Research Article

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The within-tree variation in wood density and shrinkage, and their relationship in *Populus euramericana*

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Abstract: The patterns of wood density and shrinkage in different directions in 22-year-old *Populus euramericana* trees from one clone were studied in an experimental plantation in Iran. Sample disks were taken from each tree to examine wood density and shrinkage variation from pith to bark at 5%, 25%, 50%, and 75% of total tree height. The results indicate that radial position and height significantly affected all wood physical properties. Within-tree wood density and shrinkage varied at each height level, decreasing along the stem from the base upwards. Moreover, within the samples, at the same height level wood density and shrinkage in the radial direction increased from the pith outwards. Regression analysis showed that longitudinal, radial, tangential, and volumetric shrinkage each had a significantly positive correlation with wood density.

Key words: *Populus euramericana*, wood density, wood shrinkage, variation, correlation

Introduction

Poplars are fast growing, early maturing species in temperate regions. They represent a potentially large source for timber production. All poplar species and hybrids are easily propagated by cutting and planting, and subsequent treatments are generally not very difficult (Spanos et al. 2001). Poplar tree improvement programs have emphasized improvements in growth, form, adaptability, and disease resistance (Hernandez et al. 1998). Poplar wood, which is light white in color, has no smell or taste, is easy to process, and has been widely used for many years. Some of its most important uses are in veneer, plywood, and saw wood manufacture, matches and match boxes, pulp and paper, and cellulose products (Spanos et al. 2001).

One important factor in the use of poplar is knowledge of the variation in wood properties within a stem; for instance, the wood density for pulping and mechanical processing, and shrinkage for mechanical processing. This leads to better chemical optimization; for example, high wood density is important for chemical pulping, and moderate wood density is the most suitable for plywood production (Moherdiek 1979). As forest product companies are interested in poplar wood for manufacturing a variety of products, clones must meet the specifications of

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diverse end uses requiring different wood characteristics (Zhang et al. 2003).

In general, researchers agree that wood density is one of the most important factors affecting wood quality (Keith 1986; Tsoumis 1991). The methodology for determining the variation in specific gravity within and between trees was studied by Mutibaric and Cemerikic (1971), and Panetson et al. (1969). They studied the influence of wood raw material on shrinkage and swelling properties; however, until now only a few studies on wood shrinkage in poplars have been carried out (Koubaa and Smith 1959; Karki 2001; Pliura et al. 2005). As such, data on the variation within and between poplar trees are not available. Such data are needed to enable the inclusion of wood shrinkage and wood density as selection criteria for the improvement of wood properties that play a major role in the raw material for domestic and industrial uses (Panshin and Dezeeuw 1980).

The objectives of the present study were to investigate the variation in wood density and wood shrinkage in the *Populus euramericana* stem and to examine the relationship between wood density and shrinkage in *Populus euramericana*.

Materials and methods

The sample site was located approximately 17 km north of the Dr. Bahramnia experimental plantation in southwestern Gorgan, Iran. In total, 20 *Populus euramericana* trees of the clone 77/51 were chosen. All the trees were randomly selected, taking into account stem straightness and the absence of obvious decay. The characteristics of the study site and *Populus euramericana* trees are listed in Table 1. The *Populus euramericana* trees were cut for the study in October 2004.

Less than 2 h after harvesting the trees were bucked at 3-m intervals and 4-cm wide slabs were cut through the cross sections of the separated pieces. The slabs were taken directly to the freezer to avoid loss of moisture content. Consequently, the sample disks were taken from different height levels (5%, 25%, 50%, and 75%) of total tree height. Each slab sample was cut from the pith outwards to 2 cm in the longitudinal, radial, and tangential direction, based on ASTM-D143. From each radial sample, between 3 and 6 specimens were collected, depending on the tree diameter at the different height levels of the stems. In sum, 1440 pieces were tested.

The specimens were soaked in distilled water for 72 h to ensure that moisture content was above the fiber saturation point. Then the dimensions in all 3 principal directions were measured with a digital caliper to the nearest 0.001 mm. Samples were weighed to the nearest 0.001 g for saturated weight, and the saturated volume was calculated based on these dimension measurements. The specimens were subsequently placed in a conditioning room at 20 °C and 65% relative humidity (RH) in order to reach a moisture content of approximately 12%. Once this state was reached, the samples were again weighed and the dimensions in all 3 directions were measured. Finally, the samples were oven dried at 103 °C until a constant oven-dry weight was obtained. The same measurements were then made after the samples cooled to room temperature. Thus, wood density, and longitudinal, radial, and tangential directions were measured for each specimen. Wood density was based on the ratio of oven-dry weight to green (saturated) volume. Shrinkage was calculated using the dimensional changes from the green (saturated) to air-dry condition. Differential shrinkage was calculated as the ratio of tangential shrinkage to radial shrinkage.

Table 1. Characteristics of the study location and *Populus euramericana* trees.

Type of climate	Location	Altitude (m)	Mean Annual Temperature (°C)	Annual Rainfall (mm)	Type of Clay	Tree Diameter (mm)	Tree Height (m)	Tree Age
Mediterranean	36°45′N, 54°24′E	300	18	525	spodosols	240	22	20

Statistical analysis was conducted using the SPSS program in conjunction with analysis of variance (ANOVA). Duncan's multiple range test (DMRT) was used to test statistical significance at the $\alpha = 0.05$ level. The simple linear regression model (REG procedure) was used to analyze the relationship between wood density and shrinkage.

Results

Within-tree variation

The results of ANOVA indicate that radial position and height had significant effects on wood density ($P < 0.05$), but the interaction between position and height was not significant. The pattern of variation in wood density, as a function of height in the stem, is shown in Table 2. Within tree wood density at each height level decreased from the base upwards; however, *Populus euramericana* wood density was the highest at 5% of total tree height. Within the samples, at the same height level wood density increased from the pith to the bark (Table 3).

ANOVA showed that the radial position and height had significant effects on shrinkage ($P < 0.05$), but their interaction was not significant. The pattern of variation in shrinkage, as a function of the height in the stem, is shown in Table 2. Within-tree longitudinal, radial, tangential, and volumetric shrinkage at each height level decreased along the stem, from the base upwards; however, wood shrinkage was the highest at 5% of total tree height. As shown in Table 3, within the samples, at the same height levels, shrinkage increased from the pith outwards.

Correlation between wood density and shrinkage

Few studies have analyzed the correlations between wood density and wood shrinkage in poplars and their hybrids. In the present study statistically significant regression equations between wood density and shrinkage are shown in Figures 1-4; the relationship between wood density and shrinkage was statistically significant. This result shows that wood density was positively correlated with volume shrinkage (Figure 1), tangential shrinkage (Figure 2), and radial shrinkage (Figure 4) in *Populus euramericana*. It also shows that volumetric, tangential, and radial shrinkage increased as wood density increased, but this result indicates that there was a weak positive correlation between longitudinal shrinkage and wood density (Figure 3), and that longitudinal shrinkage in some species tends to decrease as wood density increases.

Discussion

Karki (2001) reported that the wood density of the European aspen is highest in the living crown, and at lower heights of up to 12 m wood density is higher just beneath the bark, rather than in the pith. Some researchers have reported that wood density increases with age or distance from the pith (Boyce and Kaiser 1961; Farmer and Wilcox 1968; Bonneman 1980). This is supported by the fact that juvenile wood is usually known to be of lower density than mature wood (Dadswell 1958; Zobel and Buijtenen 1989). Similar patterns of wood density variation in the axial direction have also been reported in hybrids involving *P. alba*, *P. grandidentata*, and *P. tremuloides* (Johnson 1942), in *P. trichocarpa* (Okkonen et al. 1972), and in

Table 2. Variation in wood density and shrinkage in various directions at different height levels within the stem of Popu*lus euramericana.*

Height Levels of Total Tree	Wood Density (kg m^{-3})	Longitudinal Shrinkage (%)	Radial Shrinkage (%)	Tangential Shrinkage (%)	Volume Shrinkage (%)
5%	360.85 ± 2.74 a	0.19 ± 0.008 a	3.84 ± 0.18 a	6.15 ± 0.19 a	10.19 ± 0.36 a
25%	344.40 ± 3.03 b	0.16 ± 0.009 a	3.39 ± 0.19 ab	5.31 ± 0.20 b	8.86 ± 0.41 b
50%	339.25 ± 3.57 b	0.13 ± 0.01 b	3.24 ± 0.21 ab	4.79 ± 0.23 b	8.16 ± 0.45 b
75%	329.33 ± 3.87 c	0.11 ± 0.01 b	2.96 ± 0.25 b	3.79 ± 0.26 c	6.87 ± 0.52 c

Table 3. Variation in wood density and shrinkage in various directions, according to stem height and distance from the pith to the bark in *Populus euramericana.*

Height Levels of Total Tree	Distance from the Pith (cm)					
	1	3	5	7	9	11
5%						
Wood density (kg m^{-3})	339 ± 11.73 a	356 ± 35.02 b	359.1± 8.64 bc	363 ± 11.59 c	369 ± 11.73 c	379 ± 11.73 d
Longitudinal shrinkage (%)	0.24 ± 0.04 a	0.22 ± 0.05 a	0.21 ± 0.06 ab	0.18 ± 0.05 b	0.15 ± 0.05 bc	0.13 ± 0.06 c
Radial shrinkage (%)	2.41 ± 044 a	2.50 ± 0.33 a	3.23 ± 0.84 b	4.24 ± 0.44 c	4.83 ± 0.22 c	5.68 ± 0.22 d
Tangential shrinkage (%)	5.28 ± 0.58 a	5.51 ± 0.33 ab	5.89 ± 0.84 b	6.16 ± 0.44 bc	6.87 ± 0.44 cd	7.19 ± 0.44 d
Volume shrinkage (%)	7.92 ± 0.06 a	8.23 ± 0.95 b	9.42 ± 0.79 c	10.66 ± 0.03 c	11.78 ± 0.07 d	13.04 ± 0.06 d
25%						
Wood density (kg m^{-3})	330 ± 14.14 a	335 ± 10.81 a	347 ± 13.37 b	350 ± 14.14 bc	360 ± 14.14 c	-
Longitudinal shrinkage (%)	0.21 ± 0.05 a	0.19 ± 0.06 ab	0.16 ± 0.07 b	0.14 ± 0.07 bc	0.12 ± 0.07 c	-
Radial shrinkage (%)	2.30 ± 0.60 a	2.65 ± 0.61 b	3.23 ± 0.44 c	3.85 ± 0.44 cd	4.92 ± 0.44 d	-
Tangential shrinkage (%)	4.27 ± 0.75 a	4.48 ± 0.43 ab	5.28 ± 0.94 b	5.90 ± 0.94 bc	6.37 ± 0.94 c	-
Volume shrinkage (%)	6.78 ± 0.76 a	7.33 ± 0.55 ab	8.67 ± 0.15 b	9.84 ± 0.76 c	11.70 ± 0.76 d	-
50%						
Wood density (kg m^{-3})	330 ± 29.05 a	337 ± 14.94 b	340 ± 29.05 bc	350 ± 29.05 c	-	-
Longitudinal shrinkage (%)	0.15 ± 0.03 a	0.14 ± 0.06 ab	0.12 ± 0.06 b	0.11 ± 0.06 b	-	-
Radial shrinkage (%)	2.23 ± 0.36 a	2.82 ± 0.78 ab	3.55 ± 0.78 b	4.36 ± 0.78 c	-	-
Tangential shrinkage (%)	4.03 ± 0.89 a	4.46 ± 0.29 ab	5.11 ± 0.29 bc	5.56 ± 0.29 c	-	-
Volume shrinkage (%)	6.39 ± 0.83 a	7.43 ± 0.82 b	8.78 ± 0.83 bc	10.03 ± 0.83 c	-	-
75%						
Wood density (kg m^{-3})	326 ± 29.51 a	330 ± 29.51 a	336 ± 29.51 b	-	-	-
Longitudinal shrinkage (%)	0.13 ± 0.07 a	0.11 ± 0.07 ab	0.10 ± 0.07 b	-	-	-
Radial shrinkage (%)	2.41 ± 0.04 a	2.68 ± 0.04 b	3.82 ± 0.04 c	-	-	-
Tangential shrinkage (%)	3.18 ± 0.74 a	3.74 ± 0.74 bc	4.45 ± 0.74 c	-	-	-
Volume shrinkage (%)	5.72 ± 0.78 a	6.53 ± 0.78 b	8.37 ± 0.78 c	-	-	-

Values are mean ± standard deviation. Results with different letters are significantly different (Duncan's test)

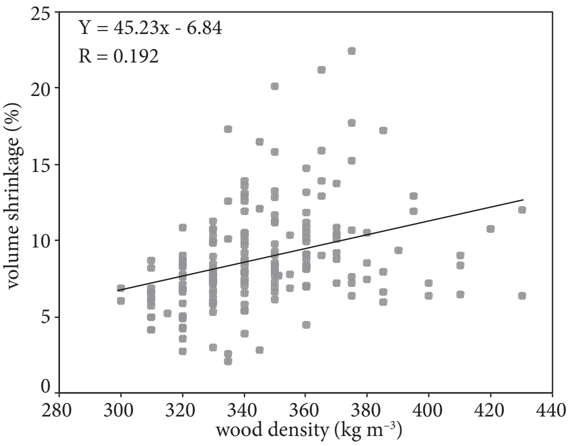

Figure 1. Relationship between wood density and volume shrinkage in *Populus euramericana.*

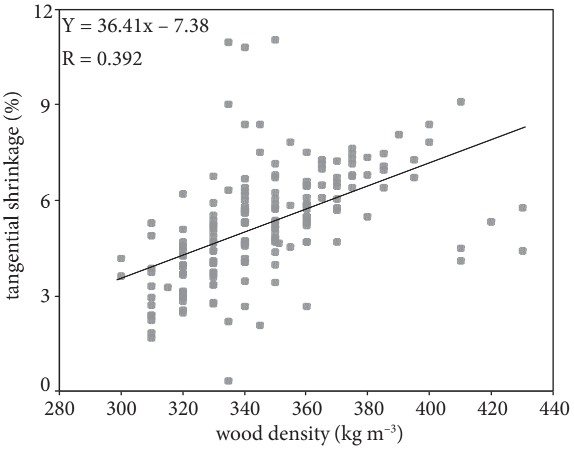

Figure 2. Relationship between wood density and tangential shrinkage in *Populus euramericana.*

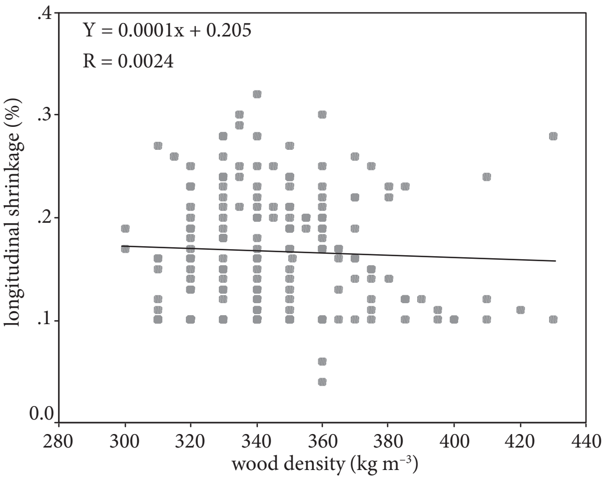

Figure 3. Relationship between wood density and longitudinal shrinkage in *Populus euramericana.*

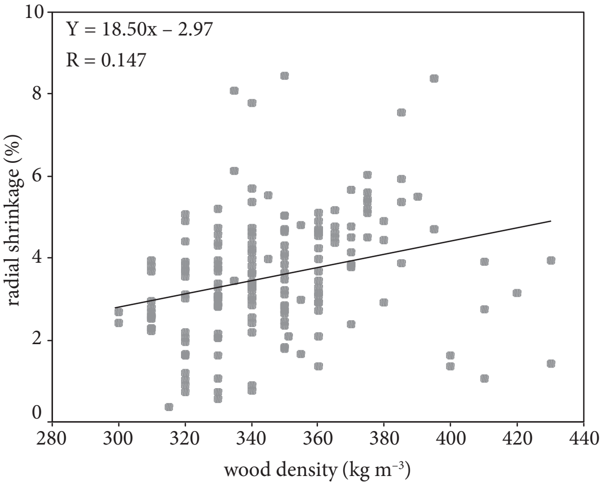

Figure 4. Relationship between wood density and radial shrinkage in *Populus euramericana.*

P. tremuloides (Yanchuk et al. 1984). Wood density changes in the present study may have been due to the inclusion of trees that had entered the wood maturity phase, thus exhibiting a corresponding increase in wood density.

Karki (2001) reported that volume shrinkage in aspen wood is maximal in the middle of the cross-section pith-surface and minimal close to the pith. Longitudinal shrinkage increased slightly upwards from the height of 3 m, radial wood shrinkage was minimal at the stump height and at the height of 15 m, and tangential shrinkage was minimal at the height of 15 m and remained quite steady within the tree (Karki 2001). Dense wood results from fiber with thick walls and a low microfibril angle produces minimal longitudinal shrinkage, and increases radial and tangential shrinkage (Dadswell 1958). Changes in wood shrinkage with cambium age are likely related to radial inter-tree variation in wood density, which often displays an inverse pattern of changes (Johnson 1942; Okkonen et al. 1972; Yanchuk et al. 1984). Jourez et al. (2001) reported a negative relationship to longitudinal shrinkage in normal *P. euramericana* wood, as opposed to a positive relationship to tension wood. Pliura et al. (2005) reported a negative correlation between wood density and longitudinal shrinkage, and positive correlations between density and both radial and tangential shrinkage. Koubaa and Smith (1959) observed significant positive correlations between basic wood density, and radial, tangential, and volumetric shrinkage in *P. euramericana* hybrid clones. The correlations between wood density and longitudinal shrinkage were negative, which is favorable for the improvement of these wood properties in tree breeding programs (Pliura et al. 2005). Timel (1986) also noted that longitudinal shrinkage in some species tends to decrease as wood density increases. Mohrdiek (1979) concluded that there is a negative relationship between wood density and longitudinal shrinkage in some poplars, although this generalization has many exceptions.

The following results were obtained in the present study:

1. ANOVA indicates that significant differences in wood density, and longitudinal, radial, tangential, and volumetric shrinkage existed between the radial position and height in *Populus euramericana* trees.

2. There was a general trend in the radial and axial directions in *Populus euramericana* trees, in which wood density, and longitudinal, radial, tangential, and volumetric shrinkage increased, from the pith to bark and from the base upwards.

3. There was a positive correlation between wood density, and radial, tangential, and volumetric shrinkage; however, longitudinal shrinkage was weakly correlated with wood density.

4. Wood near the bark and close to the bottom of *Populus euramericana* trees are suitable for pulp and paper making, and veneer, plywood, and saw wood manufacture, as the dense wood has fiber with thick walls and a low microfibril angle. Additionally, other parts of *Populus euramericana* wood are suitable for matches and boxes.

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