in a given stand (but not always), and most of the variation in cone crops is caused by climatic factors, e.g., too little moisture at the time flowers primordia are initiated, too much rain at the time of pollination, untimely freezes and droughts, etc., and variation in the severity of insect and disease attacks. Since we can't control the weather, the control of cone insects becomes even more important in securing harvestable crops more frequently.

Harvesting the cones economically has been a problem in seed production area management. In this connection the first thing to be decided is whether or not the cone crop is heavy enough to be worth harvesting; and an early answer to this question makes orderly arrangements for harvesting operations much easier. The maturing cones are large enough to count by about June 1 and several workers have developed methods of estimating cone yields (Hoekstra 1960; Wenger 1953a). In deciding whether or not to harvest a particular seed production area, we base the decision on the number of trees with a crop worth collecting; on certified slash seed production areas we set a cone count of 100 sound cones per tree as the minimum; on the other slash seed production areas and all loblolly seed production areas the minimum count is 150 cones (the actual number of cones collected is usually about twice the number counted). And we don't collect in areas where less than 20 percent of the trees have a crop of this size. The minimum acceptable cone count can be varied as seems desirable considering the size of the crop, how badly cones are wanted, etc. For most purposes this count need not be precise; all you need to know is the number of trees with a harvestable crop. With a little practice most trees can quickly be judged as harvestable or unharvestable and only borderline trees need be checked carefully.

We have done all of our cone collecting from seed production areas by climbing for the cones, rather than by cutting the trees. It is considerable trouble to prepare the areas and we want to keep them in production as long as possible. We feel that the extra cost of collection from standing trees is justified by the continued production of quality seed.

We have tried several methods of collection; climbing with aluminum tree climbing ladders, with a trailer mounted extension ladder, and with spurs and ropes. Climbing with spurs and ropes is the best method; it is cheaper, it is quicker, and so far, after two seasons, there has been no tree mortality that we can attribute to the use of spurs. Any trees which are buggy are removed at the time of harvest, however, so as to get rid of potential sources of infestation. With this system, the men climb into the trees on their spurs and descend on their ropes; this is fastest and minimizes damages to the trees. The trees that have been climbed are marked and are being watched for beetle attacks and to see how often the same trees produce worthwhile crops.

On slash seed production areas, the cones are pushed off with a cone hook with little difficulty or damage to the following season's crop. Loblolly presents more of a problem, however, and on the loblolly seed production areas a pruner is used and the whole twig is clipped off. This means the loss of the next season's cones and the flowers for the following season on these twigs but it seems to be the only economically feasible way of collecting loblolly cones from standing trees.

It is very important that the cones be ripe when collection starts. Immature cones produce less seed and the germination may be reduced (Speers 1962) which increases the cost of seed.

The first two seasons that we collected from our seed production areas, the collection was done by contract with a tree surgery company. The first season climbing was by means of aluminum tree climbing ladders. Our men and the climbers were just learning how to harvest cones; the cost of collecting slash cones was $5.65 per bushel (table 1). This figure includes climbing, moving ladders, picking up, sacking, and loading the cones for shipment to the cone warehouse. Collection costs were considerably lower when the second area (Meadows Tract) was collected that year because climbers and ground crew were more familiar with the job and some excess ground crewmen had been eliminated; but because of the marked difference in seed yield between the two, the cost per pound of seed was nearly the same on both areas.

The next time (1961) we collected from our seed production areas, climbing was done with spurs and ropes (detailed costs and yields are shown in table 2). Collection costs totaled $4.03 per bushel on the certified slash seed production areas and $3.50 per bushel on the uncertified slash seed production areas; the combined average cost was $3.71 per bushel. Costs differed because there was a lower minimum number of cones on the certified areas. Collection costs were $4.98 per bushel on the loblolly seed production areas (costs for certified and uncertified loblolly areas were lumped together since too small a part of the total came from certified seed production areas to permit an accurate comparison). Loblolly collection costs were higher than those for slash because of the greater difficulty of collecting loblolly cones and because the loblolly areas were generally more brushy. Costs were 20 to 60 percent higher whenever climbing methods other than spurs and ropes were used. Seed yields averaged 0.86 pound per bushel for cones from certified slash seed production areas, so collection costs per pound were $4.69. For uncertified slash seed production areas the figures were 0.80 pound of seed per bushel and a collection cost of $4.36. By contrast, the yield from more than 1,000 bushels of purchased slash cones was 0.71 pound per bushel and the cost per pound was $1.97 (purchase price was $1.25 per bushel and supervision, transportation, etc., added about $0.15 per bushel). The difference in seed yield

TABLE 1.—*Slash pine cone collection costs and seed yield, 1958*

Tract	Trees collected from	Quantity		Costs						Seed yields		
				Climbing		Labor		All				
		Total	Per tree	Total	Per bushel	Total	Per bushel	Total	Per bushel	Total	Per bushel	Collection costs per pound
	Number	*Bu.*	*Bu.*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Lbs.*	*Lbs.*	*Dollars*
Newman	136	150	1.1	879.37	5.86	199.50	1.33	1,078.87	7.19	175	1.17	6.16
Meadows	185	200	1.1	760.63	3.80	139.95	.70	900.58	4.50	133	.66	6.77
Total or average	321	350	1.1	1,640.00	4.69	339.45	.97	1,979.45	5.65	308	.88	6.43

TABLE 2.—*Slash and loblolly pine collection costs and seed yield, 1961*

Tract	Trees collected from	Quantity		Costs											Seed yields		
				Climbing			Brush control			Picking up, loading, etc.			All				
		Total	Per tree	Time	Total	Per bushel	Time	Total	Per bushel	Time	Total	Per bushel	Total	Per bushel	Total	Per bushel	Collection cost per pound
	Number	*Bu.*	*Bu.*	*Hours*	*Dollars*	*Dollars*	*Hours*	*Dollars*	*Dollars*	*Hours*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Lbs.*	*Lbs.*	*Dollars*
SLASH PINE																	
Certified:																	
Robinson	189	228	1.2	139.5	592.87	2.60	15.5	43.71	0.19	114.0	171.00	0.75	807.58	3.54	194.0	0.85	4.16
Blundale	52	46	.9	45.0	191.25	4.16	4.0	11.28	.25	31.0	46.50	1.01	249.03	5.41	44.0	.96	5.64
H. and P.	88	95	1.1	76.5	325.13	3.42	12.0	33.84	.36	47.0	70.50	.74	429.47	4.52	81.0	.85	5.32
Total	329	369	1.1	261.0	1,109.25	3.01	31.5	88.83	.24	192.0	288.00	.78	1,486.08	4.03	319.0	.86	4.69
Uncertified:																	
Meadows	71	65	.9	113.0	503.63	7.74	...	..	.	48.0	72.00	1.11	575.63	8.86	68.0	1.05	8.05
Blundale	334	528	1.6	274.5	1,166.62	2.21	12.0	33.84	.06	201.5	302.25	.57	1,502.71	2.85	407.0	.77	3.70
Total	405	593	1.5	387.5	1,670.25	2.82	12.0	33.84	.06	249.5	374.25	.63	2,078.34	3.50	475.0	.80	4.36
Total, all slash areas	734	962	1.3	648.5	2,779.50	2.89	43.5	122.67	.13	441.5	662.25	.69	3,564.42	3.71	794.0	.83	4.47
LOBLOLLY PINE																	
Uncertified	225	306	1.4	260.0	1,121.25	3.66	33.0	90.75	.30	208.0	312.00	1.02	1,524.00	4.98	288.0	.94	5.30
Certified	28	25	.9	...	...	...	...	.	..	..	...	..	..	4.98	31.0	1.24	4.02

between purchased cones and collected cones is due to the better control over cone quality (ripeness, freedom from insect injury, etc.) which is possible on a company job. The difference in yields between certified and uncertified areas is probably due to the fertilization and spraying for cone insects which was done on the certified seed production areas. Similar trends were evident on the loblolly seed production areas; on the certified loblolly seed production areas the seed yield was 1.24 pounds per bushel and collection costs were $4.02 per pound. On the uncertified areas the yield was 0.94 pound per bushel and collection costs were $5.30 per pound of seed (no loblolly cones were purchased so a comparison with the yield from purchased cones is not possible).

In 1962 climbing again was with spurs and ropes but the contract was on a per tree basis rather than a straight weekly rate for the crew as had been the case in the past. The Seelbach Company, of Atlanta, was the successful bidder with a bid of $3.12 per tree for slash and $3.50 per tree for loblolly.

The details of the costs of collection per bushel of cones and per pound of seed for 1962 are given in table 3. Climbing costs ranged from $1.96 to $3.93 per bushel and total collection costs ranged from $2.88 to $5.02 per bushel, depending on the bushels per tree. The collection cost per pound of seed varied from $2.81 per pound to $8.66 per pound; this is a reflection of the combined effect of bushels per tree and pounds of seed per bushel (pounds per bushel varied from $0.58 to $1.16). The yield from ordinary slash cones purchased by Continental Can Company in 1962 was 0.48 pound per bushel; at a cost of $1.40 per bushel (price of cones was $1.25 per bushel plus $0.15 per bushel for transportation, supervision, etc.) the purchased seed cost $2.92 per pound. The combined average figures for the seed production areas are 1.4 bushels of cones per tree, $2.24 per bushel for climbing, total collection costs $3.16 per bushel, average pounds per bushel 0.84, average cost per pound $3.76. There wasn't enough of a crop to make collection worthwhile on the loblolly areas so we haven't any figures on loblolly for 1962. Climbers can collect the cones from about 5 to 12 trees per day depending on the cone crop per tree and whether they are working in slash or loblolly pines.

So far we have only one set of data regarding cone collection from a loblolly seed production area in successive years (from our Hodge, La., district) but it is very interesting (table 4). There are 153 trees on the 11-acre seed production area, and in 1961 an average of 2.3 bushels of cones were collected from 95 trees by clipping the twigs with a pruner. In 1962, on the same area, 437 bushels were collected from 134 trees for an average of 3.3 bushels per tree. Of the 95 trees from which collections were made in 1961, 84 were collected from again in 1962; the average cone yield from these trees was 2.4 bushels per tree for 1961 and 3.1 bushels per tree for 1962. From an examination of yield data from the individual trees, it appears that when 3.5 or more bushels were collected from a given tree in 1961 the 1962 yield from that tree was reduced; but even so, the average 1962 yield from those high yielding trees was 2.9 bushels per tree. Thus it appears that two successive crops of cones may be collected from a loblolly seed production area even when the cones are clipped off. It will be very interesting to see when these trees will produce a crop of harvestable size again; they look rather like plucked chickens now.

TABLE 4.—*Cone yields in successive years from a loblolly pine seed production area (Hodge, La.)*

Year	Trees		Cones		Cones per bushel	Repeaters [1]	
	Total	Collected from	Total	Av. per tree		Trees	Cones per tree
	Number	*Number*	*Bu.*	*Bu.*	*Number*	*Number*	*Bu.*
1961	153	95	221.0	2.3	[2] 600	84	2.4
1962	153	134	437.0	3.3	420	84	3.2

[1] Trees from which successive cone crops were collected.
[2] Estimated.

We like contracting for cone collection on a per tree basis. It is the cheapest method we have yet developed and since payment is on a per tree basis, the pressure to keep the climbers moving is on the contractor which makes supervision easier for us. The contractor was well enough satisfied with the arrangement to have expressed an interest in doing it again; I feel that the costs are reasonable, considering the size of the cone crop.

TABLE 3.—*Slash pine collection costs and seed yield, 1962*

Tract	Trees collected from	Quantity		Costs: Climbing		Costs: Brush control			Costs: Picking up, loading, etc.			Costs: All		Seed yields		
		Total	Per tree	Total	Per bushel	Time	Total	Per bushel	Time	Total	Per bushel	Total	Per bushel	Total	Per bushel	Collection cost per pound
	Number	*Bu.*	*Bu.*	*Dollars*	*Dollars*	*Hours*	*Dollars*	*Dollars*	*Hours*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Lbs.*	*Lbs.*	*Dollars*
Robinson	34	27	0.8	106.08	3.93	2.6	11.23	0.42	12.1	18.15	0.67	135.46	5.02	15.7	0.58	8.66
Blundale	54	56	1.0	168.48	3.01	4.1	17.71	.32	25.2	37.80	.67	223.99	4.00	32.5	.58	6.90
H. and P.	58	82	1.4	180.96	2.21	5.0	21.60	.26	36.9	55.35	.67	257.91	3.15	92.0	1.12	2.81
Sav. Town	34	44	1.3	106.08	2.41	3.0	12.96	.29	19.8	29.70	.67	148.74	3.38	51.0	1.16	2.92
Total certified	180	209	1.2	561.60	2.69	14.7	63.50	.30	94.0	141.00	.67	766.10	3.67	191.2	.91	4.03
Blundale (uncertified)	212	337	1.6	661.44	1.96	16.3	70.42	.21	151.6	227.40	.67	959.26	2.85	207.0	.61	4.67
Grand total	392	546	1.4	1,223.04	2.06	31.0	133.92	.25	245.6	368.40	.67	1,725.36	3.16	398.2	.73	4.33

If the difference in cost between seed from purchased cones and those collected from our seed production areas seems alarming, in view of the combined effect of the costs of fertilization, spraying, and collection, it should be remembered that the cost of seed is only a small fraction of the costs of planting an area, especially if mechanical preparation of the site is required. On areas where site preparation is necessary, and the planting is done by machine, the cost of seed from purchased cones represents less than 1 percent of the total cost of machine planting. Thus a large increase in the cost of seed has only a small effect on planting costs.

On the other hand, a small increase in volume or quality will, by the end of a rotation, have a pronounced effect on the "dollar harvest" from the plantation. On an "average" slash site (70 foot site index at 50 years) a 1 percent increase in volume yield over a 35 year rotation would mean that the cost of seed could be increased about five times and the planter would still break even (this assumes all of the increase is considered to be in sawtimber at $35.00 per M bd. ft. at the end of the period and 5 percent interest is charged). And Perry and Wang (1958) have presented calculations to show that seed is only one-half of 1 percent superior to the average, would, under the conditions they have assumed, be worth an extra $4.52 per pound. There are other factors which eventually should reduce the cost of seed from seed production areas. On our own seed production areas and others certain trees produce most of the cone crop year after year (Hagner 1958; Matthews 1963; Thorbjornsen 1960; Timofeev 1959; Wenger 1953b). Thus, after three or four good cone crops on a seed production area, it should be possible to identify the good producers. Cultural operations could then be concentrated on the cone-producing trees with a proportional reduction in the cost of such operations.

In any case, the most important point is the degree of improvement provided by the seed from seed production areas. Easley (1963) has reported a field test of loblolly pine seedlings from a seed production area in comparison with ordinary seedlings on both sand and clay soils: "After five years in the field the seed production area stock produced 17 percent more height growth than the nursery run seedlings on deep sand. On the heavy clay soil the seed production area stock produced 27 percent more height growth than seedlings from nursery run stock . . . . This study so far indicates that the collection of seed from a local source of selected parent stocks can very well be worth the effort, time, and care required to manage a seed production area." More recently in a personal communication he said that after 8 years in the field, the seed production area stock on the deep sand site was 25 percent ahead of the nursery run seedlings in height growth. However, the difference between the two types of stock was decreasing on the heavy clay soil, indicating that the growth of the seed production area seedlings was beginning to level off on that site. He adds, "This is not unexpected on the heavy clay soil. Slash pine seedlings in the same test on the clay soil are superior in height growth to both sources of loblolly seedlings; heavy clay savannah soil is the only place where I recommend slash pine over loblolly pine in the Georgetown area."

Results such as this lend a most reassuring substance to all the theoretical arguments that have been advanced to justify the establishment of seed production areas and seed orchards. However, it cannot safely be assumed that the establishment of seed production areas will automatically assure us of a 20 percent increase in growth (or any increase at all). Each seed production area and seed orchard is a separate case and must be tested. For this purpose, our company has made test plantings of seedlings from our certified and uncertified seed production areas in comparison with nursery run seedlings on a number of sites and soil types. It will be some time before any definite results can be expected; and the results, for good or ill, will depend on the quality of the stand originally chosen for the seed production area and the care exercised in marking the trees to be left on the area. But we have enough confidence in the outcome that we are continuing to establish seed production areas, and we expect that this seed will be in demand for a long time to come.

In summation, we can say that seed production areas offer the quickest means of producing large quantities of good seed and the cost of such seed is probably quite reasonable if the stand and trees chosen for seed production are of good quality and good cultural practices and methods of harvest are used to maximize cone crops and minimize collection costs. But cone crops are extremely variable and more economical control for cone insects and diseases is needed. Finally, each seed production area needs to be tested to see if it is producing seed worth the extra cost.

Management of Seed Orchards

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Managing seed orchards in the South today is big business. The size of the seed orchard establishment increases from year to year; 2,380 acres are now devoted to producing forest seed from elite sources in the region extending from Virginia to Texas, 1,500 acres are scheduled to be producing by 1966, and another 750 acres are now in planning stages.

The development and management of seed orchards tasks the abilities of many foresters and forest workers. Interest in the program reaches high levels because of possible future benefits in forest growth and quality. This fact, plus the lack of full answers to the many involved problems which arise, provides common ground for valuable communication between seed orchard workers.

This presentation provides evidence of the cooperative work by foresters in tree improvment. The results of a questionnaire, answered by many of you in the audience, are summarized to give an overall picture of present-day seed orchard management and development. The answers come from 37 out of 38 organizations which received the questionnaires. Among the respondents were 34 companies or agencies having orchards installed or planned as of May 15, 1963.

Size and Design

Apparently the first grafting work for possible commercial seed orchards began during the winter of 1954-1955. Seed orchards have been started each year since 1955. The year 1956 marked the high spot in initiation of orchards with 11 orchards begun.

Today, individual orchards range in size from 4 acres to over 600 acres. The 40- to 70-acre size class has the largest number of orchards. The average size of all orchards approximates 65 acres.

Orchard outplanting design varies considerably. Rectangular, diagonal, square, and combinations of these designs plus random or mechanical location of clones furnish the patterns for outplanting. The majority of the orchards have a square design with random location of clones. Included in the orchards are subsections for species or geographic sources.

Loblolly pine is grown by 26 organizations; slash pine is grafted in 18 orchards; Virginia pine is included in 6; shortleaf pine in 4; and pond pine in 2. Two orchards plan to produce seed from plus sand pine trees, and four orchards plan to develop longleaf pine seed. The average orchard has three subsections for species or geographic sources.

The number of clones and trees planted per acre varies somewhat from orchard to orchard, as shown in the following tabulation:

	Orchards
	(number)
Clones per acre:	
1-9	5
10-14	0
15-25	22
26-40	5
41-60	2
Ramets per acre:	
0-50	18
51-100	8
101-150	1
151-200	8
201-250	2

Orchard Sites

The majority of seed orchards are located on old field sandy loams or sandy clays. Two orchards are on clay land, and two orchards are on alluvial soils. Clear-cut and site-prepared forest areas make the base sites for 10 orchards. Seven areas are located on deep sands. The average site index for all orchards falls around 75 feet for slash pine and 85 feet for loblolly.

Grafting

Most orchard managers use the cleft and side graft methods for propagating their elite material. Two organizations supplement their normal grafting with bottle grafting and three orchards include attempts by air-layering. Grafting from outplanted trees in the orchard to root stock (inarching) takes place in eight orchard organizations. The grafting parties use 22 shade houses of sorts, 20 field areas, and 12 nursery beds as their locations for grafting work.

Grafting success varies from orchard to orchard and from man to man. Table 1 is a compilation of grafting and transplanting success by species.

Individual clone grafting success varies from 100 percent failure to almost 100 percent success.

TABLE 1.—*Success of grafting and transplanting, based on orchard totals*

Species	Grafting success		Grafting success	
	Range	Average [1]	Range	Average [1]
	Percent	*Percent*	*Percent*	*Percent*
Loblolly pine	41-80	64	60-97	85
Slash pine	60-95	72	60-97	85
Virginia pine	52	55	90-95	92
Shortleaf pine	51-90	65	90-95	94
Sand pine	76	76	90	90

[1] Unweighted.

Growth

The growth of grafts from select trees definitely shows the vigor associated with the parent material. The unweighted average age of all trees in all orchards approximates three growing seasons. The average grafted tree has a stem diameter of 3 inches and is 12 feet tall. The largest tree in the southern orchards stands over 31 feet tall and reaches 9 inches d.b.h. after seven growing seasons. It is at Georgetown, S. C., and has had top pruning. Table 2 gives you an inkling of the growth of plus grafted material.

TABLE 2.—*Average growth of largest trees in seed orchard*

Growing seasons (number)	D. b. h.	Height
	Inches	*Feet*
7	6.1	27
6	5.5	24
5	3.9	19
4	4.1	20

Phenology

The initiation and amount of strobili development has an important bearing on early progeny testing and seed production for all orchards. The questionnaire answers give the impression that loblolly pine has a somewhat earlier seed production potential than slash. The following tabulation indicates year of first "flowering," as reported by individual orchards:

	Loblolly	Slash
	(year)	*(year)*
Earliest reported		
Male	Within year planted	1
Female	do.	1
Average of orchards		
Male	2	3
Female	2	3
Latest reported		
Male	3	4
Female	3	4

To date, clonal "flowering" varies by orchards from 1 to 100 percent of the clones in the orchard for male strobili production (averaging 44 percent of clones) and from 20 to 100 percent (averaging 59 percent) for female strobili production. The "sexiest" clonal orchards, excluding the Georgia Forestry Commission, are (1) Western Region, International Paper Co., (2) College Station, Texas Forest Service, (3) Georgetown Region, International Paper Co. The first two of the three preceeding loblolly pine seed orchards lie west of the Mississippi River. Individual ramet "flowering" as measured by the number of ramets having more than 100 male clusters or female strobili separates the men from the boys in the following manner:

Male strobili.—1. University of Florida, + 300 slash pine ramets, 2. College Station, Texas Forest Service, + 200 loblolly pine, 3. Savannah, Union Bag-Camp Paper Corp. + 200 slash pine.

Female strobili.—1. Chesapeake Corp., + 400 loblolly pine, 2. Gulf Region, International Paper Co., 80 slash pine, 3. College Station, Texas Forest Service, 62 loblolly pine.

Almost half of the orchards do not have ramets with more than 100 hundred male clusters or female strobili as yet. However, controlled pollination for progeny material is taking place in 27 orchards. Six orchard organizations pollinate for hybrid study, and one orchard makes crosses for disease resistant material. Buckeye Cellulose Corp. experiments with ultra violet ray treatment of plus seed to obtain possible mutations having worthwhile characteristics.

Mortality After Outplanting Success

Hottes (1934) quotes Dr. L. H. Bailey (circa 1890) saying, in essence, that grafting accomplishes one of the four following things: (1) increases flowering, (2) decreases flowering, (3) has no effect, (4) shortens the life of the plant.

We notice the fourth rule today in the considerable mortality apparently caused by phloem blockage due to stock-scion incompatibility and/or poor grafting technique. The questionnaire results show that an average of 11 percent of the clones in the present orchards suffer from phloem blockage and about 7.5 percent of the total ramets are dead due to graft union incompatibility (excluding the Georgia Forestry Commission). Bailey's axiom apparently holds for the mortality angle. I wonder what influence grafting has on increasing or decreasing "flowering" in our southern pines.

Drought (480 trees), insects (+ 430), wind (+ 400), disease (+ 360), and temperature (+ 260), reduce the survival rate of grafted trees by about 2 to 5 percent overall. Ice (19 trees) and lightning (6) add some insult to the mortality picture. Again, data from the Georgia Forestry Commission is not included and could change the information as presented.

Cultural Practices

Orchard culture varies with the site and problems of each individual orchard. The following information and some side comments give an idea of the different current practices of orchard organizations (number of organizations in parentheses):

1. Mulching (14): sawdust (8), pine straw (5), hay or straw (2), plastic (2), used papermakers felt (1), paper (1).

Most of the mulching is done for the first 1 or 2 years after outplanting.

2. Watering (17): mostly during critical periods in the first year of outplanting.

The Panama City Region, International Paper Co., supplements rainfall to insure a minimum of 1 inch of water per week on 2 acres in an attempt to evaluate the effect of balanced rainfall.

3. Mowing (28): frequency is shown in the following tabulation:

Mowings per year	Organizations
(number)	*(number)*
1	2
2	6
3	4
3-4	13
4	3
None	4

4. Weed control (14): Weeds can be a problem in certain areas and increase fire hazard if not checked. Seven organizations use chemicals to combat weeds, seven apply the old proven method of hoeing by hand, one scalps once a year to remove vegetation. Most orchards rely on mowing and grass invasion to keep weeds under control.

5. Discing (4): Four orchard managers disc their areas with harrows or furrow discs every year to till the soil and turn in the vegetation.

6. Cover Crops (11): crimson clover (3), Bermuda grass (3), Bahia grass (2), Dutch clover (1), hairy indigo (1), Korean lespedeza (1), ryegrass (1). Cover crops reduce the frequency of moving, can choke weeds to some extent, and provide nutrients to the soil.

7. Pruning (most orchards): Many orchard managers prune a portion or all of the stock branches of each outplant to force scion growth. Disease infected branches are removed or pruned in all orchards. Two small orchards have a pruning study underway to determine the effect of various pruning techniques on "flower" production.

8. Fertilizers—The value of fertilizing orchard trees is still nebulous, except for height growth, according to the 26 answers from orchards using fertilizers. Balanced NPK fertilizers are applied by 21 orchards; ammonium nitrate-limestone is applied by 7 organizations. Muriate of potash (1), lime (1), 0-14-14 NPK (1), and dolomite (1) are also applied in certain orchards.

Fertilizer quantities per application range from 1 ounce to 2 pounds per tree depending on tree size and fertilizer type. One pound of balanced fertilizer per 100 square feet of horizontal crown surface is in use as a guide for fertilizer amounts in quite a few orchards. Heaviest application in any one orchard amounts to 2,000 pounds of balanced fertilizer per acre, per year. The average dosage per orchard seems to be 400 pounds of 8-8-8 or 10-10-10 NPK per acre spread around each tree area once or twice a year.

Only seven orchard managers make mention of any noticeable tree response to nutrient additives. The following tabulation lists the results of the answers on fertilizer for 8 orchards out of the 26 that use them.

	Organizations
	(number)
Clonal	2
Individual trees	2
Increased flowering	7
Increased height growth	5
Decreased height growth	1

9. Fire Protection (24): Most orchard men maintain fire lines around their orchards as a preventive fire measure. Four managers strengthen the fire lines with strip burning. One organization burns the orchard each year, a practice, although hazardous, offering maximum security.

Insect Problem and Control

The following insects listed in order of magnitude make seed orchards their habitat and pose a sometimes serious or nuisance problem for the orchard manager: 1. Nantucket pine tip moth, 2. coneworms *(Dioryctria* spp.), 3. red spider mites, 4. aphids *(Cinara* spp.), 5. thrips (mostly *Gnophothrips piniphilus)*, 6. midges (gall midge larvae), 7. seedworms *(Laspeyresia* spp.), 8. scale insects *(Chionaspis* spp.), 9. ants, 10. sawfly *(Neodiprion* spp.), 11. black turpentine beetle, 12. grasshoppers, 13. Japanese beetle.

Table 3.—*Use of insecticides in seed orchards*

Insecticides	Organizations	Range in Strength
	Number	*Percent*
Malathion	22	0.1-1.0
DDT	18	.5-1.0
BHC	17	.25-.75
Guthion	3	.2
Heptachlor	2	.1
Sevin	1	. . .
Di-syston	1	10
Thimet	1	10
Kelthane	1	. . .
Aldrin	2	.2-.5
Volck	1	. . .

Experience to date seems to indicate that malathion, DDT, and Guthion give excellent control of tip moth when applied at the proper times. Guthion appears to have a longer residual effect but is much more dangerous to use. Heptachlor, Guthion, and BHC appear effective on "flower" insects but not much is known about their phytotoxic effects. BHC works well in controlling bark beetles, coneworms and seedworms, depending again on the right time for application. Aldrin should be effective against most larvae and beetles but has a high human toxicity number. The systemics, Di-syston and Thimet, seem to hold some promise for tip moth control.

Application times for chemicals range from once a week to once a year depending on the need and the chemical. Eighteen orchards spray on a regularly scheduled basis. Several orchard workers rear Nantucket pine tip moth in small enclosures and spray their orchards when the captive adults emerge and begin flight. I think the same thing can be done with other insects, especially *Dioryctria* spp.

A number of orchard managers feel that the coneworms, thrips, and red spider mites pose a large problem for the future. Eight orchards list *Dioryctria* spp. today as their number one insect problem. I think the Nantucket pine tip moth will continue to plague the orchards because of its affinity for fresh branchlets which could produce "flowers."

Disease

Fusiform rust *(Cronartium fusiforme)* heads the list of diseases striking seed orchards with cone rust *(Cronartium strobilinum)* far down in second place. Most of the fusiform rust infection appears in the branches on the stock of the grafted material with some attacks occurring in the graft unions. Cone rust strikes conelets in seven orchards located in Georgia and Florida. One orchard finds a problem with needle cast. *Fomes annosus* in one or possibly two orchards causes concern.

Pruning infected areas and spraying with ferbam (usually at the rate of 2 pounds ferbam per 100 gallons water during periods of high telial spore formation and flight) for containing and preventing fusiform rust and cone rust forms the basic control practice in the majority of orchards. Radical surgery of the stem canker of fusiform rust seems to be successful in certain instances. At least the trees involved either survived, or died very quickly instead of slowly. Champion Paper Co. applies phytoactin and grafting wax to the cut area of the bole in their radical surgery method. Ferbam sprays are in use for the control of needle cast. In dealing with *Fomes annosus,* Hiwassee Land Co. treats the area around each uprooted tree with methyl bromide gas at the rate of 11 pounds per square inch.

A recent recommendation of considerable worth calls for applying borax powder or spray to freshly cut pine stumps within the orchard area. The complete lifting of the dead stem and root system is suggested as a sanitation procedure for *Fomes annosus* in orchards where dead grafts or failures in the field are problems.

Birds

Two orchards have dealt with the yellow-bellied sapsucker who enjoyed nibbling on elite material. Several orchards have placed poles or bamboo canes as bird perches in an attempt to reduce pine leader breakage or disfigurement by bluebirds and other winged orchard visitors. I am not sure if the results were impressive.

Equipment

Apparently tractors and mowers form part of the basic equipment of each orchard. Sixteen organizations furnish trucks for use in their orchard programs. Supplemental water is applied to 13 orchards from portable tanks. Two orchards have sprinkler systems and six orchards make use of ditches or dikes for irrigation or drainage. Pressure sprayers of varied manufacture, including homemade, furnish the means of distributing chemicals for 15 orchards. Eight orchards use back pack mist blowers and two orchards rely on the truck-mounted mist blower.

The development of rigs for reaching high branchlets is quite interesting and needs more study and design.

The types of reaching equipment now in use (and the number of orchards using them) are: ladder (7 plus others not answering questions); ladder with bicycle wheels (2); ladder, truck mounted (4); ladder, trailer mounted (3); ladder, tractor mounted (4); and elevated platforms on truck (4).

Costs

The costs of managing seed orchards can be hidden from view by the simple expediency of not mentioning them. The limited number of answers furnished by the questionnaires prove that seed orchard costs are too trivial to list, too high to recall, or simply unknown. The range of rough cost estimates furnished by the questionnaires is from 15 to 350 dollars per acre per year. My estimate of annual expenses for the average seed orchard would be in the neighborhood of 40 to 50 dollars per acre which, in turn, could be higher depending on the size of the spraying and cross pollination programs.

Research

Research aids the seed orchard manager in finding answers to some of his problems. For your consideration and thought the following is a partial listing of some specific areas needing basic or applied research:

A. Physiology
   1. Stimulation of "flowering"
      a. Water requirements
      b. Nutrient requirements
      c. Other physiological developments or requirements
         (1) Climate

(2) Mechanical bending, girdling or pruning
(3) Catalysts (biochemical)
d. Genetic influences
2. Graft incompatability
a. Healing process and tissue development
(1) Translocation of water and nutrients
(2) Genetic influence
(3) Catalysts (biochemical control)
b. Graft techniques
(1) Effects of different types of grafts
(2) By-pass methods

B. Phenology
1. Reasons for seasonal variations in time and amounts of "flowering"
a. Climatic
b. Soil

C. Propagation
1. Improvements in propagation and transplanting methods
a. Rooting
b. Grafting
c. Catalysts (hormones)

D. Methods of breeding
1. Efficient and simple handling, extraction, and storage of pollen
2. Efficient low cost isolation material
3. Development of equipment to mix and distribute large quantities of pollen if necessary
4. Development of multi-use equipment for reaching

E. Insect and disease control
1. Continued research for non-phytotoxic chemicals with high residual effects
2. Systemic chemicals for insects or disease
3. Application systems
4. Natural enemies of insects and disease
5. Knowledge of genetic control of insects and disease.

Perhaps, in time, enough answers and developments will furnish aid to the orchard manager for maximum yearly seed harvests. A conservative estimate, based on the 4,500 acres of seed orchards which will exist after 1967 and a future yield of 15 bushels of cones per acre per year, will forecast the availability of enough plus seedlings to plant almost 700,000 acres per year in 20 to 30 years or less.

The answers to the questionnaires definitely emphasize the fact that we are entering the large scale area of elite forest seed production. Forest seed orchards are big business now.

Juvenile-Mature Tree Relationships

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The best criterion for selecting geographic races, progenies, or individual trees will be their performance record based on periodic measurements from the time of planting through rotation age. Many years and great expense will be required to obtain this record. Our present individual tree selections are based on performance at maturity, which is a very valuable record in genetic evaluation, but these selections must be tested to reaffirm their superiority if this degree of accuracy is required. Tree breeders have recognized the opportunity for and have written much about speeding up this testing process by predicting mature tree performance from juvenile performance. Little concrete evidence has been presented yet to show the exact nature and strength of juvenile-mature tree relationships, but records being made now of juvenile performance in progeny tests will soon provide valuable information on them.

The objectives of this paper are: (1) to discuss briefly the problems presented by juvenile selection, i.e., how the stages of plant growth affect the reliability of juvenile evaluation, and (2) to outline some of the current information on juvenile-mature tree relationships for the southern pines.

The Problem

The Stages of Plant Growth

Sax (1958) has divided the stages of plant growth into embryonic differentiation, juvenile development, maturity, and old age. Excepting the end of embryonic development, there are no clear-cut distinctions between successive stages, and all parts of the plant do not change from one stage to the next simultaneously.

The existence of these stages in trees and shrubs has not always been recognized, and there are instances in taxonomy where mere juvenile forms have been erroneously elevated to specific or varietal status (Schaffalitzky 1954). Cuttings from plants in the juvenile stage typically root and graft more easily than cuttings from older plants (Schaffalitzky 1954, Sax 1962). Generally, trees and shrubs are sterile during juvenility, although some species and individuals within other species produce flowers as early as 1 or 2 years (Greene and Porterfield 1963). The wood near the pith of the tree has been variously referred to as "juvenile wood" or "core wood," and its properties differ from those of wood produced farther from the pith (Zobel et al. 1959). We are all familiar with the S-shaped height-growth curve and its typical trend during the years immediately following establishment.

Obviously, the stages represent varying physiological processes in the life of the tree. Many different gene complexes control these processes, and their expressions are in turn affected by environmental variations.

Reliability of Juvenile Evaluation

There are numerous factors affecting the reliance that we can place on the evaluation of juvenile performance. Among these are (1) the number of progenies being tested in relation to the accuracy required, (2) the strength of the offspring-parent heritability estimate, and (3) the age at which expression of a particular trait is critical.

Number of progenies in relation to accuracy required.—Numerous statistically significant differences among progenies and seed sources have been reported for embryonic and juvenile characters, such as embryo size (Vincent 1957), height growth (Wakeley 1961), rooting habits (Snyder 1961), photosynthetic rate (Reines 1963), and dry-matter content of needles (Schmidt 1957). However, sufficient time has not elapsed to allow many of these differences to be related to meaningful values near harvest age.

Furthermore, a statistically significant juvenile-mature tree relationship is not necessarily a useful one. If a small number of progenies are being compared for juvenile performance, a higher degree of accuracy is required and mere statistical significance may not be strong enough. However, if a large number of progenies are being compared, a statistically significant juvenile-mature tree relationship can be used but with the realization that some poor progenies will be accepted and some good progenies rejected.

Strength of offspring-parent heritability.—Squillace[1] suggested that " . . . if parent tree evaluations are available, including good controls, such information can and should be used in genotypic evalu-

[1] Personal communication from A. E. Squillace, Apr. 29, 1963.

ation as well as juvenile performance." For traits exhibiting a strong offspring-parent heritability, careful measurements made on mature parent trees can add greater reliability to the evaluation of juvenile performance within 10 years or so after planting.

Age of expression.—Certain traits are critical during the juvenile stage and can be evaluated then on the assumption that they will exhibit a strong juvenile-mature tree relationship. Resistance to drought, brown spot, and fusiform rust are examples of such traits. Height growth and many other traits are expressed over a much longer period and will require continued scrutiny.

At this point, the true value of juvenile performance may be stressed by coining the phrase "juvenile rejection and mature tree selection." The juvenile performance of progenies and races is an integral part of a test. If a progeny or race does not perform well for traits critical at an early age, then it can be eliminated quickly from further costly consideration.

But what are the risks involved in using juvenile performance to predict traits critical at a later age? Many of us are faced with making decisions that cannot wait for the 20-year results. A review of current information on some traits may partially answer this.

Current Information

Current information on juvenile-mature tree relationships will be discussed primarily from the standpoint of evaluating progenies or groups of individuals rather than selecting individual trees within progenies. Callaham and Duffield (1963) postulate that "juvenile-mature correlations in height growth (of ponderosa pine) may be quite significant for predictions of growth of progenies but not for predictions of growth of individuals within progenies." This will probably be true for other traits as well as height growth.

For the purpose of this discussion, most of the traits in which we are interested can be grouped into two broad classifications: those affecting volume per acre, and those affecting wood quality.

The variables affecting volume per acre are:

1. Height
2. Diameter breast height
3. Form class
4. Competitive ability
    a. Photosynthetic efficiency
    b. Crown form
    c. Root competition
5. Disease and insect resistance
6. Drought, heat, and cold resistance

The variables affecting wood quality are:

1. Straightness
2. Specific gravity
3. Tracheid and fiber lengths
4. Cellulose content
5. Percent summerwood
6. Self pruning
    a. Branch angle
    b. Branch diameter
    c. Number of branches
    d. Photosynthetic efficiency
7. Oleoresin yield

[2] Personal communication with Keith W. Dorman April 29, 1963.

Volume Per Acre

Height growth.—The juvenile-mature tree relationship for height growth has received more attention than any other characteristic, but an exact relationship has not been established. Numerous juvenile-mature correlations have been reported for height (table 1), but r^2 provides a gauge for

TABLE 1.—*Juvenile-mature correlations for height*

Material studied	Authors	Ages correlated	[1] r	r^2	n
Races:					
Ponderosa pine	(Squillace and Silen 1962)	2-30	0.85	0.72	10
		3-30	.75	.56	10
		4-30	.48	.23	10
		5-30	.65	.42	10
		6-30	.69	.48	10
		11-30	.86	.74	10
		20-30	.86	.74	10
Scotch pine	(Schreiner et al. 1962)	2-13	.61	.37	25
European larch	(Genys 1960)	4-12	.74	.55	36
Progenies:					
Slash pine	(Squillace [2])	8-14	.79	.62	8
		8-14	.82	.67	8
Individual trees:					
Slash pine	(Barber 1961)	1-7	.53	.28	1058
		2-7	.72	.52	1058
		2-8	.67	.45	1433
		3-8	.78	.61	1433
Ponderosa pine	(Callaham and Duffield 1963)	12-20	.83	.69	--
		12-20	.75	.57	--
		12-20	.65	.42	--
		12-20	.67	.45	--

[1] All values of r are significant at the 1 percent level except those for progenies, which are significant at the 5 percent level.
[2] Squillace, A. E. Unpublished data of the Southeast. Forest Expt. Sta. on file at Olustee, Fla. April 1963.

the reliability which can be placed on these correlations. Although the correlation coefficients are statistically significant, the amount of the variation in mature height which is accounted for by juvenile height is still relatively small. Some of the authors cited presented several correlations at different ages but only the earliest ages showing a significant juvenile-mature tree relationship are given.

Dorman [2] has expressed the opinion that the length of time required to reach a height equivalent to two logs (i.e. 32 feet) may provide a usable compromise for some purposes to long-term evaluation of height growth and tree quality. By 8 to 12 years the tree has attained a height which will represent a majority of its final volume. This will probably be more applicable for short-rotation predictions than for sawtimber, although there seems to be no generally accepted rotation age for southern pines.

Diameter breast height.—Although differences in diameter growth are significant among young slash pine progenies, evaluation cannot be considered reliable until after the base of the crown has progressed above 4.5 feet and crown competition has begun.[3] Squillace[4] reported correlation coefficients of 0.72 and 0.96 between d.b.h. at 8 years and d.b.h. at 14 years for slash pine progenies. These were significant at the 5 and 1 percent levels respectively (df = 6).

Form class.—I have found no references that mention the juvenile-mature tree relationship for form class, absolute or Girard. Certainly absolute form class will mean little until crown closure has been in effect for some time, and measurement of Girard form class should be delayed until the base of the live crown is above the first 16-foot log.

Competitive ability.—Competitive ability is a composite character, and it will be difficult to ascribe to it a juvenile-mature tree relationship. Yet, it may eventually be possible to relate competitive ability to maturity with demonstrated juvenile differences among progenies in photosynthetic rate (Reines 1963; Wyatt and Beers[5]) and crown form (Barber;[6] Trousdell et al. 1963). Root competition will be one of the most complicated and difficult components of competitive ability to determine. Unless differences in rooting habits of seedlings can be related to mature tree performance, root competition cannot be practically evaluated.

Disease and insect resistance.—Southern forest geneticists are interested in combating diseases and insects that are critical early in the life of the tree; e.g., fusiform rust, brown spot, and tip moth. Because they are critical in the juvenile stage, the mature tree performance may be relatively unimportant.

In contrast, littleleaf disease usually does not appear until a later age. Although Zak (1961) found differences in susceptibility of loblolly and shortleaf seedlings to *Phytophthora cinnamomi* Rands, his laboratory tests have not yet been related to actual field performance.

Drought, heat, and cold resistance.—Resistance to drought, heat, and cold are among the characteristics which are critical during the juvenile stage. The short-term approach can be taken to test the ability of progenies to become established in spite of drought, heat, and cold. However, testing for growth rate under adverse conditions, especially drought and heat, will probably require the long-term approach.

Of the variables affecting volume per acre, the very important factors of resistance to certain diseases and insects and to drought can be evaluated at an early age, if the proper environmental conditions exist.

Wood Quality

There is more room for optimism in early testing for wood quality than is presently evident for volume per acre. The ability to correlate wood produced in early years with mature wood has provided an excellent opportunity to establish reliable relationships.

Straightness.—Perry (1960) reported striking differences in straightness and crook among loblolly pine progenies as early as 2 years in the field. Barber[7] found the same to be true for slash pine up to 8 years of age. However, for all the southern pines, straightness probably can be evaluated best on young trees around 30 feet tall, representing ages from 8 to 12 years. As mentioned with respect to height growth, this height is the first two 16-foot logs, and represents a major part of the volume of the tree. If a tree is straight up to around 30 feet, it will very likely continue to be straight to maturity. However, slightly crooked trees may smooth out and apparently become straighter by eccentric growth with resulting compression wood.

Specific gravity.—The juvenile-mature tree correlation for specific gravity is complicated by the presence of compression wood in seedlings. However, Brown and Klein (1961) found highly significant differences in specific gravity among 2-year-old seedlings of loblolly pine produced by crossing various combinations of high and low specific gravity parent trees. These seedlings reflected, to a high degree, the specific gravity of the parent trees. Zobel et al. (1960) reported highly significant correlations between juvenile or core specific gravity at breast height and the specific gravity of whole loblolly and slash pine trees. Forty slash pines showed a correlation coefficient of 0.798 and 14 loblolly pines showed a correlation of 0.890, both being significant at the 1 percent level. Together, these results indicate that a rough screening of progenies for specific gravity can be carried out on young seedlings, and a fairly accurate evaluation of specific gravity in progeny tests can be obtained at about 10 years of age.

Tracheid length.—Kramer (1957) presented data on loblolly pine that strongly discouraged the use of breast height tracheid length at two or three rings from the pith for evaluating the tracheid length of the mature tree. He suggested using the 10th or a later ring from the pith to denote the tracheid length of a particular tree. This means that progeny tests should be at least 10 years of age before any rough screening for tracheid length is attempted. Preferably, tracheid lengths should

[3] Barber, John Clark. An evaluation of the slash pine progeny tests of the Ida Cason Callaway Foundation (**Pinus elliottii** Engelm.). Ph. D. Diss., Univ. Minn. 206 pp., illus. 1961.

[4] Squillace, A. E. Unpublished data of the Southeast. Forest Expt. Sta. on file at Olustee, Fla. April 1963.

[5] Wyatt, W. R., and Beers, W. L., Jr. Growth chamber analysis of wind-pollinated plus tree progeny—slash pine (**P. elliottii** Engelm., var. **elliottii**). Unpublished manuscript. 1963.

[6] Op. cit.

[7] Ibid.

be measured from several rings to account for year-to-year environmental variations.

Cellulose content.—For the present use of tree improvement, the complex field of cellulose chemistry can be divided into water-resistant carbohydrates and alpha cellulose. These are two important constituents used to characterize wood chemically in pulp and paper manufacture (Forest Biology Subcommittee 1960). There was a significant correlation between water-resistant carbohydrates in the core wood zone at breast height and water-resistant carbohydrates for the whole tree (Zobel et al. 1960). However, the relationship between core wood alpha cellulose and alpha cellulose for the whole tree was consistently non-significant. This indicates that a rough screening for high producers of water-resistant carbohydrates might be attempted at 10 years of age, but evaluation of alpha cellulose must be delayed until later.

Percent summerwood.—Measurements of percent summerwood during the juvenile stage have little meaning because of the erratic and poorly defined summerwood in the core wood zone (Zobel et al. 1959). The seventh or eighth ring is probably as early as this characteristic can be meaningfully measured, and measurement should extend over several rings. Consequently, evaluation of a progeny test for percent summerwood will have to be delayed until 12 or 13 years of age.

Self-pruning.—Self-pruning is another complicated composite character, and the juvenile-mature tree correlations of its components are still uncertain. Photosynthetic efficiency was mentioned earlier. It is very obvious in the field that 3- to 7-year-old progenies differ widely in branch angle, diameter, length, and number of branches (Barber;[8] Trousdell et al. 1963). This may be the best age to evaluate these traits, but their exact relationship to self-pruning remains unknown. The existence of an auxin gradient is suggested by Barber's report[9] that certain slash pine progenies begin to show self-pruning well before crown closure. This is further indicated by the results of VanHaverbeke and Barber (1961) showing that branches bent to a horizontal and to a downward position showed 50 percent less elongation than branches left in their normal upward position.

Oleoresin yield.—Oleoresin yield is included under wood quality because it is closely related to certain anatomical variations. A micro-chipping method, developed for determining oleoresin yield on young trees, shows heritabilities of yield ranging from 45 to 90 percent based on 14-year-old progenies (Squillace and Dorman 1961). Results should soon be available to show the relationship between yield at various ages according to this micro-chipping method.

Summary

Selection for mature characteristics on the basis of juvenile performance cannot be as accurate as selection based on the mature tree. Yet, indications are that certain time-saving and essential information can be obtained from juvenile development. The fact that plants pass through different stages of growth affects the reliability that we can place on juvenile performance. In comparing a small number of progenies, a strong, accurate juvenile-mature tree relationship is needed, but a weaker relationship can be successfully used in screening larger numbers of progenies. Characteristics exhibiting a strong offspring-parent heritability can be selected for or against fairly soon, and other characteristics that are critical at an early age can also be evaluated at an early age.

Current information on factors affecting volume per acre indicates that resistances to certain diseases and insects and to drought, which are critical at an early age, can be evaluated during the juvenile stage. Other components of volume per acre such as height, diameter, form class, and competitive ability will require scrutiny for a longer period of time.

Of the variables affecting wood quality, the very important traits straightness and specific gravity offer encouragement for testing on the basis of juvenile performance. Other traits, such as tracheid length, cellulose content, percent summerwood, self-pruning, and oleoresin yield, will require evaluation at 8 to 10 years of age or later.

[8] Ibid.
[9] Ibid.

Economic Considerations of the Genetic Approach

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I feel that the following quote, from a company forester in the proceedings of a tree improvement conference, is apropos: "We have spent considerable time and money on a tree improvement program. We have no assurance that this will pay off; however, we believe in it firmly enough to continue every effort in this direction." I must admit I view this quote with mixed feelings. However, this forester may be speaking for many others and is honest enough to express his true feelings. I do not happen to agree with his statement concerning whether or not the tree improvement program will pay off because I happen to believe that all this work being done in the field of tree improvement is worth the time and money. I would like at this time to present some facts and figures to substantiate why I so believe.

At the outset the speaker wants to point out that the genetic approach used and referred to in this talk will be the so-called clonal seed orchard approach widely used in the South today whereby good phenotypes are selected for parents and grafted into the seed orchards. It is assumed that progeny testing will start immediately so that the genetic worth of these selected parents may be tested and assessed as soon as possible. The progeny test results will then be used to remove or rogue those parents proven inferior. Quite frankly if it were not for a direct action program such as this it is doubtful whether or not the organization I work for would be involved in a tree improvement program. We have a critical need for seed right now and want production orchards *as soon as possible*. We recognize that the immediate gain or improvement from these production orchards will not be as great as later gains. However, by moving ahead with these production orchards we will be producing seed at an earlier date and in the speaker's opinion this seed will offer considerable improvement over the seed in present day use. Quality improvement in seed orchards is really a never ending job and as time goes on we will be continually upgrading the genetic quality of our seed produced by our seed orchards.

We do know that establishing and managing seed orchards is not an inexpensive operation. Most of us have learned a long time ago that we do not get something for nothing, so costs attendant to seed orchard establishment and management must be expected. I will elaborate no further on seed orchards costs; each organization must figure its own. However, it should be remembered that seed orchard costs must be prorated over the entire life expectancy of the orchard and since this may be as long as 60 years (Dimpflmeier 1954) this will reduce the cost of seed per pound considerably.

Scarcity of Seed

We in the Virginia Division of Forestry are becoming increasingly aware of seed shortages. Each year, for us, loblolly pine seed is becoming more difficult to obtain. Let me cite our experience in 1962. Our reforestation division, in order to supply loblolly pine seed for our nursery (we have a loblolly pine nursery production of approximately 30 million seedlings annually) and direct seeding needs, wanted to collect a minimum of 7,000 bushels of loblolly pine cones. In order to secure these cones the State Forester asked that cone collection be placed second in work priority only to fire. An all out effort was made to secure these cones but in spite of this we were only able to collect a disappointing 1,200 bushels of loblolly pine cones. Seed yield per bushel of these cones was only 0.8 pound whereas normally we expect a seed yield of approximately 1 pound per bushel. Not only were loblolly pine cones scarce in Virginia last year but what seed was available was eagerly sought by other organizations. Competition for existent seed is keen in Virginia and from all indications will continue to be keen for many years to come. Our reforestation division estimates that our loblolly pine seed needs for Virginia Division of Forestry use alone projected for the next 5 years will be nearly 10,000 pounds each year. Nursery demands and direct seeding demands have made it necessary to carefully limit seed sales and as a result many Virginia landowners are unable to buy local seed from our organization for direct seeding. You may be interested to know that we sell repellant-treated loblolly pine seed for $6 per pound (based on dry weight) and that last year we were unable to fill orders for hundreds of pounds of seed. One alternative for those persons wanting local seed but unable to obtain it is to buy and use non-local seed, which many Virginia landowners did last year. We do not think this advisable and I personally shudder at not only the immediate but long-term implications of using non-local seed, but this is what is happening. I should like to make a point: for us, local seed is scarce and is in strong demand. Seed orchards, once in production, will assure ample supplies of *local* seed for our use.

Cone Collection Costs

Once seed orchards are established and producing seed, will it prove costly to collect cones? Evidence is accumulating which indicates that seed orchard cone collection costs will not be exorbitant and may compare favorably with seed collection under present-day methods. This evidence is provided by those who have kept seed production area seed collection costs. Before mentioning these costs, I would like to tell you of our Virginia Division of Forestry present cone collection and purchase method. We buy from local cone collectors and pay $2.50 per bushel for loblolly pine cones. Under normal conditions a bushel of loblolly pine cones will yield us 1 pound of seed. However, this $2.50 per bushel or per pound of seed, exclusive of extraction costs, etc., does not represent a true cost of seed per pound, which in some instances is much more. Not included in this cost are certain overhead costs, cost of locating cuttings and securing permission from the owner to collect, cost of inspecting the tops for cone ripeness and quality (used only in the sense of the cones not being damaged), inspection costs at pick-up points and cone transportation costs. Also, oftentimes it has been our experience that cones will be collected before ripe enough, thereby increasing extraction cost and decreasing seed yield per bushel of cones. I should like to emphasize that we try to maintain rigid standards with respect to our cone collections and that this adds to our costs. In 1962, exclusive of other costs mentioned above, loblolly pine seed cost us $3.12 per pound for what seed we could obtain.

Seed collected from seed production areas has not proven to be overly costly and provides us with some notion of what seed orchard seed collection costs may be. Quoted below are collection costs from standing trees; the cones were collected by climbing. Goddard (1958) reports that in Texas the average cost of collecting from tall standing loblolly pines was $4.77 per bushel of cones and that these cones yielded approximately 1½ pounds of seed. Therefore, the cost of seed per pound was $3.18. Cole (1962) reports that in collecting from standing loblolly pines in a seed production area in Georgia, seed cost was $3.88 per pound from certified areas and $4.58 per pound from uncertified areas. Cole further points out that superior seed yields from slash seed production areas were obtained versus cones purchased on the open market. Sweetland in private communication reported that in 1961 from a 65-acre seed production area in Prince George County, Va., 520 bushels of loblolly pine cones were collected from 311 pines. The seed yield was 679 pounds, and the cost per pound of clean seed amounted to $5.41. This cost figure includes charges for picking (through contract with a tree expert company), measuring, sacking, threshing and cleaning, supervision, and transportation incidental to the harvesting. Sweetland went on to say, "we think these costs can be lowered considerably by improving harvesting techniques." It should be remembered that the costs reported above are for climbing pines of considerable height and that the seed production areas had remaining some 18 to 20 trees per acre. Within our seed orchards many more trees per acre will be available for climbing and collecting purposes, thereby travel time to the tree should be less. Also, we should be able to better control when to start collection so that cones will be mature when harvested and this, in turn, should result in lower seed extraction costs and higher seed yield per bushel of cones collected. These are all very real economic considerations for us to keep in mind. Furthermore, I have confidence that we will develop and devise more efficient and easier means of collecting cones from standing pines. This will tend to lower seed costs even more.

Gains or Improvements

What basis do we have for making any claims for immediate gains through seed orchards? Evidence is accumulating daily which indicates that considerable improvement may be expected through seed orchards. Some means of providing improvement are:

1. *Through better adaptation.*— In a classic loblolly pine study (Wakeley 1944) it was found that stock from seed collected within 50 miles of the planting site produced 1.8 to 2.7 times as much merchantable pulpwood in 22 years as did stock from seed collected 350 to 450 miles from the planting site. The potential growth lost by using Arkansas seed instead of local Louisiana seed was 1.2 cords per acre per year.

Zobel and Goddard (1955) demonstrated the presence of pronounced differences in seedling survival among local strains of loblolly pine. Anything which affects tree survival must be considered economic. If a seedling fails to live it certainly will not produce wood and it costs as much money to plant this seedling which doesn't live as the one which does.

So that seed might be better adapted to its proper site most of us in the seed orchard business are establishing separate orchards for different geographic areas. This will enable us to use local seed and capitalize on these benefits mentioned.

2. *Through improved disease resistance.*—Barber (1961) found in Georgia open pollinated slash pine progenies highly significant differences in freedom of fusiform rust canker when comparing parents. The 1952 plantings varied from 19 to 88 percent of the trees free of rust comparing various parents. Wakeley (1961) also found significant differences in susceptibility to fusiform rust; the Georgia seed source had a much higher degree of infection than the other sources represented. Derr (1963) found that wind pollinated seedlings from a brown-spot resistant longleaf pine growing in central Louisiana have demonstrated a high level of resistance to the disease. This finding indicates the genetic control of this trait, and suggests the possibility of selection for resistant strains of longleaf pine. There are other references in the literature pointing toward the fact that susceptibility

or resistance to disease appears to be hereditary and that by selecting disease-resistant parents the chances of producing disease-free offspring are improved considerably. If a tree dies before it becomes merchantable it costs us money, and every merchantable tree which can be added to our harvest cut adds income. The selection of disease-resistant parent trees for seed orchard use is an important economic consideration.

3. *Through wood quality improvement.*—Zobel and Haught (1962) found that the total merchantable volume of moderately straight trees contained less than 10 percent compression wood (compression wood affects the properties of both pulp and lumber), while more crooked trees commonly had over 15 percent of the total volume as compression wood. In excessively crooked trees compression wood exceeded 50 percent of the total bole volume. Compression wood lowers actual pulp yield and also lowers quality for sawtimber purposes. Several studies on inheritance of bole straightness have been reported; some of these will be mentioned later. The substance of these studies is that straightness is controlled genetically. Straight parent trees in seed orchards should produce straighter offspring which in turn result in improved wood quality. I believe that all of us are stressing straightness in the selection of trees for our seed orchards.

Evidence is accumulating concerning the heritability of wood specific gravity. Fielding and Brown (1960) and Dadswell et al. (1961) found definite evidence of heritability of wood specific gravity in Monterey pine. Brown and Klein (1961) by regression analysis found a real association between parent tree wood specific gravity and progeny wood specific gravity in the crosses of loblolly pine tested.

Squillace et al. (1962) found high heritability of specific gravity in slash pine comparing specific gravity of parent and specific gravity of 14-year-old controlled and open pollinated progeny.

A high specific gravity correlation between 6-year-old open pollinated loblolly pine progeny and the female parent was found by van Buijtenen (1962). From one selection for specific gravity he had an estimated progress of approximately 4 percent, based on a selection differential of one standard deviation.

Zobel points out in a private communication that we should be able to increase specific gravity by about 50 to 300 pounds a cord green weight from seed orchards. Assuming an increase of 150 pounds per cord this amounts to approximately a 3-percent improvement for weight alone.

4. *By increasing growth, form and yield.*—Mergen (1955) found that certain slash pine parents produced better stem form than others. One female slash pine parent's progeny included 51.6 percent trees with sweep; another female slash parent's progeny included 40.9 percent with sweep.

Barber (1961) found that trees containing stem crook varied from 30 to 89 percent among progenies of different slash parents; that "parents that had a greater amount of crook had progenies that were among those having the greatest percentage of crooked stems." For young trees of loblolly pine Perry (1960) found that bole straightness has a fairly strong inheritance pattern. Progeny from crooked parents were significantly more crooked than those from straighter parents. Try as we might we cannot escape the importance of having straight trees. Too much depends upon it and evidence indicates that straightness is genetically controlled.

Peters and Goddard (1961) report a heritability of vigor of very roughly 15 percent in slash pine based on measurements 5 years after the progeny were outplanted.

McWilliam and Florence (1955) tested slash pine progeny in Australia in which open pollinated progeny were selected from the outstanding slash pine phenotypes in 1932 plantations. A limited number of controlled pollinated progeny were also included. For comparison purposes, a routine planting (representing the general plantation stock, resulting from seed collected from the best 160 pruned trees per acre) was included in the study. These progeny were assessed for both vigor and form. Vigor included both height and volume. Form included all other visual characteristics of the tree such as straightness, branch size and angle, and appearance. A difference of 5 percent in form represents a big improvement.

The results of the open pollinated progeny test were as follows:

Parent	**Best**	**Routine**	**Worst**
Acceptable stems per acre	272	112	80
Form percent	47	40	36
Plus stems	21	1	—
Minus stems	43	151	248

The results of the controlled pollinated progeny were as follows:

Parent	Acceptable stems per acre	Form (percent)	Plus stems per acre	Minus stems per acre
CB 74 selfed	520	62	184	--
CB 76 selfed	496	56	80	24
CB 74 × CB 76	440	56	64	32
CB 74 open pollinated	216	46	21	45
CB 76 open pollinated	176	44	7	63
Routine	112	40	1	151

Note the superiority of the controlled pollinated progeny over the routine progeny. Not including the "selfs" the controlled pollinated cross CB 74 × CB 76 progeny exhibited a difference of 16 percent in form compared to routine progeny and had 64 plus stems per acre versus 1 for the routine progeny.

McWilliam and Florence further found that a considerable improvement in the straightness of stems was obtained in comparing controlled pollinated progeny with routine plantings. They had twice the number of acceptable stems per acre comparing controlled pollinated with routine progeny. Because of its great economic importance in forest management stem form must be of considerable concern to forest managers. An undesirable tree of poor form not only yields less usable wood substance but also occupies just as much space in a forest (perhaps more) than a straight, well-formed tree.

Nikles (1962) in Queensland reports that volume production of slash pine was increased by at least 30 percent by crossing superior phenotypes. Nikles compared the controlled pollinated trees with routine plantings (routine plantings were progeny of trees selected for high pruning) and found nearly three times as many acceptable trees (trees having superior growth and straightness) among the controlled crosses versus the routine trees. A tabular summary prepared by Nikles comparing volume production and numbers of acceptable trees in 7½-year-old slash pine progeny follows:

Progeny	Mean volume [1]	Mean number acceptable trees [2]
G 11 × 15	60.9	16.5
G 34 × 16	57.9	12.5
G 15 × 13	57.7	20.0
G 34 × 11	56.2	12.0
G 8 × 9	53.4	18.0
G 9 × 15	51.3	16.0
G 17 × 15	49.1	16.75
Routine [3]	40.5	6.5
G 3 self × G 2 self	37.6	10.0

[1] Total volume of 25 trees in cubic feet; means of four plots per treatment.
[2] A tree scoring at least a certain minimum of points for straightness as well as reaching a minimum level of volume production.
[3] Progeny of trees selected for high pruning.

Nikles further points out that these crosses by producing a larger number of straight offspring will result in a higher recovery of sawn timber. Juvonen (1961) corroborates this. Nikles sums up, "in view of this, and evidence from other trials up to 16 years of age, it would be conservative to claim an increase in recoverable volume of more than 30 percent by the 10th year as a result of selection and cross breeding."

Economic Implications of Expected Improvement

Just a few studies have been mentioned which indicate the many different areas in which improvement is possible through genetic control. Considering these studies and improvements noted it seems most reasonable that we may expect at least a 5-percent improvement as a result of our seed orchard programs. It is assumed that this 5-percent improvement will manifest itself in 5 percent more wood substance or yield than is being obtained today using routine nursery stock grown from seed collected by present-day collection methods.

A 5-percent improvement in yield might not sound impressive to some but the economic implications are tremendous. Here is what a 5-percent improvement could mean to my organization's tree planting program in Virginia assuming that the planted pines would be harvested by a clear-cutting operation 20 years after being planted. We found that our loblolly pine plantations were growing, on the average, 1.64 cords of pulpwood per acre per year. Using this 1.64 cords per acre per year as a base growth rate, in 20 years the average acre would contain 32.8 cords of pulpwood. If a $6 per cord pulpwood stumpage price is assumed at the end of 20 years the average acre would have a gross pulpwood value of $196.80. If a 5-percent improvement in yield is realized as a result of using improved planting stock from our seed orchards 20 years after being planted the average acre would have a gross pulpwood value of $206.64 or an increase of $9.84 per acre. Each year the Virginia Division of Forestry distributes for planting approximately 30 million loblolly pine seedlings. Our average planting space is 6 by 8 feet or approximately 900 seedlings per acre. We, therefore, plant approximately 33,333 acres of loblolly pine annually in Virginia. If a 5-percent increase in total pulpwood yield results at the end of the first 20-year period (assuming all 33,333 acres were planted using improved planting stock) landowners stand to gain $327,996.72 *over* what their returns would have been had routine nursery planting stock been used. Once our seed orchards are producing enough seed to fully supply our nurseries it should be remembered that each year improved planting stock is used thereafter in a planting program that these benefits will accrue and become available at harvest time. It should be kept in mind that it costs just as much to plant a routine nursery stock seedling as it does an improved seedling; and it costs just as much to prepare land for planting routine nursery stock seedlings as to prepare land for planting improved seedlings. It also costs just as much to release an acre planted with routine planting stock seedlings as it does an acre on which improved planting stock has been planted. As a matter of fact, presupposing a $9.84 increase per acre in 20 years as a result of planting improved planting stock and charging a 5-percent interest rate we could afford to spend an additional $3.70 per acre for site preparation, release, etc.

Some of us may be concerned with seed orchard establishment costs because they may seem high. However, since we expect to gain considerable improvement in seed used for our reforestation programs this should not unduly concern us. An example is provided using the same set of conditions as mentioned earlier, i.e. assuming a 5-percent increase in yield and clearcutting plantations 20 years after planting, which would result in a total *increase* of $327,996.72 realized from an annual planting program of 33,333 acres. Let us assume that it will take 15 years before our seed orchards furnish enough seed for our reforestation programs (planting only) and that an additional 20 years will elapse before we are able to harvest our first pulpwood by clearcutting. We will further assume that we will recover $327,996.72 each year for a total of 6 years. Therefore, from the time of seed orchard establishment to time of harvesting our sixth successive annual pulpwood crop a period of 40 years will have elapsed. At the end of 40 years, using a 5-percent interest rate, $2,230,377.70 will have accumulated which represents the *increase* in returns alone resulting from using improved planting stock. Therefore, again charging a 5-percent interest rate one could afford to spend some $316,815.01 in seed orchard establishment and development costs and still break even 40 years after beginning the seed orchard program. In practice this will not be the case, however, since we will be collecting some quantities of improved seed from our seed orchards before the end of 15 years and this presents a more favorable financial picture because we could start to amortize our investment sooner. Also, once our seed orchards are in production, each year we use improved seed our benefits accrue and it is reasonable to expect these benefits to be available for many years to come—more years than in the example above. Furthermore, the cost of our seed orchards should be prorated over the entire life expectancy of the orchard, which may be 50 years or longer.

In all of the calculations used above only expected gains or improvement in plantations are noted. It is assumed that until seed becomes abundant in seed orchards the first seed produced will be used for planting and not for direct seeding. It should be remembered that economic gains will be realized using improved seed in direct seeding programs as well.

Cole (1962) computes improvement in another manner using slash pine on sawtimber rotations. Cole states that on an "average" slash pine site (site index 70 feet at 50 years) a 1-percent increase in volume yield over a 35-year rotation would mean that the cost of seed could be increased about 5 times and the planter would still break even (this assumes all of the increase is considered to be in sawtimber at $35 per M bd. ft. at the end of the period and 5-percent interest is charged).

Perry and Wang (1958) provide evidence that genetic improvements of as little as 1 or 2 percent more than justify the extra costs involved in programs of seed orchard establishment. They point out that frequently because of improper geographic origin or inferior genetic quality, the only seedlings available for planting will yield growth rates and profits 4 percent or more below average.

Percent improvements of a small magnitude may seem small and inconsequential. However, when one considers all the wood harvested each year in our respective states and the economic implications of using improved seed in our direct seeding programs and using genetically improved planting stock for our planting programs these small percentage figures become very impressive indeed. I have heard one company forester make the statement that if only a 1-percent improvement is realized that this would amount to more than a million dollars a year to one mill!

In summary I believe our seed orchards, once in production, will assure us of ample supplies of seed to supply our reforestation programs. It will cost no more to collect this seed and we will be able to verify its origin.

The different types of improvement possible and noted by others and reported were: (1) better adaptation of seed to site, (2) better disease resistance, (3) better wood quality, and (4) straighter, more vigorous trees of better form. In view of these I believe it entirely realistic to expect at least a 5-percent overall improvement from our seed orchard programs—this 5-percent improvement to manifest itself in increased wood yields.

It should be remembered that a small percent gain or improvement has tremendous economic implications. We stand to be amply repaid many times over for our time and expense spent on our seed orchard programs. We must be careful not to oversell our seed orchard programs but we must *not* be guilty of underselling either!

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Registrants

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Previous Publications and Reports Sponsored by The Committee on Southern Forest Tree Improvement

1. Report of the first southern conference on forest tree improvement, held in Atlanta, Georgia, January 9-10, 1951. U. S. Forest Serv., Atlanta, Ga., 65 pp., 1951.
2. Proposal for a cooperative study of geographic sources of southern pine seed. Subcommittee on Geographic Source of Seed, Philip C. Wakeley, Chairman. South. Forest Expt. Sta., 16 pp., illus. 1951.
3. Standardized working plan for local tests of seed source. Subcommittee on Geographic Source of Seed, Philip C. Wakeley, Chairman. South. Forest Expt. Sta., 11 pp., illus. 1951.
4. Hereditary variation as the basis for selecting superior forest trees. Subcommittee on Tree Selection and Breeding, Keith W. Dorman, Chairman. Southeast. Forest Expt. Sta., Sta. Paper 15, 88 pp., illus. 1952.
5. Directory of forest genetic activities in the south. Subcommittee on Tree Selection and Breeding, Keith W. Dorman, Chairman. Southeast. Forest Expt. Sta., Sta. Paper 17, 17 pp. 1952.
6. Working plan for cooperative study of geographic sources of southern pine seed. Subcommittee on Geographic Source of Seed, Philip C. Wakeley, Chairman. South. Forest Expt. Sta., 35 pp., illus. 1952.
7. Suggested projects in the genetic improvement of sourthern forest trees. Committee on Southern Forest Tree Improvement, Carl E. Ostrom, Chairman. Southeast. Forest Expt. Sta., Sta. Paper 20, 13 pp. 1952.
8. Testing tree progeny. A guide prepared by the Subcommittee on Progeny Testing, E. G. Wiesehuegel, Chairman. Tenn. Val. Authority Div. Forestry Relat. Tech. Note 14, 77 pp., illus. 1952.
9. Report of the second southern conference on forest tree improvement, Atlanta, Georgia, January 6-7, 1953. U. S. Forest Serv., Atlanta, Ga., 92 pp., illus. 1953.
10. Progress in study of pine races. Philip C. Wakeley. South. Lumberman 187 (2345): 137-140, illus. December 15, 1953.
11. The role of genetics in southern forest management. Special Subcommittee of the Committee on Southern Forest Tree Improvement, Bruce Zobel, Chairman. Pt. 1, Forest Farmer 14(1): 4-6, 14-15, illus. Pt. 2, Forest Farmer 14(2): 8-9, 14-19, illus. Pt. 3, Forest Farmer 14 (3): 8-9, 14-15, illus. 1954. (Reprint, 11 pp., illus. 1954.)
12. Proceedings of the third southern conference on forest tree improvement, New Orleans, Louisiana, January 5-6, 1955. South. Forest Expt. Sta., 132 pp., illus. 1955.
13. Better seed for better southern forests. Subcommittee on Genetic Control of Seed, T. E. Maki, Chairman. N. C. State Col. School Forestry Tech. Rpt. 9, 16 pp., illus. 1955.
14. Forest tree improvement for the south. Committee on Southern Forest Tree Improvement, T. E. Bercaw, Chairman. 13 pp., illus. 1955.
15. Supplement No. 1 to the original working plan of September 12, 1952, for the southwide pine seed source study. Subcommittee on Geographic Source of Seed, Philip C. Wakeley, Chairman. South. Forest Expt. Sta., 110 pp., illus. 1956.
16. Time of flowering and seed ripening in southern pines. Subcommittee on Tree Selection and Breeding, Keith W. Dorman, Chairman, and John C. Barber. Southeast. Forest Expt. Sta., Sta. Paper 72, 15 pp., illus. 1956.
17. Proceedings of the fourth southern conference on forest tree improvement, Athens, Georgia, January 8-9, 1957. Univ. Ga., 149 pp., illus. 1957.
18. Pest occurrences in 35 of the southwide pine seed source study plantations during the first three years. B. W. Henry and G. H. Hepting. South. Forest Expt. Sta., 7 pp., illus. 1957.
19. Proceedings of the fifth southern conference on forest tree improvement, Raleigh, North Carolina, June 11-12, 1959. School Forestry, N. C. State Col., 114 pp., illus. 1959.
20. Minimum standards for progeny-testing southern forest trees for seed-certification purposes. Subcommittee on Progeny Testing for Seed Certification Purposes. Philip C. Wakeley, Chairman. South. Forest Expt. Sta., 20 pp. 1960.
21. Proceedings of the sixth southern conference on forest tree improvement, Gainesville, Florida, June 7-8, 1961. School Forestry, Univ. Fla., 187 pp., illus. 1961.
22. Proceedings of a forest genetics workshop, Macon, Georgia, October 25-27, 1962. Sponsored jointly with the Tree Improvement Committee of the Society of American Foresters, and partly supported by the National Science Foundation through its grant No. GE-395. 98 pp., illus. 1963.