

ANNUAL GROWTH RINGS THICKNESS AND TREES TOTAL VOLUME ESTIMATE OF *Acacia melanoxylon* IN PORTUGAL

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ABSTRACT

This text presents some results on the variation of Blackwood (*Acacia melanoxylon* R. Br.) annual growth rings thickness in Portugal, as well as the best models to evaluate total volumes stand trees, under or over-bark.

Annual ring thickness evaluations were done on 261 wood sample disks collected at the usually used levels. With the purpose of obtaining those disks, 20 sample trees of 40cm *dbh* were harvested in four northwest sites of Portugal.

The study of earlywood and latewood thickness leads to the conclusion that the wood type is responsible for 16% of ring size variance, and earlywood is 61% larger in average than latewood. The site, number of ring and its interaction are responsible for 12% of annual woody increment variation. Respective residuals are very relevant in both cases - 75 and 88%.

Based on the study of those wood variables, the four places were arranged into three independent homogeneous groups. Differences between averages of earlywood and latewood thickness were significative, as well as those between North and South exposures.

The selected model ($v = \beta_1 * d^{\beta_2} * h^{\beta_3}$) that uses sites as *dummy* variables for stand tree volumes estimation is also presented. Maximum expected errors perform values between 155dm³ to mean maximum volumes of 1362dm³ under-bark, and 169dm³ to mean maximum volumes of 1459dm³ over-bark.

Keywords: Blackwood, earlywood, latewood, modelling, volumes estimates.

1. INTRODUCTION

The models used to evaluate stand tree volumes of this species stands in Portugal are almost a non-existent tool. This fact may be a consequence of the prevailing idea that, like others in the same *genus*, they are aliens of forest spaces. However, it cannot be forgotten, at least by its eventual interest in carbon sequestration. Also, it will not be negligible as generative of biomass for energetic production in forest biomass factories with very interesting growth rates, and by its capacity of nitrogen fixation and soil fertility improvement (Tavares *et al.*, 1999a; Tavares *et al.*, 1999b). Moreover, its sand soils fixation and consequent protective action as well as its less inflammability than the high pyrophyte index woody species that mostly colonize forest soils – the maritime pine and the eucalyptus (Santos *et al.*, 2006; Tavares *et al.*, 1999a; Goes, 1991) -, must be mentioned.

Recent studies have also shown that wood of acacia presents good paper potentialities, namely in the production of writing and printing papers (Santos *et al.*, 2006) as well as for solid wood products manufacturing (Nicholas *et al.*, 2002).

The eventual utilization of this woody species induces the construction of a model to evaluate total volume of stand trees, with and without bark. The acacia-tree stands, which are frequently mixed with maritime pine, eucalyptus or other hardwood species, but are also pure stands, can be an option to profit from spaces potentiality where Blackwood spontaneously appears and imposes its presence, shortly producing long, thick and rectilinear stems.

In the north of the country this species presents an annual diameter growth that will be greater than the one of maritime pine and will be close to the one of eucalyptus. Therefore, it is a strong

concurrent in wood producing (Freire *et al.*, 2003). Furthermore, its wood material properties present a contained variability, what sets up a good sign to the industrial processing (Santos *et al. in press*).

There are some methodological examples in the bibliography used for gathering data and modelling the volumetric evaluation of this *Genus* species (Sousa, 1974; Veiga *et al.*, 2000). However, Schneider (2003) uses *dummy* variables as a modelling method to the sampled places, which enables to identify individual growth differences between places and to minimize the estimative errors. This was also our methodology.

The objective of this work was to understand the *Acacia melanoxylon* growth rings thickness standard and to construct equations to evaluate its total stand volume through annual diametric increasing estimates.

2. MATERIALS AND METHODS

The 5 *Acacia melanoxylon* sample trees used to obtain disks at different levels (base, *dbh*, 50% of total height and at each 2m until the upper commercial level (d class=10cm)) were sampled for the following 4 sites in Continental Portugal (Figure 1) – the National Camarido Forest (MNC), the Forest Perimeter of Ovar Dunes – Drain of Maceda (PFDOVM), the Forest Perimeter of Rebordões de Santa Maria (PFRSM) and the Forest Perimeter of Crasto (PFC). This site selection was due to the fact that Blackwood is found in pure or mixed stands with significant dimensions.

The general characteristics of each region are shown in Table 1. We can see that PFC is placed at the higher altitude, and that MNC and PFDOVM are almost at the sea level; this last place shows few more rainfall amounts than the other three sites. Nearby the littoral the annual mean temperatures are a bit higher than in the interior (PFC).

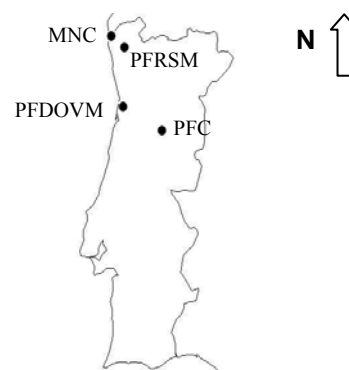


Fig. 1 – Geographical location of studied sites in Portugal.

Table 1 – Geomorphologic, climatic and forest characteristics of the studied places.

Parameters	Site			
	MNC	PFDOVM	PFRSM	PFC
Latitude	41° 53' N	40° 57' N	41° 43' N	40° 41' N
Longitude	8° 43' W	8° 34' W	8° 34' W	7° 56' W
Altitude (m)	8	7	154	548
Total rainfall (mm/year)	1339	1450	1380	1342
Mean annual temperature (°C)	14.5	13.3	14.3	12.5
Predominant exposition	East and flat	Flat	North	South
Stand age in 2005 (years)	62	73-74	52-54	62
Stand attainment	Plantation	Seedling	Seedling	Seedling

Source of the meteorological information: Normal Climatic 61/90 P-CLIMA (1999).

MNC and PFDOVM are sandy sites, while the others are granitic. All the stands are mixed with maritime pine, near aged and managed in irregular high stand regime.

Concerning inter and intra-species competition, the studied sites show that the smaller number of trees per hectare (N/ha) are found in PFC and PFDOVM (Table 2). These sites combine woody production with recreation. The more dense stands are in MNC and PFRSM, the latter

Table 2 – Mean values of sample trees competition.

Site	dbh of concurrent trees(cm)	Dist. to the compet. trees (m)	N/ha (±sd) (n=25)
MNC	30.6	4.0	693 (±290)
PFDOVM	35.7	4.7	572 (±329)
PFRSM	34.6	5.3	762 (±1410)
PFC	46.4	5.7	371 (±297)

sd – standard deviation

presenting the highest variability. So, the competition found in PFDOVM site will be higher than the one of PFC, once being higher the mean N/ha, the mean distance between the trees is smaller.

MNC is where the competition will be more relevant, seeing that this site shows the second highest density and, naturally, the more reduced distance among trees; this

fact is in agreement with the lower mean *dbh* of the 4 closest trees. However, the competition must be considered high in all sites, because mean *dbh* of the trees that are around the sample trees are greater than 30cm, and the distances between the sample trees and the surrounding ones are greater than 4m.

Sampling consisted of 5 trees of the 40cm *dbh* class per site. A semi-automatic evaluation of earlywood (Ew) and latewood (Lw) widths of the annual growth rings was carried out on the digital images of the 261 disks collected on these sample trees. A Kodak Megaplug Camera Model ES 1.0 with an objective COSMICAR/PENTAX TV 200m LENS 12,5mm – 75mm (1:1,8) was used to acquire these images. Growth rings measurement was performed with Wood Ring Analysis 1.0[®].

Bark widths were also measured on the analysed disks faces for each North and South generatrix.

The estimation of both the radial annual increments and the annual volumes was realized by WinSTEMTM 2005^a[®] program.

The reached variable values were used to study wood growth and to construct the over-bark (*vob*) and under-bark (*vub*) total volume ($v(\text{dm}^3)$) estimation models. The *dbh*(cm) over-bark and total high (h(m)) were adopted as independent variables. *Dummy* variables represent the four different study sites – MNC, PFRSM, PFC and PFDOVM.

SPSS 14[®] and STATISTICA 6.0.[®] programs allowed ANOVA and the Multiple Comparison Tests (*mct*) to run, respectively.

The 17 tested models of Table 3 were already used by several authors with identical objectives. The first 8 are linear, the remaining non-linear.

Table 3 – Tested models.

Mod.n ^o	Model	Reference
1	$v = \beta_0 + \beta_1 * d^2 * h$	Utilized by Freire <i>et al.</i> (2003)
2	$v = \beta_0 + \beta B_1 * d * h^2 \beta B_2 * d^2$	
3	$v = \beta_0 + \beta_1 * d^2 * h + \beta_2 * 1/2 \sqrt{d}$	
4	$v = \beta_0 + \beta_1 * (\sqrt{d}) * h + \beta_2 * 1/2 \sqrt{d} + \beta_3 * d^2$	
5	$v = \beta_0 + \beta_1 * h^2 + \beta_2 * d^2 + \beta_3 * 1/2 \sqrt{d}$	
6	$v = \beta_0 + \beta_1 * d^2 + \beta_2 * h + \beta_3 * d^2 * h$	Utilized by Veiga <i>et al.</i> (2000)
7	$v = \beta_0 + \beta_1 * d + \beta_2 * d^2 + \beta_3 * d * h + \beta_4 * d^2 * h$	
8	$v = \beta_0 + \beta_1 * d^2 + \beta_2 * d^2 * h + \beta_3 * d * h^2 + \beta_4 * h^2$	
9	$v = e^{(\beta + \beta_1 * (\ln(h))^2 + \beta_2 * \ln(d))}$	Utilized by Freire <i>et al.</i> (2003)
10	$v = e^{(\beta + \beta_1 * h + \beta_2 * \ln(d))}$	
11	$v = e^{(\beta + \beta_1 * (\ln(h))^2 + \beta_2 * (\ln(d))^2)}$	
12	$v = e^{(\beta + \beta_1 * h + \beta_2 * (\ln(d))^2)}$	
13	$v = \beta_1 * d^{\beta_2} * h^{\beta_3}$	
14	$v = d^2 / (\beta_0 + \beta_1 / h)$	
15	$v = d^2 * (\beta_0 + \beta_1 * h)$	
16	$v = d^2 * h / (\beta_0 + \beta_1 * d)$	
17	$v = \beta_1 * d^{\beta_2}$	

v – total volume (dm³); d – diameter at breast high *over-bark* (cm); h – total high (m).

Levenberg-Marquardt (Eyng, 2006) estimation method was used to perform the regressions to non linear models.

Table 4 – ANOVA for annual wood increments thickness.

Type of wood	Variation origin	DF	MS	F	p	Var. (%)	
Ew and Lw	Local (<i>L</i>)	3	44.33	22.52	0.000	2.03	
	Sentido (<i>Si</i>)	1	13.66	6.94	0.009	0.28	
	Nº anel (<i>N</i>)	46	6.15	3.12	0.000	2.00	
	Tipo de lenho (<i>TI</i>)	1	653.5	332.0	0.000	15.58	
	<i>L.Si</i>	3	2.13	1.08	0.356	0.02	
	<i>L.N</i>	133	4.01	2.04	0.000	3.91	
	<i>Si.N</i>	46	1.47	0.74	0.898	0.00	
	<i>L.Si.N</i>	133	1.31	0.67	0.999	0.00	
	<i>L.TI</i>	3	9.61	4.88	0.002	0.73	
	<i>Si.TI</i>	1	4.58	2.33	0.127	0.12	
	<i>L.Si.TI</i>	3	1.06	0.54	0.656	0.00	
	<i>N.TI</i>	46	1.61	0.82	0.808	0.00	
	<i>L.N.TI</i>	133	1.62	0.82	0.927	0.00	
	<i>Si.N.TI</i>	46	0.92	0.47	0.999	0.00	
<i>L.Si.N.TI</i>	133	0.99	0.50	1.000	0.00		
Resíduo	2432	1.97				75.33	
Tw	Local (<i>L</i>)	3	88.42	17.26	0.000	3.57	
	Sentido (<i>Si</i>)	1	27.51	5.37	0.021	0.41	
	Nº anel (<i>N</i>)	46	12.23	2.39	0.000	3.05	
	<i>L.Si</i>	3	4.29	0.84	0.473	0.00	
	<i>L.N</i>	133	8.03	1.57	0.000	4.99	
	<i>Si.N</i>	49	2.94	0.57	0.990	0.00	
	<i>L.Si.N</i>	133	2.63	0.51	1.000	0.00	
	Resíduo	1222	5.12				87.98

DF – Degrees of freedom; MS – Mean square; Var. (%) – Expected variation proportion.

remaining factors and significative interactions amount to 8%. Tw value is about 12%.

The *mct* (Fisher LSD test) for both mentioned woody growth evaluations (Table 5) disclose the same homogeneous grouping (hg) of sites in both cases – PFRSM (hg.1), MNC e PFC (hg.2) e PFDOVM (hg.3).

The hg organization standard and its relative positions may be due to the fact that de sites on the north (PFRSM and MNC) are less rainy and PFC more coldly. This situation, in addition with higher stand densities of the first two sites (Table 2), results in inferior dimensions of annual growth rings inside the wood. The constant differentiated position of PFDOVM will fit to its statute of rainier site and to the one with the most reduced stand densities.

3. RESULTS AND DISCUSSION

3.1. Growth rings thickness variation

The results obtained by ANOVA for the thicknesses of the two wood types, separately (Ew – earlywood and Lw – latewood) or added (Tw - total ring wood), are presented in Table 4. They show that the significances of the differences between all the factors in the expression of wood increments are diverse. However, the contributions are very different. In spite of being biologically relevant, in both analyses the factors variation (%) is quite small if compared with the relevance of the respective residue (75 and 88%).

Separately, both types of wood explain about 16% of correspondent thicknesses variation, while the

Table 5 – *mct* LSD tests – sites.

Kind of wood	Site	Thickness (mm)	hg.1	hg.2	hg.3
Ew and Lw	PFRSM	1.90	****		
	MNC	2.13		****	
	PFC	2.25		****	
	PFDOVM	2.51			****
Tw	PFRSM	3.81	****		
	MNC	4.27		****	
	PFC	4.50		****	
	PFDOVM	5.02			****

Error – MS=1.9453; DF=3133.0; Significance level $\alpha=0.050$; Dependent variables: Ew and Lw; Homogeneous group: Hg.

Error – MS=5.0847; DF=1540.0; Significance level $\alpha=0.050$; Dependent variable: Tw; Homogeneous group: Hg.

North radius points out superior thickness mean values than those of the south in about 9%. This happens if the two types of wood are considered in separate or not (Table 6).

Table 7 shows that Ew is significantly different from Lw; this one is about 60% superior.

An evaluation to 40-year-old trees shows that annual diameter growth mean rates present

Table 6 - *mct* LSD tests – senses.

Type of wood	Sense	Thickness (mm)	hg.1	hg.2
Ew e Lw	S	2.09	****	
	N	2.28		****
Error – MS=1.9453; DF=3133.0; Significance level $\alpha=0.050$; Dependent variables: Ew e Lw.				
Tw	S	4.19	****	
	N	4.56		****
Error – MS=5.0847; DF=1540.0; Significance level $\alpha=0.050$; Dependent variable: Tw.				

Table 7 – *mct* LSD tests - type of wood.

Type of wood	Thickness (mm)	hg.1	hg.2
Lw	1.68	****	
Ew	2.70		****
Error – MS=1.9453; DF=3133.0; Significance level $\alpha=0.050$; Dependent variable: Ew and Lw.			

values of 0.8 to 0.9cm/year in total height. This is why they can be considered good ones. This fact also denounces

considerable volume growths. The trees presenting superior mean ages also display more reduced mean growth rates and lead us to foresee the unavoidable relenting with age.

3.2. Wood volume estimation

The selected results to all models fittings (Table 3), *under* and *over-bark*, are presented in Tables 8 and 9. The multiple R^2_{aj} , the maximum expected errors (e^*) and residual mean square (RMS), the mean absolute residual error (MAR), the mean squares (MS), the significant tests F, and the mean residual errors (BIAS) are also expressed.

For any of the models high R^2_{aj} were registered (93 to 97%). With higher R^2_{aj} and significative coefficients of the independent variables, models 13 and 14 were pre-selected for *vub*, while 2 and 13 models were for *vob*. The election of one of these models, for each of the dependent variables, selected the one that presented the smaller e^* , RMS and MAR values, higher MS and F, and BIAS near zero. The elected model should also deserve an acceptable appreciation of its residuals distribution plot.

This analysis lead to the selection of the non-linear model number 13, seeing that it is the one that better fulfils those criteria, both for *vub* and for *vob*.

4. CONCLUSIONS

From the two studied aspects for the 4 considered sites – the evaluation of early and latewood thicknesses evolution and the construction of stand trees volume estimation models -, some conclusions may be pointed out:

- The explanation degree of the two types of wood thicknesses variations is much reduced.
- About 16% of growth rings thickness variation is due to the type of wood. The greater proportion is the one of earlywood.
- The variation of total annual wood amount is explained by its original site, by the number of the considered ring and by its respective interaction.
- With regard to total wood and to its annual fractions, the factor site is arranged into three homogenous groups, to which correspond three significative differences concerning mean ring thickness.

- It is on the North geratrix that the greater mean ring thickness is shown – about 9% superior to the one of the South.
- Earlywood thickness is about 61% greater than the one of latewood.
- The mean diameter (0.8 to 0.9cm/year) and total high growth rates (0.65 to 0.76m/year) that are noted on the trees can be considered enough good and point out appreciable volume increments. Older trees present inferior mean growth rates and already indicate the growth slowing with age.

Table 8 – Statistical fittings of models for *volumes (dm³) under-bark (vub)*.

Mod.	Equation	R ² aj.	e*	RMS	MAR	MS	F	BIAS
1	$vub = -13.855 + 0.0292 * d^2 * h + 11.748 * MNC + 86.605 * PFRSM + 39.516 * PFDOVM$	0.952	183.7	9490.0	60.0	40660535	4284.587	0.000
2	$vub = -28.0034 + 0.0267 * d * h^2 + 0.262 * d^2 - 23.904 * MNC + 36.963 * PFRSM - 17.397 * PFDOVM$	0.963	160.3	7227.1	56.6	32920450	4555.169	0.000
3	$vub = 3.375 + 0.0288 * d^2 * h - 39.504 * 1/2 * \sqrt{d} + 11.865 * MNC + 9.793 * PFRSM + 10.0798 * PFDOVM$	0.950	187.8	9947.5	63.4	30781332	3094.372	0.000
4	$vub = -263.809 + 3.682 * (\sqrt{d}) * h + 163.325 * 1/2 * \sqrt{d} + 9.484 * d^2 + 11.246 * MNC + 77.999 * PFRSM + 55.544 * PFDOVM$	0.930	222.0	13891.6	88.8	25122296	1808.459	0.000
5	$vub = -198.898 + 0.586 * h^2 + 0.571 * d^2 + 130.632 * 1/2 * \sqrt{d} + 3.161 * MNC + 57.908 * PFRSM + 22.255 * PFDOVM$	0.940	205.6	11917.0	80.8	25387874	2130.393	0.000
6	$vub = -35.14 - 0.2007 * d^2 + 6.152 * h + 0.0329 * d^2 * h - 16.506 * MNC + 40.839 * PFRSM - 4.088 * PFDOVM$	0.958	171.5	8274.5	57.9	27284601	3297.423	0.000
7	$vub = -7.881 - 2.228 * d - 0.196 * d^2 + 0.582 * d * h + 0.0231 * d^2 * h - 25.852 * MNC + 33.651 * PFRSM - 16.714 * PFDOVM$	0.963	161.8	7361.9	55.0	23500101	3192.110	0.000
8	$vub = 4.928 + 0.347 * d^2 - 0.0107 * d^2 * h + 0.049 * d * h^2 - 0.481 * h^2 - 18.442 * MNC + 55.988 * PFRSM - 12.825 * PFDOVM$	0.967	152.1	6507.1	49.6	23605127	3627.610	0.000
9	$vub = e^{(-0.908 + 0.2104 * (\ln(h))^2 + 1.542 * \ln(d) - 0.0108 * MNC + 0.118 * PFRSM + 0.0164 * PFDOVM)}$	0.964	160.1	7231.5	51.1	49914260	6902.298	-4.263
10	$vub = e^{(-0.114 + 0.0528 * h + 1.557 * \ln(d) - 0.0042 * MNC + 0.1207 * PFRSM + 0.00997 * PFDOVM)}$	0.963	162.6	7458.1	53.7	49883748	6688.522	-6.740
11	$vub = e^{(1.649 + 0.2203 * (\ln(h))^2 + 0.222 * (\ln(d))^2 - 0.0055 * MNC + 0.116 * PFRSM + 0.0124 * PFDOVM)}$	0.961	166.5	7817.0	57.1	49835423	6375.292	-8.432
12	$vub = e^{(2.492 + 0.0551 * h + 0.226 * \ln(d))^2 + 0.00224 * MNC + 0.1203 * PFRSM + 0.00708 * PFDOVM)}$	0.959	170.8	8223.1	61.6	49780724	6053.737	-11.995
13	$vub = 0.0466 * d^{1.543} * h^{1.348} * 0.988^{MNC} * 1.126^{PFRSM} * 1.023^{PFDOVM}$	0.966	155.2	6775.5	47.5	49914726	7366.980	-2.588
14	$vub = d^2 / (0.3 + 29.157 / h - 0.116 * MNC - 0.276 * PFRSM - 0.2102 * PFDOVM)$	0.956	176.3	8744.0	52.2	59556545	6811.123	8.117
15	$vub = d^2 * (0.0019 + 0.0269 * h + 0.0569 * MNC + 0.205 * PFRSM + 0.128 * PFDOVM)$	0.959	170.5	8174.0	52.0	59654927	7298.119	7.033
16	$vub = d^2 * h / (24.045 + 0.324 * d - 0.567 * MNC - 5.486 * PFRSM - 3.109 * PFDOVM)$	0.964	158.0	7025.2	50.2	59853220	8519.841	-4.918
17	$vub = 0.288 * d^{2.227} * 1.2201^{MNC} * 1.489^{PFRSM} * 1.475^{PFDOVM}$	0.931	220.2	13636.6	75.2	58712090	4305.488	-5.141

The non significant coefficients are presented in *italic*.

- The reached algebraic expressions to estimate total volumes (*vub* and *vob*(dm³)) using over-bark *dbh* (d(cm)) and total high (h(m)) followed the model $v = \beta_1 * d^{\beta_2} * h^{\beta_3}$. In both situations the estimated volumes to PFC, MNC and PFDOVM sites are very similar and nearly 13 or 14% inferior to those of PFRSM.

Table 9 – Statistical fittings of models for *volumes* (dm³) *over-bark* (*vob*).

Mod.	Equation	R ² aj.	e*	RMS	MAR	MS	F	BIAS
1	$vob = -14.449 + 0.0312 \cdot d^2 \cdot h + 12.0907 \cdot MNC + 96.908 \cdot PFRSM + 37.224 \cdot PFDOVM$	0.950	200.6	11317.7	64.2	46329889	4093.591	0.00
2	$vob = -29.188 + 0.0287 \cdot d \cdot h^2 + 0.277 \cdot d^2 - 26.3203 \cdot MNC + 43.4203 \cdot PFRSM - 24.223 \cdot PFDOVM$	0.962	175.1	8623.2	61.6	37530706	4352.310	0.00
3	$vob = 4.086 + 0.0308 \cdot d^2 \cdot h - 42.806 \cdot 1/\sqrt{d} + 12.224 \cdot MNC + 100.028 \cdot PFRSM + 42.296 \cdot PFDOVM$	0.948	205.2	11872.9	68.0	35070876	2953.865	0.00
4	$vob = -282.401 + 3.967 \cdot (\sqrt{d}) \cdot h + 175.147 \cdot 1/\sqrt{d} + 0.514 \cdot d^2 + 11.003 \cdot MNC + 87.032 \cdot PFRSM + 52.587 \cdot PFDOVM$	0.929	240.0	16244.7	95.7	28639694	1763.014	0.00
5	$vob = -212.267 + 0.629 \cdot h^2 + 0.608 \cdot d^2 + 139.556 \cdot 1/\sqrt{d} + 2.518 \cdot MNC + 65.765 \cdot PFRSM + 17.196 \cdot PFDOVM$	0.938	222.9	14008.6	87.4	28940450	2065.901	0.00
6	$vob = -37.436 - 0.2137 \cdot d^2 + 6.59 \cdot h + 0.0351 \cdot d \cdot h - 18.0906 \cdot MNC + 48.011 \cdot PFRSM - 9.311 \cdot PFDOVM$	0.956	187.9	9927.8	62.8	31089814	3131.598	0.00
7	$vob = -8.289 - 2.663 \cdot d - 0.2013 \cdot d^2 + 0.641 \cdot d \cdot h + 0.0241 \cdot d^2 \cdot h - 28.86 \cdot MNC + 39.824 \cdot PFRSM - 23.295 \cdot PFDOVM$	0.961	177.5	8865.2	60.4	26659795	3007.242	0.00
8	$vob = 6.143 + 0.392 \cdot d^2 - 0.0132 \cdot d^2 \cdot h + 0.0545 \cdot d \cdot h^2 - 0.544 \cdot h^2 - 20.278 \cdot MNC + 64.776 \cdot PFRSM - 18.867 \cdot PFDOVM$	0.965	166.6	7767.4	54.4	26915253	3465.176	0.00
9	$vob = e^{(-0.836 + 0.213 \cdot (\ln(h))^2 + 1.533 \cdot \ln(d) - 0.014 \cdot MNC + 0.133 \cdot PFRSM + 0.00187 \cdot PFDOVM)}$	0.963	173.4	8481.9	55.2	56942417	6713.401	-4.814
10	$vob = e^{(-0.0311 + 0.0534 \cdot h + 1.548 \cdot \ln(d) - 0.00749 \cdot MNC + 0.136 \cdot PFRSM - 0.00489 \cdot PFDOVM)}$	0.962	176.0	8737.2	58.0	56908041	6513.328	-7.502
11	$vob = e^{(1.705 + 0.223 \cdot (\ln(h))^2 + 0.221 \cdot (\ln(d))^2 - 0.00885 \cdot MNC + 0.132 \cdot PFRSM - 0.0024 \cdot PFDOVM)}$	0.960	180.5	9187.3	61.7	56847419	6187.586	-9.224
12	$vob = e^{(2.558 + 0.0558 \cdot h + 0.224 \cdot \ln(d))^2 - 0.00122 \cdot MNC + 0.136 \cdot PFRSM - 0.00811 \cdot PFDOVM}$	0.958	185.0	9650.7	66.6	56785025	5884.059	-13.085
13	$vob = 0.0488 \cdot d^{1.534} \cdot h^{1.364} \cdot 0.985^{MNC} \cdot 1.144^{PFRSM} \cdot 1.00847^{PFDOVM}$	0.965	168.6	7996.4	51.5	56942522	7121.009	-3.008
14	$vob = d^2 / (0.284 + 27.245/h - 0.108 \cdot MNC - 0.279 \cdot PFRSM - 0.188 \cdot PFDOVM)$	0.954	191.4	10308.5	56.5	67922371	6588.991	8.463
15	$vob = d^2 \cdot (-0.00222 + 0.0289 \cdot h + 0.0596 \cdot MNC + 0.236 \cdot PFRSM + 0.125 \cdot PFDOVM)$	0.957	184.9	9612.9	56.0	68042423	7078.233	7.460
16	$vob = d^2/h \cdot (22.438 + 0.305 \cdot d - 0.479 \cdot MNC - 5.584 \cdot PFRSM - 2.582 \cdot PFDOVM)$	0.963	171.8	8305.5	54.4	68276385	8220.611	-5.692
17	$vob = 0.308 \cdot d^{2.225} \cdot 1.219^{MNC} \cdot 1.517^{PFRSM} \cdot 1.46^{PFDOVM}$	0.929	238.6	16016.3	81.1	66953212	4180.314	-5.763

The non significant coefficients are presented in *italic*.

- Models maximum expected errors of 155.2dm³ for *vub* and 168,6dm³ for *vob* point out to estimated maximum errors of 11.4 and 11.6% respectively, corresponding to maximum tree mean volumes of 1362(±312)dm³ and 1459(±329)dm³.

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