

Biomass production and nutrient content in different *Eucalyptus* genotypes in Pampa Gaúcho, Brazil

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ABSTRACT: The objective of this study was to estimate the biomass, nutrient stocks, and simulate the export of nutrients, in different genotypes of *Eucalyptus*. The experiment was conducted in São Gabriel, RS, Brazil, in 43-month-old stands. The selected trees were fractionated into leaves, branches, stembark and stemwood. An estimate of nutrient exports by biomass was calculated for three scenarios. The amount of total biomass ranged from 33.68 to 84.00 Mg ha⁻¹, with the highest production being *E. urolobulus*, and *E. dunnii* the lowest. The tree canopy accumulated between 47% and 65% of the total macronutrients and 46% to 67% of the total micronutrients (*E. benthamii* (P2) and *E. urograndis*). The highest amount of nutrients exported with biomass harvesting, for the first and second scenario (harvesting the stemwood and harvesting the stemwood with stembark), occurred in *E. urolobulus* (N, K, and S), *E. urograndis* (P, Mg, and Cu) and *E. saligna* (Fe, Zn, and B). For the third scenario (stem and canopy), the highest nutrient exportation occurred in *E. urograndis*, except for S, where the highest removal occurred in *E. urolobulus*. The harvesting of only the stemwood resulted in the removal of the least nutrients from the system, independent of the genotypes.

Key words: clonal *Eucalyptus*; forestry nutrition; silviculture; sustainability

Produção de biomassa e conteúdo de nutrientes em diferentes genótipos de *Eucalyptus* no Pampa gaúcho

RESUMO: O objetivo deste trabalho foi estimar a biomassa, o estoque de nutrientes e simular a exportação de nutrientes em diferentes genótipos de *Eucalyptus*. O experimento foi conduzido em São Gabriel, RS, em povoamentos com 43 meses de idade. As árvores selecionadas foram fracionadas em folhas, galhos, casca do fuste e madeira do fuste. A estimativa da exportação de nutrientes por biomassa foi calculada para três cenários. A quantidade de biomassa total variou de 33,68 a 84,00 Mg ha⁻¹, destacando-se o *E. urolobulus* com a maior produção e o *E. dunnii* com a menor. A copa das árvores acumulou entre 47% e 65% do total de macronutrientes e 46% a 67% do total de micronutrientes (*E. benthamii* (P2) e *E. urograndis*). Para o primeiro e segundo cenário (colheita da madeira do fuste e colheita da madeira do fuste com casca), a maior quantidade de nutrientes exportados ocorreu no *E. urolobulus* (N, K e S), *E. urograndis* (P, Mg e Cu) e *E. saligna* (Fe, Zn e B). Para o terceiro cenário (fuste e copa), a maior exportação de nutrientes ocorreu no *E. urograndis*, com exceção de S, onde a maior remoção ocorreu no *E. urolobulus*. A colheita apenas da madeira do fuste apresentou a menor remoção de nutrientes do sistema, independente do genótipo.

Palavras-chave: clones de *Eucalyptus*; nutrição de florestas; silvicultura; sustentabilidade

Introduction

In recent years, the Brazilian planted forest sector has gained great importance worldwide. With a planting area of 9.8 million hectares, the genus *Eucalyptus* occupy 75.2% of the planted area (IBGE, 2017). The wide range of *Eucalyptus* species adapted to different soil and climatic conditions and the possibility of using eucalypts wood for a variety of purposes has stimulated the establishment of plantations by large and small enterprises (Gonçalves et al., 2013). One of the main benefits of eucalypts stands is that it offers an alternative supply of wood, thereby reducing the pressure on native forests. This is important because even if the native forests could be used sustainably, they would not be sufficient to meet the growing demand of wood (Viera et al., 2012).

Forestry biomass is an important information in maintaining the balance of biogeochemical cycles and its measurement provides an efficient means of evaluating energy conversion and nutrient cycling within the stand (Viera et al., 2015). This variable is determined by the amount of solar radiation intercepted by the canopy and by the conversion efficiency of the biomass radiation (Santana et al., 2008).

The distribution of nutrients in the components of the trees has great importance in the nutrition of forest stands managed in successive rotations, because of the intensive management of eucalypts plantations can not only increase biomass production, but it also can augment nutrient removal (Viera et al., 2013). Therefore, knowledge of the distribution of biomass and nutrients in the different components of the tree can support numerous practices aimed at maintaining productivity, such as: definition of age and harvest intensity, management of forest residues, replacement fertilization, and soil preparation, among others (Schumacher et al., 2013).

The continued success of future plantations will depend on the ability of forest managers to achieve high production levels of wood sustainable (Gonçalves et al., 2013). That is, utilizing site management techniques that keep crop residues at the on the soil surface for maximum efficiency of nutrient cycling (Santana et al., 2002). Therefore, knowledge of the nutrient export rate by different genotypes is essential for the adoption of nutrient conservation and replenishment techniques to the ecosystem (Santana et al. 1999).

Thus, studies on the production of biomass and nutrient stocks of different species/provenances planted in the same soil and climatic conditions is essential for the selection of genotypes needed for achieving higher productivity in a sustainable way. This study aims to estimate the biomass and the nutrient stocks, and to simulate the export of nutrients in different genotypes of *Eucalyptus*.

Materials and Methods

Characterization of the site

The experiment was conducted in the Region of the Campanha in São Gabriel, Rio Grande do Sul, Brazil, in the Horto Florestal Batovi, owned by Celulose Riograndense -

CMPC (30°26'51.68"S and 54°32'25.89"W). The site is more than 300 km from the South Atlantic Ocean at an approximate altitude of 154 m.

The climate of the region is characterized as subtropical humid (Cfa), according to the climatic classification of Köppen. The average annual temperature is approximately 18.1 °C, with 24.2 °C being the mean maximum temperature and 12.6 °C the mean minimum temperature. The average annual precipitation reaches 1,854 mm (Alvares et al., 2013).

The soil in the experimental area is of the typical Luvisol Haptic Otic type. Luvisols comprise non-hydromorphic mineral soils, ranging from well to imperfectly drained, usually shallow, with horizons A, Bt and C (Embrapa, 2009). Table 1 presents the physical and chemical attributes of the soil at depths from 0 to 100 cm.

Planting was happened out in November 2012, with a spacing of 3.50 m × 2.14 m, with density of 1,335 trees per ha. Settling of the ground, liming with 2 Mg ha⁻¹ of limestone, subsoiling down to 50 cm, and setting up of ridges (40 cm high). During planting, 200 kg ha⁻¹ of single superphosphate was applied to the groove at a rate of 100 g plant⁻¹ in the form of N-P₂O₅-K₂O (06:30:06) + Zn on the occasion of planting.

Subsequently, two post-planting fertilizations were performed at six and twelve months in the form of 150 kg ha⁻¹ of N-P₂O₅-K₂O (12:00:20) + 0.5% B and 150 kg ha⁻¹ of N-P₂O₅-K₂O (24:00:26), respectively. In addition, the following cultural practices were performed: prior to planting, chemical weeding was performed in total area with 2.5 kg ha⁻¹ Scout (glyphosate). At 10 days after planting, 3.5 L ha⁻¹ of the pre-emergent Oxyfluofen was applied. At four and nine months after planting, weed and chemical weeding were performed using 1.7 kg ha⁻¹ of Scout (glyphosate).

The following *Eucalyptus* clones were planted: *E. benthamii* (P1), *E. benthamii* (P2), *E. saligna*, *E. dunnii*, hybrid of *E. urophylla* × *E. globulus* (*E. uroglobulus*), and hybrid of *E. urophylla* × *E. grandis* (*E. urograndis*). *E. benthamii* (P1) is a provenance originating from Guarapuava, Paraná, Brazil and *E. benthamii* (P2) is from Telêmaco Borba, Paraná, Brazil. At the time of data collection, the stands were 43 months old.

For each genotype, a plot of 8 lines per 10 plants was demarcated, where the DBH (diameter at breast height, measured at 1.30 m above ground level) of all individuals was measured with diametrical tape. The heights of 20% of the plants were measured using a Vertex hypsometer; thus, the heights that were not measured in the field were estimated through hypsometric models. Table 2 presents the dendrometric variables obtained in the different genotypes of *Eucalyptus*, at 43 months of age established in São Gabriel, RS, Brazil.

Biomass and nutrient stocks

Based on the data obtained in the plot inventory, three trees mean were sampled for each genotypes. The selected trees were felled and separated in the following components: leaves, branches, stembark and stemwood. Sampling of the wood and bark of the stem was done by dividing the trunk into three sections of equal parts, with the sampling performed on three points in the median position of each section.

Table 1. Physical and chemical attributes of the soil of the area implanted with different genotypes of *Eucalyptus* at 43-month-old age in São Gabriel, RS, Brazil.

Genotypes	Depth (cm)	pH	Sd (g cm ⁻³)	Clay	O.M	M	t	Al	Ca	Mg	P	K	S	B	Cu	Zn
				(%)			(cmol _c dm ⁻³)					(mg dm ⁻³)				
<i>E. benthamii</i> (P1)	0-10	4.7	1.30	15	3.4	13.7	7.3	1.0	3.9	2.3	2.3	53.0	8.1	0.5	2.1	1.7
	10-20	5.1	1.31	19	2.8	27.1	6.7	1.8	3.3	1.5	1.3	31.0	5.9	0.6	2.2	0.8
	20-40	5.3	1.35	21	2.1	33.3	6.6	2.2	3.1	1.2	0.8	27.0	2.5	0.3	1.5	0.4
	40-60	5.4	1.19	47	2.1	14.6	19.2	2.8	11.6	4.7	0.6	70.0	2.4	0.5	1.9	0.5
	60-80	5.5	1.47	33	0.9	0.0	26.0	0.0	18.0	7.7	0.4	92.0	20.0	0.4	2.1	1.1
	80-100	6.0	1.65	33	0.7	0.0	27.8	0.0	19.4	8.1	0.6	96.0	29.0	0.5	0.9	0.5
<i>E. benthamii</i> (P2)	0-10	4.9	1.23	23	2.8	33.4	6.6	2.2	3.4	1.0	1.2	33.0	4.1	0.3	2.5	0.7
	10-20	5.1	1.34	25	2.2	48.9	7.6	3.7	3.3	0.5	0.7	29.0	3.4	0.3	2.1	0.5
	20-40	5.3	1.44	29	1.3	49.8	6.6	3.3	2.6	0.7	0.5	26.0	2.5	0.2	1.4	0.4
	40-60	5.2	1.55	41	1.3	40.7	10.6	4.3	4.6	1.6	0.5	45.0	2.9	0.3	1.6	0.6
	60-80	5.3	1.51	41	1.0	28.9	12.8	3.7	6.5	2.5	0.2	52.0	5.8	0.3	1.1	0.4
	80-100	5.3	1.52	47	1.0	21.0	15.7	3.3	8.5	3.8	0.2	63.0	4.9	0.3	1.7	0.5
<i>E. saligna</i>	0-10	5.1	1.20	17	3.0	30.5	6.5	2.0	2.7	1.8	1.4	35.0	13.0	0.3	2.4	1.0
	10-20	5.1	1.25	19	2.7	35.3	7.4	2.6	3.3	1.4	1.0	30.0	12.0	0.2	2.4	0.8
	20-40	5.2	1.37	25	1.9	61.5	6.0	3.7	1.8	0.5	0.5	21.0	9.7	0.2	2.0	0.6
	40-60	5.3	1.32	37	1.4	60.5	10.4	6.3	3.1	0.9	0.4	33.0	13.0	0.3	2.2	0.6
	60-80	5.3	1.31	43	1.3	26.4	14.8	3.9	7.5	3.3	0.4	65.0	12.0	0.3	2.6	0.7
	80-100	5.3	1.53	19	1.0	9.7	18.7	1.8	12.3	4.4	0.2	73.0	15.0	0.3	2.6	1.0
<i>E. dunnii</i>	0-10	5.1	1.34	13	2.7	30.4	6.6	2.0	2.8	1.7	1.1	33.0	9.2	0.3	2.2	0.9
	10-20	5.3	1.36	21	1.9	37.1	6.5	2.4	2.8	1.2	0.5	28.0	6.8	0.3	1.5	0.9
	20-40	5.3	1.38	29	1.5	26.8	10.4	2.8	5.3	2.3	0.5	44.0	8.3	0.3	1.4	0.5
	40-60	5.2	1.08	47	2.2	30.6	22.5	6.9	11.4	4.0	0.3	79.0	12.0	0.3	2.1	0.6
	60-80	5.1	1.34	55	1.5	7.7	28.5	2.2	18.8	7.1	0.2	108.0	12.0	0.3	2.7	0.9
	80-100	5.3	1.49	41	0.8	2.2	27.9	0.6	19.7	7.2	0.2	124.0	11.0	0.5	1.8	0.6
<i>E. urolobulus</i>	0-10	5.0	1.26	21	2.8	31.4	7.0	2.2	3.2	1.5	1.3	30.0	5.7	0.3	2.2	0.8
	10-20	5.1	1.26	25	2.4	41.6	7.9	3.3	3.4	1.2	0.6	34.0	4.4	0.2	1.6	0.4
	20-40	5.2	1.34	27	1.7	56.3	8.4	4.7	2.7	0.9	0.4	32.0	5.0	0.2	1.3	0.4
	40-60	5.4	1.34	31	1.4	43.9	10.7	4.7	4.5	1.4	0.3	49.0	1.9	0.3	1.6	0.6
	60-80	5.4	1.22	49	1.7	24.2	21.9	5.3	12.0	4.4	0.2	87.0	2.5	0.4	2.2	0.8
	80-100	5.4	1.38	53	1.1	6.1	26.4	1.6	17.4	7.1	0.2	131.0	3.2	0.3	2.3	0.7
<i>E. urograndis</i>	0-10	5.2	1.33	17	2.7	27.3	8.1	2.2	3.8	2.0	1.4	46.0	16.0	0.2	2.8	1.1
	10-20	5.3	1.39	23	2.5	36.5	8.2	3.0	3.7	1.5	1.4	32.0	9.2	0.1	2.8	1.2
	20-40	5.3	1.39	27	1.9	47.9	8.6	4.1	3.4	1.0	0.6	34.0	9.5	0.1	2.1	0.8
	40-60	5.5	1.52	13	1.5	1.9	21.6	0.4	15.6	5.4	0.5	83.0	14.0	0.2	3.1	0.9
	60-80	5.9	1.71	45	0.9	0.0	21.4	0.0	15.8	5.4	0.5	95.0	13.0	0.3	1.3	0.6
	80-100	6.3	1.73	41	0.4	0.0	27.8	0.0	20.2	7.3	0.5	103.0	10.0	0.2	1.0	0.7

Sd: soil density; O.M: organic matter, digestion by wet combustion (K₂Cr₂O₇ + H₂SO₄); pH in H₂O (1:1); Al, Ca e Mg exchangeable, solution extraction KCl (1 mol L⁻¹); P available and K exchangeable, extracted with Mehlich³; t: Effective cation exchange capacity; m = Saturation by aluminum. S, by solution of Ca (H₂ PO₄)₂ the 500 mg of P L⁻¹.

Table 2. Dendrometric characterization of different genotypes of *Eucalyptus* at 43-month-old in São Gabriel, RS, Brazil.

Genotypes	Nº of individuals per ha ⁻¹	Basal area (m ² ha ⁻¹)	Volume (m ³ ha ⁻¹)
<i>E. benthamii</i> (P1)	1168 ± 174	17.5bc ± 4.4	48.18c ± 19.8
<i>E. benthamii</i> (P2)	768 ± 190	12.1d ± 4.5	36.01d ± 15.7
<i>E. saligna</i>	1268 ± 281	19.3ab ± 3.3	57.85bc ± 18.5
<i>E. dunnii</i>	1135 ± 227	10.9d ± 3.2	26.83d ± 9.4
<i>E. urolobulus</i>	1285 ± 395	16.3c ± 3.4	69.56a ± 36.1
<i>E. urograndis</i>	1302 ± 326	20.4a ± 3.6	66.54ab ± 22.2

Mean of each variable in different treatments (genotypes) followed by equal letters, do not differ significantly by the Tukey test at the 5% level of error and, values preceded by ± are the standard deviation of the mean.

All biomass samples were weighed in the field with a precision scale and packed in paper bags. Subsequently they were sent to the laboratory and dried in an oven at 70 °C with circulation and air exchange until weight stabilization, to determine the moisture content. Based on the dry biomass of each component and the number of trees per hectare of each genotypes, the total biomass per hectare was estimated.

For the determination of nutrients, the samples were ground in a Wiley mill with a 30-mesh screen and subsequently subjected to chemical analysis to determine macronutrient (N, P, K, Ca, Mg, and S) and micronutrients (B, Cu, Fe, Mn, and Zn), concentrations according to the methodology of Tedesco et al. (1995) and Miyazawa et al. (1999).

The estimates of the nutrient stock for each component was obtained by multiplying the dried biomass by the

concentration of nutrients. The estimate per hectare was performed by extrapolating the stock per individual based on the number of individuals present in each sampling unit.

Estimation of nutrient removal by harvest

Estimation of nutrient removal through biomass harvesting was performed for three scenarios based on the nutrient stock of each biomass component:

- 1) Harvesting the stemwood;
- 2) Harvesting the stemwood with stembark;
- 3) Harvesting of all aboveground biomass.

Statistical procedures

Statistical analyses were performed at a 5% error probability level with the aid of the statistical software Assistat 7.7 (Silva & Azevedo, 2009). The biomass and nutrient concentration data were subjected to analysis of variance and Tukey's test for comparison of means between treatments (genotypes).

Results and Discussion

Aboveground biomass

The hybrids *E. uroglabulus* and *E. urograndis* produced the highest total biomass (84.00 and 80.79 Mg ha⁻¹, respectively), which corresponded to 55.36 and 44.33 Mg ha⁻¹ of stemwood biomass, respectively (Figure 1). The clone *E. dunnii* produced the lowest total biomass (33.68 Mg ha⁻¹), providing the lowest biomass for all components, except for the branches, where the lowest value was found in *E. benthamii* (P2). Similar results were also found by Schumacher & Caldeira (2008) who evaluated a four-year-old *E. saligna* in the Central Region of RS, Brazil; and by Turner & Lambert (2008), in a study on five-year-old *E. grandis* in northern New South Wales, Australia. In terms of biomass production of stemwood, the *E. uroglabulus* hybrid produced 39%, 40% and 66% more than the clones *E. benthamii* (P2), *E. benthamii* (P1), and *E. dunnii*, respectively. According to Bellote & Silva (2005), the main factors that

interfere with forest productivity are related to the genotypes and the soil conditions used.

When treating the components separately, the percentage distribution of aboveground biomass for clones *E. benthamii* (P1), *E. uroglabulus* and *E. urograndis* followed the following sequence: stemwood > branches > leaves > stembark. The same order of distribution was found in four-year-old *Eucalyptus* spp. in Vera Cruz, RS, Brazil (Schumacher et al., 2011); in 18-month-old *E. urograndis* in Piratini, RS, Brazil (Viera et al., 2012); in the biomass in a clone of *E. urophylla* × *E. grandis*, at 5.5 years of age, in the southeastern region of Brazil (Ribeiro et al., 2015); and in the biomass of *Eucalyptus* spp. in Kenya (Kuyah et al., 2013).

The clones *E. dunnii*, *E. benthamii* (P2) and *E. saligna* presented the following order of distribution and relative partitioning: stemwood > branches > stembark > leaves. Comparing the same components, the relative biomass distribution was the same as that found by Guimarães et al. (2015) in a four-year-old stand of *E. dunnii* in the city of Alegrete, RS, Brazil. According to Schumacher et al. (2011), the factors that affect the percentage distribution of the biomass in the different components of the trees are species, age, soil fertility and planting density. Therefore, since the genotypes were of the same age, and were planted at the same planting density in the same soil type, the species was the predominant factor that affected biomass distribution.

We verified that the stem (wood and bark) represented 63% -79% of the total biomass produced, with the lowest value in clone *E. urograndis* and the highest in *E. benthamii* (P2). Meanwhile, the canopy (leaves and branches) accounted for 21% -37% of the total biomass. In contrast, Schumacher & Caldeira (2008), evaluating a four-year-old stand of *E. saligna*, reported that 82% of the aerial biomass was distributed in the wood.

Zewdie et al. (2009) studied *E. globulus* stands with ages between one and nine years and observed that at year one, the leaves and the branches were the components of the trees that presented with the greatest accumulation of biomass. However, at four, five, seven, and nine years, the leaves and branches were responsible for a decreasing percentage of biomass above the soil. Viera et al. (2012), evaluating a hybrid stand of *E. urograndis* at 18 months of age, found that the wood and bark components contributed to approximately 45% of the total biomass.

Nutrients in biomass

The different genotypes, belonging to the same genus or even the same species but with different origins, showed variations in nutrient concentrations (Tables 3 and 4). In general terms, the highest concentrations occurred in the leaves and the lowest in the wood of the stem.

We found that N, P, and S of the macronutrients concentrated more in the leaves, while Ca and Mg accumulated more in the stembark (Table 3), except in *E. dunnii*, where the highest concentration of these elements occurred in the leaves, and in *E. urograndis*, where Ca also

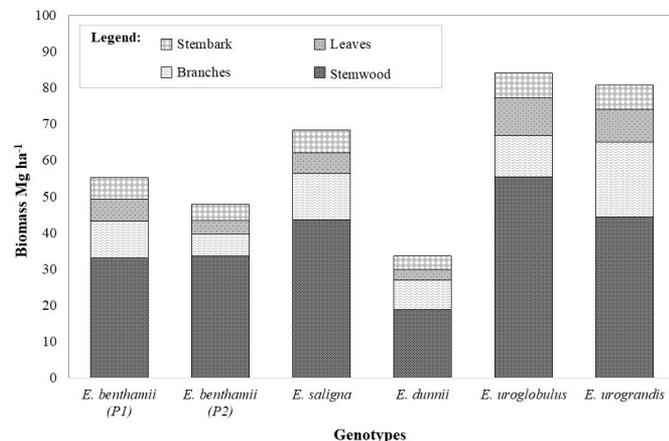


Figure 1. Production and partitioning of biomass for the different components of *Eucalyptus* genotypes at 43-month-old established in São Gabriel, RS, Brazil.

Table 3. Macronutrient concentration in the different biomass components of different genotypes of *Eucalyptus* at 43-month-old established in São Gabriel, RS, Brazil.

Genotype	Fractions	(g kg ⁻¹)					
		N	P	K	Ca	Mg	S
<i>E. benthamii</i> (P1)	Leaves	18.11ab	1.05ab	5.96ab	11.33ab	2.77a	1.56a
	Branches	1.98b	0.14a	1.90b	10.14a	1.71ab	0.29a
	Stembark	4.03a	0.41ab	4.16bc	14.16a	3.12a	0.43a
	Stemwood	1.58a	0.15a	1.94a	1.17ab	0.49bc	0.20a
<i>E. benthamii</i> (P2)	Leaves	21.03a	1.16a	6.14ab	6.16c	2.39a	1.23b
	Branches	3.02a	0.22a	2.48ab	4.98b	0.85bc	0.24ab
	Stembark	4.10a	0.50a	3.82bc	10.40b	3.31a	0.39ab
	Stemwood	1.51ab	0.16a	1.77ab	0.51c	0.22bc	0.14bc
<i>E. saligna</i>	Leaves	15.85ab	0.80bc	6.35ab	10.96ab	3.11a	0.88c
	Branches	1.63b	0.09a	1.83b	10.61a	2.00a	0.22ab
	Stembark	4.61a	0.25b	2.50d	11.01ab	3.67a	0.29ab
	Stemwood	1.17b	0.08a	1.35b	0.84bc	0.50bc	0.12c
<i>E. dunnii</i>	Leaves	17.52ab	0.92abc	5.68ab	10.69abc	3.24a	1.06bc
	Branches	2.33ab	0.18a	3.48a	8.76ab	1.76ab	0.26ab
	Stembark	2.64a	0.40ab	6.47a	9.38b	2.91a	0.25b
	Stemwood	1.44ab	0.15a	2.22a	1.50a	0.96a	0.19ab
<i>E. uroglobulus</i>	Leaves	12.83b	0.73c	4.69b	8.04bc	1.40b	0.81c
	Branches	1.59b	0.13a	2.44ab	6.50ab	0.59c	0.24ab
	Stembark	3.38a	0.44ab	4.80b	8.96b	2.77a	0.29ab
	Stemwood	1.30ab	0.10a	1.81ab	0.56c	0.20c	0.18ab
<i>E. urograndis</i>	Leaves	15.82ab	0.89abc	6.53a	12.93a	2.39a	0.86c
	Branches	1.56b	0.16a	2.15ab	10.71a	1.88ab	0.22b
	Stembark	3.25a	0.37ab	3.64c	12.09ab	3.54a	0.24b
	Stemwood	1.45ab	0.14a	2.07a	0.82bc	0.52b	0.18ab

Averages of each fraction of biomass in different treatments (genotypes) followed by equal letters, do not differ significantly by the Tukey test at the 5% level of error.

concentrated in the leaves. It has also been observed that the highest concentrations of Ca and Mg are present in the bark of 9-year-old *E. grandis* (Freitas et al., 2004), and 10-year-old *E. urophylla* x *E. globulus* (Viera et al., 2013) as well as with *E. nitens* (González-García et al., 2015). According to Freitas et al. (2004), Ca is more concentrated in the bark compared to the other components of the biomass because of its low mobility in the phloem since it is a less redistributed element in plant tissue.

The highest concentrations of micronutrients occurred in the leaves (Table 4), with the exception of clones *E. benthamii* (P2), *E. saligna* and *E. urograndis*, where the concentration of Mn was higher in the stembark. In general, the macronutrients tended to be distributed in the tree components in the following order: leaves > stembark > branches > stemwood. Similar patterns of distribution were found in 10-year-old *E. urograndis* in Eldorado do Sul, RS, Brazil (Viera et al., 2012); and for the elements N, P, and K in 2- and 5-year-old *E. nitens* in Spain (Gonzales-Garcia et al., 2015). The micronutrients were also distributed in the same order, except for clones *E. saligna*, *E. dunnii*, and *E. urograndis*, where higher concentrations of nutrients occurred in the branches than in the stembark. This may be due to the inherent species-to-species variation in nutrient requirement of the trees (Freitas et al., 2004).

There was great variation in the allocation of macro- and micronutrients in the different *Eucalyptus* species, and in the different components of the same species (Tables 5 and 6). Among the macronutrients, the greatest amount of N was found in the leaves, ranging from 47 to 55% for *E. dunnii* and

E. urograndis, respectively. Similarly, the highest amount of P was found in the leaves, with the exception of *E. benthamii* (P2) and *E. dunnii*, in which the largest content of P was found in the stemwood. In general, the highest amounts of K and S were also observed in the stemwood, ranging from 38% to 53% for *E. dunnii* and *E. benthamii* (P2) for K and from 31% to 43% for *E. benthamii* (P1) and *E. uroglobulus* for S.

With the exception of *E. benthamii* (P2) (N > Ca > K > Mg > P > S) and *E. dunnii* (Ca > K > N > Mg > S > P), the total quantity of macronutrients had the following order of distribution: Ca > N > K > Mg > S > P. This order was similar to what has been reported for 9-year-old *E. grandis* in Alegrete, RS, Brazil (Freitas et al., 2004), 4-year-old *E. dunnii* also in Alegrete (Guimarães et al., 2015), and *E. saligna* between 2 and 7 years of age in the Region of Guaíba, RS, Brazil (Witschoreck & Schumacher, 2015). Viera et al. (2012), studied 18-month-old *E. urograndis* of in Piratini, RS, Brazil and observed the same sequence, except for an inversion of the values of S and P.

In terms of micronutrients, the highest amount of Zn was found in the stemwood at levels ranging from 38% to 62% (*E. dunnii* and *E. benthamii* (P2)). With the exception of *E. benthamii* (P1) and *E. dunnii* for Cu (branches), and *E. dunnii* and *E. urograndis* for Fe (branches), the largest quantities of Fe and Cu were also observed in the stemwood at levels ranging from 23% to 50% (*E. benthamii* (P1) and *E. uroglobulus*) for Fe, and from 21% to 49% (*E. dunnii* and *E. saligna*) for Cu.

Therefore, with the exception of *E. benthamii* (P2), in which the amount of Zn was higher than that of B, the order of total distribution for the other micronutrients in *Eucalyptus*

Table 4. Micronutrient concentration in the different biomass components of different genotypes of *Eucalyptus* at 43-month-old established in São Gabriel, RS, Brazil.

Genotype	Fractions	(mg kg ⁻¹)				
		B	Cu	Fe	Mn	Zn
<i>E. benthamii</i> (P1)	Leaves	38.21a	5.74bcd	132.40ab	1.187.01a	11.96ab
	Branches	10.19b	3.72a	62.62a	759.29a	8.80a
	Stembark	15.67a	2.55ab	45.35a	1.116.22a	11.08a
	Stemwood	5.57a	0.80a	28.00a	176.38a	5.77ab
<i>E. benthamii</i> (P2)	Leaves	26.40b	7.12abc	105.83bc	974.88ab	12.80a
	Branches	11.44ab	4.28a	32.09a	629.74a	8.01a
	Stembark	20.53a	3.54a	26.69a	1.080.40ab	12.77a
	Stemwood	3.81ab	1.96a	16.52a	112.33a	7.18a
<i>E. saligna</i>	Leaves	30.08b	5.44cd	96.77bc	795.97b	10.59ab
	Branches	11.66ab	4.83a	80.73a	672.05a	10.42a
	Stembark	15.70a	2.30ab	35.89a	971.83ab	5.71a
	Stemwood	5.49a	1.60a	39.51a	75.12a	6.99a
<i>E. dunnii</i>	Leaves	26.55b	8.24a	159.42a	986.48ab	9.48ab
	Branches	14.23a	4.71a	65.06a	712.64a	8.07a
	Stembark	18.64a	1.38b	51.98a	883.25b	7.14a
	Stemwood	5.92a	2.08a	17.16a	153.90a	3.98ab
<i>E. uroglobulus</i>	Leaves	24.02b	4.42d	60.12c	952.22ab	8.09b
	Branches	11.15ab	3.48a	37.46a	570.40a	4.59a
	Stembark	18.73a	2.42ab	48.16a	923.76ab	6.31a
	Stemwood	3.05b	1.85a	18.26a	92.98a	3.12b
<i>E. urograndis</i>	Leaves	42.88a	7.15ab	113.31ab	881.03ab	12.12ab
	Branches	11.29ab	4.94a	84.99a	751.30a	8.33a
	Stembark	14.67a	2.31ab	36.67a	978.55ab	7.74a
	Stemwood	5.24a	2.39a	21.75a	114.68a	5.43ab

Averages of each fraction of biomass in different treatments (genotypes) followed by equal letters, do not differ significantly by the Tukey test at the 5% level of error.

Table 5. Amount of macronutrients in the biomass components of different genotypes of *Eucalyptus* at 43-month-old established in São Gabriel, RS, Brazil.

Genotypes	Fractions	(kg ha ⁻¹)					
		N	P	K	Ca	Mg	S
<i>E. benthamii</i> (P1)	Leaves	110.29	6.36	36.30	69.09	16.89	9.51
	Branches	20.17	1.39	19.27	103.17	17.40	2.89
	Stembark	23.99	2.43	24.72	83.85	18.51	2.55
	Stemwood	52.27	5.08	64.61	38.78	16.14	6.60
	Total	206.72	15.26	144.89	294.89	68.94	21.55
<i>E. benthamii</i> (P2)	Leaves	78.82	4.28	22.31	22.41	8.85	4.56
	Branches	18.48	1.38	15.27	29.67	5.18	1.46
	Stembark	18.01	2.18	16.62	46.40	14.50	1.68
	Stemwood	50.34	5.34	60.06	17.06	7.48	4.68
	Total	165.64	13.18	114.27	115.53	36.01	12.39
<i>E. saligna</i>	Leaves	92.87	4.66	37.16	63.83	18.18	5.11
	Branches	20.71	1.13	23.35	133.81	25.39	2.80
	Stembark	28.28	1.53	15.48	68.17	22.67	1.79
	Stemwood	51.29	3.64	59.05	36.77	21.69	5.31
	Total	193.15	10.96	135.04	302.58	87.94	15.01
<i>E. dunnii</i>	Leaves	49.58	2.60	16.05	30.42	9.31	3.00
	Branches	19.40	1.43	28.60	72.05	14.85	2.17
	Stembark	9.82	1.49	24.32	34.85	10.88	0.93
	Stemwood	26.92	2.72	41.61	28.23	17.87	3.61
	Total	105.71	8.24	110.58	165.55	52.90	9.71
<i>E. uroglobulus</i>	Leaves	133.34	7.59	48.76	83.30	14.54	8.46
	Branches	18.19	1.52	27.98	74.96	6.75	2.75
	Stembark	22.61	2.96	32.25	60.29	18.63	1.95
	Stemwood	71.89	5.32	100.21	30.90	11.24	9.94
	Total	246.03	17.39	209.21	249.46	51.15	23.09

Continues on the next page

Continued from Table 5

Genotypes	Fractions	N	P	K	Ca	Mg	S
		(kg ha ⁻¹)					
<i>E. urograndis</i>	Leaves	142.99	8.03	59.01	117.18	21.60	7.76
	Branches	32.43	3.38	44.77	222.54	38.96	4.52
	Stembark	21.70	2.49	24.23	80.53	23.61	1.61
	Stemwood	64.32	6.40	91.76	36.14	22.92	8.04
	Total	261.43	20.30	219.77	456.39	107.09	21.93

Table 6. Amount of micronutrients in the biomass components of different genotypes of *Eucalyptus* at 43-month-old established in São Gabriel, RS, Brazil.

Genotypes	Fractions	B	Cu	Fe	Mn	Zn
		(g ha ⁻¹)				
<i>E. benthamii</i> (P1)	Leaves	232.91	34.96	807.86	7246.14	72.86
	Branches	103.52	37.84	633.15	7724.68	89.40
	Stembark	93.01	15.10	269.57	6619.54	65.78
	Stemwood	185.40	26.61	938.24	5893.36	191.70
	Total	614.84	114.52	2648.83	27483.72	419.74
<i>E. benthamii</i> (P2)	Leaves	97.25	26.29	393.68	3568.63	48.04
	Branches	71.64	26.45	192.24	3902.22	46.94
	Stembark	92.13	15.54	117.35	4793.05	52.87
	Stemwood	128.72	66.64	552.20	3707.66	242.54
	Total	389.75	134.92	1255.47	15971.56	390.40
<i>E. saligna</i>	Leaves	175.35	31.89	567.13	4657.27	62.03
	Branches	148.13	61.46	1032.35	8514.80	132.11
	Stembark	98.11	14.18	225.10	6032.84	35.32
	Stemwood	240.94	69.78	1765.68	3309.26	307.66
	Total	662.53	177.31	3590.27	22514.16	537.12
<i>E. dunnii</i>	Leaves	75.49	23.37	457.13	2802.39	26.87
	Branches	117.45	39.06	543.18	5873.21	66.11
	Stembark	69.71	5.17	194.45	3308.41	26.86
	Stemwood	111.26	38.79	323.09	2884.73	74.93
	Total	373.91	106.39	1517.86	14868.75	194.77
<i>E. uroglobulus</i>	Leaves	250.35	45.93	623.97	9884.07	84.10
	Branches	127.94	40.39	430.87	6556.34	52.94
	Stembark	125.44	16.35	325.35	6195.22	42.41
	Stemwood	168.88	102.30	1013.28	5126.07	171.83
	Total	672.61	204.97	2393.47	27761.70	351.28
<i>E. urograndis</i>	Leaves	387.63	64.75	1026.00	7967.63	109.80
	Branches	234.21	102.64	1777.39	15634.53	173.32
	Stembark	97.86	15.35	244.60	6526.83	51.82
	Stemwood	231.87	105.97	966.68	5086.16	240.82
	Total	951.57	288.71	4014.67	35215.16	575.76

species was: Mn > Fe > B > Zn > Cu. This trend was similar to that reported by Viera et al. (2012) for *E. urograndis* and by Guimarães et al. (2015) for *E. dunnii*.

The *E. urograndis* hybrid showed the highest total amounts of macro- and micronutrients, with the exception of S that was present in greater quantity in *E. uroglobulus*. Compared to the clones *E. dunnii*, *E. benthamii* (P2), and *E. saligna*, *E. urograndis* showed 60%, 37%, and 26% higher N; 59%, 35%, and 46% higher P; and 50%, 48%, and 39% higher K, respectively.

The distribution of nutrients generally differs from the observed biomass standard because of the difference in nutrient concentrations between the components of the trees (Reis & Barros, 1990). In this context, tree canopy biomass (leaves and branches) ranged from 21% to 37% (*E. benthamii* (P2) and *E. urograndis*) of the total biomass and accumulated

47% to 65% of total macronutrients and 46% to 67% of total micronutrients (*E. benthamii* (P2) and *E. urograndis*), while wood biomass (wood and bark) ranged from 63% to 79% (*E. urograndis* and *E. benthamii* (P2)) and accumulated 35% to 53% of total macronutrients and 33% to 54% (*E. urograndis* and *E. benthamii* (P2)) of total micronutrients. In young stands, according to Reis & Barros (1990), the contribution of the canopy is high and since the concentration of nutrients is higher in the leaves, the canopy contains more than 50% of the nutrients of the plant.

Exportation of nutrients by biomass harvest

Tables 7 and 8 shows the macro and micronutrients export estimates for the three proposed harvest scenarios. Harvesting only the stemwood showed the lowest nutrient removal from the system, regardless of the genotypes. This scenario

Table 7. Macronutrient export estimates for the three proposed harvest scenarios.

Genotypes	Intensity	N	P	K	Ca	Mg	S
		(kg ha ⁻¹)					
<i>E. benthamii</i> (P1)	1*	52.27	5.08	64.61	38.78	16.14	6.60
	2	76.25	7.51	89.33	122.63	34.65	9.15
	3	206.72	15.26	144.89	294.89	68.94	21.55
<i>E. benthamii</i> (P2)	1	50.34	5.34	60.06	17.06	7.48	4.68
	2	68.34	7.52	76.69	63.45	21.98	6.37
	3	165.64	13.18	114.27	115.53	36.01	12.39
<i>E. saligna</i>	1	51.29	3.64	59.05	36.77	21.69	5.31
	2	79.57	5.16	74.53	104.94	44.36	7.10
	3	193.15	10.96	135.04	302.58	87.94	15.01
<i>E. dunnii</i>	1	26.92	2.72	41.61	28.23	17.87	3.61
	2	36.73	4.21	65.93	63.08	28.75	4.54
	3	105.71	8.24	110.58	165.55	52.90	9.71
<i>E. urolobulus</i>	1	71.89	5.32	100.21	30.90	11.24	9.94
	2	94.51	8.28	132.46	91.19	29.87	11.89
	3	246.03	17.39	209.21	249.46	51.15	23.09
<i>E. urograndis</i>	1	64.32	6.40	91.76	36.14	22.92	8.04
	2	86.01	8.89	115.99	116.66	46.53	9.66
	3	261.43	20.30	219.77	456.39	107.09	21.93

1* - Harvesting the stemwood; 2 - Harvesting the stemwood with stembark; 3 - Harvesting of all aboveground biomass.

Table 8. Micronutrient export estimates for the three proposed harvest scenarios.

Genotypes	Intensity	B	Cu	Fe	Mn	Zn
		(g ha ⁻¹)				
<i>E. benthamii</i> (P1)	1*	185.40	26.61	938.24	5893.36	191.70
	2	278.41	41.72	1207.82	12512.90	257.48
	3	614.84	114.52	2648.83	27483.72	419.74
<i>E. benthamii</i> (P2)	1	128.72	66.64	552.20	3707.66	242.54
	2	220.86	82.18	669.55	8500.72	295.42
	3	389.75	134.92	1255.47	15971.56	390.40
<i>E. saligna</i>	1	240.94	69.78	1765.68	3309.26	307.66
	2	339.05	83.96	1990.79	9342.09	342.99
	3	662.53	177.31	3590.27	22514.16	537.12
<i>E. dunnii</i>	1	111.26	38.79	323.09	2884.73	74.93
	2	180.97	43.96	517.54	6193.15	101.79
	3	373.91	106.39	1517.86	14868.75	194.77
<i>E. urolobulus</i>	1	168.88	102.30	1013.28	5126.07	171.83
	2	294.32	118.65	1338.63	11321.29	214.25
	3	672.61	204.97	2393.47	27761.70	351.28
<i>E. urograndis</i>	1	231.87	105.97	966.68	5086.16	240.82
	2	329.74	121.32	1211.28	11612.99	292.64
	3	951.57	288.71	4014.67	35215.16	575.76

1* - Harvesting the stemwood; 2 - Harvesting the stemwood with stembark; 3 - Harvesting of all aboveground biomass.

maintained the macro and micronutrients accumulated in the other biomass components, which varied from 70% to 75% of N (*E. benthamii* (P2) and *E. urograndis*); 59% to 69% of P (*E. benthamii* (P2) and *E. urolobulus*); 47% to 62% of K (*E. benthamii* (P2) and *E. dunnii*); 83% to 92% Ca (*E. dunnii* and *E. urograndis*); 66% to 79% of Mg (*E. dunnii* and *E. benthamii* (P2)); 57% to 69% of S (*E. urolobulus* and *E. benthamii* (P1)); 64% to 76% of B (*E. saligna* and *E. urograndis*); 50% to 77% Cu (*E. urolobulus* and *E. benthamii* (P1)); 51% to 79% of Fe (*E. saligna* and *E. dunnii*); 77% to 86% of Mn (*E. benthamii* (P2) and *E. urograndis*); and 38% to 62% of Zn (*E. benthamii* (P2) and *E. dunnii*). On the other hand, harvesting the stemwood and the stembark resulted in the reduction in nutrient levels in the other biomass components by the following amounts:

from 59% to 67% of N; from 43% to 56% of P; from 33% to 47% of K; from 45% to 74% Ca; from 39% to 57% of Mg (*E. benthamii* (P2) and *E. urolobulus*); and from 49% to 58% of S (*E. urolobulus* and *E. benthamii* (P1)); from 43% to 65% of B (*E. benthamii* (P2) and *E. urograndis*); from 39% to 64% of Cu (*E. benthamii* (P2) and *E. benthamii* (P1)); from 44% to 70% of Fe (*E. urolobulus* and *E. urograndis*); from 47% to 67% of Mn, and from 24% to 49% of Zn (*E. benthamii* (P2) and *E. urograndis*).

In the case of macronutrients, it was observed that, in the first scenario (harvesting of stemwood), in all the genotypes, the element removed in the greatest quantity was K. In the second scenario (harvesting of stemwood with bark) the highest removal occurred with Ca (*E. benthamii* (P1), *E. saligna*

and *E. urograndis*), and with K (*E. benthamii* (P2), *E. dunnii* and *E. uroglobulus*). In the third scenario (harvesting of all biomass aboveground), the macronutrient removed in the greatest quantity was Ca, except in *E. benthamii* (P2), where the largest export occurred with N. Therefore, when removing the trunk, debarking of the trees in the stands should be carried out to reduce the export of Ca. In this way, soils with lower concentrations of this nutrient could have their productivity preserved for a longer period. In the case of the micronutrients, in all the studied scenarios, the elements removed in greatest and least quantities were Mn and Cu, respectively.

The highest amount of nutrients exported with the biomass harvest for the first and second scenarios occurred in *E. uroglobulus* (N, K and S), *E. urograndis* (P, Mg and Cu) and *E. saligna* (B, Fe and Zn). For the third scenario, the highest amount of export of nutrients occurred in *E. urograndis*, except for S, where the highest removal occurred in *E. uroglobulus*. In contrast, for the first and second scenarios, *E. dunnii* exported the smallest amounts of (scenario 1) N, P, K and Ca; and (scenario 2), S, B, Cu, Fe, Mn, and Zn. Therefore, the knowledge of the export rate of nutrients by different species and provenances is of paramount importance for implementing sustainable forest management techniques. In this context, for sustainable land use, the nutrient loss must be remedied by application of fertilisers, which usually increases the input costs and hence the energy cost from the biomass (Guo et al., 2002).

It should be noted that the age of cut exerts a marked influence on the export of nutrients. The harvest of young stands tends to export more nutrients per unit of biomass, and with the increase in age, there is a greater efficiency in the use of nutrients and consequently less export of these elements (Viera et al., 2015).

Conclusions

Different genotypes produced different levels of biomass, and the hybrids *E. uroglobulus* and *E. urograndis* showed superior biomass production levels compared to the other clones. In contrast, *E. dunnii* showed the lowest production.

There was great variation in the concentration and allocation of the amount of nutrients in the different *Eucalyptus* species, and in the different components of the same genotypes.

E. urograndis presented the highest total amounts of macro and micronutrients, with the exception of S that was present in greater quantity in *E. uroglobulus*.

Harvesting only the stemwood showed the lowest nutrient removal from the system, regardless of the genotypes.

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