WOOD QUALITY RANKING OF PLANTATION TREES

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ABSTRACT

A population of plantation hybrid poplars and some geographically adjacent native aspen stands were evaluated in terms of the industrially important characteristics: fibre properties, wood density, growth rate, total lignin, extractives content and carbohydrates composition. Significant levels of clonal variation were seen for each of the measured parameters. Of particular interest were the variations in wood density (0.30 – 0.37 g/cm^3), growth rate (0.43 – 1.04 DBH cm/yr) and holocellulose content (67.7 – 72.3%). Poor correlations were found between growth rate and wood density indicating the potential for selection of progeny using multiple traits simultaneously.

To evaluate traits other than gross physical growth characteristics when identifying “superior” clones, this extensive testing procedure was used to develop a non-weighted ranking system for the examined clones. Superior candidates for potential implementation in future plantations were identified.

INTRODUCTION

The concept of hardwood utilization as an incremental fibre supply applied to the projected shortage of softwood chips in the next millennium is rapidly developing [1-3]. Members of the *Populus* genus are suitable sources of fibre as they produce pulp of high natural brightness [4], and can be grown to harvestable sizes in plantations in less than 15 years, as fast as 30 m^3/ha/yr [5]. In addition, the commercially important species of poplar in Canada — trembling aspen, *Populus tremuloides*; balsam poplar, *P. balsamifera*; eastern cottonwood, *P. deltoides*; and black cottonwood, *P. trichocarpa* — offer the potential for genetic improvement through hybridization of superior naturally occurring parents (usually judged by growth performance indicators) to produce progeny with superior growth rates and a wide range of wood, fibre, and chemical properties [6]. Improvement of hybrid poplar properties such as growth rate, wood density, fibre length, extractives and lignin content to produce consistent, value-added fibre sources has become an important area of research [7-11].

This paper describes the evaluation of a number of boreal plantation-grown hybrid poplars in terms of growth, wood and fibre and chemical properties. For the purpose of comparison, samples of balsam poplar and native aspen of approximately the same age and from near the same site were included. The objective was to identify possible candidates, for implementation in plantations, not based solely on growth characteristics.

METHODS AND MATERIALS

Sample Description

9–13 stems of each of nine hybrid poplars, two balsam poplars (*Populus balsamifera*), and a range of native aspens (*P. tremuloides*) were received as bolts of 1 to 1.3 metres in length from around the plantation site in northern Alberta (**Table I**).

Clone	Sample Description
AW1	aspen
AW2 K94	aspen
AW2 K96	aspen
AW2 K100	aspen
AW2 K103	aspen
8	balsam poplar
10	hybrid poplar
13	balsam poplar
18	hybrid poplar
24	hybrid poplar
26	hybrid poplar
33	hybrid poplar
36	hybrid poplar
37	hybrid poplar
42	hybrid poplar
48	hybrid poplar

Table I. Sample descriptions.

Diameter At Breast Height (DBH) Measurements

The DBH of each stem was determined by measuring the diameter of the top of each piece, since the pieces were approximately breast height (1.3 m) and assuming each was cut near the base of the tree.

Wood Density

The mean wood density for each clone was determined and reported as acetone extracted mass/green volume. A 10 mm increment core sample was taken from each approximately sized bolt and the green volume was calculated. The cores were then Soxhlet extracted with reagent grade acetone (CPPA Standard G.13 and G.20) and oven dried for at least 17 h (CPPA Standard G.3) to determine the oven dried weight per green volume.

Chemical Analysis

A butt end disc sample, representative of each clone was hand chipped, and air-dried to approximately 90% consistency. Each sample was ground in a Wiley mill fitted with a 0.5 mm screen according to CPPA Standard G.31P. The ground samples were analyzed for lignin, carbohydrates, acetone extractives, and ash content. (TAPPI standard methods, T222 om-98, T249 cm-85, TM 204 cm-97, T15 wd-80).

Fibre Analysis

A second disc was cut from the butt end of each bolt, the tree age determined, and the growth rings segregated into two-year age classes. For fibre analysis, samples of approximately 1 g (wet weight) were taken, cut into matchstick size chips and oven dried. These chips were placed into test tubes and boiled in water in a heating block for ~3 hours to rehydrate the wood. The water was then decanted off and enough maceration fluid (a 1:1 mixture of glacial acetic acid and 40% w/w hydrogen peroxide) was added to cover the wood sample. Each test tube was covered with aluminum foil to minimize evaporation and allowed to cook for 48 hours at 70°C. After delignification, the maceration fluid was decanted and the delignified wood was gently washed once with deionized water [12].

Fibre length and coarseness analysis was performed using a Kajaani FS-200 fibre analyzer. The delignified wood tissue was first dispersed in a small Hamilton Beach mixer for 1 minute in ~500 mL of deionized water then diluted to ~1 L (Dilution 1), measured and recorded accurately by weight. A 100 mL sample (Aliquot 1) was then taken from the first dilution and diluted up to ~4 L (Dilution 2), also recorded accurately by weight. Aliquots of ~100 mL were then taken from the second dilution for analysis by the FS-200. The remaining fibre from the 1 L dilution was recovered by filtration through oven dried, weighed filter papers and dried to determine the macerated pulp yield and for the calculation of fibre coarseness. The equations used for the calculations were:

- $MPY = (P_{odw})/(W_{odw}) \times 100\%$
- $P_{odw} = C \times (\text{Dilution 1})$
- $C = (\text{weight dry fibre recovered})/(\text{volume filtered})$
- Weight fibre/sample aliquot = [(C) × (Aliquot 1) / (Dilution 2)] × (sample aliquot volume)

Where:

MPY = Macerated Pulp Yield (%)
P_{odw} = Dried Pulp Weight (g)
W_{odw} = Dried Wood Weight (g)
C = Consistency (g/L)

RESULTS AND DISCUSSION

Tree Age And Diameter At Breast Height (DBH)

All of the hybrid poplar samples tested were four years old. The native aspen samples taken from near the plantation site ranged from 8 to 12 years.

Table II shows the mean DBH for all of the clones and also the mean DBH/year based on the average age of the samples for comparison**. Figure 1** shows the samples ranked according to decreasing DBH/yr. Many of the hybrid poplar samples outperformed the balsam poplars and native aspens in terms of growth rate, in particular clones 24, 26, 36, and 42.

Clone	Avg. Age / Years	Density / g/cm^3	SD / g/cm^3	N	DBH / cm	SD / cm	N	DBH/ Yr/ cm/yr
8	4	0.305	0.014	6	1.9	0.5	12	0.429
10	4	0.326	0.019	6	4.3	0.6	5	0.771
13	4	0.344	0.029	13	2.7	0.4	10	0.567
18	4	0.354	0.014	6	3.3	0.2	5	0.679
24	4	0.358	0.019	10	5.2	0.2	8	1.030
26	4	0.366	0.018	10	4.5	0.4	8	0.908
33	4	0.330	0.011	6	2.9	0.5	7	0.564
36	4	0.334	0.025	11	4.4	0.7	8	0.880
37	4	0.326	0.022	8	4.2	0.6	5	0.650
42	4	0.301	0.015	10	5.4	0.6	7	1.044
48	4	0.303	0.016	10	4.2	0.1	6	0.635
AW1	10	0.373	0.021	10	4.3	0.8	6	0.643
AW2	9	0.347	0.048	11	3.9	0.4	6	0.616

N = number of samples
SD = standard deviation

Table II. Average age, wood density, and diameter at breast height.

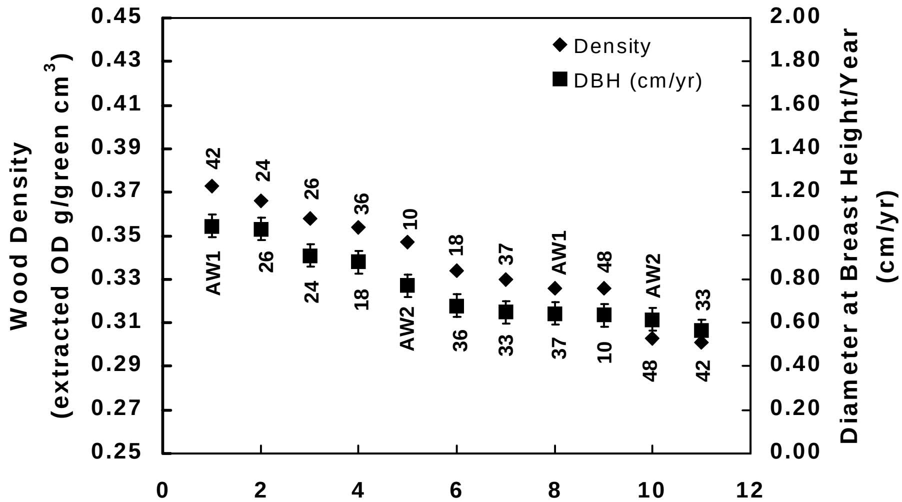

Figure 1. Samples ranked according to diameter at breast height per year and samples ranked in decreasing wood density.

Wood Density

The mean densities for the 15 samples, (Table II), are plotted in decreasing order in Figure 1. Densities ranged from 0.301 to 0.373 g/cm^3, which compares well to literature values for hybrid poplar of 0.360 to 0.400 g/cm^3 [1]. The pooled standard error ($SE = \frac{SD}{\sqrt{N}}$) for wood density was determined to be 0.0068 g/cm^3. The densities of the hybrid poplars were in the same range as the balsam poplars and native aspens. The common assumption that faster growing trees should exhibit lower wood densities does not hold in this group of samples since no correlation was seen between wood density and DBH/year (**Figure 2**).

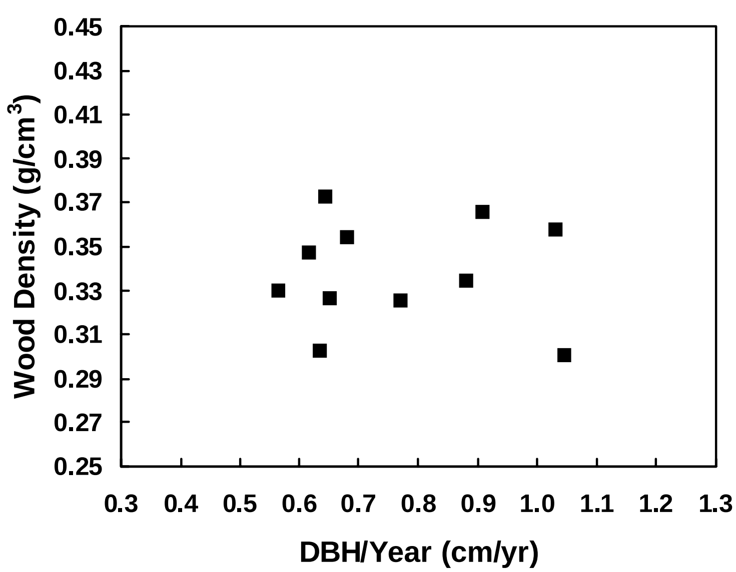

Figure 2. Plot of wood density vs. growth rate (DBH/yr).

Chemical Analysis

The complete results of the chemical analysis of the 15 samples are shown in **Table III**. The yield of these analyses ranged from 95.2–98.6% ensuring that analytical effects have been eliminated from the experiment. **Figure 3(a)** shows the carbohydrate compositions of the 15 samples ordered by decreasing glucan content. Hybrid poplars 24, 26, and 42 had glucan carbohydrate contents superior to the other hybrid poplars, balsam poplars, and native aspens. The holocellulose contents of the 15 samples ranged from 67.7 to 72.3%, (a very significant range of 4.6%). It has been previously shown that the alpha-cellulose content prepared from holocellulose can be used to predict kraft pulp yield for hybrid poplars [13]. The glucan component (adjusted for a typical hardwood ratio of 1:2 for glucan: mannan) of these data can be related to alpha-cellulose content [14,15] and by extension used to predict the swings in yield that could be expected from the industrial usage of these clones [6]. It is worth noting however, that such yield changes do not necessarily translate into changes in pulp production as other factors such as digester packing (related to wood density) come into play.

Figure 3(b) shows the total lignin contents of the clones ranked in order of decreasing lignin and also shows the levels of other wood components; ash and acetone extractives. Total lignin contents ranged from 21.37 to 24.31% and extractives from 1.85 to 4.74% of wood weight. The native aspens and hybrid poplars 26 and 42 showed the lowest levels in accordance with the previously observed holocellulose contents.

Clone	LWFL / mm	SD / mm	Coarseness / mg/m	SD / mg/m	N
8	0.592	0.033	0.071	0.004	13
10	0.621	0.042	0.098	0.006	10
13	0.592	0.061	0.086	0.011	15
18	0.604	0.018	0.084	0.004	6
24	0.647	0.041	0.09	0.016	11
26	0.605	0.033	0.097	0.014	11
33	0.508	0.02	0.086	0.007	10
36	0.689	0.047	0.1	0.01	11
37	0.663	0.022	0.079	0.006	9
42	0.538	0.026	0.09	0.007	9
48	0.537	0.019	0.085	0.005	10
AW1	0.51	0.054	0.07	0.008	7
AW2	0.553	0.054	0.081	0.017	10

LWFL = length weighted fibre length
SD = standard deviation

Table III. Fibre analysis and macerated pulp yield at tree age 4.

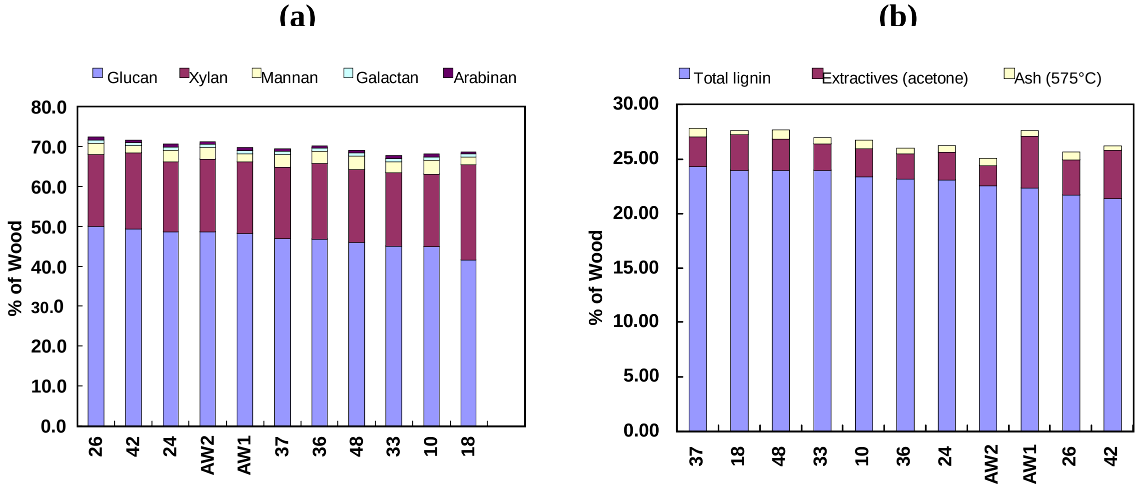

Figure 3. Carbohydrate compositions ranked in order of (a) decreasing glucan content and (b) lignin, extractives, and ash conents of the samples ordered in decreasing lignin content.

Fibre Length And Coarseness

Figure 4 shows a plot of length weighted mean fibre length (LWFL) as a function of tree age for all of the 15 different samples. Fibre lengths were shown to increase with age in all cases and the fibre lengths of the native aspen samples AW1 and AW2 were still increasing after nine years as these trees are in their juvenile growth phase.

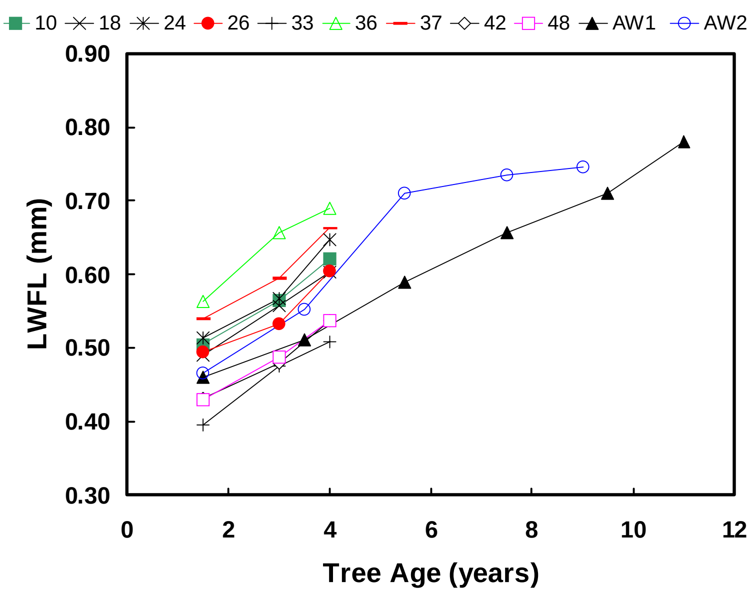

Figure 4. Increasing fibre length as a function of tree age.

Since the native aspens were older than the hybrid poplars and balsam poplars, the fibre properties of all the samples were normalized at age 4. The growth rings in the native aspens were very close together, and difficult to distinguish. Consequently the year 3 and 4 growth rings were pooled (as age class 3.5) to compare to the 4 year rings from the other trees. For all trees, the pith to year 2 rings were pooled and designated as age class 1.5.

Figure 5 shows the samples ranked according to decreasing fibre length at age 4 with the fibre coarseness overlaid. The length weighted fibre lengths ranged from 0.508 to 0.713 mm with a pooled standard error of ± 0.019 mm. Many of the hybrid poplars showed fibre lengths longer than the native aspens and balsam poplars, particularly clones 10, 24, 36, and 37**. Figure 6** shows a SYSTAT hierarchical cluster analysis of the samples based on fibre length with the longest at the bottom of the chart. The cluster analysis groups the sample into families based on numerical distance from each other and implies that the variability within a family is less than the variability between families. Four distinct groups were seen in the analysis with the native aspens and hybrid poplars 42, 48, and 33 occurring in the shortest fibre length groups.

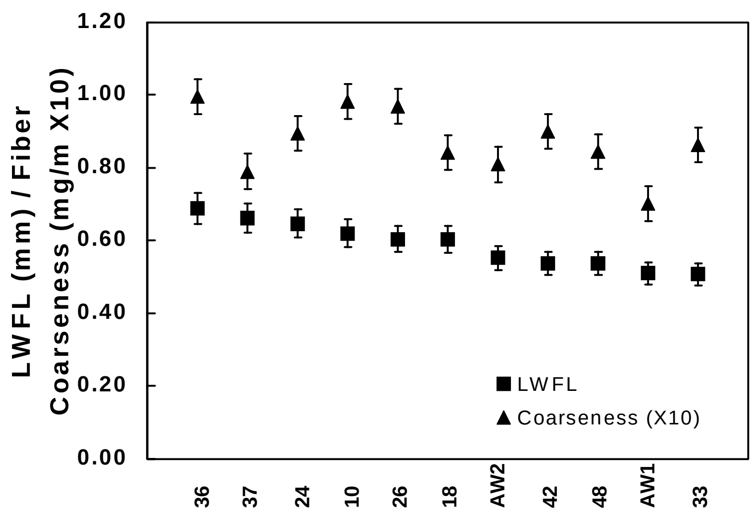

Figure 5. Samples ranked in order of decreasing fibre length at age 4. Fibre coarseness (overlaid) at age 4 shows no correlation between the two fibre properties.

Figure 5 also shows mean fibre coarseness data at age 4 ranging from 0.068 to 0.100 mg/m (c.f. the range of hybrid poplar coarseness reported by Cisneros *et. al.* [1] of 0.060 to 0.173 mg/m). The pooled standard error for fibre coarseness was ± 0.0047 mg/m. Samples with lower coarseness values would be expected to have thinner walled fibres on average. (It must be noted that the coarseness values obtained from the maceration technique employed here are only indicative of the true coarseness values which must be obtained by pilot-scale kraft pulping of the samples).

No correlation was seen between fibre length and coarseness in these samples. Two of the hybrid poplars with longer fibres, 36 and 37, had significantly different coarseness values; 0.100 and 0.079 mg/m, respectively. This indicates that there is an opportunity to select hybrid poplars for specific end uses; long, fine fibres for printing and writing paper grades where smoothness and formation are important, and shorter, bulkier fibres for grades where bulk and absorbency are important, such as in tissue grades. This type of variation in fibre morphology has been seen in eucalyptus where *E. grandis* has long, fine fibres and *E. globulus* has short stiff fibres [16].

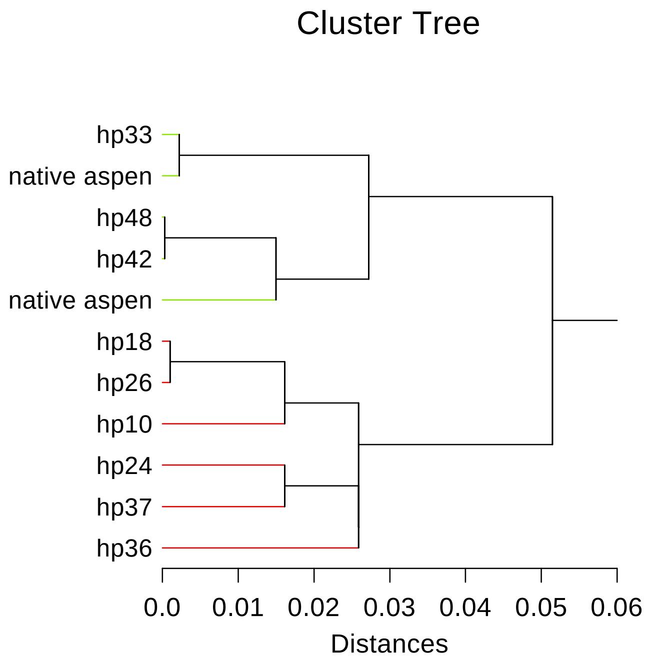

Figure 6. Hierarchical cluster analysis by LWFL. The shortest fibre groups are at the top of the chart with the samples ranked in decreasing order.

Clone Ranking

In order to better identify the clones with the best overall wood and pulp properties, the clones were ranked from best to worst in each of six important categories: fibre length, wood density, DBH/year (as a reflection of growth rate), total lignin, extractives content, and glucan composition (**Table IV**). In the cases of lignin and extractives content, lower levels were considered to be better. The number of occurrences of a sample in the top five (arbitrarily) of each category were counted and are resultant rankings shown in **Table V**. For this study, an equal weighting was given to each parameter measured. Identification of superior clones will, of course, alter if different weightings (based on genetic heritabilities or economic factors) are assigned to the traits. For example, it has recently been suggested that wood density should be given an economic weighting 8 times that given to growth rate [17].

Two hybrid poplars, 24 and 26, ranked in the top five in five out of the six categories. These clones exhibited long fibres combined with good growth rates, wood densities, and chemical properties compared to the other samples from the plantation site. They also seemed to outperform the native aspens and the balsam poplars. Clones 36 and 42 also performed relatively well in some categories.

Clone	LWFL / mm	Clone	Density / g/cm^3	Clone	DBH/yr / cm/yr	Clone	Total lignin / %	Clone	Extractives / %	Clone	Glucan / %
36	0.689	AW1	0.373	42	1.044	42	21.37	AW2	1.85	26	50.1
37	0.663	26	0.366	24	1.03	26	21.74	13	2.09	42	49.4
24	0.647	24	0.358	26	0.908	AW1	22.38	36	2.39	AW2	48.9
10	0.621	18	0.354	36	0.88	AW2	22.61	33	2.46	24	48.9
26	0.605	AW2	0.347	10	0.771	8	22.74	24	2.54	AW1	48.3
18	0.604	13	0.344	18	0.679	24	23.11	10	2.6	8	47.9
13	0.592	36	0.334	37	0.65	36	23.16	37	2.76	37	47.1
8	0.592	33	0.33	AW1	0.643	10	23.36	48	2.85	36	46.9
AW2	0.553	37	0.326	48	0.635	33	23.97	26	3.25	48	46.2
42	0.538	10	0.326	AW2	0.616	18	23.98	18	3.31	13	45.6
48	0.537	8	0.305	13	0.567	48	23.98	8	3.78	33	45.1
AW1	0.51	48	0.303	33	0.564	13	24.04	42	4.52	10	45
33	0.508	42	0.301	8	0.429	37	24.31	AW1	4.74	18	41.7

Table IV. Ranking of samples in 6 wood and fibre properties. Samples are arranged from most desirable (top) to least (bottom).

# Top 5's	Clone	Parentage
5	24	hybrid poplar
	26	hybrid poplar
4	AW2	aspen
3	36	hybrid poplar
	42	hybrid poplar
	AW1	aspen
2	10	hybrid poplar
1	8	balsam poplar
	13	balsam poplar
	18	hybrid poplar
	33	hybrid poplar
	37	hybrid poplar
0	48	hybrid poplar

Table V. Results of ranking samples in 6 wood and fibre properties. Occurrences in the top 5 of each category were counted.

CONCLUSIONS

No correlation was observed between wood density and diameter at breast height per year for any of the poplars evaluated. The density of the faster growing trees were not affected by growth rate which implies that more desirable high density trees require trait specific selection, i.e. high density trees can exhibit excellent growth rates.

Holocellulose contents ranged 4.6% between the 15 samples tested. This may translate to significant hybrid differences in kraft pulping yields, particularly when projected to the mill scale. No relationships were seen between the macerated pulp yield, density, or holocellulose contents of the samples. However, the delignification process used for the fibre analyses in this study may not necessarily be indicative of the yields expected during kraft pulping (as pulping rates may differ between clones).

Significantly different fibre length groups were observed when comparing the year 4 growth rings. Many of the hybrid poplar samples performed as well as or better than the balsam poplars and native aspens in terms of fibre length.

Overall, clones 24 and 26 showed a combination of good growth rates, high wood density, long fibres, and desirable chemical properties by comparison with the other samples.

It is evident from this study that plantation trees should be selected on the basis of a range of important properties and several candidates were identified for potential implementation in plantations. In addition, given the variety of fibre properties observed, in combination with other desirable growth traits, the hybrids trialed include trees which can be potentially selected to produce a variety of pulp grades suited for different end uses.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the technical support provided during this project by Paul Bicho, Jik Ing, and co-workers; Ken Hunt, Wai Gee, Maxwell McRae, Trevor Mischki, and Joanne LeGrand.

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Received: September 23, 1999
Accepted: July 3, 2000

This paper was accepted for abstracting and publication in the December 2000 issue of *TAPPI JOURNAL.*

TAPPI Website: www.tappi.org