Original Research Article

Effects of Soil Type in Nutrient Amount in *Eucalyptus urograndis*: Macronutrients

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ABSTRACT

The aim of the present study was to quantify macronutrient stock in the hybrid *Eucalyptus urograndis*, for different soil types inTelemaco Borba, Parana, Brazil. Sandy texture (Cambisols Inceptisols), and clayey texture (Ferralsols Oxisols) soils were selected for the study. Based on the diameter at breast height (DBH) survey of all the trees comprising each plot, 12 trees were selected per soil type for biomass sampling. The trees were sectioned at soil level and separated into: leaves, branches, stembark, stemwood, tree tops wood, tree tops bark and roots, and a representative sample of each component was collected and grounded in a Wiley-type mill for analytical determination of the macronutrients. The analyses of the experiment were performed considering a completely randomized design. The concentrations of the macronutrients in the different biomass components were significantly different in both types of soil. With the exception of calcium, in the sandy soil and calcium and magnesium in the clayey soil, which were more present in the stembark component, the other components present the highest concentration values in the leaves component. The lowest concentration values of macronutrients, both for the sandy soil and for the clayey soil, were found in the stemwood and roots components. Total nutrient stock found in the biomass, in the sandy soil was 1.65 Mg ha^{-1}, distributed in the following order of magnitude: stemwood > root > stembark > leaves > branches > tree tops wood > tree tops bark. For the clayey soil the order was: stemwood > stembark > root > branches > leaves > tree tops wood > tree tops bark, presenting a total stock of 2.41 Mg ha^{-1}. The highest amount of macronutrients in the biomass was found in soil with a clayey texture.

Keywords: forest nutrition, forest soils, sandy soil, clayey soil.

1. INTRODUCTION

The growing demand for products of forest origin has turned Brazilian plantations of fast-growing, high-yield exotic tree species into a prominent factor in the world forestry scenario, due to its economic, social and environmental benefits to the country. Plantations in tropical regions provide an increasing share of timber for global supply and competition with other land uses will require sustainable production of these stands to meet market demand [1]. Among these forest species *Eucalyptus urograndis*, a hybrid of *Eucalyptus urophylla* S.T., stands out in importance. In this study, *Eucalyptus urophylla* S. T. Blake and *Eucalyptus grandis* Hill ex Maiden presented good adaptation to several regions of the country, as well as high yield and better characteristics of wood for several industrial purposes [2].

Nutrients' quantification in different components of biomass arefundamental importance for trees' nutrition, especially when requested to estimate the productivity of a certain species under edaphoclimatic condition within an evaluated site. Furthermore, it is used to enable the prediction of critical situations of the stands, chemical characteristics of the soil and analysis of the effects caused by forest harvest, with the evaluation of the nutrients' export from the site [3] [4].

The concentration and amount of nutrients stored in the trees may vary according to the species, age, soil type, climatic conditions of the site and the management practices adopted in the stand besides within the same biomass component there may be variations due to internal translocations [5]. The productive capacity of a species depends on external factors of an edaphic, climatic and biological nature, whether or not it is manageable, among these factors, nutrition has the greatest management potential [6].

Thus, evaluations of the nutritional requirement of the species through the quantification of the stock of nutrients in the different components of biomass and the soil properties at different sites are useful for adjusting fertilization programs in order to maintain the nutrient stock of the soil throughout successive rotations [1]. Silva et al. [7] also emphasized out that it is necessary to consider the relationship between the amount of nutrients in the biomass components and the soil's climatic conditions to suit the nutritional need of the species.

Forest plantations established in gleisols and podzols tend to be more affected in the nutrient stock of the soil, by the biomass harvest, than stands growing in acrosols and cambisols [8]. Sandy soils with low nutrient retention and high hydraulic conductivity are highly susceptible to nutrient leaching, hindering the fertilization program to be adopted [7].

The amount of nutrient accumulated components of trees above ground (leaves, branches, stemwood, stembark and roots) throughout the growing cycle represent an estimate of the entire nutrient demand in forest stands [9]. Thus, the aim of the present work was to quantify the stock of macronutrients in *Eucalyptus urograndis* stands established in sandy and clayey soils.

2. MATERIAL AND METHODS

2.1 Characterization of the area and experimental design

The present study was carried out in a plantation with the hybrid *Eucalyptus urograndis*, in the municipality of Telêmaco Borba, Paraná - Brazil. The climate of the region, according to the classification of Köppen, is of the type Cfb (Humid subtropical climate), with rains well distributed during the year and mild summers, without dry season. Average annual temperatures vary around 19 ºC and rainfall reaches about 1,184 mm annually with the average of the hottest month at around 27 °C and the coldest month around 13 °C [10].

The soils selected for the study were the Cambisol Inceptisol and the Ferralsol Oxisol, denominated as sandy and clayey soil, respectively. Cambisols present a moderate A horizon of clay of low activity and light average texture (sandy loam) with the occurrence of rocks in the soil mass. A moderate A-horizon with a clayey or very clayey texture, on the other hand, characterizes Ferralsols. Clayey soils naturally present higher cation exchange capacity (2.95 $cmol_c\ dm^{-3}$) than sandy soils (2.39 $cmol_c\ dm^{-3}$), especially in the first layer of 0 cm to 20 cm of depth where they present higher levels of organic matter (Table 1).

Table 1. Chemical and physical attributes of distinct soils planted with *Eucalyptus urograndis* in the region of Telêmaco Borba, Paraná, Brazil

Atribute	Sandy			Clayey		
	0-20 cm	20-40 cm	40-60 cm	0-20 cm	20-40 cm	40-60 cm
O.M. * (%)	1.79	1.32	1.42	3.39	2.45	1.72
pH (H_2O)	3.97	3.97	3.95	3.98	4.19	4.41
P* (mg dm^{-3})	1.61	1.12	0.89	0.86	0.68	0.68
K* (mg dm^{-3})	30.92	20.08	35.11	45.04	32.59	27.63
S (mg dm^{-3})	9.08	10.28	13.03	26.13	23.36	11.26
B (mg dm^{-3})	0.55	0.63	0.67	0.61	0.61	0.56
Cu (mg dm^{-3})	1.25	1.22	1.19	2.65	2.06	1.40
Zn (mg dm^{-3})	0.54	0.48	0.43	0.58	0.25	0.19
Ca ($cmol_c$ dm^{-3})	0.09	0.06	0.06	0.18	0.05	0.03
Mg ($cmol_c$ dm^{-3})	0.07	0.05	0.05	0.45	0.11	0.03
ECEC ($cmol_c$ dm^{-3})	2.30	2.41	2.47	3.72	2.85	2.29
V (%)	2.54	1.53	2.68	2.89	1.00	0.75
m (%)	89.92	96.19	93.36	80.02	91.76	94.25
Coarse sand (%)	39.89	40.33	40.72	14.68	16.51	16.18
Fine sand (%)	40.36	40.50	37.05	6.87	5.79	6.73
Silt (%)	4.19	2.11	3.67	28.23	31.48	26.87
Clay (%)	15.56	17.06	18.56	50.22	46.22	50.22

Where: O.M. = organic matter; P = Phosphorus; K = Potassium; S = Sulfur; B = Boron; Cu = Copper; Zn = Zinc; Ca = Calcium; Mg = Magnesium; ECEC = Effective Cation Exchange Capacity; V = saturation per exchangeable base; m = exchangeable aluminum saturation; *Determination of nutrients using the Mehlich^{-1} extractor.

For each soil type, 4 sample plots with an area of 2,550 m^2 and composed of 340 plants were set. Planting was carried out manually, with spacing of 3.0 m x 2.5 m and initial density of 1,333 plants per hectare. Prior to planting, the lines were sub-soiled in a depth of 45 cm, where 200 kg ha^{-1} of natural rock phosphate were incorporated. After the planting, two other fertilizations were carried out, the first being a basic fertilization of 15 kg ha^{-1} of N, 35 kg ha^{-1} of P, 15 kg ha^{-1} of K, and the second one a cover fertilization with 40 kg ha^{-1} of N, 5 kg ha^{-1} of P, 65 kg ha^{-1} of K + 1,5 kg ha^{-1} of B.

2.2 Measurements of biomass and nutrients

Based on the diameter at breast height (DBH) survey of all the trees comprising each plot (disregarding dead and missing trees), 12 trees were selected per soil type for above-ground biomass sampling (tree mean diameter minus standard deviation, tree mean diameter and tree mean diameter plus standard deviation of each plot).

The selected trees were sectioned at soil level and separated in the following above-ground components: leaves, branches, stembark, stemwood, tree tops wood and tree tops bark (shaft diameter below 8 cm). Root biomass was estimated by digging in the useful area (7.5 m^2), to the depth of one meter, of the four medium DBH trees, in each soil type.

Representative samples (200 g) of each component of the tree biomass were collected. The samples of the stembark and the stemwood were obtained by the collection of discs in the following positions according to the commercial height: 0%, 25%, 50%, 75%, 100% (minimum diameter of 8 cm) and tree tops wood and tree tops bark.

All samples were sent to laboratory, dried at 70 °C in a forced air oven, until reaching constant mass, and then weighed again to determine biomass through the humidity of the samples of each component. The determination of tree biomass was performed indirectly through the moisture content of the samples of each component. The moisture content in the disc was used at the corresponding height of the stem to estimate the biomass of the stemwood, stembark, tree tops wood and tree tops bark.

The total biomass per hectare was estimated based on the biomass of each tree and the number of trees per hectare. A detailed description of the methodology adopted for biomass determination can also be found in Salvador et al. [11].

All samples were grounded in a Wiley-type mill for analytical determination of the macronutrients N, P, K, Ca, Mg and S according to the methodology described by Tedesco et al. [12] and Miyazawa et al. [13]. For the estimation of total nutrient stock per hectare, mean nutrient concentration was multiplied by the biomass of each component per hectare.

2.3 Statistical analysis

Due to the similarity of the local site conditions, analyses of the experiment was with a completely randomized design. Statistical analyses were performed with the aid of the statistical program SAS [14], at the level of 5% probability of error. Tukey's test was used to separate the contrasts of averages, considering a completely randomized design, where each tree analyzed corresponds to one repetition in each type of soil.

3. RESULTS AND DISCUSSION

The concentration of macronutrients in the different biomass components were significantly different (p=.05) in the two soil types (Table 2). The highest concentration of nutrients was found in the leaves component, in the two soil types, with the exception of calcium, which presented higher values in the stembark component. The lowest concentrations of macronutrients were found in stemwood and roots component. According to Viera et al. [3] leaves present higher concentration of nutrients due to the greater metabolic activity (photosynthesis and transpiration) of these tissues when compared to others.

Table 2. Concentration of nutrients in biomass components in 7 years-old *Eucalyptus urograndis* stands at different soil types, in the region of Telêmaco Borba, Parana - Brazil

Soil	Component	N	P	K	Ca	Mg	S
		g kg^{-1}					
Sandy	Leaves	21.28 a (±2.34)	1.21 a (±0.21)	11.74 a (±2.32)	4.36 b (±0.56)	2.50 a (±0.38)	0.97 a (±0.18)
	Branches	3.20 c (±0.85)	0.32 c (±0.13)	5.30 b (±1.03)	2.89 c (±0.98)	0.85 b (±0.41)	0.39 b (±0.03)
	Tree tops bark	4.61 b (±0.55)	0.80 b (±0.40)	6.86 b (±1.73)	9.31 a (±1.07)	3.19 a (±0.55)	0.25 cd (±0.05)
	Tree tops wood	2.31 d	0.22 c	3.18 c	0.55 e	0.43 b	0.30 c

		(±0.41)	(±0.04)	(±0.71)	(±0.16)	(±0.14)	(±0.04)
	Stembark	3.89 bc (±0.21)	0.56 b (±0.10)	10.09 a (±1.53)	8.21 a (±1.37)	2.30 a (±0.24)	0.41 b (±0.04)
	Stemwood	1.02 e (±0.08)	0.07 d (±0.01)	0.93 e (±0.09)	0.47 e (±0.09)	0.12 e (±0.02)	0.24 d (±0.04)
	Roots	3.93 b (±0.26)	0.19 c (±0.05)	1.54 d (±0.34)	1.59 d (±0.98)	0.59 b (±0.14)	0.42 b (±0.03)
Clayey	Leaves	22.18 a (±1.26)	1.21 a (±0.10)	12.18 a (±1.93)	6.66 b (±1.18)	2.93 a (±0.41)	1.10 a (±0.23)
	Branches	4.69 b (±1.00)	0.41 c (±0.14)	4.83 dc (±1.69)	8.60 ab (±2.65)	1.77 b (±0.45)	0.26 b (±0.03)
	Tree tops bark	4.43 b (±1.09)	0.86 b (±0.41)	6.05 bc (±2.18)	7.39 b (±1.01)	3.60 a (±0.56)	0.27 b (±0.05)
	Tree tops wood	1.40 c (±0.23)	0.12 e (±0.03)	1.53 e (±0.25)	0.64 d (±0.27)	0.25 d (±0.07)	0.24 b (±0.07)
	Stembark	3.88 b (±0.33)	0.54 bc (±0.15)	7.89 b (±1.95)	12.31 a (±1.87)	2.86 a (±0.53)	0.28 b (±0.04)
	Stemwood	1.03 d (±0.12)	0.06 f (±0.02)	1.01 f (±0.17)	0.65 d (±0.16)	0.18 e (±0.03)	0.25 b (±0.06)
	Roots	3.73 b (±0.21)	0.24 d (±0.03)	4.08 d (±0.46)	2.42 c (±0.61)	1.10 c (±0.20)	0.26 b (±0.01)

* Values in italics indicate the standard deviation of each component. Different vertical letters indicate significant differences between the biomass components, by the Tukey test (p=.05)

Highest nutrient concentration in the leaves were also found by Leite et al. [9], Boulliet et al. [15], Turner and Lambert [16], Gatto et al. [17] and Carvalho et al. [18]. Analyzing the concentration of macronutrients in the different components of 6.75 year-old *Eucalyptus grandis* in Ferralsols, Leite et al. [9] found higher concentrations of nitrogen and phosphorus in the leaves (leaves > branches > stembark > stemwood), potassium and magnesium in the stembark (leaves > stembark > branches > stemwood) and calcium in the bark (stembark > leaves > branches > stemwood).

Potassium plays a key role in regulating the osmotic potential of plant cells in addition to activating the enzymes of respiration and photosynthesis [19] and is highly mobile in phloem and readily redistributed to new growing organs [20], thus presenting a tendency to concentrate in the leaves, a result obtained in the present study.

Phosphorus also presents high mobility within the plant and tends to concentrate on the newer organs [21], in the case of this study, on the leaf component. Moreover, the high concentration of phosphorus in the leaves is related to the role of this element as an integral component of important plant compounds, which are used as energy sources [22].

The high Ca content in the stembark component was also found in other studies by Guimaraes et al. [23] and Carvalho et al. [18], which can be justified as being a virtually immobile element in the plant phloem and a structural component of the middle lamella of the cell wall.

Component differentiations, besides the physiological importance of each plant component, affect nutrient accumulation, and the lowest concentrations of nutrients in this study were found in the wood component. This result is related to the internal re-translocation of nutrients, since wood presents less intense physiological activity.

Among the factors that cause variations in nutrient contents in the leaves component, we can cite: day length; trees' age; the effect of pests and diseases; the position of the leaves in the canopy; sampling season; physiological state of the leaves; soil parameters; species used; site conditions and provenances [24]. In addition, differences in nutrient concentration between the components and within the plant components are related to the biochemical cycle that involves the retranslocation of a certain element from one organ to another [19].

The total amount of nutrients found in the sandy soil was 1.65 Mg ha^{-1}, in the following order: N > K > Ca > Mg > S > P. For the clayey soil there was an inversion in the values presenting the following order: K > Ca > N > Mg > S > P, summing up a total stock of 2.41 Mg ha^{-1} (Table 3). The largest stock of nutrients observed in the clayey soil is directly related to higher biomass production in this type of soil.

Table 3 - Amount of nutrients in the different biomass components in a 7-years-old *Eucalyptus urograndis* stands at different soil types, in the region of Telêmaco Borba, Parana - Brazil

Soil	Component	Biomass	N	P	K	Ca	Mg	S
		Mg ha^{-1}	kg ha^{-1}					
Sandy	Leaves	2.61	52.73	2.90	28.15	11.06	6.20	2.40
	Branches	6.95	19.81	1.81	33.65	18.57	5.16	2.64
	Tree tops bark	1.42	5.99	1.04	8.92	12.06	4.12	0.33
	Tree tops wood	11.64	26.05	2.45	36.11	6.28	4.71	3.46
	Stembark	12.07	46.23	6.44	115.19	100.67	28.31	4.84
	Stemwood	180.26	186.18	12.02	169.22	87.37	22.44	40.45
	Roots	43.05	166.39	7.78	63.57	57.30	24.11	17.98
	Total	258.00	503.38	34.44	454.81	293.29	95.05	72.09
Clayey	Leaves	4.01	88.98	4.82	46.44	25.07	11.08	4.18
	Branches	11.44	52.46	4.49	56.59	98.25	19.41	2.87
	Tree tops bark	2.07	8.77	1.21	7.35	11.38	5.91	0.38
	Tree tops wood	12.52	16.86	1.44	19.07	8.25	2.99	3.06
	Stembark	23.01	87.13	9.99	165.34	252.06	61.69	6.76
	Stemwood	211.21	213.66	13.30	218.63	132.86	39.27	52.50
	Roots	36.95	137.57	8.64	149.60	87.59	40.32	9.63
	Total	301.20	605.42	43.90	663.02	615.46	180.67	79.38

The magnitude of values, for different above-ground biomass components found by Viera et al. [3] in a 10 years-old *Eucalyptus urophylla* x *E. globulus* stand was: Ca > N > K > Mg > P > S. This result is similar to the order found by Guimarães et al. [23] in a 4 years-old *Eucalyptus dunnii* stand: Ca > N > K > Mg > S > P. Santos et al. [25], on the other hand, found the following order for 5 years-old *E. urograndis*: N > K > Ca > Mg > P.

Regarding the mean values of nutrient concentrations in the biomass components of 7 years-old *Eucalyptus saligna*, Witschoreck and Schumacher [6], order Ca > N > K > Mg > P, similar to the sandy soil in this study. Verão et al. [26], evaluating 7 years-old *Eucalyptus urograndis*, observed that the mean concentration of macronutrients was, in decreasing order, N > Ca > K > S > Mg > P. Despite the differences in the sequences, phosphorus was always the element with lower concentration in the aforementioned studies.

At the sandy soil, the amount of macronutrients within different biomass components presented the following order: stemwood > root > stembark > leaves > branches > tree tops wood > tree tops bark. For the clayey soil, there was an inversion in the amounts, presenting the following order: stemwood > stembark > root > branches > leaves > tree tops wood > tree tops bark (Figure 1).

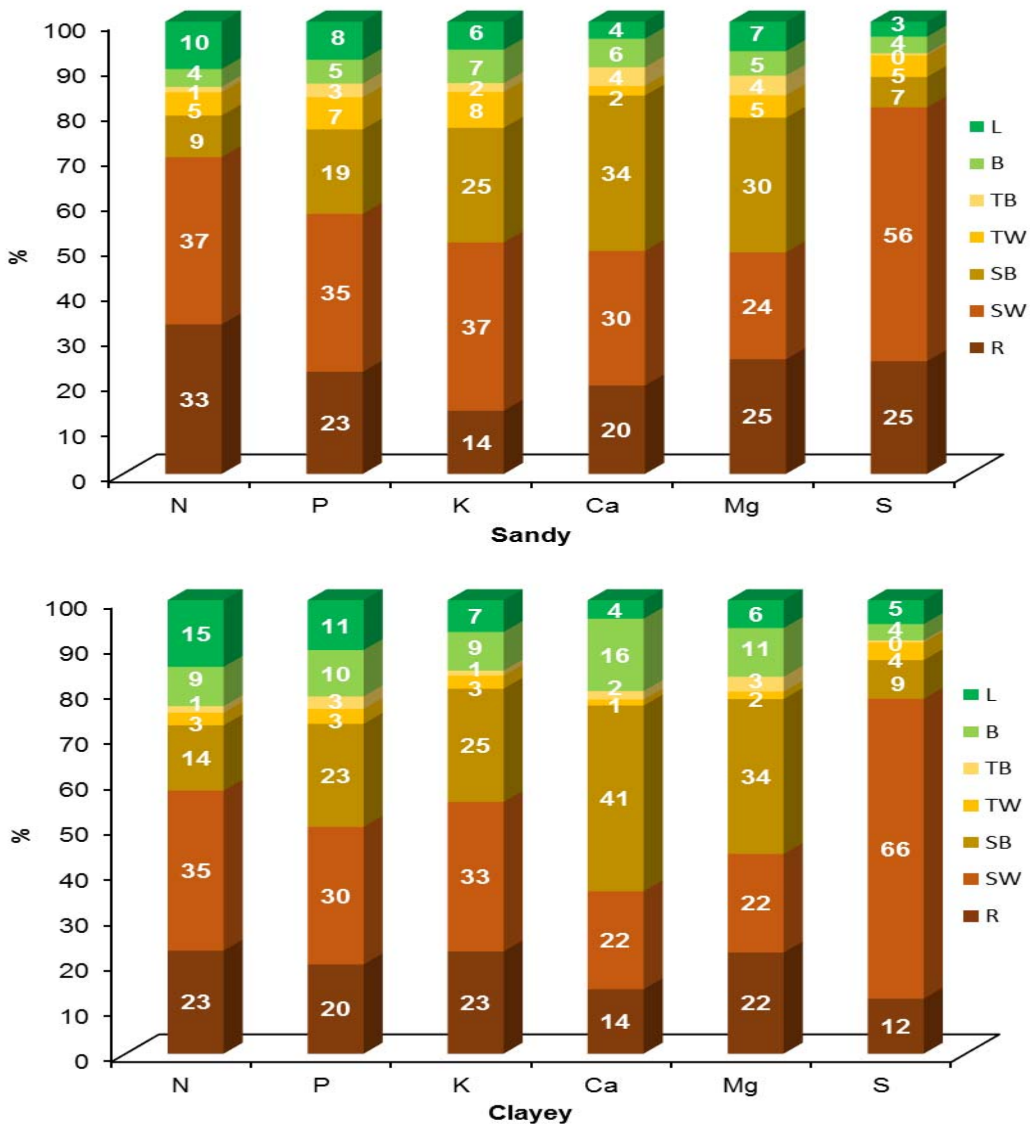

Figure 1. Distribution of nutrients in different biomass components of a 7-years-old *Eucalyptus urograndis* stands at different soil types, in the region of Telêmaco Borba, Parana - Brazil

Where: L = Leaves; B = Branches; TB = Tree tops bark; TW = Tree tops wood; SB = Stembark; SW = Stemwood; R = Roots.

Schumacher and Caldeira [27] stated that 67.9% of the total amount of Ca in above-ground biomass is allocated in stembark and stemwood, with the rest being found in the canopy (leaves and branches). Similarly, considering above-ground biomass, 80% and 73% of the Ca in the present study was found in the stem (stemwood + stembark), at sandy and clayey soil, respectively.

The relative distribution of nutrintes found by Witschoreck and Schumacher [6] in *Eucalyptus saligna* stands, at 7 years-old, for the leaves component was 15% of N, 9% of P, 8% of K, 7% of Mg, 5% of Ca, of the total nutrient stock in the tree. The same authors observed that the stemwood accumulated 6% of the P, 53% of the K, 48% of the N, 34% of the Mg and 24% of the Ca. The branches accumulated 10% of the K, Ca and Mg, 7% of the N and 6% of P.

Analyzing the distribution of nutrients in biomass components of a 10 years-old *Eucalyptus urophylla x E. globulus* stand, Viera et al. [3] observed the following order stemwood > stembark > branches > leaves. Guimarães et al [23], evaluating a 4-year-old *E. dunnii* stand, found the following order of nutrient distribution among the components: stembark > stem wood > roots > branches > leaves.

On the other hand, Witschoreck and Schumacher [6], observed that amount of nutrients in biomass components of a 7 years-old *Eucalyptus saligna* follows the order: stemwood > root > leaves > stembark > branches; The amount of nutrients in the components of hybrid *Eucalyptus urophylla* x *Eucalyptus grandis*, at 4.5 years-old, observada por Carvalho et al. [18] was: stemwood > root > stembark > branches > leaves.

Viera et al. [28], reports that the highest concentrations of nutrients in trees are found in the tissues that form the crowns. However, the largest amount of biomass is stored in the stem (stemwood + stembark), which is the part normally harvested, as can be observed in the results found by this study. Changes in nutrient allocation in different plant components are related to the ability of the root system to absorb nutrients and the degree of efficiency that the trees have in the translocation and metabolization of these nutrients [29].

4. CONCLUSION

The highest amount of macronutrients was found in soil with clayey texture, which is directly related to higher biomass production in this soil.

The leaves present the highest concentration and the wood has the largest amount of macronutrients, regardless of soil type.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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