

BREEDING FOR HIGH-QUALITY WOOD

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Engineers, chemists, architects, furniture designers, and other major users of forest products think of wood primarily as an engineering material that has a rather wide range of physical properties and comes in a variety of sizes, grades, colors, grain patterns, and textures. They will continue to use wood as a raw material only to the extent that it is readily available, reasonable in price, and better adapted to their particular product or use than metals, plastics, or some competing organic fiber. Their choice of materials is little influenced by sentiment, forestry tradition, watershed protection problems, recreational needs, or even by the striking beauty of a fine stand of tall, straight, clean-boled trees. The important pulp and paper industry, for example, probably would not hesitate in turning to bagasse, cattails, or even corn silk, if such materials proved cheaper or better adapted to their product than wood fiber.

Therefore, if we are realistic, we shall not overlook the requirements of the principal consumers of wood products in planning our forest genetics research program. I think one of our major objectives should be the development of trees that will produce more of the kinds of wood desired by the major users of forest products. In other words, we should give quality and end-use requirements a more prominent place in our thinking and planning. In some of the preceding papers and discussion, considerable emphasis was placed upon attaining exceptional growth rates. In this connection, I should like to point out that growth rate in itself is of questionable importance if the wood thus produced has little or no value in the market place. The Forest Survey figures show that in this country we are already growing an enormous volume of wood, principally hardwood species, that is largely unmerchantable. The deficit in our growth-drain balance is in high-quality material, for which there is a great present and potential demand.

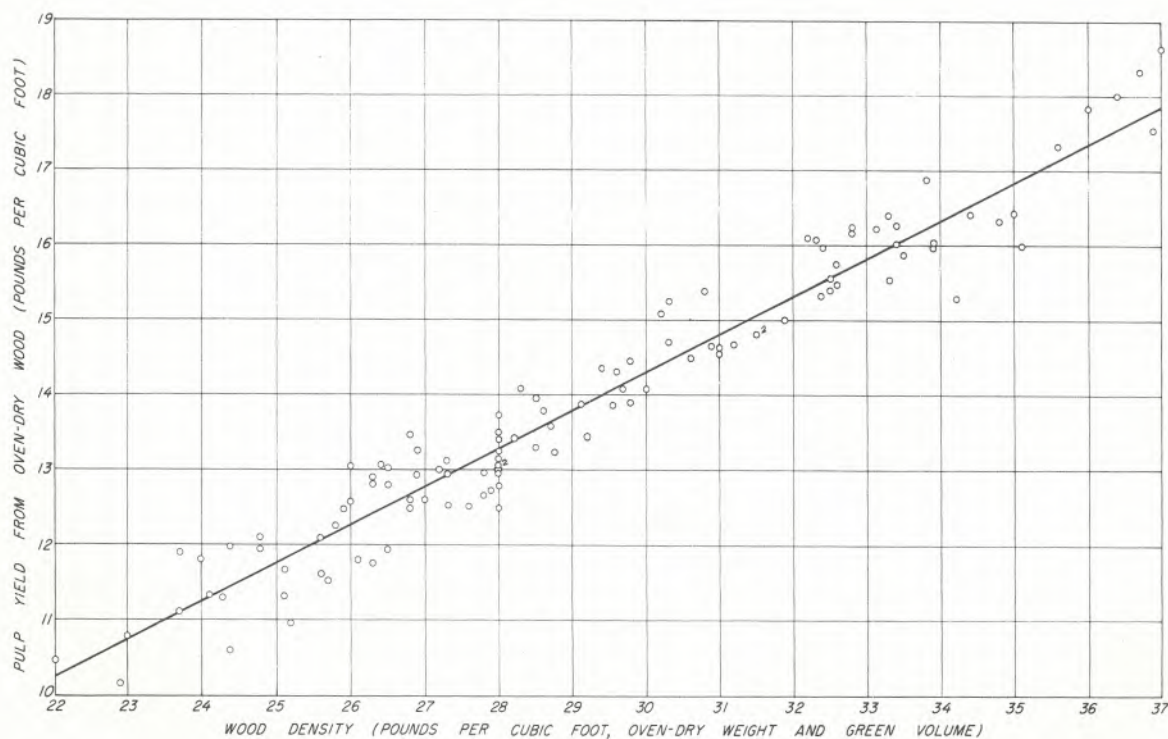
DEFINITION OF WOOD QUALITY

So far we have used the term "high-quality" in the sense usually employed by both foresters and laymen; that is, fast-growing, vigorous, pest-resistant trees with long, straight, clear boles, free of all visible defects. This concept of quality is all right as far as it goes. In the interest of breeding truly elite trees, however, it should be expanded to include the basic anatomical and physical properties that, in the final analysis, determine the suitability of wood for a given use, be it pulpwood, boards, structural timbers, poles, or veneer. Of particular importance are such properties as the density of the wood, the proportion of

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summerwood to springwood in the annual rings, the number of rings per inch, the length and thickness of the wood fibers, the orientation of the fibrils with respect to the axis of the fibers, and the occurrence of compression wood or other abnormalities that affect strength, shrinkage, warpage, or pulp quality and yields.

Wood density, usually expressed as pounds per cubic foot, or as specific gravity, is perhaps the simplest and most useful single index to wood quality from the standpoint of physical properties. To illustrate, every 2-pound increase in wood density of southern yellow pines produces about 1 pound more kraft pulp (fig. 1). Stated another way, a cord of low-density southern pine wood will yield about 847 pounds of kraft pulp, but a cord of high-density wood of the same species will produce 1,477 pounds--almost twice as much. The same general relationship between wood density and kraft yields is true of other species.



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Figure 1.--Relationship between wood density and kraft pulp yields of southern yellow pine pulpwood.

In this paper I will draw heavily on southern pine data for illustrations, partly because more is known about southern pines than any of our other major species, and partly because research in forest genetics started earlier and is moving more rapidly in the South than in most other sections of the country.

There is a well-established relationship between specific gravity and mechanical strength, expressed as modulus of rupture (fig. 2). Specific gravity is, therefore, a primary factor in the segregation of structural-grade timbers that command premium prices in the lumber market, and also in the selection of material for high-grade piling, transmission poles, and other uses where strength is of major importance.

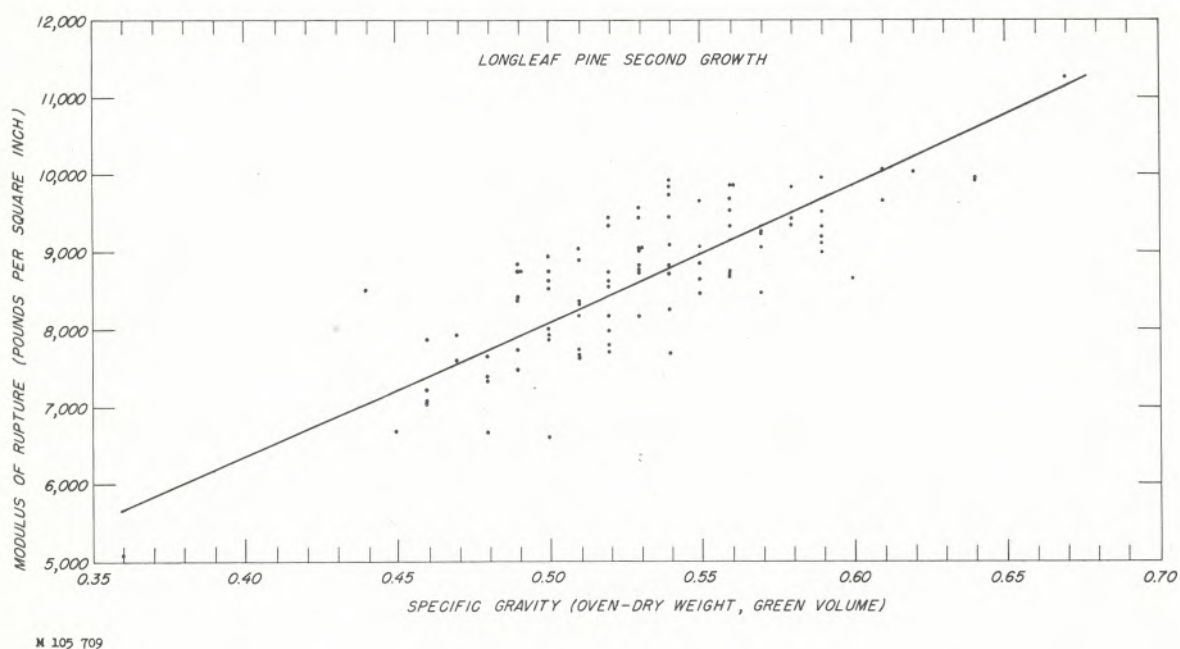


Figure 2.--Relationship between the specific gravity of longleaf pine wood and its modulus of rupture.

High-density wood also shrinks less along the grain than low-density wood. Accordingly, when high- and low-density wood occurs in the same board, differential shrinkage causes the board to warp upon drying. This condition, which may produce pronounced bow, twist, or crook, is common in southern pines grown under certain conditions, and to some extent in other conifers.

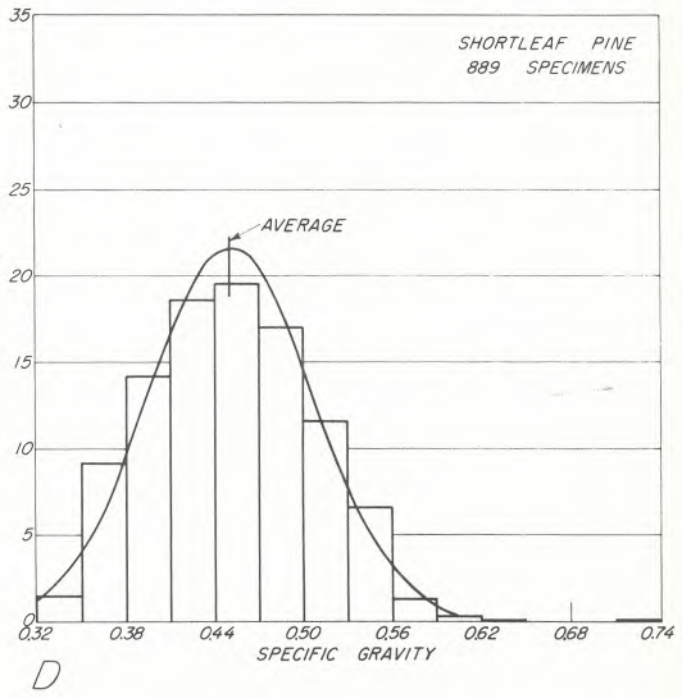
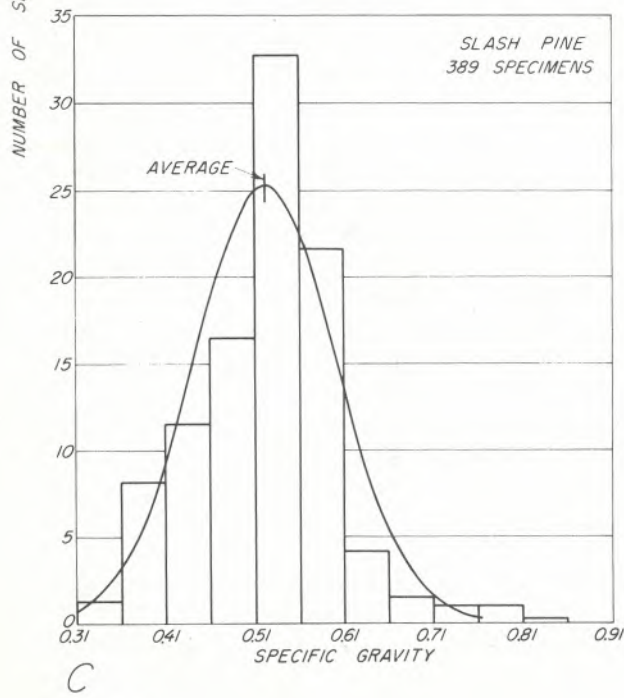
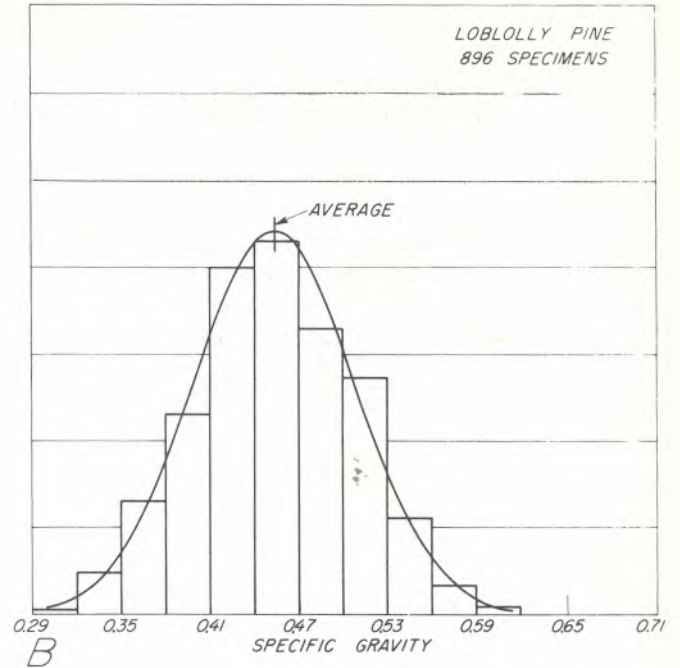
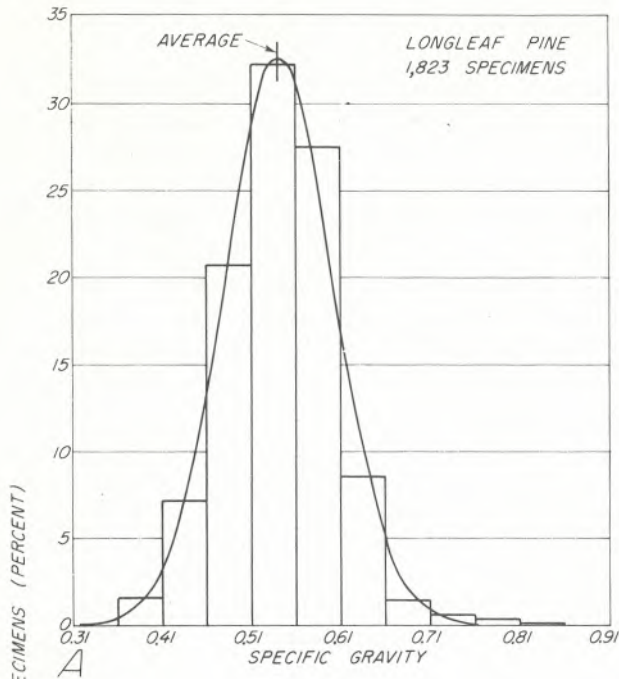
Another key feature is the proportion of summerwood to springwood in the annual growth ring. Springwood is the inner portion of the growth ring, formed early in the growing season, and summerwood is the outer portion formed later in the year. Springwood is composed of relatively large-diameter, thin-walled cells, and summerwood of smaller, thicker walled cells. Springwood is lighter in weight, softer, and weaker, and shrinks more along the grain than summerwood. Thus, the greater the proportion of summerwood to springwood in the growth rings, the greater the strength of the wood and the pulp yield therefrom, and the less the longitudinal shrinkage.

The significance of another feature--fibril angle--looms larger as we learn more about it (2, 4). Fibrils, which are believed to be composed of strands of cellulose chains, make up the layers of the secondary wall of the wood fibers. Their orientation with respect to the long axis of the fibers is termed the fibril angle. Large fibril angles are the rule in compression wood, an abnormal wood (formed on the under side of leaning trees) that has extremely poor strength and shrinkage properties, and in normal wood of low density and low mechanical strength. Small fibril angles, in some cases practically parallel to axis of fibers, are typical of high-density, strong wood of low shrinkage along the grain.

I could give you additional examples of the importance to the forest genetics program of intrinsic wood quality--that is, the basic anatomical characteristics that determine the suitability of wood for lumber, pulp, or any other use;. However, I believe I have presented sufficient evidence to convince you that volume growth and external indicators of quality Are not in themselves adequate criteria to use ill the selection and rating of :plus or elite trees.

In this connection, I should like to call your attention to the fact that tree species vary about as much in anatomical features as in growth rate, vigor, branching habit, and other readily determined characteristics. An idea of the variation in specific gravity found in nature can be obtained from the frequency-distribution curves for four southern pines (fig. 3). - Considerable variation in fibril angle and proportion of summerwood to springwood has also been found, even in pines of the same species and age growing on the same site.

Some of the observed variation in physical features is no doubt attributable to direct and indirect effects of environment. The remainder probably is due largely to inherent differences in the individual trees within a species or racial strain.



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Figure 3.--Frequency distribution of specific gravity values for four species of southern yellow pine.

RATING PLUS TREES FOR INTRINSIC WOOD QUALITY

In the individual tree selections made to date, as in the majority of hybridization studies, emphasis has been placed upon such readily determined desirable characteristics as vigor, growth rate, form, branching habit, resistance to pests, drought resistance, and gum yields. This was a natural development because few of the organizations that pioneered forest genetics research in this country were staffed or equipped to make precise wood-quality evaluations. Another obstacle was lack of fast, accurate, non-destructive techniques for making such analyses. I wish to make it clear, however, that leaders in this field were fully aware of the importance of wood quality as here defined, and have repeatedly emphasized the need for such quality determinations.

It was to meet this need that the Forest Products Laboratory a year ago undertook to develop the kind of techniques needed to facilitate this phase of the forest tree improvement program. Most of the needed "tools" are now available. These new techniques permit rapid, accurate determinations on large numbers of small samples from living trees. One is Smith's (6) maximum moisture method for determining specific gravity of aggregate or single annual rings in increment cores and of exceedingly small samples of separated springwood and summerwood. Another, developed by Marts (3), involves the use of fluorescent microscopy for measuring fibril angles directly on cores from standard increment borings, thus eliminating the need for sectioning the material and mounting on slides.

We are now set up to make a considerable number of wood-quality evaluations of certain softwood species. We plan to concentrate on southern pines, for reasons previously stated. Next in order of priority will come Douglas-fir and ponderosa pine. For the present, we shall work mainly on the backlog of plus trees that have been selected by other field units of the U. S. Forest Service in connection with their tree improvement research, largely on the basis of growth rate, form, and other external indicators of quality. It is important that these otherwise potentially elite trees at least meet minimum wood-quality standards. Next, we shall work with the Forest Experiment Stations in seeking out individual trees that appear to be truly outstanding in anatomical features as well as external characteristics.

In our current work with these coniferous species, wood-quality evaluations are based largely on three anatomical and physical features; namely, percentage of summerwood, fibril angle, and wood density. As we have seen, all are strongly correlated with such quality factors as mechanical strength, shrinkage, pulp yields, and properties. Collectively, they should provide a reasonably reliable index to the suitability of wood for lumber, pulp, or other common uses.

Results of previous research--such as the well-established relationship between wood density and pulp yields--provide a standard of comparison or rating scale. Trees can thus be classified as below average, average, above average, or outstanding from the standpoint of intrinsic wood quality,

In setting up our working hypothesis we assumed that these anatomical and physical features, especially fibril angle and wood density, are subject to strong genetic control, as in the case of growth rate, gum yield, and the tendency to crook. There is considerable evidence to support this assumption. In any event, this study of selected plus trees, and later their progeny, together with related studies also in progress, should provide reliable data on the extent to which these anatomical and physical features are inherited in southern pines. This research should also contribute to present information on trends and range of variability of these features.

Other properties will, of course, have to be taken into consideration when we get to the rating of hardwoods that are used chiefly for furniture, cabinet work, and interior paneling. For such uses, machining properties and appearance will be about as important as strength, dimensional stability, and freedom from reaction wood or other abnormalities.

Let us consider figure, for example. "Bird's eye," curly grain, and other distinctive grain patterns are much sought after in fine cabinet woods, and command premium prices. There has been much speculation, but little experimental data, regarding the extent to which such grain patterns are inherited. In my opinion, this would be a fruitful field for research, especially here in the Lake States.

A promising lead in this connection was discovered more or less by accident in connection with some natural hybrid poplars located in Iowa about 2 years ago by the Ames Research Center of the Central States Forest Experiment Station and Iowa State College School of Forestry. Of particular interest are trees from a small stand which apparently originated as root suckers from an individual natural hybrid of good form and growth rate. Bolts from two of these trees were sent to the Laboratory for routine testing, especially for pulp yields. However, a few of the bolts were run through the new veneer slicer, largely to try the machine, and it was noted that the resulting veneer had a very attractive curly grain. Additional samples were then obtained from the stand, sliced into veneer, and all were found to have the same distinctive grain pattern.

If all the hybrid poplars in this particular stand originated from a single clone, as seems probable, then there is a chance that the distinctive grain pattern is subject to strong genetic control. Progeny tests are now under way to test this hypothesis.

SIGNIFICANCE TO WOOD-USING INDUSTRIES

I have tried to give you an appreciation of the importance of intrinsic wood quality in forest genetics research, including a few examples of how present information is being put to practical use, and a brief summary of the status and objectives of current work in this field at the Forest Products Laboratory. Thus far I have stayed pretty close to factual data. Now I hope you will permit me to speculate a little and make some educated guesses as to what forest genetics may contribute to industry in the foreseeable future.

A simple example will serve to illustrate the economic potentialities of some of the tree improvement research already in progress. We know that a well-stocked, well-managed stand of run-of-the-woods southern pine growing on a good site will produce an average of 1 cord of pulpwood per acre per year over a 40- to 50-year rotation. We know, too, that there are found in nature individual southern pines capable of much more rapid growth--trees that produce merchantable pulpwood of a given size in a shorter period. At least part of their superiority is believed due to genetic factors, as in the case of hybrid poplars. Assume that we can increase the inherent growth rate of southern pine by one-half through selection and breeding of superior trees. The result would be an equivalent increase in kraft pulp yield per acre per year; that is, from 0,55 up to 0,84 ton per acre per year (fig. 4).

Now assume that we can develop a strain of southern pine inherently capable, under average conditions of growth rate, stocking, site, and management, of producing wood with a specific gravity of 0.68, only 0,23 higher than the present average of about 0.45 for run-of-the-woods, pulpwood-size trees of these species. If specific gravity is subject to genetic control, as seems probable, such an improvement in wood density should be readily attainable through selection and breeding. (We have already found southern pines with specific gravities ranging up to 0.75 and above.) The effect of such a modest (50 percent) increase in wood density upon kraft pulp yields is the same as an equivalent increase in growth rate (fig. 4). In other words, increasing the density of the wood by one-half has the same effect on fiber yields per acre per year as increasing the volume of wood by one-half. This further illustrates the importance of wood density, a factor so often overlooked in forest management as well as in genetics research.

If, through selection and breeding, we can achieve a 50-percent increase in both growth rate and specific gravity, kraft pulp yields per acre per year from southern pines would be increased by about 2.3 times (fig. 4), and fiber-production costs at the woods level would be substantially reduced. In monetary terms, assuming that a ton of kraft pulp is worth \$90, such elite trees would yield enough fiber to make kraft pulp valued at \$114.30, as compared to \$49.50 worth of pulp per acre per year from run-of-the-woods trees. The financial advantage of the greater fiber yields would be sufficient to justify clear cutting existing natural stands when they are ready for harvest and then replanting with superior stock instead of managing the stand for natural restocking with seed of poorer parentage. I believe that Lake States species can be similarly improved.

Lumbermen too would be interested in this kind of elite tree from the standpoint of volume increment and because the higher specific gravity would substantially improve the strength and dimensional stability, and therefore the value, of lumber, structural timbers, and other products cut therefrom.

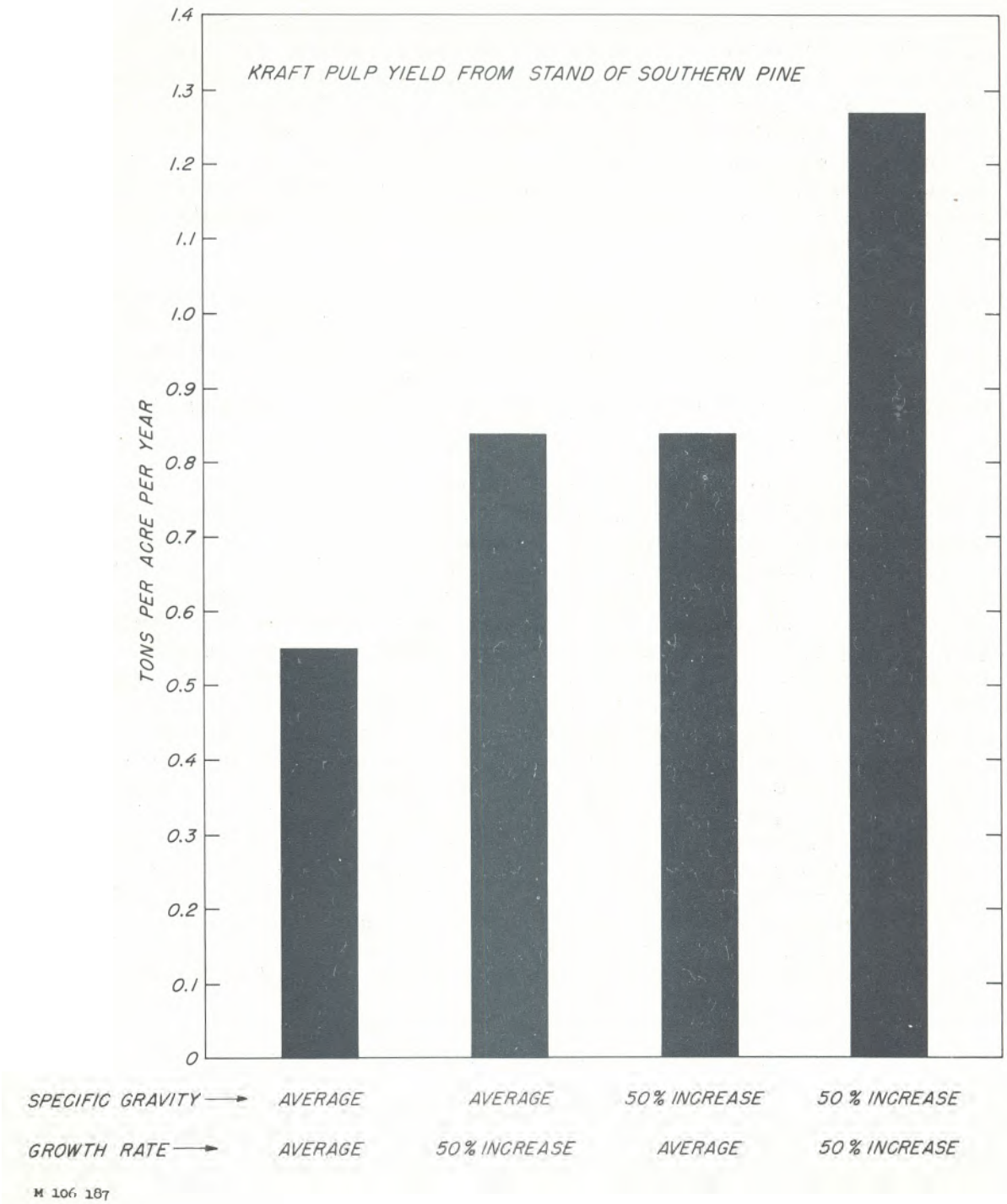


Figure 4.--The estimated effects of increases in specific gravity and growth rate on kraft pulp yields from southern pine.

Now let us consider the possibilities of selection and breeding to attain strictly qualitative objectives, Take the proportion of summerwood to springwood, for example. It is known that pulp sheets made experimentally of practically pure springwood felt better than those made of summerwood (1)- also, that the bursting strength and tensile strength of paper tend to increase with increases in the proportion of springwood to summerwood. On the other hand, the stiffer summerwood fibers make rougher sheets of paper whose resistance to tearing increases with the proportion of summerwood to springwood.

As pointed out earlier, trees differ considerably in the proportion of summerwood to springwood produced in their annual rings. Selection and breeding might therefore develop new strains capable of producing either higher or lower proportions of these two component parts of the annual ring, depending upon the proportion best adapted to the requirements of the end product.

We know, too, that the occurrence of compression wood, and of normal wood with large fibril angles resembling those found in compression wood, tends to reduce pulp yields and bleachability, and has an adverse effect on important strength properties (5). Wide fibril angles are also typical of lumber of low strength, high longitudinal shrinkage, and a tendency to warp and twist. Fibril angles must therefore be given a prominent place in forest genetics research aimed at improving pulp- and lumber-producing softwoods. Then there is the important and largely unexplored field of breeding to modify the thickness, length, and other properties of wood fibers, and the adhesive characteristics of the lignin that cements them together. It might even be possible to reduce the amount of lignin. My own feeling is that genetics research directed at achieving such qualitative modifications may prove more beneficial to the wood-using industries than current studies that largely emphasize more limited quantitative objectives. With the great variety of species we have, and with the wide variations in anatomical and physical features we find within species, the opportunity for improvements along such lines is almost limitless. I believe we can eventually develop new hybrids that will yield wood fibers tailor-made to the requirements of a particular product or end use.

THE ROLE OF INDUSTRY IN GENETICS RESEARCH

Industry has done an outstanding job of research and development in the processing of wood in the form provided by nature. Advances in paper chemistry and engineering, for example, have improved pulp-making efficiency to the point where, in some cases, processing costs now represent not more than 30 to 40 percent of the value of a ton of pulp. The lumber and plywood industries have made similar improvement in their processing equipment and techniques. But the basic raw material used by industry has remained the same, or declined in quality, and has greatly increased in price. Would it not be to industry's advantage to strengthen research aimed at making the production of their basic raw material as efficient as their processing methods? I am thinking especially of some

of the opportunities I have mentioned for improving the quality and lowering the cost of the raw material.

We sometimes forget that quality control starts in the woods--not in the pulpmill, sawmill, or plywood plant. We are dealing not with a mineral that is mined, but with organic fibers produced in living trees that, like all agricultural crops, can be modified and improved in both yield and quality through culture, selection, and breeding.

I am not suggesting that every major user of wood embark upon his own program of research on forest tree improvement. Neither do I wish to imply that industry now is doing nothing in this field. I know that some companies have modest programs of their own, that others are contributing funds and facilities to strengthen the genetics work of established public and private research agencies, and that the wood-using industries are ably represented on both national and regional forest tree improvement committees and advisory groups.

I sincerely believe, though, that industrial agencies' support of such research is nowhere near in line with either the current or long-term benefits they stand to gain. I think it would be definitely to their advantage to step up their own research in this field, and to increase their support of those established public and private agencies which are sufficiently well staffed, equipped, and experienced to conduct effective tree improvement research,

in conclusion, I should like to put in a plug for basic research of the kind that usually pays the largest dividends in the long pull, Too often such research is sidetracked by the inevitable pressures for quick results. However, real progress of the break-through type will not be possible until fundamental research provides new knowledge and basic principles on which to build° I sincerely hope that the Lake States Forest Tree Improvement Committee, and especially the industry representatives, will not neglect fundamental research along some of the lines I have suggested.

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