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EMPIRICAL STATISTICAL MODEL FOR PREDICTING WOOD PROPERTIES OF *Paulownia fortunie.* PART 1: PHYSICAL AND BIOMETRICAL PROPERTIES

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ABSTRACT

This paper describes the development of model to predict the within-tree variation of wood density, shrinkage, fiber length, fiber diameter and cell wall thickness from pith-to-bark and bottom-to-top, using data collected from a 13-year-old paulownia (*Paulownia fortunie*) stand where trees were planted in an experimental plantation in Iran. The sample disks were taken from each tree to examine the wood density, shrinkage, fiber length, fiber diameter and cell wall thickness variation from pith to bark at 5, 25, 50 and 75% of the total tree height. The study was laid out in a randomized complete block design. Linear prediction model were developed using longitudinal direction (bottom-to-top) and radial direction (pith-to-bark) indices as explanatory variables. The results indicated that, the wood density, shrinkage, fiber length, fiber diameter and cell wall thickness, considerably changes from pith to bark and from the base upwards. Based on the final model, it was found that the physical and biometrical properties were significantly influenced by longitudinal and radial directions. The model equation were based on the model used to describe the within-tree variation in the wood density, shrinkage, fiber length, fiber diameter and cell wall thickness of *Paulownia*, and is functions of radial and longitudinal directions.

Keywords: Density, fiber length, *Paulownia fortunie*, shrinkage, within-tree variation.

INTRODUCTION

Paulownia is an extremely fast-growing deciduous tree species with vegetative propagation and tolerance to different soil and climate conditions and is original of China and its natural distribution ranges from tropical through to cool temperate climates. Paulownia is an appropriate tree for intensive management in short rotation hardwood plantations because of its rapid growth, its ability to stump sprout, in exact words, paulownia does not require replanting after harvest because it regenerates from stump sprouts (Kang *et al.* 1999, Zhu *et al.* 1986). Besides, the use of short rotation forestry plantations is a promising tool for reducing atmospheric carbon dioxide concentration through fossil fuel substitution (Hakan Akyildiz and Kol 2010). It is soft, lightweight, ring porous, straight-grained, and mostly knot-free with a satiny luster. Under appropriate conditions, a 5- to 7-year-old tree can reach a height of about 15–20 m and the annual production is as much as 150 t/ha (Kalaycioglu *et al.* 2001, Hakan Akyildiz and Kol 2010). Paulownia wood is used for a variety of applications such as furniture, construction, musical instrument, shipbuilding, aircraft, packing boxes, coffins, paper, plywood, cabinetmaking, and molding (Clad and Pommer 1980). Paulownia wood is marketed primarily for specialty solid wood products, oriented strand board, veneer, and for pulp to produce fine papers (Bergmann 1998, Rai *et al.* 2000).

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The wood properties have been reported to depend on such factors as climatic, provenance, ecological conditions, as well as wood positions in different parts of tree, between, and within species (Koch 1985, Haygreen and Bowyer 1982). Wood properties such as density, fiber length and chemical components determine the end-product quality in industrial processes and are both positively correlated with tear strength (Einspher *et al.* 1967, Koch 1985, Haygreen and Bowyer 1982). Wood basic density is considered one of the most important features in "genetic improvement programmers", and it is one of the most often studied wood quality traits. It is a complex feature influenced by cell wall thickness, the proportion of the different kind of tissues, and the percentages of lignin, cellulose and extractives (Panshin and De Zeeuw1980, Zobel and Buijtenen 1989). Both physical and biometrical characteristics of wood determine whether the quality of raw material is suitable for a specific use in the paper industry. Fiber length also has impacts on paper characteristics, such as strength, optical properties and surface quality (Dadswell 1958, Farmer and Wilcox1968, Panshin and De Zeeuw1980, Zobel and Buijtenen 1989).

Considering the increasing demand for new species from fast-growth plantations as alternative timbers for hardwood, and because there is little or no information about the variation of wood biometrical dimensions, density, shrinkage, and chemical components above mentioned properties within stem, even though these characteristics are a means of assessing the pulp and paper making and the dimensional stability of wood (Panshin and De Zeeuw1980, Zobel and Buijtenen 1989).

There are good reasons to predict wood properties in the forest instead of at the mill from a logistic point of view. If measurements of wood properties are taken at mill gates it is too late to redirect the wood to another, more suitable mill without incurring considerable extra costs. In planning of wood flows it may be possible and desirable to determine not just wood volumes, but the amount of wood with predicted properties. This offers new scope for matching supplies to industrial requirements. Detailed stand and tree information only available in the forest could improve the property description of the wood flow. However, the cost of providing relevant input data is a crucial issue for the application of prediction models in forestry planning and harvester assessing systems. Models based on existing or easily measured input data are clearly preferable if they are to be of practical use (Cown *et al.* 1999, Wilhelmsson *et al.* 2002, Gardiner *et al.* 2011, Antony *et al.* 2012).

Thus, the objectives of this study are: (a) to investigate the variation of within-tree physical and biometrical property indices of wood from *Paulownia*, (b) to develop model for predicting wood properties in *Paulownia*.

EXPERIMENTAL

Materials

A total of five trees from the *Paulownia* (*Paulownia fortunie*) were harvested from Shastcolateh educational Forest, Groan (Iran). All trees were randomly selected, taking into account the stem straightness and the absence of obvious decay. The characteristics of site location and paulownia trees are listed in table 1. The paulownia trees were cut for the study in June 2012. Less than two hours after the harvest, the trees were bucked at three meter 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 losing their moisture content. Consequently, the sample disks were taken at different height levels: 5%, 25%, 50% and 75% of the total tree height. Each of the slab samples were cut from the pith outwards at the dimension of 2 cm in the longitudinal, radial and tangential direction based on the ASTM D143. From each radial sample, between 3 and 6 specimens were collected, depending on the tree diameter at different height levels within the stems.

Table 1. The characteristics of site location and *Paulownia fortunie* trees.

Type of climate	Mediterranean
Direction	36° 45′ N 54° 24′ E
Altitude (m)	300
Mean Annual Temperature (°C)	18
Annual Rainfall (mm)	525
Type of Clay	Spodosols
Tree Diameter (mm)	275
Tree Height (m)	21
Tree Ages	13

These specimens were soaked in the distilled water for 72 hours to ensure the moisture content above the fiber saturation point. At this point, the dimensions in all three principal directions were taken 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) with to reach approximately 12% moisture content. Once this state was reached, the samples were weighed again, and dimensions were measured in all three directions. Finally, the samples were oven dried at 103 ± 2 °C until a constant oven-dry weight was attained. The same measurements were taken on the oven-dry specimens after samples were cooled by the room temperature. Thus, wood density, longitudinal, radial and tangential directions were measured for each specimen with 50 replicates. The values of physical properties were calculated using the following equations:

$$D_o = \frac{m_o}{v_o} \times 100, \text{ oven-dry density} \quad (1)$$

$$D_b = \frac{m_o}{v_s} \times 100, \text{ basic density} \quad (2)$$

$$B_v = \frac{v_s - v_o}{v_s} \times 100, \text{ volume shrinkage} \quad (3)$$

where m_o, v_o *and* v_s are the oven-dried weight, oven-dried volume and saturated volume of specimen respectively.

Maceration was carried out as Franklin method (1964) for all the samples. In this method, small slivers of wood were taken from the samples collected into the test tube and then filled with 30% hydrogen peroxide and glacial acid in a 64 °C oven for 24 hours. After that, the material was thoroughly washed with distilled water till traces of the acid were removed. The mixture was shaken thoroughly to separate the wood elements and stained with 1 % safranin and mounted in glycerine on microscopic slides. The measurements of wood fiber elements were made from macerated material, with the help of ocular-stage micrometry. One hundred measurements were made from unbroken fibers for fiber length (Fl), fiber diameter (Fd) and cell wall thickness (Cw).

The main statistical analyses were performed using the SPSS software. Multiple regression and analysis of variance was used to analyze the response variables (oven-dry density, basic density, volume shrinkage, fiber length, fiber diameter and cell wall thickness) in terms of the two explanatory variables:

longitudinal direction (at different height levels with the stem or from the bottom to the top of tree) and radial direction (at different distance from the pith to the bark) in the paulownia stem. The analysis of variance was used to evaluate the significance of terms in both the fixed and the random effects and also to test the significance of the correlation. Only those parameters that were significant (P < 0,05) were retained in the final models. Model performance was evaluated from visual analyses of residuals plots and with the following error statistics, calculated from the fixed part of each model:

$$E = \frac{\sum y_i - \hat{y}_i}{n}, \text{ mean error} \quad (4)$$

$$|E| = \frac{\sum |y_i - \hat{y}_i|}{n}, \text{ mean absolute error} \quad (5)$$

$$RMSE = \sqrt{\frac{\sum (y_i - \hat{y}_i)^2}{n}}, \text{ root-mean-square error} \quad (6)$$

$$E\% = \frac{100}{n} \sum \frac{|y_i - \hat{y}_i|}{\hat{y}_i}, \text{ mean percentage error} \quad (7)$$

where y_i is the observed value, $\hat{y}_i$ the predicted value and n is the number of observations.

For model a fit index (R^2) was also calculated. Two sets of fit indices were calculated. In the first set, the predicted values ($\hat{y}_i$) were estimated from only the fixed-effects terms of each model, and in the second they were calculated from the fixed and random effects combined. In the model, the wood properties have the general form as:

$$Y_{ij} = \mu + f(A, B, C, ...) + R_i + L_j + \varepsilon_{ij} \quad (8)$$

Where Y_{ij} = measured wood property, μ= intercept, = the specific function of explanatory variables for wood property, R_i = radial direction (from the pith to the bark), and L_j is the longitudinal direction (from the bottom to the top).

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RESULTS AND DISCUSSION

The result of within-tree variation of physical properties is shows in Tables 2 and 3. Within the tree, the oven-dry density, basic density and volume shrinkage significantly decreased at each height level from the base upwards. Also, within the samples, at the same height levels, the oven-dry density, basic density and volume shrinkage increased form the pith to the bark. An analysis of variance showed that variables (radial and longitudinal direction) had significant difference on the oven-dry density, basic density and volume shrinkage of paulownia Also, the interaction between variables was significant on the physical properties of paulownia. Significant differences between groups were determined individually for these tests by Duncan's multiple comparison tests. The results of Duncan's grouping are shown in Tables 1 and 2 by letters. The highest oven-dry density (356 $kg.m^{-3}$), basic density (370 $kg.m^{-3}$) and volume shrinkage (11,32 %) values were measured for wood near the bark at 5% of the total tree height. Besides, the lowest oven-dry density (310 $kg.m^{-3}$), basic density (319 $kg.m^{-3}$) and volume shrinkage (5,88 %) values were determined for wood near the pith at 75% of the total tree height. Some researchers have found that the wood density increase with age or distance from pith (Bonneman 1980, Boyce and Kaiser 1961, Farmer and Wilcox 1966). This is supported by the fact that the juvenile wood is usually known to be of the lower density than the mature wood (Dadswell 1958, Zobel and Buijtenen 1989, Lachenbruch *et al.* 2011, Vallejos *et al.* 2015). The wood density changes in the present experiment may be due to the trees which have entered the wood maturity phase and thus displayed a corresponding increase in wood density. The dense wood results from the fiber with thick walls and low microfibril angle produce high volumetric shrinkage (Dadswell 1958, Zobel and Buijtenen 1989, Lachenbruch *et al.* 2011). Changes in the wood shrinkage with cambium age are likely related to the radial inter tree variation of the wood density, which often displays an inverse pattern of changes (Johnson 1942, Okkonen *et al.* 1972, Yanchuk *et al.* 1983, Kord *et al.* 2010).

Based on the findings in this study, desirable values for density may be provided by either the 5% of height level and near the bark of stem, since the preference for high or low density in a species depends on the desired end-use (Zobel and Buijtenen 1989). Lachenbruch *et al.* 2011, reported that high-density wood is preferred for construction and furniture uses and it has generally been assumed to be preferable for pulping. However, if the main purpose is the conversion to sawn lumber, then high density will confer the best strength properties and high density should be the criterion when selecting for this feature. Also, the higher density species tend to have stronger modulus of elasticity (low stiffness) and bending strength than lower density species (Zobel and Buijtenen 1989). Numerous studies (Johnson 1942, Dadswell 1958, Okkonen *et al.* 1972, Zobel and Buijtenen 1989, Lachenbruch *et al.* 2011, Vallejos *et al.* 2015) have shown that that the shrinkage influences on wood stiffness and dimensional stability. These strong property gradients lead to warping and twisting of timber. Such dimensional instability can cause significant serviceability problems in timber structures, even if it only affects a small number of the pieces of timber within a structure. Also, Simpson 1991, reported that the maximum moisture content in lumber is important because of its influence in controlling kiln-drying schedules. From a practical standpoint, when determining kiln schedules, the largest number of moisture samples should be selected from the slowest-drying material. Thus, the engineered wood products from paulownia have poorer performance if they are made from corewood near the top of stem.

Table 2. Duncan test results for physical properties of *Paulownia* at longitudinal direction.

Different height levels	Oven-dry density ($kg\ m^{-3}$)	Basic density ($kg\ m^{-3}$)	Volume shrinkage (%)
5%	347,42 ± 9,11[a]	363,09 ± 10,36[a]	11,23 ± 0,49[a]
25%	332,15 ± 8,77[b]	355,28 ± 9,12[b]	9,67 ± 0,33[b]
50%	328,91 ± 7,50[b]	350,72 ± 9,06[bc]	8,34 ± 0,28[c]
75%	319,08 ± 7,19[c]	348,31 ± 8,11[c]	6,71 ± 0,19[d]

Values are mean ± standard deviation.

Table 3. Duncan test results for physical properties of *Paulownia* at radial direction.

Different height levels	Distance from the Pith (cm)					
	1	3	5	7	9	11
5%						
Oven-dry density (kg m^{-3})	325,18 ± 9,54^{a}	331,06 ± 10,15^{b}	339,19 ± 10,64^{b}	345,57 ± 11,14^{c}	351,09 ± 11,73^{d}	356,42 ± 11,90^{d}
Basic density (kg m^{-3})	341,30 ± 11,27^{a}	349,60 ± 11,09^{b}	357,11 ± 11,52^{c}	362,45 ± 12,03^{c}	366,78 ± 12,32^{d}	370,71 ± 12,41^{d}
Volume shrinkage (%)	8,35 ± 0,14^{a}	8,91 ± 0,19^{a}	9,51 ± 0,21^{b}	10,08 ± 0,08b^{c}	10,82 ± 0,10^{c}	11,32 ± 0,17^{d}
25%						
Oven-dry density (kg m^{-3})	320,25 ± 9,13^{a}	326,70 ± 9,52^{a}	330,38 ± 9,13^{b}	337,06 ± 0,11^{bc}	341,10 ± 10,08^{c}	-
Basic density (kg m^{-3})	331,91 ± 10,70^{a}	338,12 ± 10,44^{b}	343,61 ± 10,63^{bc}	350 ± 11,32^{c}	355,52 ± 11,65^{d}	-
Volume shrinkage (%)	7,51 ± 0,10^{a}	8,02 ± 0,08^{b}	8,77 ± 0,13^{b}	9,32 ± 0,15^{c}	10,41 ± 0,22^{d}	-
50%						
Oven-dry density (kg m^{-3})	316,32 ± 8,05^{a}	321,08 ± 8,13^{b}	327,11 ± 9,05^{b}	333,47 ± 8,74^{c}	-	-
Basic density (kg m^{-3})	325,91 ± 9,19^{a}	330,26 ± 9,42^{b}	339,04 ± 9,11^{c}	342,29 ± 9,20^{c}	-	-
Volume shrinkage (%)	6,61 ± 0,06^{a}	7,15 ± 0,09^{b}	7,69 ± 0,05b^{c}	8,14 ± 0,08^{c}	-	-
75%						
Oven-dry density (kg m^{-3})	310 ± 8,10^{a}	316 ± 7,68^{a}	319 ± 8,03^{b}	-	-	-
Basic density (kg m^{-3})	319 ± 8,29^{a}	328 ± 8,77^{a}	339 ± 9,42^{c}	-	-	-
Volume shrinkage (%)	5,88 ± 0,05^{a}	6,20 ± 0,06^{b}	7,16 ± 0,04^{c}	-	-	-

Values are mean ± standard deviation.

The multiple linear regression models (MLR) showed independent evidence for effects of two explanatory variables (radial and longitudinal direction) on the physical properties of paulownia. From these results, a suitable model was selected. The adequacy of the model was residual analysis. Through the estimation of all modeled as a polynomial equation that shows the effect of radial and longitudinal direction on the physical properties. The linear function equation and correlation coefficient obtained is given in Table 4. As can be seen, there is strong relationship between variables and physical properties of *Paulownia*.

Table 4. Multiple regression model of the relationship between variables and physical properties of *Paulownia*.

Model		Coefficients		t	Sig.	R^2
		B	Std. Error			
Oven-dry density	(Constant)	0,479	0,008	61,544	0,005	0,89
	R_i	-0,017	0,002	-9,341	0,002	
	L_j	-0,024	0,002	-11,618	0,008	
Basic density	(Constant)	0,394	0,005	75,188	0,001	0,85
	R_i	-0,008	0,001	-6,917	0,006	
	L_j	-0,017	0,001	-12,026	0,002	
Volume shrinkage	(Constant)	22,167	1,410	15,721	0,004	0,81
	R_i	-2,258	0,327	-6,908	0,003	
	L_j	-2,451	0,382	-6,423	0,005	

The determination coefficient (R^2) between the measured and predicted values is another important indicator to check the validity of the prediction models. As the R^2 values approach 1, prediction accuracy increases. This means that there is a consistent agreement between the measured results and the prediction results. According to table 4, R^2 values for oven-dry density, basic density and volume shrinkage are 0,89; 0,85 and 0,81 respectively. Thus, R^2 values obtained in this study with MLR modeling approach are greater than 0,80% for data sets. This result implies that the model designed is capable of explaining at least 0,8% of the measured data. These values also support the applicability of using MLR. On the other hand, the R^2 value was obtained as 89% in the prediction of oven-dry density with the MLR model. These results indicated that the used models can be considered for accurate predictions, since they have a high explanatory values. By applying the MLR analysis on the same data is obtained the MLR model for physical properties are as follows:

$$D_o = R_i\left(-0,017\right) + L_j\left(-0,024\right) + 0,479$$
$$D_b = R_i\left(-0,008\right) + L_j\left(-0,017\right) + 0,394$$
$$B_v = R_i\left(-2,258\right) + L_j\left(-2,451\right) + 22,167$$

The result of within-tree variation of biometrical properties is shows in Tables 5 and 6. Within the tree, the fiber length, fiber diameter and cell wall thickness of paulownia wood significantly decreased at each height level from the base upwards. Also, within the samples, at the same height levels, the fiber length, fiber diameter and cell wall thickness increased form the pith to the bark. An analysis of variance showed that variables (radial and longitudinal direction) had significant difference on the fiber length, fiber diameter and cell wall thickness of paulownia Also, the interaction between variables was significant on the physical properties of paulownia. Significant differences between groups were determined individually for these tests by Duncan's multiple comparison tests. The results of Duncan's grouping are shown in Tables 6 and 7 by letters. The highest fiber length (µm), fiber diameter (µm) and cell wall thickness (µm) values were measured for wood near the bark at 5% of the total tree height. Besides, the lowest fiber length (µm), fiber diameter (µm) and cell wall thickness (µm) values were determined for wood near the pith at 75% of the total tree height. The increase of the fiber biometry in the paulownia wood near the bark at the bottom of the stem can be attributed to the same reasons as discussed concerning physical property. It is well established that, the juvenile wood has thinner cell walls and smaller cell dimensions as a compared with the mature wood. This is supported by the fact that the juvenile wood has higher fiber length, fiber diameter and cell wall thickness compared to the mature wood (Dadswell 1958, Zobel and Buijtenen 1989, Lachenbruch *et al*. 2011). Based on our findings, the wood near the bark at the bottom of the stem has longer and thicker fibers. Researchers found that fiber characteristic such as fiber length, fiber diameter and cell wall thickness had the greatest influence on the strength properties of pulp (Panshin and Zeeuw 1980, Zobel and Buijtenen 1989, Rai *et al.* 2000, Hedenberg and Olsson 2002, Oluwadare *et al.* 2007). Thus, the samples taken from near the bark at 5% of the total tree height have higher pulp strength properties.

Table 5. Duncan test results for biometrical properties of *Paulownia* at longitudinal direction .

Different height levels	Fiber length (μm)	Fiber diameter (μm)	Cell wall thickness (μm)
5%	838,13 ± 20,16^{a}	24,58 ± 10,36^{a}	762,19 ± 13,41^{a}
25%	806,49 ± 17,38^{b}	21,09 ± 9,12^{b}	739,71 ± 10,50^{b}
50%	764,72 ± 15,60^{c}	17,23 ± 9,06^{c}	705,07 ± 9,33^{b}
75%	729,61 ± 12,02^{c}	14,51 ± 8,11^{d}	688,19 ± 9,11^{c}

Values are mean ± standard deviation.

Table 6. Duncan test for biometrical properties of *Paulownia* at radial direction.

Different height levels	Distance from the Pith (cm)					
	1	3	5	7	9	11
5%						
Fiber length (μm)	815,46 ± 14,32^{a}	823,74 ± 13,08^{a}	831,18 ± 15,11^{b}	840,26 ± 15,18^{bc}	847,09 ± 14,66^{c}	855,32 ± 15,12^{d}
Fiber diameter (μm)	21,62 ± 3,20^{a}	23,75 ± 3,06^{b}	25,18 ± 3,41^{bc}	26,33 ± 2,87^{c}	28,67 ± 3,16^{d}	30,09 ± 3,69^{d}
Cell wall thickness (μm)	738,14 ± 9,23^{a}	746,91 ± 9,40^{a}	762,07 ± 9,17^{b}	771,35 ± 10,11b^{b}	784,63 ± 10,27^{c}	795,47 ± 10,48^{d}
25%						
Fiber length (μm)	796,80 ± 12,05^{a}	810,26 ± 10,70^{b}	823,19 ± 10,26^{c}	834,6 ± 11,08^{d}	838,75 ± 11,22^{d}	-
Fiber diameter (μm)	19,45 ± 2,18^{a}	21,56 ± 2,29^{b}	23,07 ± 2,11^{b}	24,87 ± 2,79^{c}	26,19 ± 3,05^{d}	-
Cell wall thickness (μm)	726,81 ± 8,74^{a}	733,19 ± 8,85^{a}	742,67 ± 8,49^{b}	758,16 ± 9,01^{c}	766,39 ± 9,22^{d}	-
50%						
Fiber length (μm)	774,19 ± 8,03^{a}	792,36 ± 8,40^{b}	813,46 ± 9,18^{c}	820,47 ± 9,36^{c}	-	-
Fiber diameter (μm)	17,16 ± 2,43^{a}	19,60 ± 2,16^{b}	21,14 ± 1,88^{c}	23,59 ± 2,43^{d}	-	-
Cell wall thickness (μm)	714,22 ± 7,59^{a}	728,07 ± 7,66^{b}	739,15 ± 7,58b^{c}	750,82 ± 7,67^{d}	-	-
75%						
Fiber length (μm)	760,48 ± 8,10^{a}	784,39 ± 7,21^{b}	802,83 ± 8,11^{c}	-	-	-
Fiber diameter (μm)	16,08 ± 1,88^{a}	18,05 ± 1,33^{a}	20,17 ± 1,55^{c}	-	-	-
Cell wall thickness (μm)	708,43 ± 7,14^{a}	718,57 ± 7,21^{b}	730,97 ± 7,40^{c}	-	-	-

Values are mean ± standard deviation.

The multiple linear regression models (MLR) showed independent evidence for effects of two explanatory variables (radial and longitudinal direction) on the biometrical properties of paulownia. From these results, a suitable model was selected. The adequacy of the model was residual analysis. Through the estimation of all modeled as a polynomial equation that shows the effect of radial and longitudinal direction on the biometrical properties. The linear function equation and correlation coefficient obtained is given in Table 7. As can be seen, there is strong relationship between variables and biometrical properties of Paulownia.

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Table 7. Multiple regression model of the relationship between variables and biometrical properties of *Paulownia*.

Model		Coefficients		t	Sig.	R^2
		B	Std. Error			
Fiber length	(Constant)	861,079	6,203	138,813	0,002	0,97
	R_i	38,800	1,438	26,986	0,007	
	L_j	-29,255	1,679	-17,424	0,001	
Fiber diameter	(Constant)	19,364	0,140	138,545	0,005	0,93
	R_i	0,339	0,032	10,460	0,002	
	L_j	-0,534	0,038	-14,105	0,003	
Cell wall thickness	(Constant)	4,385	0,042	105,568	0,003	0,98
	R_i	0,197	0,010	20,485	0,008	
	L_j	-0,206	0,011	-18,317	0,002	

According to Table 4, R^2 values for fiber length, fiber diameter and cell wall thickness are 0,97; 0,93 and 0,98; respectively. Thus, R^2 values obtained in this study with MLR modeling approach are greater than 0,92% for data sets. This result implies that the model designed is capable of explaining at least 0,92% of the measured data. These values also support the applicability of using MLR. On the other hand, the R^2 value was obtained as 98% in the prediction of cell wall thickness with the MLR model. These results indicated that the used models can be considered for accurate predictions, since they have a high explanatory values. By applying the MLR analysis on the same data is obtained the MLR model for biometrical properties are as follows:

$$Fl = R_i(38,80) + L_j(-29,255) + 861,079$$
$$Fd = R_i(0,339) + L_j(-0,534) + 19,364$$
$$Cw = R_i(0,197) + L_j(-0,206) + 4,385$$

CONCLUSIONS

The following conclusions are obtained from this study:

The wood density, shrinkage, fiber length, fiber diameter and cell wall thickness of paulownia changed considerably with respect to sampling in longitudinal and radial direction.

Based on the final model, it was found that the physical and biometrical properties were significantly influenced by longitudinal and radial directions indices as two explanatory variables.

The model was designed to be practical and useful for determining the optimal rotation period in paulownia for industrial requirements.

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