

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.



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	14.34
h (m)	11.55	21.91	30.40	4.63

Results and Discussion

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

- $M = \beta_0 + \beta_1 d + \beta_2 h$
- $M = \beta_0 d^{\beta_1} h^{\beta_2}$
- $M = \beta_0 + \beta_1 d + \beta_2 d^2 + \beta_3 h^2$
- $M = \beta_0 d + \beta_1 d^2$
- $M = \beta_0 h + \beta_1 h^2$
- $M = \beta_0 (d+h)^2$
- $M = \beta_1 d^{\beta_2} h^{\beta_3}$

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

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	Coeff.	EM	imPRESS	maPRESS	R ²	P95	P5
N	(1) M_Bark	0.507 10 ⁻⁴	0.957	-0.003	0.033	0.862	0.005	-0.101
	(2) M_Ltot	0.718 10 ⁻⁴	0.837	0.007	0.076	0.715	0.264	-0.163
	(3) M_Bliv	0.237 10 ⁻⁴	0.767	0.023	0.148	0.538	0.673	-0.258
Mg	(1) M_Wood	0.284 10 ⁻⁴	0.830	0.054	0.180	0.417	0.530	-0.286
	(4) M_Stem	0.257 10 ⁻⁴	0.944	0.096	0.611	0.803	2.853	-1.168
	(11) M_Tot	0.538 10 ⁻⁴	0.900	0.083	0.431	0.720	1.929	-0.829
K	(3) M_Bark	0.216 10 ⁻⁴	0.895	0.522 10 ⁻³	0.005	0.632	0.106	-0.010
	(1) M_Ltot	0.372 10 ⁻⁴	0.831	0.665 10 ⁻³	0.005	0.672	0.015	-0.008

The analysis

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	Mean	St. Dev.
N	0.009	0.001
P	0.002	0.000
K	0.007	0.001
Ca	0.004	0.000
Mg	0.003	0.000
S	0.001	0.000
B	0.000	0.000
C	0.000	0.000

Final mineralomass equations fitted by OLS method

- Nitrogen:**
 N_Bark = 0.6260 10⁻⁵ d² h;
 N_Ltot = 0.1768 10⁻³ d²;
 N_Bliv = 0.2505 10⁻³ d²;
 N_Wood = 0.3232 10⁻³ d²;
 N_Tronc = 0.00193 d²;
 N_Total = 0.4138 10⁻⁴ d² h;
- Magnesium:**
 Mg_Bark = 0.4750 10⁻⁴ d²;
 Mg_Ltot = 0.2991 10⁻⁴ d²;
 Mg_Bliv = 0.8383 10⁻⁴ d²;
 Mg_Wood = 0.3080 10⁻⁵ d² h;
 Mg_Tronc = 0.2325 10⁻⁴ d² h;
 Mg_Total = 0.0336+0.9950 10⁻⁵ d² h;

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

Final compatible mineralomass equations

- Nitrogen:**
 N_Bark = 0.5877 10⁻⁵ d² h; EM 0.8971
 N_Ltot = 0.1700 10⁻³ d²; 0.7266
 N_Bliv = 0.2930 10⁻³ d²; 0.5437
 N_Wood = 0.3660 10⁻³ d²; 0.4609
 N_Total 0.7209
- Phosphorus:**
 P_Bark = 0.1400 10⁻⁴ d²; 0.6318
 P_Ltot = 0.1200 10⁻⁴ d²; 0.6954
 P_Bliv = 0.3400 10⁻⁴ d²; 0.3639
 P_Wood = 0.3800 10⁻⁴ d²; 0.2128
 P_Total 0.4951
- Potassium:**
 K_Bark = 0.2812 10⁻⁵ d² h; 0.5853
 K_Ltot = 0.6600 10⁻⁴ d²; 0.6634
 K_Bliv = 0.1480 10⁻⁴ d²; 0.5638
 K_Wood = 0.7100 10⁻⁴ d²; 0.0932
 K_Total 0.7427
- Calcium:**
 Ca_Bark = 0.4730 10⁻⁴ d²; 0.2546
 Ca_Ltot = 0.2600 10⁻⁴ d²; 0.4772
 Ca_Bliv = 0.2491 10⁻⁴ d²; 0.4221
 Ca_Wood = 0.8796 10⁻⁵ d² h; 0.5882
 Ca_Total 0.7998
- Magnesium:**
 Mg_Bark = 0.4300 10⁻⁴ d²; 0.4369
 Mg_Ltot = 0.3000 10⁻⁴ d²; 0.7398
 Mg_Bliv = 0.9700 10⁻⁴ d²; 0.5323
 Mg_Wood = 0.3100 10⁻⁵ d² h; 0.7125
 Mg_Total 0.7246
- Sulfur:**
 S_Bark = 0.2441 10⁻⁶ d² h; 0.5537
 S_Ltot = 0.7388 10⁻⁴ d²; 0.7147
 S_Bliv = 0.1100 10⁻⁴ d²; 0.6622
 S_Wood = 0.1872 10⁻⁵ d² h; 0.3827
 S_Total 0.5925
- Boron:**
 B_Bark = 0.3330 10⁻³ d²; 0.8000
 B_Ltot = 0.9200 10⁻⁴ d²; 0.5354
 B_Bliv = 0.655 10⁻³ d²; 0.6128
 B_Wood = 0.7940 10⁻³ d²; 0.6011
 B_Total 0.7830
- Carbon:**
 C_Bark = 0.010008 (d²h)^{0.960258}; 0.9491
 C_Ltot = 0.004172 d²; 0.7175
 C_Bliv = 0.041554 d²; 0.5124
 C_Wood = 0.010784 (d²h)^{0.960756}; 0.9314
 C_Total 0.9103

Final compatible mineralomass equations

Min.	Model	Coeff.	EM	imPRESS	maPRESS	R ²	P95	P5
N	(1) M_Bark	0.786 10 ⁻⁴	0.752	0.016	0.096	0.524	0.274	-0.135
	(11) M_Wood	0.156 10 ⁻⁴	0.428	0.025	0.079	0.880	0.192	-0.143
	(1) M_Stem	0.002	0.868	0.034	0.393	0.618	1.034	-0.753
Ca	(7) M_Tot	0.036	0.925	0.023	0.171	0.719	0.898	-0.274
	(3) M_Ltot	0.337 10 ⁻⁴	0.749	0.002	0.016	0.451	0.049	-0.021
	(1) M_Wood	0.359 10 ⁻⁴	0.707	0.027	0.198	0.401	0.631	-0.492
Mg	(1) M_Wood	0.293 10 ⁻⁴	0.773	0.023	0.148	0.538	0.673	-0.258
	(1) M_Stem	0.088	0.991	0.119	2.260	0.498	5.256	-6.362
	(1) M_Tot	0.114 10 ⁻⁴	0.962	0.020	0.286	0.979	0.067	-0.565
K	(3) M_Bark	0.592 10 ⁻⁴	0.852	-0.009	0.274	0.242	0.580	-0.629
	(1) M_Ltot	0.357 10 ⁻⁴	0.749	0.002	0.016	0.451	0.049	-0.021
	(1) M_Wood	0.359 10 ⁻⁴	0.707	0.027	0.198	0.401	0.631	-0.492
Mg	(1) M_Wood	0.293 10 ⁻⁴	0.773	0.023	0.148	0.538	0.673	-0.258
	(1) M_Stem	0.088	0.991	0.119	2.260	0.498	5.256	-6.362
	(1) M_Tot	0.114 10 ⁻⁴	0.962	0.020	0.286	0.979	0.067	-0.565
S	(3) M_Bark	0.552 10 ⁻⁴	0.779	0.480 10 ⁻³	0.024	0.357	0.064	-0.048
	(1) M_Ltot	0.229 10 ⁻⁴	0.822	0.002	0.014	0.719	0.040	-0.022
	(1) M_Wood	0.293 10 ⁻⁴	0.759	0.016	0.059	0.465	0.232	-0.083
B	(1) M_Wood	0.229 10 ⁻⁴	0.874	0.006	0.037	0.681	0.151	-0.071
	(1) M_Stem	0.001	0.893	0.025	0.243	0.637	0.845	-0.540
	(1) M_Tot	0.179 10 ⁻⁴	0.818	0.023	0.125	0.642	0.356	-0.203
C	(1) M_Bark	0.321 10 ⁻⁴	0.835	0.128 10 ⁻³	0.003	0.510	0.010	-0.009
	(1) M_Ltot	0.155 10 ⁻⁴	0.852	0.145 10 ⁻³	0.003	0.912	0.009	-0.009
	(1) M_Wood	0.351 10 ⁻⁴	0.797	0.001	0.007	0.619	0.036	-0.010
P	(1) M_Wood	0.260 10 ⁻⁴	0.616	0.008	0.036	0.314	0.183	0.054
	(1) M_Stem	0.056 10 ⁻⁴	0.775	0.008	0.074	0.641	0.019	-0.126
	(1) M_Tot	0.397 10 ⁻⁴	0.827	0.008	0.034	0.631	0.159	-0.060
Mg	(3) M_Bark	0.119 10 ⁻⁴	0.915	0.004	0.129	0.780	0.273	-0.292
	(1) M_Ltot	0.091 10 ⁻⁴	0.684	0.001	0.055	0.507	0.216	-0.190
	(1) M_Wood	0.125 10 ⁻⁴	0.786	0.088	0.397	0.562	1.154	-0.513
K	(1) M_Wood	0.150 10 ⁻⁴	0.886	0.011	0.407	0.576	0.097	-1.191
	(1) M_Stem	0.168 10 ⁻⁴	0.927	0.083	1.475	0.822	4.063	-1.473
	(1) M_Tot	0.237 10 ⁻⁴	0.915	-0.006	0.881	0.819	2.335	-2.487
Ca	(3) M_Bark	0.377 10 ⁻⁴	0.863	0.071	3.674	0.568	0.388	-2.686
	(1) M_Ltot	0.004	0.838	0.152	1.976	0.712	5.862	-3.541
	(1) M_Wood	0.087	0.757	0.031	35.974	0.560	188.415	-52.166
Mg	(1) M_Wood	0.012	0.978	-1.141	26.027	0.933	64.773	-60.100
	(1) M_Stem	0.090	0.982	-3.611	52.653	0.946	156.171	-101.883
	(1) M_Tot	0.069	0.981	-0.042	31.370	0.977	66.810	-107.467

component:

- Nitrogen:**
 N_Bliv = 0.3070 10⁻⁴ d²;
 P_Wood = 0.3217 10⁻⁴ d²;
 P_Tronc = 0.1713 10⁻³ d²;
 P_Total = 0.1030 10⁻³ d²;
Potassium:
 K_Bark = 0.2400 10⁻⁵ d² h;
 K_Ltot = 0.6220 10⁻⁴ d²;
 K_Bliv = 0.1370 10⁻³ d²;
 K_Wood = 0.2430 10⁻⁵ d² h;
 K_Tronc = 0.3036 10⁻⁴ d² h;
 K_Total = 0.4060 10⁻³ d²;
Calcium:
 Ca_Bark = 0.4152 10⁻³ d²;
 Ca_Ltot = 0.2824 10⁻⁴ d²;
 Ca_Bliv = 0.2671 10⁻³ d²;
 Ca_Wood = 0.8670 10⁻⁵ d² h;
 Ca_Tronc = 0.2041 10⁻³ d² h;
 Ca_Total = 0.1062+0.3777 10⁻⁴ d² h;
- Magnesium:**
 S_Bliv = 0.1063 10⁻⁴ d²;
 S_Wood = 0.1550 10⁻⁵ d² h;
 S_Tronc = 0.4420 10⁻⁵ d² h;
 S_Total = 0.2580 10⁻⁵ d² h;
Boron:
 B_Bark = 0.3386 10⁻³ d²;
 B_Ltot = 0.9340 10⁻⁴ d²;
 B_Bliv = 0.6070 10⁻³ d²;
 B_Wood = 0.7160 10⁻³ d²;
 B_Tronc = 0.00438 d² h;
 B_Total = 0.9437 10⁻⁴ d² h;
Carbon:
 C_Bark = 0.0076 (d²h)^{0.9800};
 C_Ltot = 0.0045 d²;
 C_Bliv = 0.0490 d²;
 C_Wood = 0.0138 (d²h)^{0.9360};
 C_Tronc = 0.0034 (d²h)^{0.9290};
 C_Total = 0.0630 d² 2.3754.

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. 683:727-732.

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 (41° 14' 46" N, 7° 55' 04" W), Padrela (41° 30' 41" N, 7° 37' 15" W) and Bornes (41° 29' 42" N, 6° 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 (°)	5-10	25-30	15-20
Main soil type*	Umbric Regosols	Dystric Regosols	Dystric Cambisols
Mean annual temperature (°C)	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±2°C, while the log samples and branches