INTERCLONAL, INTRACLONAL AND WITHIN-TREE VARIATION IN WOOD DENSITY OF POPLAR HYBRID CLONES

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ABSTRACT

Twenty-eight nine-year-old trees from ten clones of the hybrid *Populus* × *euramericana* at one site in south-central Quebec were sampled to determine the pattern of wood density variation within stems, within clones, and between clones. Sample disks were taken from each tree to examine the variation at four heights, whereas an increment core of 10 mm in diameter was extracted at breast height. Clones, trees, and heights have a highly significant effect on wood density, and the individual-tree broad-sense heritability is 0.64. The wood density of this hybrid tends to be high at the bottom of the tree, decreases to a minimum at mid-height, then increases again near the top of the merchantable stem. There is also a highly significant correlation between the weighted average wood density of the merchantable stem and the wood density of the increment core taken at breast height. Finally, wood density decreases as growth rate increases. However, the correlation is weak ($r = -0.49$) but statistically significant.

Keywords: Wood density, *Populus* × *euramericana*, intraclonal variation, interclonal variation, hybrid variation.

INTRODUCTION

The poplars (*Populus* spp.) are a diverse group of plants that have become an economically important part of forestry in Canada and in the United States (Keays et al. 1974). They represent the fastest growing trees in the temperate regions and produce wood that is widely used by the forest industry (mainly aspen). Considering that wood supplies in the future may become more scarce, wood production from poplar plantations could play a larger role as raw material for domestic and industrial uses (Maini and Cayford 1968). To do so, many hybrids have been selected, planted, and tested. In the northeastern regions of North America, the euramericana clones have been the most widely planted hybrids. They have performed well in several site conditions and generally show good commercial potential as raw material or breeding stock. However, little attention has been paid to the wood quality of these clones.

In general, researchers agree that wood density is the single most important factor affecting wood quality (Zobel 1961; Keith 1986). The natural variation encountered in wood results from the combined influence of genetic and environmental factors. Knowledge of the relative influence of these factors is of basic importance. Remarkable differences exist among both individual poplar trees and forest stands (e.g., Walters and Bruckmann 1965; Farmer and Wilcox 1966; Posey et al. 1969). Before among-tree variation can be accurately evaluated, however, patterns of within-tree variation must be known, especially in young trees with large proportions of juvenile wood (Zobel and van Buijtenen 1989).

A number of studies have dealt with interclonal and intraclonal variation of wood density in some poplar species like black cottonwood (Gabriel 1956; Cech et al. 1960), and eastern cottonwood (Gabriel 1956; Walters and Bruckmann 1965; Farmer and Wilcox 1968). However, little information is available on the variation of the wood density in hybrids of these species. The purpose of this paper is to provide information on patterns of wood density variation within tree, within clones, and between clones of *Populus* × *euramericana* hybrid trees coming from one site in a south-central area of Quebec. This research presents also an evaluation of a nondestructive method for estimating the average wood density of the stem from increment cores obtained at breast height.

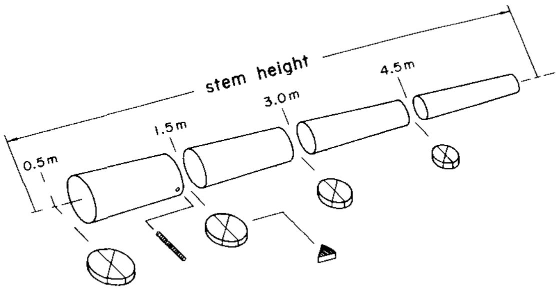

FIG. 1. Schematic diagram showing the sampling method of the stem.

MATERIALS AND METHODS

The sample site was located approximately 50 kilometers south of Sorel in south-central Quebec (45°50′ north latitude, 73°13′ west longitude). This location is in the Champlain marine deposit site, where there is a rich silty-clay soil (40% clay). A total of twenty-eight trees from ten adjacent clones of *P.* × *euramericana* (*P. deltoides* × *P. nigra*) were chosen in a clonal plantation on this site. All trees were nine years of age and were randomly selected, taking into account stem straightness and absence of obvious decay. The number of acceptable trees by clone varied from two to four depending on availability. Four 8-cm-thick disks were taken from each tree at progressive heights of 0.5, 1.5, 3.0, and 4.5 m above the ground (Fig. 1). Since Walters and Bruckmann (1965) determined that wood density did not differ significantly between cardinal directions for eastern cottonwood, two 45-degree opposite wedges were removed at random cardinal directions from each disk. Furthermore, Yanchuk et al. (1983) suggested that sampling from one radius adequately represents wood density at any height. Wedges were kept frozen until measurement of wood density. The density measurement of all wedges was obtained by soaking them for 24 h in water, removing excess moisture from the surface of the samples with a damp cloth, and weighing each sample according to the water displacement method (measured to 0.01 g), which gave its green volume. Moisture content of the wedges after soaking varied from 69% to 182%. According to Goulet and Hernández (1991), this should be sufficient to ensure that the volume of the wedges is at its maximum. Oven-dry mass was obtained by drying the wedges for 24 h at 103 ± 2 C, weighing them and recording the dry mass to the nearest 0.01 g after the samples had cooled down to room temperature over phosphorus pentoxide.

In addition to measuring the density of the wedges, an increment core of 10 mm in diameter was extracted from each tree, through the pith from bark to bark, at breast height (1.3 m above ground). Each core was labeled and wrapped in plastic in order to avoid de-

TABLE 1. *Average values of wood density for ten* P. × euramericana *clones.*

Clone code[1]	Number of trees	Wood density (kg/m^3)	Standard deviation (kg/m^3)
37	2	366.31	4.37
131	2	323.69	2.00
136	2	302.37	3.24
205	3	364.66	3.46
1102	4	355.89	3.08
1132	2	352.68	3.93
3005	3	370.44	3.59
3301	2	362.03	4.30
3307	4	360.33	2.33
3308	4	334.76	2.55
Average		349.46	1.77

[1] Numbers specific to the Ministère de l'Energie et des Ressources of Quebec. Information on origin, cultivar, etc., available from the authors.

hydration and breakage. Only knot-free cores were used and they were held in cold storage until density determinations were made. These measurements were realized by the maximum moisture content method developed by Keylwerth (1954). Increment cores were placed into a desiccator filled with distilled water. Cycles of 24 h of vacuum and 24 h of atmospheric pressure were applied in order to ensure that the samples have reached their maximum moisture content. After that, they were weighed both in air and under water on a Mettler electronic balance (measured to 0.00001 g), and then oven-dried at 103 ± 2 C for 24 h. After cooling, their oven-dry weights were measured to the nearest 0.00001 g. The increment core density is reported on an oven-dry weight to green volume ratio.

In order to calculate the weighted wood density of the merchantable stem, the inner bark diameter of each disk was recorded. This weighted wood density was estimated between 0.5 m and 4.5 m above the ground, according to the formula used by Verville (1981). On the other hand, the means presented are simple averages calculated from two to four trees in each clone or from twenty-seven and seven trees from both hybrids. Analyses of variance were conducted on the data with the significance given to the 95% and 99% probability level.

RESULTS AND DISCUSSION

The overall average wood density of the merchantable portion of the stem is 349.5 kg/m^3 where averages for individual trees range from 284.4 kg/m^3 to 407.0 kg/m^3. Table 1 shows the average values for each clone. The average wood density of the euramericana hybrid is close to the average value of native Canadian eastern cottonwood reported by Jessome (1977), but it is slightly lower than that reported for the commercial eastern cottonwood growing in the United States (Walters and Bruckmann 1965; Farmer and Wilcox 1966, 1968; Farmer 1970a, b).

Interclonal, intraclonal, and within-tree variation of wood density

The analysis of variance for the *P.* × *euramericana* clones (Table 2), carried out on the arithmetic average of two wedges at each height, indicated that significant differences exist between the average wood density of the ten clones. Trees within clones and heights within trees also have a significant effect on wood density.

Interclonal variation and heritability of wood density.—The analysis indicated that there are significant differences among the ten clones for wood density (Table 2). The estimated variance components suggested that the effect of clones accounts for approximately 64% of the total variation (phenotypic variation) of this property. This ratio of variance components, referred to as broad-sense heritability, was calculated on an individual tree basis. Similar heritability values for euramericana hybrids have also been reported by Nepveu et al. (1978) as well as for eastern cottonwood clones (Farmer and Wilcox 1968; Farmer 1970a). Heritability is somewhat high, but this can be explained in part by the fact that all clones came from the same site, thus reducing the environmental variation. Therefore, the variance ratios obtained on the wood density of euramericana poplar hybrid appear to be under relatively strong genetic control. Since there was such a significant difference between the clones, Duncan's multiple-range test was ap-

TABLE 2. *Analysis of variance of wood density for ten* Populus × euramericana *clones.*

Source	df	Type III sum of squares	Mean squares	F	Variance components[1]
Clone	9	70,218.31	7,802.03	71.81**[2]	403.22 (s_c^2)
Tree	3	3,480.09	1,160.03	10.68**	82.11 (s_t^2)
Height	3	5,455.30	1,818.43	16.74**	100.27 (s_h^2)
Clone × height	27	6,274.61	232.39	2.14**	
Tree × height	9	725.97	80.66	0.74 ns[3]	
Error	137	14,885.03	108.65		48.50 (s_e^2)
Corrected total	188	101,039.31	537.44		634.10

[1] As calculated by the nested procedure.
[2] **, significant at 99% probability level.
[3] ns, nonsignificant at 95% probability level; broad-sense heritability $H^2 = 0.64$.

plied to determine which of the clones may differ at the 95% probability level. Results are presented in Table 3. The practical implication of these tests for silviculturists is that if a range of clones is available, it should be possible to select one that will have a high density or low density, depending on the end use of the wood. In this study, clones 3005, 37, and 205 would be preferred to clones 3308, 131, and 136 if denser wood was desired. Judging by the lack of significant clone-site interaction in the works of Farmer and Wilcox (1968) and Nepveu et al. (1985), this selection, although restricted to particular site conditions, could be extended to other sites without appreciable loss of valuable clones. However, this assumption must be more substantiated by other works before a generalization for poplar hybrids can be made.

Intraclonal and within-tree variation of wood density.—The analysis of variance also shows that there is a significant difference between trees within clones but accounts for only 13% of the phenotypic variation (Table 2). This low intraclonal variation can be explained in part by the fact that this investigation has considered only one particular site, hence limiting the environmental variation. Furthermore, this behavior of the wood density variation for different poplars coming from only one site has been noticed in previous works. In fact, measurements obtained on three poplar hybrid clones (*P. maximowiczii* × *P. trichocarpa*; *P.* cultivar Angulate × *P. trichocarpa*; *P. maximowiczii* × *P.* cultivar Berolensis) have shown that planting trees at different spacings does not affect the wood density of these hybrids (Holt and Murphey 1978; Murphey et al. 1979). Yanchuk et al. (1983) tested wood density variation of trembling aspen and reported an absence of variation among trees for three clones of this species. This suggests that wood quality studies on poplar hybrids could consider this behavior in their sampling techniques.

On the other hand, there is also a significant difference between the four sampling heights

TABLE 3. *Duncan's multiple-range test of wood density for ten* Populus × euramericana *clones.*

Clone code	3005	37	205	3301	3307	1102	1132	3308	131	136
Density (kg/m³)	370.4	366.3	364.6	362.0	360.3	355.9	352.7	334.8	323.7	302.4

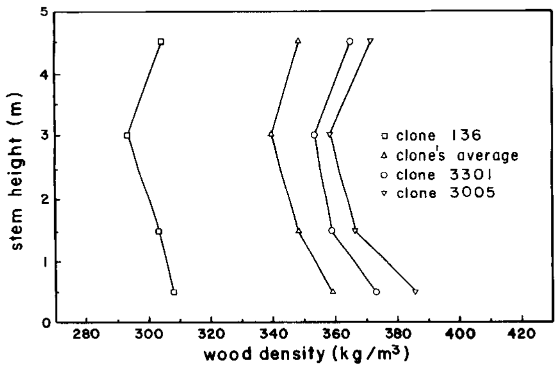

FIG. 2. Wood density variation as a function of stem height for some euramericana poplar clones.

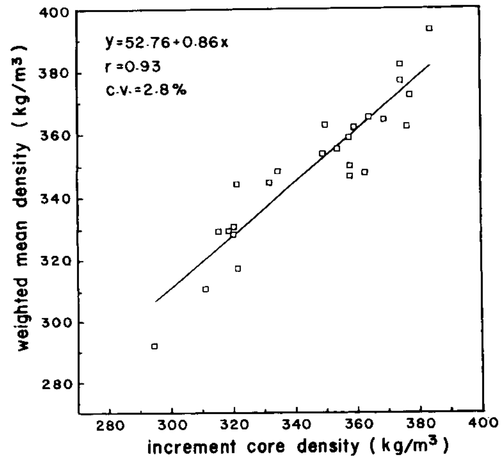

FIG. 3. Weighted average density of the stem as a function of the increment core density for ten euramericana poplar clones.

within trees, which explains about 15% of the phenotypic variation (Table 2). The pattern of variation of wood density as a function of height in the stem is shown in Fig. 2. The wood density is high at the base of the stem, decreases at the mid-height, and increases near the top of the merchantable stem. Similar patterns of wood density variation in the axial direction have also been shown in hybrids involving *P. alba, P. grandidentata,* and *P. tremuloides* (Johnson 1942), in *P. trichocarpa* (Okkonen et al. 1972) and in *P. tremuloides* (Yanchuk et al. 1983). The height variation of wood density can be explained essentially by the radial variation of the wood density. In fact, an additional test was carried out with a second increment core obtained at breast height in each tree. These cores were separated in sections of 15 mm each and their wood density was determined. This test revealed that the wood density is high near the pith, decreases at mid-diameter, and increases near the outside of the stem. Wood of trembling aspen also exhibits similar patterns of variation (Yanchuk et al. 1983).

In a study of eastern cottonwood, Isebrands (1972) found that wood produced by the juvenile crown usually had a lower percentage of vessels than the wood formed by a more mature crown. Moreover, he reported a noticeable decrease in the percentage of fibers as tree height increases. If similar differences exist in hybrids of cottonwood, the percentage and size of vessels and fibers, as well as the distribution of tension wood, may be the major underlying causes of wood density variation with height.

Concerning the interactions "clone × height" and "tree × height" presented in Table 3, the difference between these relationships should be considered as meaningless because the wedges at fixed height intervals did not correspond to similar crown positions in all trees.

Relationships between weighted average wood density of the stem and the wood density of the increment core

The possibility of evaluating wood qualities from small nondestructive samples is very interesting to the forest geneticist. Correlations between wood properties measured on increment cores and the wood quality of the whole tree or of the merchantable part of the stem are helpful in evaluating the usefulness of such data. Wood density measurements made on 10-mm increment cores were compared with the weighted wood density of the merchantable part of the stem. Hence, a simple correlation and a simple regression were carried out as a means of evaluating the usefulness of 10-mm breast height increment cores. Figure 3 shows the linear relationship between the wood

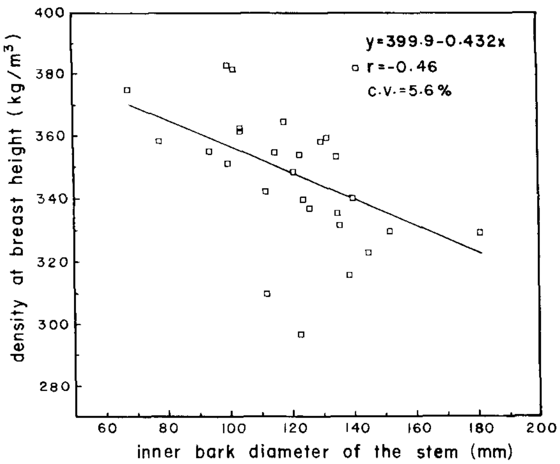

FIG. 4. Wood density at breast height as a function of growth rate for ten euramericana poplar clones.

density of the increment core and the weighted average density of the stem (Y = 52.76 + 0.86x). The coefficient of correlation is significant and positive at +0.93, while the coefficient of variation of 2.8% indicates that the power of prediction of this model is very high. Therefore the wood density of an increment core taken at breast height can be used with reasonable confidence to estimate the wood density of the whole merchantable stem. These results refer only to *P.* × *euramericana* grown on the site in which the sampling was made, although they are in agreement with those reported by a number of researchers including Einspahr et al. (1963).

Relationship between wood density and growth rate

In general, poplar hybrids have a rapid growing rate, so it is important to know the influence of this growth rate on wood density. According to Kennedy (1968), this influence is rather controversial. In fact, in analyzing data of poplar species and hybrids, he concluded that there is an inverse relationship between growth rate and density. This particularity is somewhat discouraging because the beneficial influence of fast growth rate on the volumetric growth of trees may be counterbalanced for a reduction in density of wood. In our study, Fig. 4 shows that there is indeed a negative correlation ($r = -0.46$) between growth rate (based on the inner bark diameter) and wood density, both measured at breast height. These results also correspond to those reported earlier for *Populus* (Paul 1956; Kennedy and Smith 1959; Cech et al. 1960; Farmer and Wilcox 1966, 1968; Farmer 1970b; Yanchuk et al. 1984). This indicates that growth rate has a weak but significant negative influence on wood density. All this suggests that this relationship is not perfect and that there will be exceptions to the rule; but in clonal forestry these exceptions, called correlation breakers, must be exploited.

CONCLUSIONS

Results from this study led to the following conclusions:

1. An analysis of variance indicates that a significant difference in wood density exists between the ten clones of *P.* × *euramericana* studied and it explains 64% of the phenotypic variation.
2. The intraclonal variation of wood density is also significant, and it is explained by the variation of wood density between trees and between heights within trees.
3. The wood density is high at the base of the tree, decreases at mid-height, and increases near the top of the merchantable stem.
4. A 10-mm-diameter increment core taken bark to bark at breast height can be a good estimator for the density of the whole merchantable stem.
5. There is also a slight significant negative correlation between the growth rate and the wood density at breast height.

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