

Quantification of nutrient content in above-ground biomass of young *Acacia mearnsii* De Wild., provenance Bodalla

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Abstract – The present study deals with the quantification of the nutrient content of the Australian acacia (*Acacia mearnsii* De Wild.), provenance Bodalla, at the age of 28 months. The experiment is located at a site of low fertility of the AGROSETA company in Butiá, Rio Grande do Sul (Brazil). Above-ground biomass components (leaves, living branches, dead branches, bark and wood) of nine sampled trees were analysed. The nutrient contents in the total biomass of Bodalla were 182 kg ha⁻¹ of N, 8.17 of P, 104 of K, 66.7 of Ca, 16.2 of Mg, and 10.1 of S. In total, 42.6% of the dry matter accounted for leaves and living and dead branches, which in turn account for 74% of N, 72% of P, 63% of K, 68% of Ca, 69% of Mg, and 74% of S of the above-ground biomass. In the trunk (bark and wood), which represents the remaining 57.4% of the total above-ground biomass, 26% of N, 28% of P, 37% of K, 32% of Ca, 31% of Mg, and 26% of S were accumulated.

Acacia mearnsii De Wild. / biomass / nutrients / mineralmass / biogeochemical cycles

Résumé – Quantification des nutriments dans la biomasse aérienne de jeunes *Acacia mearnsii* De Wild., provenance Bodalla. Cette étude concerne la quantification, à l'âge de 28 mois, des nutriments dans la biomasse aérienne de l'Acacia australien (*Acacia mearnsii* De Wild.), provenance Bodalla. L'expérience est localisée dans un site de faible fertilité appartenant à la compagnie AGROSETA, à Butiá, Rio Grande do Sul (Brésil). Les compartiments de la biomasse aérienne (feuilles, branches vivantes, branches mortes, écorce et bois) de 9 arbres échantillons ont été analysés. Les quantités de nutriments dans la biomasse totale de Bodalla étaient de 182 kg ha⁻¹ de N, 8,17 de P, 104 de K, 66,7 de Ca, 16,2 de Mg et 10,1 de S. Au total, 42,6 % de la matière sèche était composée de feuilles et de branches vivantes et mortes, représentant 74 % de N, 72 % de P, 63 % de K, 68 % de Ca, 69 % de Mg, et 74 % de S par rapport à la biomasse aérienne totale. Dans le tronc (écorce et bois), qui représente les 57,4 % restant de la biomasse aérienne totale, se sont accumulés 26 % de N, 28 % de P, 37 % de K, 32 % de Ca, 31 % de Mg et 26 % de S.

Acacia mearnsii De Wild. / biomasse / nutriments / minéralomasse / cycles biogéochimiques

1. INTRODUCTION

Nutrient content in the above-ground biomass increases from boreal to tropical forests [20]. On the other hand, the amount of nutrients accumulated in litter and other above-ground deposits increases from tropical to boreal forests. This is generally due to the low activity of decomposing organisms in boreal forests inhibited by low temperatures and/or drought [14]. Furthermore, nutrient deficiency and water stress are seen to be a major constraint in forestry in the seasonal tropics [20], such as the Brazilian *Cerrado*.

In general, the annual absorption of nutrients in forests is lower than that of agricultural areas, but in forests most of the absorbed nutrients are returned to the site and only small quantities are retained in the forest biomass. According to Young and Carpenter [38], nutrient absorption is influenced by species, age, crown covering and edafo-climatic conditions. Furthermore, nutrient absorption in forest plantations is closely associated with the increase in biomass and attains its maximum in the initial stage of a rotation period [18]. After that stage, nutrient demand can generally be satisfied by translocation or internal cycling. Bellote et al. [6] showed that most of the biomass and nutrients accumulated by

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planted *Eucalyptus grandis* occurred between 2 and 5 years of age. When leaf area is expanding, nutrient uptake from the soil is high. After stand crown closure, nutrient allocation shifts from the crown (leaves) to the trunk [15, 20].

Nutrient export from a forest site is proportional to the quantity of biomass removed. Further nutrient losses can be due to erosion and outwashing after tree felling when the soil remains bare [20].

Total nutrient cycle in a forest ecosystem is represented by the sum of nutrients in the different ecosystem components such as above- and below-ground tree biomass, understorey vegetation, litter and soil [25]. In boreal forests, most of the nutrients can be found in the active tree tissues, such as leaves [37]. According to Van Den Driessche [34], conifers tend to have a higher proportion of leaf biomass than broad-leaved trees. In contrast to broad-leaved trees, a major percentage on total nutrient content can be found in the leaves of conifers, although nutrient concentration in the leaves of conifers is lower than in broad-leaved trees.

It seems to be a general observation that nutrient contents in tree compartments vary with species. Lugo [17] found significant differences in biomass and nutrient accumulation for N, P, and K in different tropical plantation species under similar edafo-climatic conditions in Costa Rica, thus emphasizing the different nutrient-use-efficiencies of the species involved.

Plantation species of the genus *Eucalyptus*, *Pinus*, or *Acacia* play a major role in Brazilian wood industry supply. Although industrial plantations only encompass 7×10^6 ha (out of the 553×10^6 ha of total forest area in Brazil, 546×10^6 ha are natural forests), they contribute 60% to wood production [20]. *Acacia mearnsii* is considered to be an important tree species in Rio Grande do Sul, the southernmost state of Brazil. The total area with this species is approximately 160×10^3 ha, planted mostly by small landowners.

The knowledge of nutrient quantity in the nutrient stock of the soil, above and below-ground biomass is of fundamental importance to the understanding of a forest ecosystem. A deeper insight into nutrient dynamics is also a precondition for guaranteeing ecological sustainability in these forest plantations [29]. In studies with *Eucalyptus* sp. it was shown that short rotations led to higher nutrient export per area per year than long rotations [26]. Poggiani [24] also calculated the length of time before the nutrient capital in the soil is exhausted in relation to nutrient quantities accumulated in forest biomass.

In the face of the lack of knowledge concerning nutrition and nutrient cycling of *Acacia mearnsii* [7] in Rio Grande do Sul, the objective of the present study is to quantify nutrient content of above-ground biomass in a 28-month-old stand of Australian acacia (*Acacia mearnsii* De Wild.), provenance Bodalla, as the first step in the analysis of *Acacia* plantations over a complete rotation period.

2. MATERIALS AND METHODS

2.1. Experimental area

The present study was carried out on an experimental site belonging to AGROSETA Florestal Company, which is located in the city of Butiá, Rio Grande do Sul (Brazil). The study site is situated in the so-called “Serra do Sudeste” (southeastern mountain range) of Rio Grande do Sul, with the following geographical coordinates: latitude $30^{\circ} 07' 12''$ South and longitude $51^{\circ} 57' 45''$ West. The study site is situated at an altitude of 40 m a.s.l. and the relief is slightly undulating.

According to Köppen, the climate of the region is Cfa type, i.e., subtropical humid [19]. Mean annual air temperature ranges from 18–19 °C, with mean annual temperatures of 24 °C in the hottest month (January) and 14 °C in the coldest month (July). Annual, January, and July precipitation are 1400 mm, 130 mm, and 120 mm, respectively.

The geological parent material of the study region is granite. The weathered granite substrate yields significant contents of clay. According to EMBRAPA [11], the soils of the study region belong to the soil mapping unit of “São Jerônimo” with high amounts of silicates. In general these dark-red podzolic soils are deep and have good drainage. Furthermore, they are acid and have small amounts of soil organic matter [11, 21]. According to the International Soil Taxonomy this soil can be classified as Ultisol.

2.2. Chemical analysis of soils

Low values of soil pH and poor soil organic matter content are typical of many sites in southern Brazil with plantations of *Acacia*. Another characteristic is the low content of soil available P which, in general, is due to the high P-fixing capacity of the soil [11, 21]. Al concentration (in the form of hydrous oxides) is high in these soils and correlates positively with a low cation exchange capacity [7]. Furthermore, the base saturation value below 50% is linked to the rather low fertility of the experimental site (table I). Chemical analysis of the sampling site was carried out using standard extraction methods at the Soil Department laboratory of the Federal University of Rio Grande do Sul in Porto Alegre (Brazil).

2.3. Provenance

The *Acacia* variety under study was Bodalla from New South Wales, Australia, with the following geographical coordinates: latitude $36^{\circ} 11'$ South; longitude $149^{\circ} 58'$ East (altitude: 15 m a.s.l.).

2.4. Determination of the nutrient concentration in above-ground biomass

The experimental stand was planted in August 1994 with an initial spacing of 1.7 m \times 3.0 m. A homogeneous area was selected for this experiment according to the criteria (e.g., soil type, soil bulk density, and penetration resistance) of the soil mapping unit “São Jerônimo”. Four rectangular sampling areas of 18 m \times 24 m (altogether 1728 m²) were established. Diameter distribution of the experimental stand is shown in table II. All diameters at breast height (dbh, in cm) were measured within the experimental area. The heights of 10% of the trees were measured. Also, a height (h, in m) estimation was carried out using the following model: $\log h = (b_0 + b_1/dbh)^2 + 1.30$.

Table I. Chemical analysis of the soil from the sampling site of *Acacia mearnsii*, provenance Bodalla (AGROSETA Florestal Company, experimental sites, Rio Grande do Sul, Brazil).

Soil horizon (depth) (cm)	pH (H ₂ O) 1:1	soil organic matter (mg g ⁻¹)	avail. P (mg L ⁻¹)	avail. K (mg L ⁻¹)	exchang. Al ³⁺ (cmol(+) kg ⁻¹)
0–10	4.7	32	5.3	111	0.6
10–20	4.5	21	2.6	71.5	1.7
20–30	4.5	16	2.0	68.5	2.5
Soil horizon (depth) (cm)	exchang. Ca ²⁺ (cmol(+) kg ⁻¹)	exchang. Mg ²⁺ (cmol(+) kg ⁻¹)	CEC (cmol(+) kg ⁻¹)	Base saturation (%)	
0–10	2.2	1.5	4.6	44	
10–20	0.9	0.7	3.4	22	
20–30	0.5	0.4	3.5	12	

mg L⁻¹ = milligram per liter; CEC = cation exchange capacity.

Table II. Distribution of diameter at breast height in the experimental stand of *Acacia mearnsii*.

Diameter class (cm)								
3.0–4.0	4.1–5.0	5.1–6.0	6.1–7.0	7.1–8.0	8.1–9.0	9.1–10.0	10.1–11.0	11.1–12.0
6	21	55	51	63	37	11	2	3

Tree volume (v , in m³) was calculated with the equation: $v = b_0 + b_1 \times dbh^2 \times h$.

Thus, mean diameter and mean height, tree number, basal area, as well as tree volume over bark was calculated for each sampling area.

Nine trees (one tree in each diameter class) were sampled for subsequent nutrient analysis. In the intermediate part of the tree crown, leaves were collected at four cardinal points. Branches were separated from the trunk and classified as alive (green) and dead (dry). All the leaves were collected from living branches. Then, total fresh weight of leaves, living and dead branches, bark and trunk wood of the sampled trees were determined in the field.

The samples were dried in a circulation oven for 72 hours at temperatures ranging from 70 to 75 °C, until a constant weight was attained. Finally, samples were weighed with an analytical balance in order to obtain dry weight (dw). A disk 5 cm thick was removed at the mid-point of each trunk, as proposed by Young & Carpenter [38]. For each disk, the bark was separated from the wood. This measurement served as a reference for dw determination. The bark and wood samples were ground in a Wiley mill and then passed through a 1.0 mm sieve.

Biomass (Y) of the trees was determined by using the following regression equations:

$$\ln Y = a + b \times \ln dbh \text{ (for leaves/ living branches);}$$

$$\text{and } \ln Y = a + b \times \ln dbh + c \times \ln h \text{ (for bark and wood) [7].}$$

Y is expressed in Mg ha⁻¹ and dbh in cm; a , b , and c are regression coefficients.

The nutrient concentrations of total N, P, K, Ca, Mg, and S in biomass were obtained using the methods of Tedesco et al. [32]. This method allows that the five macroelements can be determined with one solution of H₂O₂ and H₂SO₄. The nutrients are restored, similar to the Kjeldahl method for N and with a nitric-perchloric solution for the other elements.

2.5. Nutrient quantification in above-ground biomass

Macronutrient stock (kg ha⁻¹) in the above-ground biomass was calculated on the basis of the biomass estimation (kg ha⁻¹) made by Caldeira [7] and the macronutrient concentrations (g kg⁻¹) obtained in the present study. The sum of the values for each component provided the total nutrient content (kg ha⁻¹) of above-ground biomass.

3. RESULTS AND DISCUSSION

Different nutrient concentrations in different tree species (or provenances) can be due to environmental conditions or genetic characteristics of the species [15, 20]. Nutrient concentrations of the different tree components are related to the production of above and below-ground biomass, stand density, and soil. The concentrations of N, P, K, Ca, Mg, and S in the components of above-ground biomass of Bodalla are shown in *table III*.

It is evident that most of the nutrients are concentrated in the leaves. Similar results were found by Tandon et al. [31] in Australian plantations of *Eucalyptus grandis*, Baggio [3] in *Mimosa scabrella*, Vezzani [35] in pure and mixed stands of *Eucalyptus saligna* and *Acacia mearnsii*, Pereira et al. [22] in *Acacia mearnsii*, and by George and Varghese [12] in *Eucalyptus globulus*. Nutrient concentration in leaves is influenced by diverse factors such as site conditions, age, position of leaves and season [34]. Bellote [5], who worked with *Eucalyptus grandis* in Brazil, observed that nutrient concentration in leaves varies with stand age and the season.

The high amount of N in the leaves of *Acacia mearnsii* is due to the capacity of this species to fix N. In tropical soils *Acacia mearnsii* is able to fix up to 200 kg N ha⁻¹ yr⁻¹ [2].

The elevated nutrient concentration in the leaves (especially N, K, and Ca) makes this tree component an important reserve of bioelements, although it represents only a small percentage of whole tree biomass (see *table IV*). In the living cells of the leaves, major amounts of nutrients are accumulated in relation to the processes of transpiration and photosynthesis [15].

Major concentrations of Ca are found in the bark (*table III*); Bodalla also has high concentrations of Ca in the leaves. According to Attiwill et al. [1], Ca plays a major role in the process of cell wall lignification and is not redistributed to new plant tissues. Various authors have proved that bark is the tree component with the highest concentrations of Ca. For example, Sharma and Pande [30] found this to be the case in hybrid *Eucalyptus* in 5 and 7 years old stands, and in *Acacia auriculiformis* in 3, 5, 7 and 9 years old stands; Campos [9] in *Ilex paraguariensis* (12 years); Leles et al. [16] in *Eucalyptus*

camaldulensis and *Eucalyptus pellita* (4.3 years); Pereira et al. [22] in *Acacia mearnsii* (9 years); and Vezzani [35] in *Acacia mearnsii* (3.7 years).

The highest concentrations of Mg were also found in leaves (*table III*), which have already been proved in several species at different stand ages [8, 10, 13, 22, 33]. According to Kramer and Kozłowski [15], leaf concentrations of Mg and Ca vary significantly with the season.

The highest concentrations of P and K are found in the leaves, whereas the lowest are in the dead branches probably due to a nutrient shift (resorption) into younger plant tissues or leaching during the dying process of the branches. However, the lowest concentrations of N, Ca, Mg, and S are found in the wood which implies that this is generally rich in C, H, and O (*table III*).

Mean nutrient contents in the above-ground biomass of the Bodalla are shown in *table IV*. Nutrient content in the total biomass components of the Bodalla follows the order: N > K > Ca > Mg > S > P.

Table III. Nutrient concentrations with their respective standard deviations (\pm s.d.) in tree components of Bodalla (AGROSETA Florestal Company, experimental sites, Rio Grande do Sul, Brazil).

Components	Nutrients (g kg ⁻¹)					
	N	P	K	Ca	Mg	S
leaves	23.6	1.00	9.20	6.80	1.60	1.18
(\pm s.d.)	0.3	0.003	0.1	0.1	0.003	0.002
living branches	8.00	0.40	6.20	3.90	1.00	0.60
(\pm s.d.)	0.2	0.002	0.2	0.008	0.003	0.002
dead branches	4.50	0.10	2.30	4.20	0.70	0.20
(\pm s.d.)	0.01	0.0004	0.006	0.008	0.002	0.0005
bark	11.4	0.42	4.60	6.20	1.10	0.62
(\pm s.d.)	0.2	0.0004	0.5	0.1	0.003	0.002
wood	2.30	0.14	3.30	0.70	0.20	0.12
(\pm s.d.)	0.003	0.001	0.1	0.001	0.007	0.0004

Table IV. Mean nutrient contents in different components of above-ground biomass of Bodalla (AGROSETA Florestal Company, experimental sites, Rio Grande do Sul, Brazil). In parenthesis, percentage on total above ground biomass.

cp ¹	ag ² biomass (kg ha ⁻¹)	Nutrients in the biomass (kg ha ⁻¹)					
		N	P	K	Ca	Mg	S
l ³	4377 (22.5%)	103	4.38	40.4	29.8	7.2	5.2
lb ⁴	3851 (19.8%)	30.7	1.54	24.0	15.2	4.0	2.3
db ⁵	75.4 (0.4%)	0.3	0.007	0.2	0.3	0.1	0.02
b ⁶	2421 (12.4%)	27.6	1.02	11.2	15.1	2.8	1.5
w ⁷	8751 (44.9%)	20.3	1.22	28.6	6.3	2.1	1.1
t ⁸	19475.4	181.9	8.17	104.4	66.7	16.2	10.1

¹ Components of above-ground biomass; ² above-ground biomass of each component; ³ leaves; ⁴ living branches; ⁵ dead branches; ⁶ bark; ⁷ wood; ⁸ total above-ground biomass.

Table V. Percentage of accumulated nutrients in the components of above-ground biomass of Bodalla (AGROSETA Florestal Company, experimental sites, Rio Grande do Sul, Brazil).

Components	Nutrients (%)					
	N	P	K	Ca	Mg	S
leaves	56.8	53.0	39.0	45.0	45.0	51.0
living branches	17.0	19.0	23.8	23.0	24.0	23.0
dead branches	0.2	0.1	0.2	0.5	0.3	0.2
bark	15.0	12.9	11.0	22.5	17.0	12.0
wood	11.0	15.0	26.0	9.0	13.7	13.8

This result is similar to that found by Baggio and Carpanezzi [4] in *Mimosa scabrella*. Pereira et al. [22] found the following ranking of nutrients in above-ground biomass in a 9-year-old stand of *Acacia mearnsii*: N > Ca > K > Mg > P.

The different ranking of Ca in the latter study is due to an enrichment of Ca in the bark at the end of the forest rotation age (7 years).

In terms of nutrient exportation it is recommended that only trees (including bark) bigger than a diameter of 6.0 cm should be harvested. In this case, a considerable amount of residues remain on the forest floor as a protective layer between the atmosphere and the soil.

Caldeira [7] pointed out that there are no significant differences in nutrient export with respect to different harvest strategies of three Australian provenances (Bodalla, Lake George, and Batemans Bay) of *Acacia mearnsii*.

Baggio and Carpanezzi [4] analysed nutrient distribution in above-ground biomass of *Mimosa scabrella* in southern Brazil and found that 73% of all nutrients (N, P, K, Ca, Mg, S, Cu, Fe, Mn, and Zn) was found in the wood and only 27% in the crown. However, several authors have shown that tree crowns contain about 50% of the nutrients, with a major concentration in the leaves [22, 23, 27, 28, 30, 36].

In the present study, leaves account for more than 50% of the total content of N, P, and S (table V). It can also be illustrated that nutrient quantity in the leaves is superior to that of other above-ground biomass components, such as wood, although wood comprises the greatest proportion of the above-ground biomass [7]. This is usual in boreal forests but can also be seen in temperate forests [14, 37].

Considering the usual subdivision into crown and trunk biomass, 43% of the dry matter was composed of leaves and living and dead branches, with the following above-ground biomass contents: 74% of N, 73% of P, 62% of K, 68% of Ca, 70% of Mg, and 75% of S. The trunk components (bark and wood) accumulated 26% of N, 27% of P, 38% of K, 32% of Ca, 30% of Mg, and 25% of S (table V). In terms of nutrient distribution Vezzani [35] obtained similar results in another study in a 3.7-year-old stand of *Acacia mearnsii*.

Nutrient measurements are important in the analysis of ecologically sustainable management systems of tropical and subtropical plantations; e.g., harvest strategies can be optimised by taking into account the different nutrient contents of tree components in different stand stages. In particular, harvests in very young stands (so-called “mini-rotations”) with high amounts of juvenile wood can lead to higher nutrient export compared to older stands.

4. CONCLUSIONS

According to the previously described results on *Acacia mearnsii*, provenance Bodalla, it can be concluded that:

- the highest nutrient concentrations were found in the leaves;
- the lowest concentrations of P and K were found in the dead branches, and those of N, Ca, Mg, and S in the wood;
- the following nutrient distribution was found in the trunk biomass (bark and wood): 26% of N, 27% of P, 38% of K, 32% of Ca, 30% of Mg, and 25% of S. By reverse, 74% of N, 73% of P, 62% of K, 68% of Ca, 70% of Mg, and 75% of S of the total above-ground biomass were found in the leaves, living and dead branches (mostly crown).

This work is a first approach towards optimising management in South Brazilian plantations of *Acacia mearnsii*; further investigations are necessary, especially relating to crop rotations, below-ground biomass, and nutrient dynamics, such as fluxes and resorption processes.

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