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Anatomical and Pulping Properties of Fast- and Slow-Grown Norway Spruce

Investigations of wood and pulp quality from fast and slow grown Norway spruce (*Picea abies* K.) were made with material from even-aged trees growing in New York State. No significant difference was found in comparing the slow-growth to the fast-growth trees for summerwood-percent, specific gravity, and fiber length, diameter, and wall thickness. Pulp quality evaluations, including strength properties, fiber coarseness, and chemical analyses, were made following cooking by sulfite-bisulfite, and kraft processes, and also from refiner groundwood. Generally superior pulp values were obtained from the fast-growth trees; while total wood volume was about 2.25 times that of slow-growth trees. The fast-grown trees gave higher pulp yields and slgihtly higher paper strength properties than was obtained from the slow-growth trees. Chemical data showed lower alcohol benzene extractives but higher water soluble extractives for the fast-growth trees. Thus the increased volume coupled with equal or improved pulp quality and yield suggests that significant gains may be obtained by maintaining optimum growth rates.

Keywords: *Picea* · *Picea abies* · Softwoods · Growth · Wood structure · Sulfate pulps · Sulfite pulps · Groundwood · Yield · Physical properties · Extractives

The quality of pulp obtained from a coniferous tree is dependent to a large degree upon the physical properties of the wood. These properties, in turn, are influenced by the genetic makeup of the tree and by the enviroment under which it is grown. Thus investigations to determine a means for optimizing pulpwood production must first deal with the relationship between genetic and environmental control of growth rate as it effects the pulp yield and quality.

In reviewing the genetic control of wood properties in conifers, Zobel (1) has suggested that tracheid length and specific gravity have both shown high enough heritabilities to allow significant gains through genetic selection programs. Other physical factors had not received sufficient investigation to permit a generalization. In addition to heritability studies, significant variations between seed sources have been reported (*2–7*). More significant to this writing however, are the reports of greater tree-to-tree variations within a stand than are found by making mean comparisons throughout the range of a species (*8–10*).

Despite a convincing amount of evidence for significant genetic control of wood quality, considerable environmental modification is possible (for a review see Goggans, (*11*)). We know that we may increase per-acre yield of pulpwood by planting genetically superior trees and by altering the environment through spacing, fertilization, or irrigation. The potential interaction between genotype and environment is always an important factor, and several such studies are currently in progress to add to our growing knowledge of genetic and environmental control of wood quality. Both the tree improvement worker and the pulp and paper researcher have an interest in these studies, and the most practical analysis will include field and laboratory study to define the maximum growth rate allowable, commensurate with maintaining desired pulp characteristics. Such a study is by definition a long term project if one is to sufficiently evaluate both genetic and environmental components during a normal pulpwood harvest cycle. Nevertheless, certain studies can be initiated by utilizing existing stands and superimposing genetic selection or environmental modification upon them. One method for comparing "fast" and "slow" growth as it relates to pulp quality and yield is the selection of representative trees from both growth-rate-groups, within even-aged plantations growing on relatively uniform sites. For the study herein reported selections were made from an even-aged, uniform-

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spaced planting of *Picea abies*, (L.) Karst.; two slow-growing and two fast-growing trees were analyzed for wood quality and pulping properties.

EXPERIMENTAL

Materials

The trees selected for analysis were growing in a 32-year-old plantation at the Svend O. Heiberg Memorial Forest, located near Tully, N. Y. Two trees were chosen to represent the slow-growth group while two others were chosen as representative of the faster-growing trees. The selected trees were dominant or strongly co-dominant, and paired samples were prepared by selecting one tree representing each group, growing in close proximity to the other, in two areas of the plantation. The heights and diameters of the selected trees were as follows: Area I: 11.8 in. dbh, 52 ft height, and 8.6 in. dbh, 49 ft height; Area II: 11.6 in. dbh, 55 ft height, and 7.8 in. dbh, 51 ft height. Four-foot sections were taken from each tree, starting at a point 4.5 ft above the ground. Samples for wood quality determinations were obtained by sawing a 1-in. disk from each section. The remaining section was de-barked and chipped to $^5/_8$ in. chip size in a Carthage 10-knife chipper.

Wood Quality

An analysis of the percentage of summerwood, specific gravity, and fiber length, diameter, and wall thickness was undertaken to provide an estimate of wood quality. Each sample disk was sawed into 1-in.^{2} sections through the disk center and two samples selected, 180° in opposition. These paired samples were then smoothed on the radial surface to allow microscopic determination (100×, incident light) of the percentage of summerwood. The samples were then divided into 5-year-growth segments, and specific gravity determinations were made by the maximum moisture method (*12*). Following the determination of specific gravity, the segments were macerated in a 1:1 solution of glacial acetic acid and 15% hydrogen peroxide (*13*), and five slides per 5-year-growth segment were prepared by mounting the fibers in an aqueous solution of sodium silicate. For fiber length determination a total of 20 fibers were measured from each slide by microprojection at 26×. Cell diameter and wall thickness were determined by microscopic viewing of the individual springwood and summerwood fibers at 430×. Coarseness was determined as the summation of fiber weight per unit length of sample. Statistical analysis was made by application of Student's *t* test to the recorded data.

Table I. The Mean and Range Values of Wood Characteristics for Fast- and Slow-Grown Trees

Characteristic	*Fast growth*		*Slow growth*	
	Mean	*Range*	*Mean*	*Range*
Summerwood, %	18.7	11.9–26.6	15.6	7.8–21.8
Specific gravity (o.d. wood)	0.341	0.316–0.391	0.301	0.285–0.358
Fiber length, mm	3.5	2.7–4.3	3.2	2.0–4.1
Springwood fiber width, μ	42.4	28.7–50.2	38.1	27.6–49.5
Summerwood fiber width, μ	33.4	24.5–37.2	31.8	25.7–39.7
Springwood wall thickness, μ	2.1	1.7–2.3	2.2	2.1–2.5
Summerwood wall thickness, μ	4.8	4.4–5.4	4.5	3.8–5.1

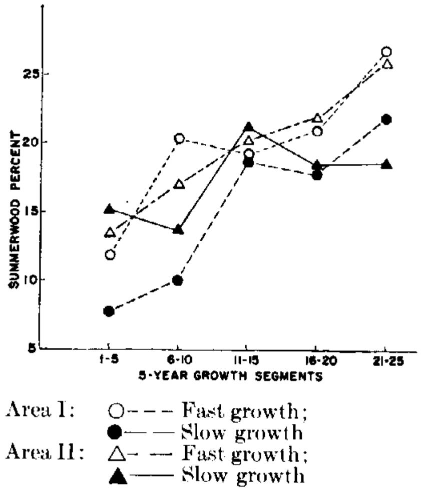


Fig. 1. Relationship between summerwood percent and 5-year growth segments for fast- and slow-growth trees grown in two adjacent areas

Chemical Analyses

Chemical analyses were performed on wood ground in a Wiley mill (60 mesh fraction) to determine: (1) alcohol-benzene extractives; (2) hot-water extractives; (3) lignin content; and (4) pentosan content. The alcohol-benzene extractives were determined according to TAPPI Standard T 6; the hot-water extractives by TAPPI Standard T 1; lignin content according to TAPPI Standard T 13; and pentosan content by TAPPI Standard T 19. No attempt was made to separate springwood from summerwood, thus the sample estimates whole-tree values from the 4.5 ft sampling point.

Pulping

The two samples from Area I were subjected to a series of sulfite-bisulfite cooks at a pH of 5.6. The liquor was composed of 6.7 g/liter Na_2SO_3 and 48.7 g/liter $NaHSO_3$. Cooking time was 4 hr at 170°C; operating temperature was reached in 70 min. This group will be referred to as the first series of sulfite-bisulfite cooks.

The samples chipped from Area II were divided into three equal portions for pulping by the following three methods: (1) Six cooks were prepared by the sulfite-bisulfite process as described above, except that the operating temperature was reached in 60 min. We shall refer to this set of cooks as the second sulfite-bisulfite series. (2) Six cooks were made by the kraft process using 25% sulfidity and 18% active alkali; the total chemicals used were 19.4% as Na_2O on wood. The cooking temperature of 165°C was reached in 1 hr; cooking time was 3 hr. (3) The third portion of the chips was made into refiner groundwood in a Bauer Model 148, 8-in. disk refiner equipped with type 8117 Bauer plates. All refining was done at consistency of 1.5%. The stock was first subjected to six passes with 80 mils clearance between plates. The next two passes were made at 40 mils clearance, followed by successive passes at 30, 20, 10, and 5 mils. The rejects from the slow-growth pulp then received a final refining at 5 mils clearance and were returned to the main stock. This final step brought the slow-growth pulp down to the same freeness (150 ml) as the fast growth.

Testing

In the first sulfite-bisulfite series, two cooks were conducted simultaneously. One sample from each cook was washed and immediately oven-dried to provide a precise yield determination. A second sample from each cook was washed, screened, and refined in a Papirindustriens Forskningsinstitut refiner (PFI),

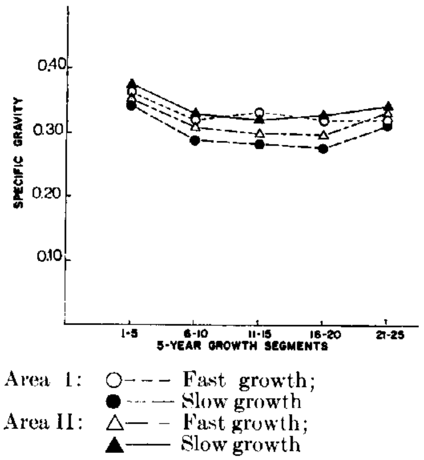
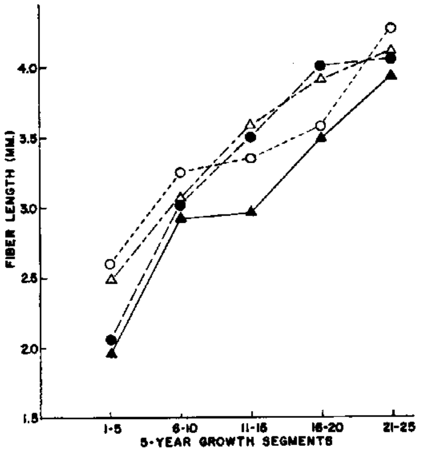


Fig. 2. Relationship between specific gravity and 5-year growth segments for fast- and slow-growth trees, grown in two adjacent areas



Area I: ○--- Fast-growth;
●—— Slow-growth
Area II: △— - Fast-growth;
▲—— Slow-growth

Figure 3. Relationship between fiber length and 5-year growth segments for fast- and slow-growth trees grown in two adjacent areas

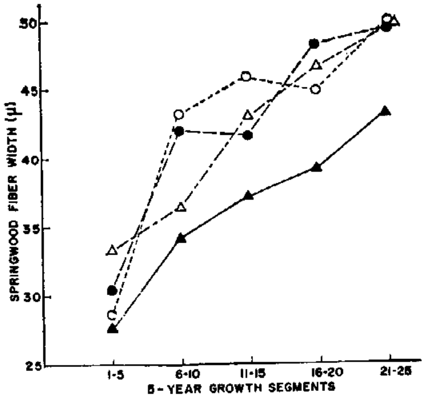
at 10% consistency to various freeness levels. In the second sulfite-bisulfite series, four cooks were used for yield determination and two were refined in the PFI under the conditions previously described. A similar procedure was followed for the kraft pulps. At each freeness level handsheets were made according to TAPPI Standard T 205 and tested according to Standard T 220, Optical properties were measured with a Zeiss-Elrepho reflectometer.

RESULTS AND DISCUSSION

Wood Quality

A summary of the wood quality investigations is shown in Table 1 and in Figs. 1–6.

The summerwood values showed considerable variation within all trees (Fig. 1) with a trend for increasing amounts of summerwood per growth segment in going from the pith to the 25th annual ring. The faster-growing trees showed a slight but consistent trend for a higher percentage of summerwood, and this was also reflected in the specific gravity values shown in Fig. 2. The average percentage of summerwood for the slow- and fast-growing trees was 15.6 and 18.6%, respectively. Specific gravity ranged from a mean of 0.319 for the slow-growing trees, to 0.324 for the fast-growing groups. A somewhat unexpected drop in specific gravity was found in going from the first 5-year segment adjacent to the pith, to the next three segments. After the 20th ring, the trend was reversed and specific gravity values showed a slight increase in going toward the cambium. Since there was only slight within tree variation observed in cell wall thickness (Fig. 6), the variation in specific gravity values may reflect the fiber width differences shown in Figs. 4 and 5. In both the springwood and summerwood, fiber widths were smaller in the 5-year segment nearest the pith. Average springwood fiber width values for the slow- and fast-growing trees were 38.0 and 42.3 μ respectively; in the summerwood, these values were 31.7 and 33.4 μ. The fiber length values showed a close positive correlation ($r = 0.70$ summerwood, 0.87 springwood) with the fiber widths. In all trees the fiber lengths increased rapidly in progressing toward the cambium, with no apparent "plateau" effect up to the 25th ring. However, from experience with similar material from older trees it is anticipated that the values were approaching a maximum in rings near the cambium. The mean fiber length for slow-growth trees was 3.22 mm, and for fast-growth trees it was 3.48 mm.



Area I: ○--- Fast growth;
●—— Slow-growth

Area II: △— - Fast growth;
▲—— Slow growth

Fig. 4. Relationship between springwood fiber width and 5-year growth segments for fast- and slow-growth trees grown in two adjacent areas

Table II. Chemical Data for Wood From Fast- and Slow-Grown Spruce Trees

	Fast growth	*Slow growth*
Alcohol-benzene extractives, %	0.90	2.05
Water soluble extractives, %	1.00	0.46
Klason lignin, %	28.2	28.0
Pentosans, %	13.0	12.2

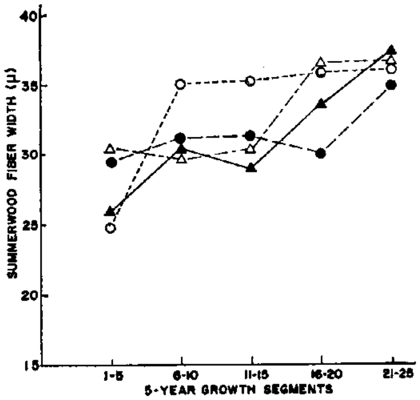
Statistical analysis by means of a t test failed to show significant variation between total growth-rate means for any of the factors investigated. Comparison was made between growth rate groups within areas, and total analysis disregarding areas. The lack of statistical significance was no doubt due to the small sample size plus a considerable amount of variation within sub-classes. Despite the lack of statistical significance between growth rate groups, the consistent trend for superiority of the fast-growth trees is encouraging. Although based on a small sample the data suggests that simultaneous selection for increased growth rate and wood quality in Norway spruce is a distinct possibility.

Chemical Composition of Wood

The results of the chemical analyses are shown in Table II. The content of alcohol-benzene extractives was approximately twice as great in the slow-grown trees as in the fast-growth trees, while the reverse was observed for the hot-water extractives. The Klason lignin content and the pentosan content did not vary significantly between growth-rate groups. For papermaking purposes, this is one point in favor of the fast-growth wood, since it contained less of the troublesome alcohol-benzene extractives, while the hot-water extractives are not considered a handicap in the papermaking process.

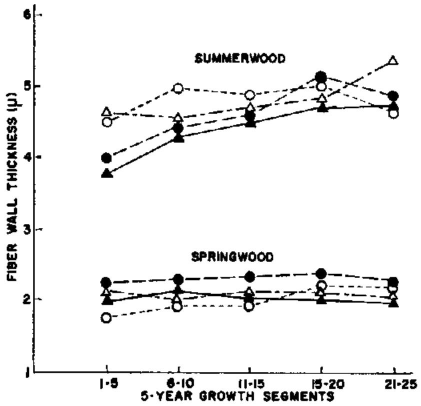
Table III. Properties of Sulfite-Bisulfite Pulps from Fast- and Slow-Grown Spruce

	Slow growing						*Fast growing*						
Yield, %	*First series, 57.8*			*Second series, 56.1*			*First series, 60.8*			*Second series, 61.5*			
CS freeness, ml.	690	350	150	700	380	140	710	250	150	690	315	105	50
No. of revolutions on PFI	0	2,150	3,470	0	1,000	2,000	0	2,700	3,350	0	1,000	2,000	3,000
Density, g/cm³	0.714	0.909	0.926	0.546	0.797	0.788	0.704	0.917	0.943	0.640	0.794	0.840	0.854
Breaking length, m	6,050	8,500	8,050	7,140	9,830	10,350	7,350	8,840	9,280	8,970	11,560	11,690	11,460
Burst factor	48	60	61	40	60	62	44	62	61	59	70	70	74
Tear factor	72	50	47	93	56	32	67	53	54	71	52	41	39
Fold (double fold)	220	600	900	...	...	...	164	800	1,765	...	...	...	...
Brightness, %	64	49	42	60	41	41	57	45	41	60	47	40	36
Scattering coefficient, m²/g × 10⁴	196	100	67	...	...	...	187	76	63	...	...	...	...



Area I: ○– – – Fast growth;
●— — Slow growth
Area II: △— – Fast growth;
▲—— Slow growth

Fig. 5. Relationship between summerwood fiber width and 5-year growth segments for fast- and slow-growth trees grown in two adjacent areas



Area I: ○– – – Fast growth;
●— — Slow growth
Area II: △— – Fast growth;
▲—— Slow growth

Fig. 6. Relationship between wall thickness and 5-year growth segments for fast- and slow-growth trees growing in two adjacent areas

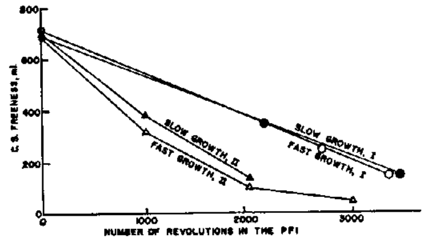


Fig. 7. Refining of pulps from slow and fast grown Norway spruce

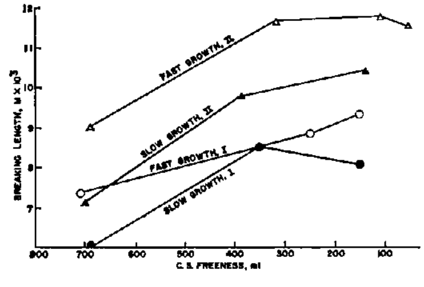


Fig. 8. Relationship between breaking length and freeness for sulfite pulps from slow- and fast-grown Norway spruce

The results of the pulping experiments are summarized in Tables III–VI, and are depicted graphically in Figs. 7–13.

The yield obtained from fast-growth trees was a few percent higher than that obtained from the slow-growth individuals under equal pulping conditions. The same relationship was observed in both the sulfite-bisulfite and the kraft processes, and was reproducible in comparing trees from Area I with those from Area II. This comparison is important since it shows that on a weight basis, equal or greater pulp yields may be obtained from the fast-growth trees compared to the slow-growth ones. Thus the trend for superior wood quality values from the fast-growth trees seemed to be reflected in pulp yield determinations—the remaining consideration was to determine whether the individual pulps were at least equivalent in terms of refining, strength, optical, and coarseness properties.

A comparison of the beatability of the fast- and slow-growth spruce was made using pulp from the sulfite-bisulfite process. The comparison was made by observing the decrease in freeness associated with beating in the PFI mill. Figure 7 shows that the two pulps responded almost identically to the beating process. Differences between the freenesses of the two was only a few millimeter, with the fast-growth pulp giving the lowest freeness in each instance. A similar trend was also observed in the kraft process cooks.

The strength properties of the pulps were analyzed in terms of breaking length, burst, tearing resistance, and double fold. From Fig. 8, it can be seen that the breaking lengths for fast-growing sulfite pulps were significantly (on the order of 20–25%) higher than those for slow-growth pulps. These differences were consistent over most of the freeness range tested, and the same relationship was verified with the kraft and refiner groundwood pulps, where the differences were about 8 and 23% respectively.

The analysis of burst factors (see Fig. 9) is in general agreement with the breaking length trends. In all three pulping processes, the kraft, the sulfite-bisulfite, and the refiner groundwood, the burst factor was equal or higher for the pulps made from the faster-growing trees.

The tear factors of sulfite-bisulfite and kraft pulps, in the unrefined state, were higher for the slow-growth groups. However, as the fibers were refined this trend was reversed, and the tearing resistance of the fast growth pulp became superior. These differences were slight (see Fig. 10) and did not permit any significant conclusions.

Folding endurance was measured only

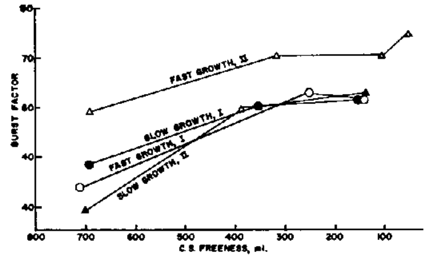


Fig. 9. Relationship between burst factor and freeness of pulps from slow- and fast grown Norway spruce

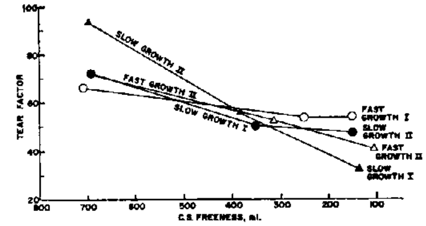


Fig. 10. Relationship between freeness and tear factor of pulps from slow- and fast-grown Norway spruce

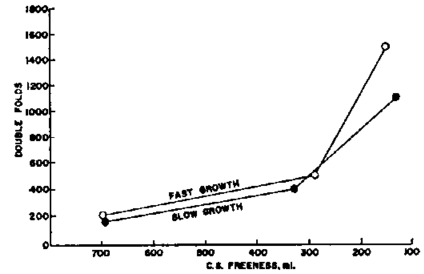


Fig. 11. Relationship between folding endurance of pulps from slow- and fast-grown Norway spruce (average values from six cooks)

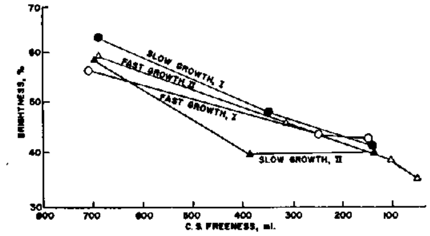


Fig. 12. Relationship between brightness and freeness of pulps from slow- and fast-grown Norway spruce

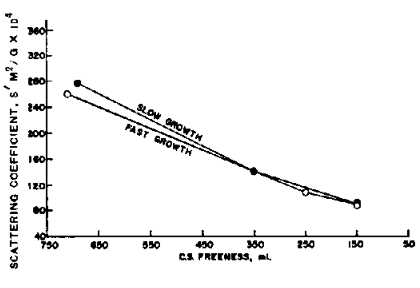


Fig. 13. Relationship between freeness and scattering coefficient of pulps from slow- and fast-grown Norway spruce

Table IV. Properties of Kraft Pulps from Fast- and Slow-Grown Spruce

	Slow growing		*Fast growing*	
	First series	*Second series*	*First series*	*Second series*
Yield, %	50.0	. . .	50.9	. . .
CS freeness, ml	695	710	685	690
Density, g/cm³	0.556	0.512	0.543	0.498
Breaking length, m	7700	7500	6260	8150
Burst factor	50	51	36	53
Tear factor	156	174	141	170
Brightness, %	24.3	19.9	33.3	23.5

for the sulfite-bisulfite pulps. In Fig. 11 it can be observed that there was little difference between the pulps from different growth-rate-groups in the unrefined or slightly refined pulps. The differences increased upon refining in favor of the fast-growth pulp.

In summary, the strength properties of pulp from the fast-growth trees were as good or slightly better than those from the slow-grown wood. Again these results seem consistent with the wood quality data previously presented.

A comparison of optical properties (brightness and scattering coefficients) for the sulfite cooks gave results differing from those obtained in the kraft and refiner groundwood processes. The comparative brightness of the two sulfite cooks shown in Fig. 12 are in disagreement, while results from other sulfite cooks have shown a general trend for higher brightness among pulps from slow-growth trees. The same relationship was found for scattering coefficients; the sulfite slow-growth pulps have slightly higher scattering coefficients than their fast-growth counterparts. Conversely the highest values for brightness and scattering coefficients in the kraft and refiner groundwood were from the fast-growth pulps (see Figs. 12 and 13).

The coarseness and lengths of fibers from the spruce pulps were measured to provide an estimate of the changes occurring in fiber properties during the pulping process. These data are depicted in Table V. The values indicate that the fibers of chemical pulps from the slow-growth trees are more slender than those from fast-growth trees. This is in general agreement with the previously mentioned wood quality estimates of fiber width and may reflect a lessened resistance to the cooking chemicals. In turn, this difference may help to explain why the pulps from the slow-growth trees exhibited lower sheet strength properties. In this respect the variation between growth-rate-groups recalls the differences in behavior of pulps prepared from springwood and summerwood parts of the same log.

Table V. Properties of Refiner Groundwoods from Fast- and Slow-Grown Spruce

	Slow growing	*Fast growing*
CS freeness, ml.	150	150
Density, g/cm³	0.328	0.344
Breaking length, m	2799	3454
Burst factor	11.5	14.9
Tear factor	46.8	52.4
Brightness, %	61.0	62.3
Scattering coefficient, m²/g × 10⁴	675	680

CONCLUSIONS

The study of anatomical and pulping properties of fast- and slow-grown Norway spruce was undertaken as part of a larger study to aid silvicultural and genetic selection practices. The results obtained suggest that a significant increase in growth rate between trees in a 32-year-old plantation of Norway spruce did not produce an adverse effect on pulp yield or pulp and wood quality. In fact, the faster-growing trees produced a generally superior pulp and paper quality while the yield on a weight basis was equal or superior to that from the slow-growth trees. Assuming about equal quality and yield on a weight basis, there is still a large difference in the amount of pulpable wood to be obtained from the two types of trees. On the average, the fast-growth trees contained about 2.25 times as much wood per foot of log as the slow-growth trees. Also it must be considered that the fast-growth tree will have a greater merchantable length. The economic implications of such a situation are clear, but in viewing them one must consider that growth rate *per se* is a relative factor. Trees recorded here as fast- or slow-growth might be thought of as normal- and suppressed-growth on other sites or in other geographic regions. In addition, it should be realized that both genetic and environmental factors are inseparably bound in such a simple comparison of trees growing in a random population. Nevertheless, it is this summation of growth under natural conditions that the silviculturist usually deals with in today's less-than-intensive management practices.

Table VI. Coarseness and Fiber Length of the Longest Fraction of Pulps from Fast- and Slow-Grown Spruce

	Coarseness, mg/ 100 m	*Fiber length, mm*
Kraft, fast-growth	21.12	2.54
Kraft, slow-growth	17.78	2.25
Sulfite, fast-growth	28.38	1.80
Sulfite, slow-growth	19.77	2.21
Refiner groundwood, fast-growth	48.02	2.52
Refiner groundwood, slow-growth	113.20	2.02

The present supply and demand situation for pulpwood production suggests that we are still years away from universally applied intensive cultural practices such as fertilization or irrigation of forest growing stock. Still there is a recognized need for maximizing production under existing silvicultural practices of regeneration and spacing control. The study herein reported adds to a growing volume of literature suggesting that rapid growth rate need not detract from the quality of the wood for pulp and paper use. In reporting no significant difference between growth rate groups despite considerable variation among all trees examined, the tree breeder is encouraged to select for growth rate as the primary character. Once trees are selected on the basis of growth rate, additional screening may be made for desirable wood quality. The generally good correlations found in this study between wood quality and pulp and paper quality provide confidence in using the former as a primary evaluation tool in tree improvement work. Additional studies are planned with a variety of species to further determine the nature and constancy of these correlations.

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