SPIN-OFF FROM FOREST GENETICS RESEARCH

W. T. Gladstone [1]

INTRODUCTION

When Dr. Ledig proposed the title for this paper, he left me considerable latitude within which to select my points of departure from the forest genetics research circle. To effectively relate to many of the other presentations, I have elected to confine my discussion to a single aspect of wood quality, namely, pulp yield per unit weight of dry wood.

The activities by which this parameter can be controlled are both genetic and silvicultural. Any current interest in it, and in my estimation there is far too little, has been spurred by the realization that a significant amount of genetic and environmental variability in pulp yield per unit weight of dry wood does indeed exist within many species and among interspecific hybrids. Further, it is fair to state that this variability has been detected through research which perhaps should be classified as interdisciplinary, involving forest geneticists, pulp technologists, and their hybrids.

The path described by this particular "spin-off tangent" can be more easily traced into the economics of pulp manufacturing than that of any other wood quality trait, with the exception of wood specific gravity when wood is being purchased on a volume basis. In the latter case, the advantages of purchasing (or growing) wood with high specific gravity are obvious insofar as pulp yield per unit volume of wood is concerned.

In a 1958 paper which reviews research on the quality of wood in relation to its utilization as papermaking fibers, Wangaard (3) observed that the near constancy of pulp yield per unit of dry weight of wood reduces the practical problem of estimating yield per unit volume of wood to a consideration of the density or specific gravity of wood." Evidence is cited in this review which indicates that, for a chemical process well adapted to the pulping of a particular species, the variation in yield of pulp per unit weight of wood which is attributable to the chemical composition of that wood is slight and seldom exceeds three percent.

It should be pointed out here that:

1. Most conventional pulping processes produce approximately 50 pounds of pulp for every 100 pounds of dry wood introduced.

2. An increase of <u>three percent</u> in pulp yield per unit weight of wood (calculated <u>on a wood basis)</u> is thus equivalent to a six <u>percent</u> increase in pulp yield per unit weight of wood calculated <u>on a pulp basis.</u>

3. Most pulp mills costing procedures are based on cost per ton of pulp produced (i.e., on a pulp basis).

[1] Assistant Professor, State University College of Forestry at Syracuse University, Syracuse, New York 13210.

Three examples of yield variability which fall within Wangaard's zero to three percent range and which can apparently be controlled in practice are the subject of this paper. Though the variations are small, the large acreages and annual tonnages involved in woodland-mill operations make it imperative that they be considered in management decisions and can easily justify support for continued research in genetic and silvicultural areas which bear on aspects of pulp yield.

EXAMPLES OF CONTROLLABLE YIELD VARIATION

Hybrid Poplars

The data in table 1, consolidated from Marton, et al. (2), represent some of the results of a study of the wood anatomy and pulping properties of hybrid poplar grown by Dr. Schreiner at Williamstown, Massachusetts.

Table 1.--Pulping data from six hybrid poplars (P. maximowiczii x P. trichocar.a) [1]

Property	Clone NE-41			Clone NE-42		
	Tree 37	Tree 89	Tree 92	Tree 24	Tree 62	Tree 20
DBH, in.	4.2	5.3	6.6	3.6	5.3	6.6
Unscreened yield, %	52.7	55.3	53.1	53.6	52.0	51.9
Kappa number	10.6	10.3	10.7	13.1	13.9	13.6
Wood lignin content, %	23.2	20.4	21.9	23.7	25.1	26.8

[1] Consolidated from: Marton, R., G. R. Stairs, and E. J. Schreiner. 1968. Influence of growth rate and clonal effects on wood anatomy and pulping properties of hybrid poplars. Tappi 51(5):230-235.

Age at breast height for this material was 13-14 years. There are three salient features of these data which bear on their interpretation and practical implications:

1. There is little difference in the mean yields of Clone 41 and Clone 42.
2. There is a striking and significant difference between the Kappa numbers of Clone 41 and Clone 42.
3. Wood lignin contents of these clones closely parallel their Kappa numbers.

It is evident that the wood produced by Clone 42 is chemically different from that produced by Clone 41 and that this difference is genetically based, since the trees were grown in a "common environment." Pulping of these woods under identical cooking conditions resulted in similar yields of pulps with somewhat different characteristics, as reflected in their different Kappa numbers (a measure of delignification).

In a commercial pulping operation, however, the usual objective is to produce a pulp with a given Kappa number and to let the yield fluctuate accordingly. If, for example, a target Kappa number of 13 was desired, the pulps prepared from Clone 42 wood would be acceptable. Cooking conditions for wood from Clone 41 would have to be modified in the direction of less rigorous digestion, until a Kappa number of 13 was attained. Yields from Clone 41 would be expected to increase under the new cooking regime.

To test this expectation, we returned to Williamstown in 1969 and harvested ten trees each from Clones 41 and 42. As listed in table 2, the diameters of these trees are considerably larger than those utilized in the initial study, and a much wider range of diameters was included in each sample.

Table 2.--Pulping data from twenty hybrid poplars (P. maximowiczii X P. trichocarpa)

	Clone NE-41										
	1	2	3	4	5	6	7	8	9	10	Means
DBH, in.	7.3	7.5	7.8	8.5	9.4	9.6	9.9	10.0	10.3	10.9	9.1
Yield, % (extracted)	56.5	54.7	55.8	58.2	57.5	56.0	57.9	58.4	59.2	53.8	56.8
Wood lignin content, %	18.59	18.28	20.40	18.70	18.63	19.60	17.71	18.17	19.02	17.94	18.70
Kappa number	14.87	15.44	15.00	15.44	14.93	14.79	14.49	14.74	15.18	14.68	14.96
Cooking time min.	140	150	150	150	145	145	150	150	140	140	146
	Clone NE-42										
	1	2	3	4	5	6	7	8	9	10	Means
DBH, in.	5.6	7.3	8.0	8.1	8.8	8.9	9.0	10.0	10.3	11.3	8.7
Yield, % (extracted)	54.5	53.6	53.6	56.9	54.8	52.4	55.9	56.2	55.3	55.4	54.9
Wood lignin content, %	22.15	20.82	20.27	20.90	21.83	22.37	21.25	20.70	19.92	20.64	21.09
Kappa number	14.86	15.32	14.68	15.35	15.00	15.26	15.35	14.82	15.44	14.99	15.11
Cooking time min.	185	165	165	165	165	165	165	165	165	165	167

was adjusted to yield pulp with a Kappa number within the range 14.50-15.50 (target Kappa number of 15.00).

Cooking conditions for chip samples from all trees were held constant with the exception of cooking time. That parameter was adjusted by trial, error, and experience until a pulp with an acceptable Kappa number was obtained for each tree. The target Kappa number was arbitrarily set at 15.00 with an acceptance range of 14.50 to 15.50.

Mean Kappa numbers for pulps from Clones 41 and 42 were 14.96 and 15.11, respectively, hence these pulps are virtually identical, at least with respect to their states of delignification. A more legitimate between-clone comparison of yields can now be made and data in table 2 indicate that the yield pattern changed as anticipated. The mean yield of pulp from Clone 41, on an extracted, oven-dry weight of wood basis, is 1.9 percent higher than that of Clone 42. Calculated on a pulp basis, and using Clone 42's 54.9 percent as a standard, this increase is approximately 3.5 percent.

As in the earlier study, the lignin contents of wood from Clone 42 trees were consistently and appreciably higher than those of Clone 41, the mean difference being approximately 2.4 percent. This is incontrovertible evidence that heritable chemical differences exist in the woods produced by these two clones, differences which are substantial enough to influence the selection of clones for inclusion in planting programs.

Not only were yields from Clone 41 wood higher at the prescribed Kappa level, but considerably less cooking time (an average of 21 minutes) was needed to delignify this wood type, another factor which has favorable implications for commercial operations.

The strength properties of the pulps and the specific gravities of the woods from the two clones were essentially the same, hence there were no obvious factors which would detract from the desirability of utilizing Clone 41. The morphological characteristics of these wood samples are currently being examined in detail in an effort to relate clonal differences in lignin content to cell structure and distribution.

<u>Loblolly Pine</u>

Figures 1, 2, and 3 are based on data taken from a comparative study of kraft pulp yields of earlywood and latewood from three loblolly pine trees (1). Each figure portrays a regression of earlywood and latewood pulp yields on the lignin contents of those pulps. A series of pulps with differing residual lignin contents was produced from each tree by varying cooking time. Though standard size, handmade chips were used, the earlywood and latewood zones were distinct after cooking, regardless of the degree of delignification. These two wood types were separated with a razor blade after cooking and their independent and collective yields were determined.

It can be stated quite conservatively that the latewood fractions of the wood included in this study yielded 2-7 percent more kraft pulp, calculated on an unextracted wood weight basis, than their associated earlywood fractions. It is also apparent that larger yield differences will be realized in higher yield (high pulp lignin content) processes, due to the convergent nature of these regressions.

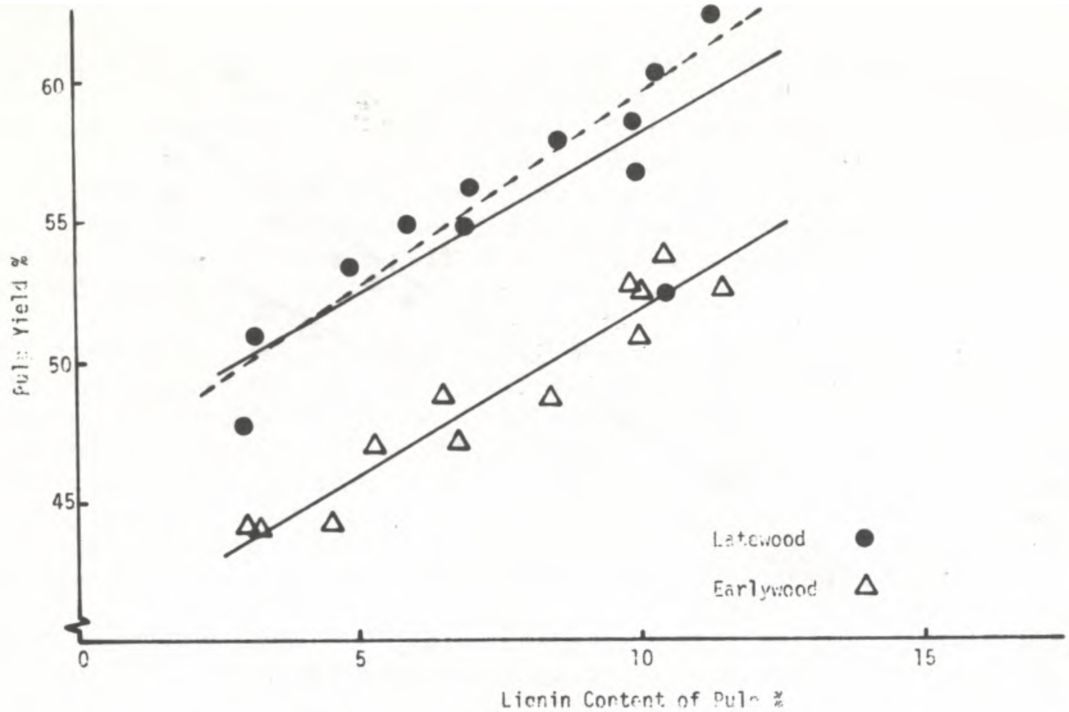

Figure 1. Regressions of Tree 1 (loblolly pine) earlywood and latewood pulp yields on lignin contents of the respective pulps. Dashed line represents latewood regression calculated after excluding outlying point at 10.5 percent lignin content. Yields are expressed on an oven-dry, extracted wood basis. From Gladstone, et al. (1).

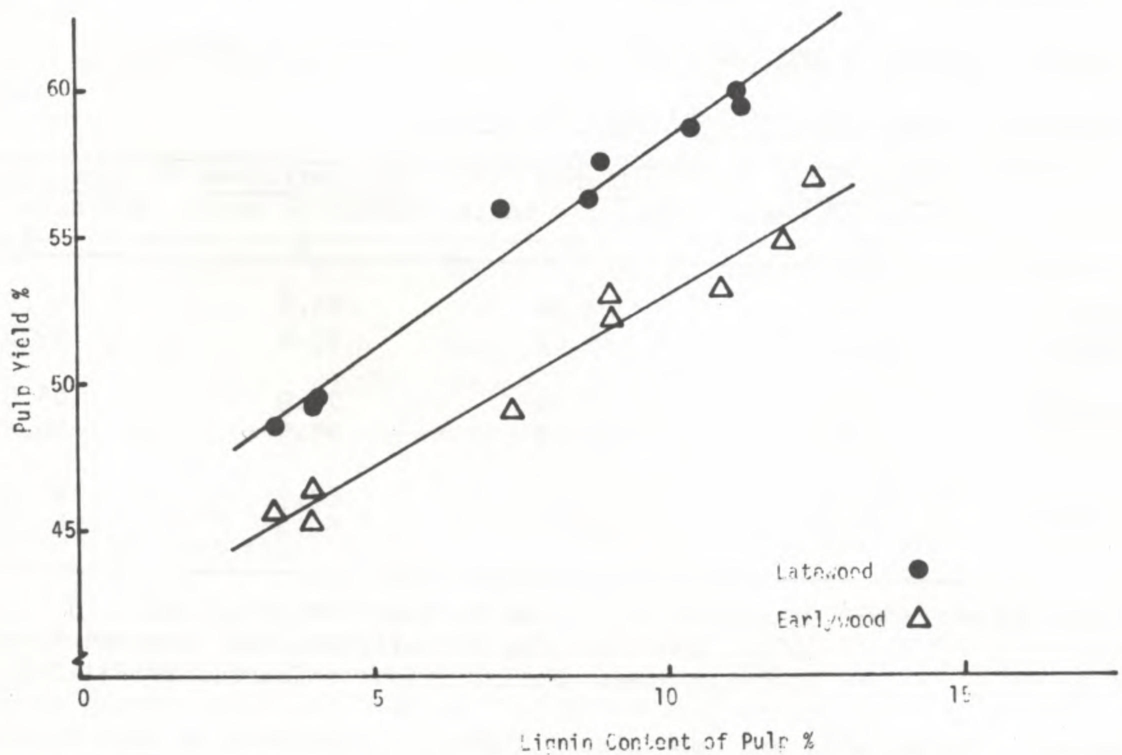

Figure 2. Regressions of Tree 2 (loblolly pine) earlywood and latewood pulp yields on lignin contents of the respective pulps. Yields are expressed on an oven-dry, extracted wood basis. From Gladstone, et al. (1).

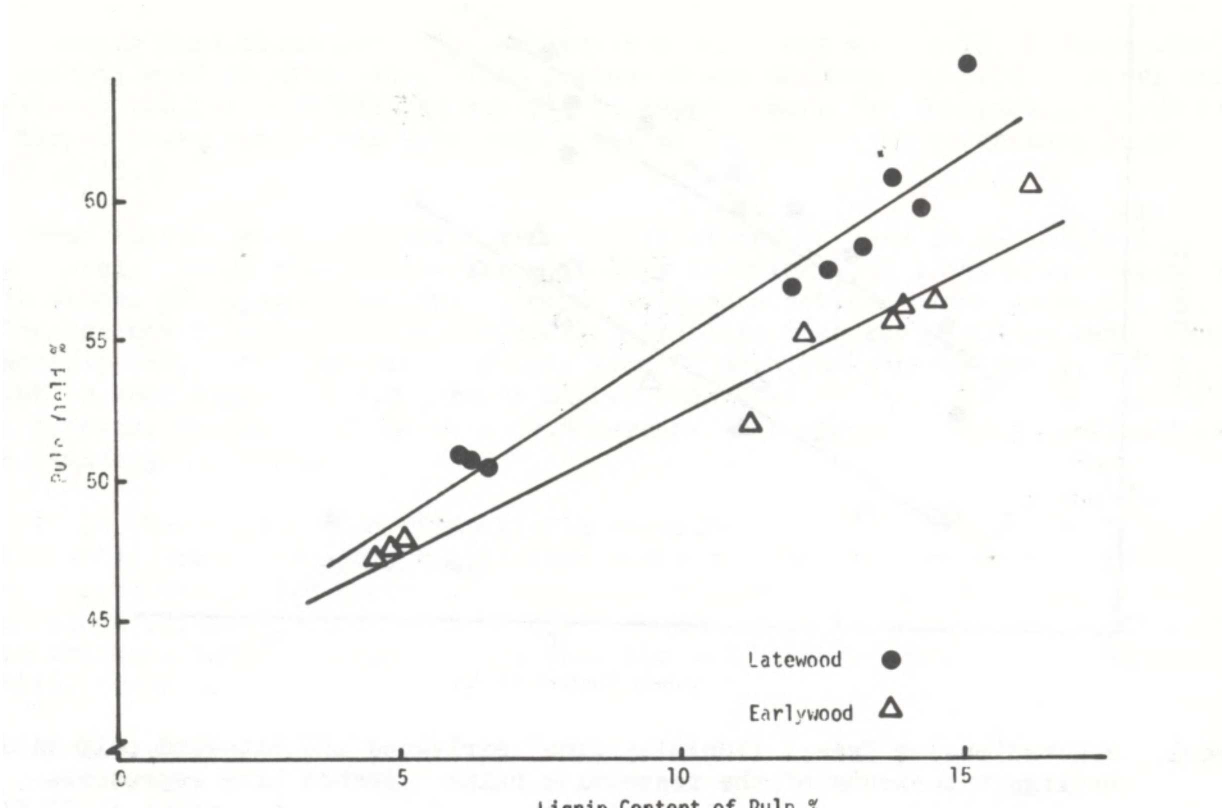

Figure 3. Regressions of Tree 3 (loblolly pine) earlywood and latewood pulp yields on lignin contents of the respective pulps. Yields are expressed on an oven-dry, extracted wood basis. From Gladstone, et al. (1).

Information in table 3 indicates why the yield differences appear.

Table 3.--Chemical composition of loblolly pine chips [1]

Tree No.	Component	Extractives Unextracted basis %	Lignin Extracted basis %	Holocellulose Extracted basis %	Alpha cellulose Extracted basis %
1	Earlywood	5.44	28.94	71.0	45.5
	Latewood	4.21	26.85	72.4	49.5
2	Earlywood	6.00	28.64	74.9	45.8
	Latewood	3.19	26.27	75.5	50.5
3	Earlywood	5.56	30.21	67.9	41.7
	Latewood	3.16	28.76	69.9	47.37

[1] Consolidated from: Gladstone, W. T., A. C. Barefoot, Jr., and B. J. Zobel. 1970. Kraft pulping of earlywood and latewood from loblolly pine. Forest Products Journal 20(2):17-24.

Extractives were consistently and appreciably higher in earlywood as were lignin contents. Latewood holocellulose values were slightly higher than earlywood values. Alpha cellulose contents of the latewood fractions were 4-5 percent higher than the earlywood alpha contents in each comparison.

The distribution of latewood within the stems of many pine species is predictable, the general pattern being related to the distribution pattern of juvenile and mature wood. A major aspect of the transition from juvenile to mature wood in pines is the addition of substantial proportions of thick-walled latewood tracheids. The established fact that pulp yields from mature wood usually exceed those from associated juvenile wood, even when calculated on a dry wood weight basis, correlates well with the earlywood-latewood yield differences illustrated in Figures 1-3.

Silvicultural practices which alter the proportions of juvenile and mature wood, or which alter the amounts of earlywood and latewood within these zones, will also affect pulp yield. A reduction of rotation age in loblolly pine, for example, will increase the proportion of juvenile wood received at the mill. Pulping of wood produced at low rotation ages will thus result not only in well documented losses of yield per unit volume of wood, but also in losses per unit weight of dry wood. It is estimated that the latter yield loss could be as high as 1.2 percent, on a pulp basis, for a reduction in rotation age from 30 to 20 years.

Because of the high correlation normally found between percent latewood and specific gravity in pines, it is tempting to speculate that there may be a hidden yield bonus in the selection of individuals with high specific gravity for tree improvement programs which are pulpwood oriented. Such a bonus would be dependent on the existence of genetic correlation between pulp yield and specific gravity as well as some degree of heritability for these factors. Heritabilities for specific gravity are proving to be substantial. Little is known about the other parameters, although the current estimates of the narrow sense heritability of chemical composition are very low.

Douglas-fir

Pulping data from fertilized and unfertilized Douglas-fir trees is presented in table 4.

Table 4.--Pulping data from four fertilized and four unfertilized Douglas-fir trees [1]

Tree	Unfert. 1	& Fert. 25	Unfert. 2	& Fert. 12	Unfert. 3	& Fert. 61	Unfert. 4	& Fert. 34
Pulp Yield, %	45.5	47.8	47.3	51.1	44.6	46.8	46.1	47.2
Kappa No.	24.21	25.28	25.36	25.60	29.40	31.31	29.06	32.19

	Unfertilized	Fertilized
Mean Yield, %	45.9	48.2
Mean Kappa Number	27.01	28.60

[1] Unpublished data from Empire State Paper Research Institute. Wood pulped represented outer 7 rings of fertilized (400#/acre total N) and unfertilized trees. All trees were 44- 52 years old. Each pair of cooks as tabulated was digested simultaneously in a single microdigester.

The fertilized trees were treated with 400 pounds per acre of total nitrogen in 1963 and all of the trees were cut after the completion of the 1969 growing season. Ages of these trees ranged from 44 to 52 years. Only the outer seven rings of the treated and control samples were pulped in order to maximize any differences in wood composition which might be traceable to fertilization. Each pair of samples, as tabulated, was digested simultaneously in a single microdigester to insure comparable conditions for these relatively small chip lots. There was not sufficient material to attempt to cook to a constant Kappa number in this instance.

Mensurational data collected six years after fertilization (1968) established that the fertilized plots exceeded the control plots in volume growth by 174 percent during the first six years. This volume increase was accompanied by a small decrease in wood specific gravity, the few measurements in hand indicating a decrease from a mean of 0.466 to a mean of 0.424, or about 10 percent.

Utilizing these specific gravity figures, the stated volume increase of 174 percent is diminished to 158 percent when productivity is calculated on a weight basis;

$$174\% \times (.424/.466) = 158\% \text{ increase on a wood weight basis}$$

This is still an impressive result. Yield data from table 4, however, demonstrate that pulp yield per unit weight of wood is not constant in this case. Wood produced by fertilized trees consistently produced more pulp, the mean yield difference being 2.3 percent. Calculated on a pulp basis, this mean yield difference is approximately 4.5 percent. Admittedly, the Kappa numbers of the "fertilized" pulps are slightly higher than the "unfertilized" pulps, consequently a slightly lower mean difference is probably more realistic.

The weight productivity figures can now be adjusted as follows:

$$159 \times (48.2/45.9) = 166\% \text{ increase on a wood weight basis.}$$

Thus, half of the loss in productivity attributed to the lower specific gravity of "fertilized" wood has been recovered by properly accounting for a substantial gain in pulp yield per unit of wood. Again, many characteristics of these wood types are being examined in an effort to relate chemical composition differences to cell morphology. Conventional strength properties of handsheets made from each cook were essentially equivalent.

SUMMARY

I am confident that these examples of controllable yield variability are tangible and worth pursuing. Continued, patient study will probably reveal many others, both genetically and silviculturally based, and encompassing most of our commercial species.

It is hardly realistic to suggest that the entire wood supply of a given mill could be converted to a "high yield" wood. Since the yield differences discussed earlier ranged from one to five percent, however, even partially wooding a mill with improved wood could produce substantial savings.

An example of kraft pulp mill costs which would be directly affected by changes in pulp yield per unit weight of wood is presented in table 5. These figures represent reasonable estimates of <u>operating</u> costs only and are appropriate for a bleachable grade of screened kraft pulp in slush form.

Table 5.--An example of kraft pulp mill costs which would be directly affected by changes in pulp yield per unit weight of wood[1]

A. Stock Cost	Approx. Cost per Pulp Ton	
1.6 cords/ton at $19/delivered cord	$30.00	
Wood handling	2.50	
Pulping chemicals	3.00	
Total stock cost		$35.00
B. Conversion Costs		
Labor	2.50	
Maintenance and supplies	4.00	
Power, steam, water	3.00	
Total conversion cost		$ 9.50
C. Total Pulp Mill Operating Cost		$45.00

At 500 tons/day, Total Pulp Mill Operating Cost = $22,500

Each 1% increase in yield/unit weight of wood = $225/day (yield calculated on pulp basis)

[1] These figures represent operating costs only and are appropriate for a bleachable grade of screened kraft pulp in slush form.

Whether considered from the aspect of extra pulp produced at no cost or as a reduction in cost per ton applicable to the entire mill output, a one-percent increase in yield per unit weight of wood can justify much more than a tree improvement research effort. It is from such a research effort, however, that efficiencies will be improved and profits realized.

LITERATURE CITED

1. Gladstone, W. T., A. C. Barefoot, Jr., and B. J. Zobel. 1970. Kraft pulping of earlywood and latewood from loblolly pine. Forest Prod. Jour. 20(2):17-24.

2. Marton, R., G. R. Stairs, and E. J. Schreiner. 1968. Influence of growth rate and clonal effects on wood anatomy and pulping properties of hybrid poplars. Tappi 51(5):230-235.

3. Wangaard, F. F. 1958. Research on quality of wood in relation to its utilization as fiber for papermaking. Norsk Skogindustri 12(8):286-295.