*According to World Reference Base for Soil (FAO, 1998).

Allometric equations for predicting mineralomass in high-forest chestnut stands in Portugal

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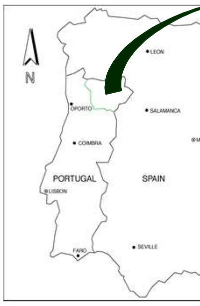
Introduction

The information of the content of mineral elements in the tree-component biomass is essential to understand their status and flow in the whole system, as well as to assess the productive capacity of ecosystems and the management implications for forest sustainability. However, the evaluation of nutrients in biomass tree-components is a process time consuming and expensive, often involving tree felling, not always possible or desirable. On the other hand, the concentration of minerals in tree-biomass components for a given species varies considerably between tree-components, sites and it is not always available in the literature. Given the importance of the relationship of biomass and nutrients (mineralomass) for dynamic and sustainable management chestnut woodlands, aboveground mineralomass was studied in sweet chestnut (*Castanea sativa* Mill.) high-forest stands located in Northern Portugal.

Objective: To provide allometric equations for chestnut high-forest woodlands for estimating the mineralomass using the dendrometric variables diameter breast height (d) and total height (h) of the tree.



Northern of Portugal

Bornes

Marão

Padrela

Data analysis:

- ✓ The mineralomass equations were fitted by the ordinary least squares method (OLS) associated with both the PROC REG (linear models) and PROC NLIN (non-linear models) procedures of SAS/STAT. The modified Gauss-Newton iterative method was applied in the non-linear model fitting.
- ✓ A simultaneous fit by SUR method using iterative seemingly unrelated regression (ITSUR) by PROC MODEL procedure of SAS/STAT was used for the final compatible selected models.

Table2. Biometric variables of the 34 sampled trees

Variable	Minimum	Mean	Maximum	Stand. deviation
DBH (cm)	10.25	33.98	64.20	14.14
h (m)	11.55	21.91	30.40	4.63

DBH, diameter breast height, h, total height

Materials and Methods

The present study was carried out in the three high-forest mature chestnut stands located in three mountains of Northern Portugal: Marão (41º 14' 46" N, 7º 55' 04" W), Padrela (41º 30' 41" N, 7º 37' 15" W) and Bornes (41º 29' 42" N, 6º 55' 12" W) which have been monitored over time. Sampling followed a west-to-east transect across to northern Portugal from a more-Atlantic-to-less-maritime influence.

In order to obtain biomass data, 34 trees were felled according to the existent diameter classes. The methodology of biomass collection was described by Patrício et al. (2005). These samples of tree-biomass components were analyzed to determine their mineral concentrations.

Table1. General characteristics of the studied chestnut stands (Northern Portugal).

Chestnut stands	Marão	Padrela	Bornes
Altitude (m a.s.l.)	900	850	800
Slope (º)	5-10	25-30	15-20
Main soil type*	*Umbric Regosols*	*Dystric Regosols*	*Dystric Cambisols*
Mean annual temperature (ºC)	11.5-12.0	12.5	11.9
Mean annual precipitation (mm $year^{-1}$)	2505	1132	1009
Age (years)	71	64	53
Density (tree ha^{-1})	360	470	1260
Mean DBH (cm)	41.2±9.0	33.6±6.3	26.1±6.1
Mean height (m)	28.7±2.7	21.7±2.4	22.4±2.7

*According to World Reference Base for Soil (FAO, 1998).

- ✓ The collected samples of biomass of leaves, flowers and barks were dried in a stove at 70±2ºC, while the log samples and branches, were dried at 103±2ºC (until constant weight) for determining the water content and estimating the dry matter.
- ✓ After the drying process the biomass samples were finely ground. Sub-samples of these were taken for chemical analysis. The following elements were determined: N, P, K, Ca, Mg, S, B and C in all tree-components biomass above ground.
- ✓ We consider the following mineralomass of tree-components: bark (M_Bark), leaves and flowers (M_Ltot), live branches (M_Bliv), main stem under bark (M_Wood), main stem over bark (M_Stem) and the total aboveground mineralomass (M_Tot).

Model selection:

✓The models were evaluated in terms of measures of fit and prediction ability: modelling efficiency (EM), mean square error (MSE), models parameter significance, R^2 of prediction (R^2pred), mean of PRESS residuals (m_PRESS), and mean of the absolute values of the PRESS residuals (ma_PRESS) as well as the percentiles 95% (P95) and 5% (P5) of the PRESS residuals.

✓The normality of the studentized residuals was analysed using normal QQplots. The presence of heterocedasticity associated with the error term of the models was checked by plotting the studentized residuals against the predicted values.

✓The regression assumptions departure was solved with non-linear iteratively re weighted least squares (IRWLS) using the Huber function with the maximum value of r=1 and weighting factors. The procedure was repeated for each mineral.

Results and Discussion

✓ **To model the mineralomass (M) by tree-components, the following candidate allometric equations were tested:**

(1) $M = \beta_0 + \beta_1 d^2 h$
(1.1) $M = \beta_1 d^2 h$
(2) $M = \beta_0 + \beta_1 d + \beta_2 d^2$
(2.2) $M = \beta_1 d + \beta_2 d^2$
(3) $M = \beta_1 d^2$
(4) $M = \beta_1 d + \beta_2 h$
(5) $M = \beta_1 (d^2 h)^{\beta_2}$
(6) $M = \beta_1 d^{\beta_2}$

d represent the DBH and *h* the total height of the tree

Table 3. Mean value and respective standard deviation (in brackets) of the mineralomass (n=34 trees) for the minerals N, P, K, Ca, Mg, S, B and C

Mineral	M_Wood (kg)	M_Bark (kg)	M_Bliv (kg)	M_Ltot (kg)	M_Tot (kg)
N	0.489	0.203	0.379	0.225	1.451
	(0.572)	(0.155)	(0.476)	(0.199)	(1.489)
P	0.047	0.017	0.048	0.015	0.140
	(0.062)	(0.015)	(0.062)	(0.011)	(0.151)
K	0.105	0.085	0.201	0.074	0.500
	(0.161)	(0.085)	(0.205)	(0.065)	(0.427)
Ca	0.307	0.594	0.394	0.036	1.448
	(0.414)	(0.436)	(0.389)	(0.028)	(1.143)
Mg	0.107	0.065	0.129	0.037	0.379
	(0.114)	(0.047)	(0.166)	(0.030)	(0.379)
S	0.059	0.008	0.016	0.010	0.097
	(0.081)	(0.008)	(0.019)	(0.008)	(0.106)
B*	0.977	0.461	0.904	0.116	2.703
	(1.966)	(0.360)	(1.084)	(0.100)	(2.623)
C	226.714	26.034	73.731	5.289	354.902
	(179.350)	(18.832)	(92.717)	(4.446)	(310.320)

*

* Mineralomass of B in (g), (M_Wood) mineralomass of main stem under bark, (M_Bark) minetalomass of stem bark, (M_Bliv) mineralomass of branches, (M_Ltot) mineralomass of leaves and flowers, (M_Tot) the total aboveground mineralomass.

Table 4. Fitting and prediction statistics of the models with the best performance for the mineralomass by tree-component and by mineral, after weighting.

Min	Model	Comp.	MSE	EM	mPRESS	maPRESS	R^2_{pred}	P95	P5
N	(1.1)	M_Bark	0.507 10^{-7}	0.957	-0.003	0.033	0.862	0.065	-0.101
	(3)	M_Ltot	0.718 10^{-5}	0.837	0.007	0.076	0.715	0.264	-0.163
	(3)	M_Bliv	0.2357 10^{-4}	0.767	0.043	0.181	0.477	0.832	-0.260
	(3)	M_Wood	0.284 10^{-4}	0.830	0.054	0.180	0.417	0.530	-0.286
	(3)	M_Stem	0.257 10^{-3}	0.944	0.096	0.611	0.803	2.853	-1.168
	(1.1)	M_Tot	0.536 10^{-5}	0.900	0.083	0.431	0.720	1.929	-0.829
P	(3)	M_Bark	0.216 10^{-7}	0.895	0.522 10^{-3}	0.005	0.632	0.016	-0.010
	(3)	M_Ltot	0.372 10^{-7}	0.831	0.665 10^{-3}	0.005	0.672	0.015	-0.008
	(3)	M_Bliv	0.608 10^{-7}	0.660	0.006	0.027	0.309	0.102	-0.040
	(3)	M_Wood	0.825 10^{-6}	0.600	0.004	0.036	0.174	0.133	-0.097
	(3)	M_Stem	0.466 10^{-5}	0.882	0.004	0.081	0.634	0.211	-0.193
	(3)	M_Tot	0.005	0.803	0.008	0.066	0.509	0.327	-0.145
K	(1.1)	M_Bark	0.350 10^{-7}	0.822	0.005	0.031	0.578	0.099	-0.049
	(3)	M_Ltot	0.144 10^{-5}	0.763	0.004	0.033	0.633	0.081	-0.056
	(3)	M_Bliv	0.786 10^{-5}	0.752	0.016	0.096	0.524	0.274	-0.135
	(1.1)	M_Wood	0.156 10^{-3}	0.428	0.025	0.078	0.088	0.192	-0.143
	(1.1)	M_Stem	0.002	0.868	0.034	0.393	0.618	1.034	-0.753
	(3)	M_Tot	0.036	0.925	0.023	0.171	0.719	0.398	-0.274
Ca	(3)	M_Bark	0.392 10^{-4}	0.852	-0.009	0.224	0.242	0.580	-0.629
	(3)	M_Ltot	0.337 10^{-6}	0.749	0.002	0.016	0.451	0.049	-0.021
	(3)	M_Bliv	0.359 10^{-4}	0.707	0.027	0.198	0.401	0.631	-0.492
	(1.1)	M_Wood	0.352 10^{-3}	0.773	0.023	0.148	0.538	0.673	-0.258
	(1.1)	M_Stem	0.088	0.891	0.119	2.260	0.498	5.256	-6.362
	(1)	M_Tot	0.414 10^{-5}	0.882	0.020	0.286	0.870	0.687	-0.565
Mg	(3)	M_Bark	0.752 10^{-6}	0.779	0.408 10^{-3}	0.024	0.357	0.064	-0.048
	(3)	M_Ltot	0.229 10^{-6}	0.822	0.002	0.014	0.719	0.040	-0.022
	(3)	M_Bliv	0,283 10^{-5}	0.759	0.016	0.059	0.465	0.232	-0.083
	(1.1)	M_Wood	0.229 10^{-4}	0.874	0.006	0.037	0.681	0.151	-0.071
	(3)	M_Stem	0.001	0.893	0.025	0.243	0.637	0.845	-0.540
	(1)	M_Tot	0.479 10^{-6}	0.818	0.023	0.125	0.642	0.326	-0.203
S	(1.1)	M_Bark	0.321 10^{-9}	0.835	0.128 10^{-4}	0.003	0.510	0.010	-0.009
	(3)	M_Ltot	0.155 10^{-7}	0.852	0.143 10^{-3}	0.003	0.692	0.009	-0.009
	(3)	M_Bliv	0.351 10^{-7}	0.797	0.001	0.007	0.619	0.036	-0.010
	(1.1)	M_Wood	0.260 10^{-4}	0.616	0.008	0.036	0.314	0.183	0.054
	(1.1)	M_Stem	0.956 10^{-4}	0.775	0.008	0.074	0.461	0.239	-0.126
	(1.1)	M_Tot	0.397 10^{-7}	0.827	0.008	0.034	0.631	0.159	-0.060
B*	(3)	M_Bark	0.119 10^{-4}	0.915	0.004	0.129	0.780	0.273	-0.292
	(3)	M_Ltot	0.491 10^{-5}	0.684	0.001	0.055	0.507	0.236	-0.090
	(3)	M_Bliv	0.125 10^{-3}	0.786	0.088	0.397	0.562	1.154	-0.513
	(3)	M_Wood	0.150 10^{-3}	0.806	0.011	0.407	0.576	0.997	-1.191
	(3)	M_Stem	0.168 10^{-3}	0.927	0.083	1.475	0.822	4.063	-3.473
	(1.1)	M_Tot	0.237 10^{-4}	0.915	-0.006	0.831	0.819	2.335	-2.487
C	(5)	M_Bark	0.437 10^{-3}	0.963	0.071	3.074	0.950	8.348	-7.686
	(3)	M_Ltot	0.004	0.838	0.152	1.976	0.712	5.862	-3.541
	(3)	M_Bliv	0.887	0.757	8.031	35.974	0.5602	188.415	-52.166
	(5)	M_Wood	0.012	0.978	-1.141	26.027	0.933	64.273	-40.100
	(5)	M_Stem	0.090	0.982	-3.611	52.653	0.946	156.171	-103.883
	(6)	M_Tot	0.860	0.984	-0.942	34.370	0.972	66.810	-107.667

* Mineralomass of B in (g), Mineralomass of the remaining minerals in (kg). (MSE) mean square error, (EM) modelling efficiency, (m_PRESS) mean of PRESS residuals, (ma_PRESS) mean of the absolute values of the PRESS residuals, (R^2pred) R^2 of prediction, (P95) and (P5) percentiles 95% and 5% of the PRESS residuals.

✓ **The analysis accomplished led to the selection of the following equations for each tree component:**

✓ Final mineralomass equations fitted by OLS method

Nitrogen:
N_Bark = $0.6260\ 10^{-5} d^2 h$;
N_Ltot = $0.1768\ 10^{-3} d^2$;
N_Bliv = $0.2505\ 10^{-3} d^2$;
N_Wood = $0.3232\ 10^{-3} d^2$;
N_Tronc = $0.00193\ d^2$;
N_Tot = $0.4138\ 10^{-4} d^2 h$;

Phosphorus:
P_Bark = $0.1250\ 10^{-4} d^2$;
P_Ltot = $0.1230\ 10^{-4} d^2$;
P_Bliv = $0.3070\ 10^{-4} d^2$;
P_Wood = $0.3217\ 10^{-4} d^2$;
P_Tronc = $0.1713\ 10^{-3} d^2$;
P_Total = $0.1030\ 10^{-3} d^2$;

Potassium:
K_Bark = $0.2400\ 10^{-5} d^2 h$;
K_Ltot = $0.6220\ 10^{-4} d^2$;
K_Bliv = $0.1370\ 10^{-3} d^2$;
K_Wood = $0.2430\ 10^{-5} d^2 h$;
K_Tronc = $0.3036\ 10^{-4} d^2 h$;
K_Total = $0.4060\ 10^{-3} d^2$;

Calcium:
Ca_Bark = $0.4152\ 10^{-3} d^2$;
Ca_Ltot = $0.2824\ 10^{-4} d^2$;
Ca_Bliv = $0.2671\ 10^{-3} d^2$;
Ca_Wood = $0.8670\ 10^{-5} d^2 h$;
Ca_Tronc = $0.2041\ 10^{-3} d^2 h$;
Ca_Total = $0.1062+0.3777\ 10^{-4} d^2 h$;

Magnesium:
Mg_Bark = $0.4750\ 10^{-4} d^2$;
Mg_Ltot = $0.2991\ 10^{-4} d^2$;
Mg_Bliv = $0.8383\ 10^{-4} d^2$;
Mg_Wood = $0.3080\ 10^{-5} d^2 h$;
Mg_Tronc = $0.2325\ 10^{-4} d^2 h$;
Mg_Total = $0.0336+0.9950\ 10^{-5} d^2 h$;

Sulfur:
S_Bark = $0.2466\ 10^{-6} d^2 h$;
S_Ltot = $0.7520\ 10^{-5} d^2$;
S_Bliv = $0.1063\ 10^{-4} d^2$;
S_Wood = $0.1550\ 10^{-5} d^2 h$;
S_Tronc = $0.4420\ 10^{-5} d^2 h$;
S_Total = $0.2580\ 10^{-5} d^2 h$;

Boron:
B_Bark = $0.3386\ 10^{-3} d^2$;
B_Ltot = $0.9340\ 10^{-4} d^2$;
B_Bliv = $0.6070\ 10^{-3} d^2$;
B_Wood = $0.7160\ 10^{-3} d^2$;
B_Tronc = $0.00438\ d^2$;
B_Total = $0.9437\ 10^{-4} d^2 h$;

Carbon:
C_Bark = $0.0076\ (d^2 h)^{0.7880}$;
C_Ltot = $0.0045\ d^2$;
C_Bliv = $0.0490\ d^2$;
C_Wood = $0.0138\ (d^2 h)^{0.9360}$;
C_Tronc = $0.0342\ (d^2 h)^{0.9299}$;
C_Total = $0.0630\ d^{2.3754}$.

✓ **The selected final models were simultaneously fitted by SUR method with the ITSUR procedure for each mineral.**

✓ Final compatible mineralomass equations

Equation	EM
Nitrogen:	
N_Bark = $0.5877\ 10^{-5} d^2 h$;	0.8871
N_Ltot = $0.1700\ 10^{-3} d^2$;	0.7266
N_Bliv = $0.2930\ 10^{-3} d^2$;	0.5437
N_Wood = $0.3660\ 10^{-3} d^2$;	0.4609
N_Total	0.7209
Phosphorus:	
P_Bark = $0.1400\ 10^{-4} d^2$;	0.6318
P_Ltot = $0.1200\ 10^{-4} d^2$;	0.6954
P_Bliv = $0.3400\ 10^{-4} d^2$;	0.3639
P_Wood = $0.3800\ 10^{-4} d^2$;	0.2128
P_Total	0.4951
Potassium:	
K_Bark = $0.2812\ 10^{-5} d^2 h$;	0.5853
K_Ltot = $0.6600\ 10^{-4} d^2$;	0.6634
K_Bliv = $0.1480\ 10^{-3} d^2$;	0.5638
K_Wood = $0.7100\ 10^{-4} d^2$;	0.0932
K_Total	0.7427
Calcium:	
Ca_Bark = $0.4730\ 10^{-3} d^2$;	0.2546
Ca_Ltot = $0.2600\ 10^{-4} d^2$;	0.4772
Ca_Bliv = $0.2491\ 10^{-3} d^2$;	0.4221
Ca_Wood = $0.8796\ 10^{-5} d^2 h$;	0.5882
Ca_Total	0.7998
Magnesium:	
Mg_Bark = $0.4300\ 10^{-4} d^2$;	0.4369
Mg_Ltot = $0.3000\ 10^{-4} d^2$;	0.7398
Mg_Bliv = $0.9700\ 10^{-4} d^2$;	0.5323
Mg_Wood = $0.3100\ 10^{-5} d^2 h$;	0.7125
Mg_Total	0.7246
Sulfur:	
S_Bark = $0.2441\ 10^{-6} d^2 h$;	0.5537
S_Ltot = $0.7388\ 10^{-5} d^2$;	0.7147
S_Bliv = $0.1100\ 10^{-4} d^2$;	0.6622
S_Wood = $0.1872\ 10^{-5} d^2 h$;	0.3827
S_Total	0.5925
Boron:	
B_Bark = $0.3330\ 10^{-3} d^2$;	0.8000
B_Ltot = $0.9200\ 10^{-4} d^2$;	0.5354
B_Bliv = $0.655\ 10^{-3} d^2$;	0.6128
B_Wood = $0.7940\ 10^{-3} d^2$;	0.6011
B_Total	0.7830
Carbon:	
C_Bark = $0.010008\ (d^2 h)^{0.760258}$;	0.9491
C_Ltot = $0.004172\ d^2$;	0.7175
C_Bliv = $0.041554\ d^2$;	0.5124
C_Wood = $0.010784\ (d^2 h)^{0.960756}$;	0.9314
C_Total	0.9103

✓ We present the modeling efficiency (EM) of the equations, a measure similar to the adjusted R^2 in linear models. The *EM* obtained by *SUR* method is generally lower than that obtained by *OLS*, but with a smaller standard error of the coefficients and with the guarantee of the additivity of the mineralomass of the tree-components to obtain the total mineralomass of the tree.

Conclusions

✓At the end of this study we available equations of mineralomass by tree-components and mineral for the sweet chestnut high-forest management. The information obtained with these mineralomass equations, applicable to data of individual trees, can be applied to the forest inventories as well as to a great variety of ecological problems, like wildfire studies, the carbon sequestration and to evaluate the harvesting impact on site nutrient export and site sustainability.

References: FAO. (1998). World reference base for soil resources. World Soil Resources Reports, Rome, 84.
Patrício, M.S., Monteiro, M.L. and Tomé, M. (2005). Biomass Equations for *Castanea sativa* High Forest in the Northwest of Portugal. Acta Hort. 693:727-732.

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