INTERCLONAL, INTRACLONAL, AND WITHIN-TREE VARIATION IN FIBER LENGTH OF POPLAR HYBRID CLONES

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ABSTRACT

Variation in fiber length pattern within the stem, within clones, and between clones of the hybrid *Populus* x *euramericana* was investigated. Samples were taken from a total of twenty-seven nine-year-old trees representing ten clones from one site in south-central Quebec. Sample disks from each tree were taken from four heights. Each even-numbered ring from the pith was also sampled at each height to determine the radial variation pattern in fiber length. Clones, heights, and the position of annual rings from pith had significant effects on average fiber length. Individual tree broad-sense heritability was 0.41. The main source of variation was the position of annual rings from pith, which accounted for about 80% of total variance. Fiber length increased from pith to bark for all sampled heights. For a given annual ring, fiber length was low at the bottom of the tree and tended to reach a maximum at mid-height. Weighted average fiber length at breast height was significantly correlated to weighted average fiber length of the merchantable stem. Finally, the correlation between fiber length and growth rate varied over the age of the tree. At early ages, correlation between ring width and fiber length was not significant; at older ages, slight negative but significant correlation was found between these two traits.

Keywords: Fiber length, *Populus* x *euramericana*, intraclonal variation, interclonal variation, hybrid variation.

INTRODUCTION

Increasing demand for wood and fiber and declining availability of wood supplies have prompted investigations into the potential of fast-growing species as raw material for the various wood industries. The poplars (*Populus spp.*) are among the fastest growing trees in the temperate regions and produce wood that is widely used by the forest industry. Many hybrids have been selected, planted, and tested. In the northeastern regions of North America, *euramericana* clones have been the most widely planted hybrids. They have shown excellent performance under several different site conditions and have generally shown commercial potential as raw material or breeding stock. However, little attention has been paid to the wood quality of these clones. In a prevous paper, Beaudoin et al. (1992) reported on interclonal, intraclonal, and within-tree varia-

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tion of poplar wood density. Except for wood density, the fiber length, often considered to be a limiting factor in wood use, has been the most studied wood property in hardwoods (Zobel and Jett 1995). Fiber length is particularly important for the pulp and paper industry since it determines to a large extent the physical and mechanical properties of paper and paperboard (Van Buijtenen et al. 1962; Einspahr et al. 1963; Keays et al. 1974; Zobel and Van Buijtenen 1989). Few studies have examined interclonal, intraclonal, and within-tree variation of fiber length in poplars and their hybrids (Yanchuk et al. 1984). Hence, the purpose of this study was to provide information on patterns of fiber length variation within tree, within clones, and between clones of *Populus* x *euramericana* hybrid trees coming from one site in south-central Quebec.

MATERIALS AND METHODS

The sampling site was approximately 50 kilometers south of Sorel in south-central Quebec (45°50′ north latitude, 73°13′ west longitude). The site is part of the Champlain marine deposit with rich silty-clay soil (40% clay). A total of twenty-seven trees from ten adjacent clones of *P.* x *euramericana* (*P. deltoides* x *P. nigra*) were chosen from a clonal plantation on the site. All trees were nine years old and were randomly selected after taking into account stem straightness and absence of obvious decay. The number of acceptable trees per clone was between two and four. Four 8-cm-thick disks were taken at progressive heights of 0.5, 1.5, 3.0, and 4.5 m above the ground. Cardinal direction does not affect the fiber length of poplars (Kaeiser 1956; Zenker 1968), and we removed one wedge at a random cardinal direction from each disk. Wedges were kept frozen until sample preparation. Small parallelepiped samples (3 mm × 3 mm × 5 mm) were extracted from the outer part of the initial wood from each even ring (2, 4, 6, and 8). These samples were macerated with Jeffrey's solution (15%) for 24 h then washed with distilled water until complete removal of

TABLE 1. *Average values of fiber length for ten* Populus x euramericana *clones.*

Clone code	Number of trees	Fiber length (mm)	Standard deviation (mm)
37	2	1.028	0.028
131	2	0.956	0.025
136	2	0.900	0.027
205	3	1.050	0.031
1102	4	1.026	0.024
1132	2	1.047	0.026
3005	3	1.021	0.031
3301	2	0.987	0.031
3307	3	1.013	0.032
3308	4	1.054	0.034
Average		1.015	0.033

the Jeffrey's solution. The defibrillated samples were stained in a Safranin solution for 24 h, then spread and glued onto microscope slides. The fiber images were projected onto a numeric surface of a Micro-Plan II planimeter, an apparatus for analyzing images in two dimensions. Forty random unbroken fibers were measured to the nearest 0.001 mm from each sampled ring. The inner bark diameter of each disk, the ring width, and its distance from the pith were recorded to estimate the weighted average fiber length. The weighted average fiber length at each sampled height was estimated based on the areas of the rings. The weighted average fiber length of the merchantable stem was estimated from the weighted averages at each height and on the inner bark disc diameter. Data were evaluated using analyses of variance at 95% and 99% probability levels.

RESULTS AND DISCUSSION

The overall average fiber length of the ten euramericana clones was 1.015 mm with a coefficient of variation of 3.2% (Table 1). The average fiber length for the rings 2, 4, 6 and 8 from the pith at breast height along with previously reported data are shown (Table 2). The average for the sixth annual ring (1.06 mm) agreed with the reported average for the same hybrid (*P.* x *euramericana*) by Smith and Rumma (1971) at the same annual ring

TABLE 2. *Average fiber lengths of individual annual rings for various* Populus *species and hybrids.*

Reference	Species or hybrids	Fiber length at annual ring number (mm)				
		2	4	6	8	10
Present work[1]	*P.* x *euramericana*	0.75	0.90	1.06	1.13	—
Smith and Rumma (1971)	*P.* x *euramericana*	—	—	1.05	—	—
Holt and Murphey (1978)	*P. maximowiczii* x *P. trichocarpa*	0.64–0.67	0.74–0.86	—	—	—
Murphey et al. (1979)	*P. maximowiczii* x *P. trichocarpa*	—	0.72	—	—	—
Cheng and Bensend (1979)	*P. deltoides*	—	0.66–0.78	—	—	—
Marton et al. (1968)	*P. deltoides* x *P. caudina*	—	—	—	—	1.08
Geimer and Crist (1980)	*P. deltoides*	—	—	—	0.83	—
Delucchi (1981)	*P. deltoides*	—	—	—	0.96	—

[1] Averages taken at breast height.

(1.05 mm). The *Populus* x *euramericana* clones showed higher fiber lengths than other poplars and hybrids at the same annual ring. For example, at the second annual ring from the pith, the overall average (0.75 mm) from this study was higher than that reported by Holt and Murphey (1978) for the hybrid *P. maximowiczii* x *P. trichocarpa* (0.64–0.67 mm). The same holds at the fourth annual ring where the overall average (0.90 mm) was higher than the value reported for the hybrid *P. maximowiczii* x *P. trichocarpa* by Holt and Murphey (1978) and by Murphey et al. (1979), as well as for *P. deltoides* by Cheng and Bensend (1979). It is also interesting to note that the fiber length at the eighth annual ring (1.13 mm) of *P.* x *euramericana* clones was higher than the fiber length at the tenth annual ring (1.08 mm) of the hybrid *P. deltoides* x *P. caudina* (Marton et al. 1968). All of the above suggests that the *P.* x *euramericana* clones from this study may have potential as raw material for the pulp and paper industry, since for various hardwood species, the physical and mechanical properties of paper are highly and positively correlated with fiber length (Horn 1978).

Interclonal, intraclonal, and within-tree variation of fiber length

The analysis of variance of the arithmetic average of 40 fiber lengths of each even ring at each height showed significant differences among the ten *P.* x *euramericana* clones (Table 3). Trees within clones had no significant effects on fiber length, while the effects of heights and the position of annual rings from pith were highly significant.

Interclonal variation and heritability of fiber length

Even though there were significant differences in fiber length among the ten clones (Table 3), the estimated variance component suggested that the clone effect accounted for only

TABLE 3. *Analysis of variance of fiber length of ten* Populus x euramericana *clones.*

Source	df	Mean square	F	Variance components	%
Model	25	0.23416	62.77**		
Error	291	0.00373		0.0037	11.4
Clone	9	0.03332	8.93**	0.0012	3.7
Tree	3	0.00893	2.39 n.s.	0	n.s.
Height	3	0.09715	26.04**	0.0012	3.7
Annual ring	3	1.60245	429.58**	0.026	80.5
Height × annual ring	7	0.00753	2.10*	0.0002	0.6

** Significant at the 99% probability level; * significant at the 95% probability level; n.s. not significant at 95% probability level.

TABLE 4. *Analysis of variance of weighted average fiber length of ten* Populus x euramericana *clones.*

Source	df	Mean square	F	Variance components	%
Interclone	9	0.00481	4.44**	0.00108	41
Intraclone	3	0.00124	1.15 n.s.	0.00001	0
Error	14	0.00109		0.00156	59

** Significant at the 99% probability level; n.s. not significant at 95% probability level.

3.7% of the total variation. This is due to the fact that the wood of the clones studied is juvenile wood, and the fiber length is controlled mainly by a combination of physiological and environmental factors. The little effect of clone (Table 3) was in good agreement with the results of Cheng and Bensend (1979) on a number of hybrid poplar clones. In a similar study on clone and age effects on the anatomical properties of *Populus* x *euramericana* clones, Peszlen (1994) reported that the clone effect on the fiber length is not significant.

In order to estimate the broad-sense heritability, the analysis of variance on the whole tree weighted average fiber length was carried out (Table 4). There were significant differences in the weighted average fiber length among the ten clones. The estimated variance component suggested that the effect of clones accounted for approximately 41% of the phenotypic variation in fiber length. The broad-sense heritability on individual tree was found to be 0.41. Such a heritability value is somewhat moderate, thus indicating that the fiber length of poplar hybrid clones appears to be under moderate genetic control. Similar heritability values have also been reported by Nepveu et al. (1978) for *P.* x *euramericana* hybrids (0.45) and by Yanchuk et al. (1984) for *Populus tremuloides* (0.43). Van Buijtenen et al. (1959) and Einspahr et al. (1963) also reported similar heritability values (0.51 and 0.50) for *Populus tremuloides*. Ivkovich (1996) found lower heritability values (from 0.19 to 0.30) for the fiber length of 30 balsam poplar (*Populus balsamifera*) clones grown in three different locations. On the other hand, Mohrdiek (1979) reported no significant differences in fiber length among a number of *Populus* hybrid progenies.

Duncan's multiple-range test was used to determine which averages may differ at the 95% probability level. Results suggested that clones 131 and 136 should not be recommended, if high fiber length is desired (Table 5). The average weighted fiber lengths of the remaining eight euramericana clones were not statistically different. This can be partially explained by the relatively low range of fiber length variation between clones. Averages for individual clones range from 0.90 mm to 1.05 mm. Even if this variation in fiber length between clones may be important, in a practical sense it is rather small. However, there is some interest in increasing fiber length in poplar trees and even a small percentage improvement may affect the utility of the wood. For example, Labosky et al. (1983) attributed the significant variation between the tear strength of three hybrid poplars to fiber length variation. In addition, Horn (1978) found that a low range of fiber length variation in different hardwoods significantly affected pulp and paper properties. Judging by the lack of significant clone-site interaction found by Farmer and Wilcox (1968) and Nepveu et al. (1985), and by the lack of significant site effect on fiber length (Yanchuk et al. 1984), other sites may also contain low variability and also be used without appreciable loss of valuable clones. Additional work, however, is required before a generalization for poplar hybrids can be made.

Intraclonal and within-tree variation of fiber length

There were no significant differences between trees within clones (Table 3). This nonsignificant intraclonal variation may be explained in part by the small number of replications used in a single site, hence limiting environmental variation.

On the other hand, the effect of the position of annual rings from pith on fiber length was highly significant. This effect accounted for approximately 80% of the total variation (Ta-

TABLE 5. *Duncan's multiple-range test of fiber length for ten* Populus x euramericana *clones.*

Clone code	3308	205	1132	37	1102	3005	3307	3301	131	136
Fiber length (mm)	1.05	1.05	1.05	1.03	1.03	1.02	1.01	0.99	0.96	0.90

ble 3). This percentage was higher than that reported by Boyce and Kaeiser (1961) for eastern cottonwood (*Populus deltoides*) (50% of the total variation), and could be explained by the young age of our material. Consequently, the physiological variation is quite high for young trees. Peszlen (1994) reported that the age accounts for 76% of the total variation of fiber length from three euramericana poplar clones. Such a result is similar to what we have found in this study, even though Peszlen (1994) did not consider the height effect. The pattern of fiber length variation as a function of rings from pith at breast height is shown in Fig. 1. The fiber length was initially quite short near the pith, then steadily increased before showing a tendency to level off at the eighth annual ring. This indicated that wood maturity is not yet reached at age 8. A similar pattern has frequently been reported for poplars and their hybrids (e.g., Cheng and Bensend 1979; Delucchi 1981; Yanchuk et al 1984; Bendtsen and Senft 1986; Sierra-Alvarez and Tjeerdsma 1995).

The effect of height on the fiber length was also significant but accounted for only 3.7% of the total variation (Table 3). The age × height interaction was also significant, which means that the degree of variation in fiber length at a stem height is a function of the annual ring considered. The slope of the fiber length variation with height increased slightly with age (Fig. 2). The weighted average fiber length for heights 0.5 (1.03 mm), 1.5 (1.03 mm), and 3 m (1.01 mm) did not differ even though the maximum age at 3 m was 6 years compared to 8 years for 0.5 and 1.5 m (Fig. 2). The average fiber length at 4.5 m (0.97 mm) was lower than that of other sampled heights. At that height (4.5 m), the average fiber length was based on two annual rings (2 and 4), which were characterized by shorter fibers (Fig. 1).

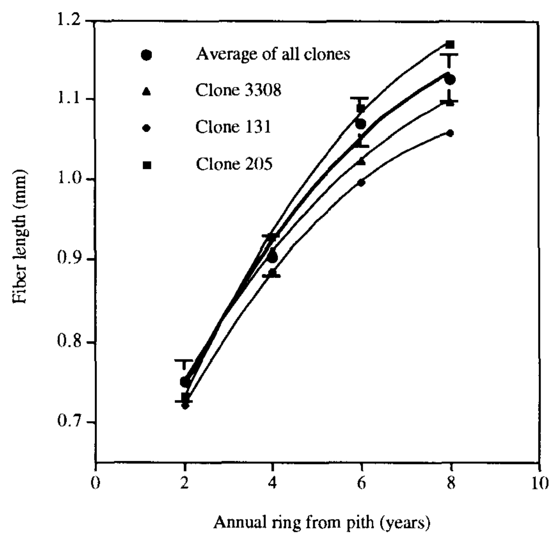

FIG. 1. Fiber length as a function of the annual ring at breast height for some euramericana clones. Bars indicate standard errors.

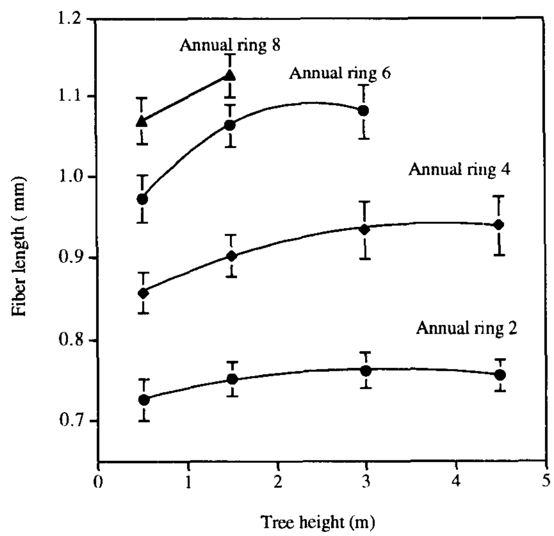

FIG. 2. Fiber length of individual rings as a function of the stem height for ten euramericana poplar clones. Bars indicate standard errors.

TABLE 6. *Correlations between individual ring fiber lengths, weighted average fiber lengths and growth rate of ten* P. x euramericana *clones.*

	Tree height			
	0.5 m	1.5 m	3 m	4.5 m
Ring number	Fiber length of each even ring versus weighted fiber length at different heights			
2	0.36 n.s.	0.21 n.s.	0.46*	0.33 n.s.
4	0.55**	0.50**	0.45*	0.57**
6	0.87**	0.62**	0.93**	—
8	0.90**	0.90**	—	—
	Tree weighted fiber length versus weighted fiber length at different heights			
	0.83**	0.85**	0.71**	0.78**
	Weighted fiber length versus inner bark diameter at different heights			
	−0.11 n.s.	0.22 n.s.	0.12 n.s.	0.45*
Ring number	Fiber length versus width of each even ring at different heights			
2	−0.10 n.s.	−0.09 n.s.	0.40 n.s.	0.02 n.s.
4	−0.18 n.s.	−0.22 n.s.	−0.29 n.s.	0.13 n.s.
6	−0.07 n.s.	−0.42*	−0.023 n.s.	—
8	−0.30 n.s.	−0.53*	—	—

** Significant at the 99% probability level; * significant at the 95% probability level; n.s. not significant at 95% probability level.

Relationships between fiber lengths for individual annual rings and for different heights

Correlations between the weighted average fiber length and that of individual annual rings measured at different heights are shown in Table 6. For example, at breast height, the correlation between the fiber length of the second annual ring and the weighted fiber length was not significant (Table 6). Consequently, selecting clones having long fibers at an early age could be misleading. In contrast, the correlations for the fourth (r=0.50), the sixth (r=0.62), and the eighth (0.90) annual rings were significant. This may have practical applications, since it allows the selection of clones with long fibers using a single annual ring. However, the annual ring used should not be at an early age. It was impossible to estimate genetic and phenotypic correlations between the weighted average fiber length and that of individual rings since the clone effect was generally not significant for the fiber length within individual rings.

There were significant correlations between weighted average fiber lengths from the whole tree and from each sampled height (Table 6). Therefore, the weighted average fiber length measured at a single height could be used with reasonable confidence to estimate the fiber length of the whole stem.

Relationship between fiber length and growth rate

Since most poplar hybrids are fast-growing, it is useful to know the growth rate influence on fiber length. Previous results on this relationship are rather contradictory. Van Buijtenen et al. (1959) and Yanchuk et al. (1984) reported significant positive correlations (r = 0.31) for *Populus tremuloides.* Kennedy (1957) and Cech et al. (1960) reported similar findings for *Populus deltoides.* These results were encouraging since selecting fast-growing clones could also have resulted in wood with longer fibers. However, our results show no significant correlation between the fiber length and the inner bark diameter at breast height (Table 6), and agree with Johnson (1942) and Marton et al. (1968) using *Populus deltoides.* When dealing with the growth rate at ring level, there were no significant relationships between the fiber length and the ring width at early ages (second and fourth) showing no effect of growth rate at the ring level (Table 6). However, slight negative but significant correlations were found between the ring width at breast height and the fiber length of the sixth ($r = -0.42$) and the eighth ($r = -0.53$) annual rings. These results are in good agreement with Delucchi (1981), who also found a slight negative correlation at the eighth annual ring of *Populus deltoides*. These results confirm the theory proposed by Bailey (1954) and Kennedy (1957) suggesting that in fast-growing species, the division of the cambium initials is rapid in order to keep pace with the rapid rate of circumferential growth. Consequently, when a tree is rapidly increasing in diameter, the average length of daughter cells produced by the cambium might be expected to shorten, due to the large number of cambial initials which divide anticlinally. Similarly, trees slowly growing in diameter would not increase in circumference at a rapid rate, fewer cambial cells would need to divide anticlinally. Therefore, the fibers of slower growing trees would be expected to be longer.

CONCLUSIONS

For the ten *Populus* x *euramericana* clones studied, the following conclusions can be drawn:

1) A statistically significant difference in weighted average fiber length exists among clones, and individual tree broad-sense heritability was 0.41.

2) The position of annual rings from pith is the main source of variation, explaining 80% of the total variation.

3) At breast height, fiber length rapidly increases from the pith outward, followed by a lower rate of increase from the sixth to the eighth annual ring, with a tendency to level off at the eighth annual ring.

4) For a given annual ring, the average fiber length increases from the base of the tree upward and tends to level off at mid-height.

5) The relationship between growth rate and fiber length depends on which annual ring is examined. At an early annual ring, no significant correlations were found. However, by annual rings 6 and 8, there are slight but significant negative correlations.

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