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Aboveground biomass production and nutrient accumulation in a five year old *Eucalyptus grandis* and *E. urophylla plantation*

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Abstract

Nutrient concentrations in tree biomass components may vary with the component considered, age and genetic material and its measurement is important to understand forestry nutrient management. Due to it, aboveground biomass production and nutrient accumulation and its potential removal through thinning in two species of five-year-old *Eucalyptus* with were evaluated in the southern of Brazil. Treatments were arranged in a randomized block design with three replications in a 2 x 4 factorial scheme, being 2 species (*E. grandis* and *E. urophylla)* and four diametric classes (C1: 3.0 - 8.8; C2: 8.9 - 14.7; C3: 14.8 - 20.6; C4: 20.7 - 26.5 cm). Average annual accumulation of dry matter in both species was of 16.9 Mg ha^{-1}. Biomass was mainly allocated in the stem (wood and bark). Trees' canopy (branches and leaves) represent the smallest fractions, with only 14,3% of the total biomass. *E. grandis* showed highest values of wood and leaf compartments. The highest content of N and K were found in the leaves, with N levels of 33.2 and 30.5 g.Kg^{-1} respectively to *E. grandis* and *E. urophylla*. Trees bark represent an important Ca and Mg reserve to the development of the plant, with values of 18.02 and 3.24 g.kg^{-1} respectively. The average concentration of Ca, N, K, Mg and P in the total biomass of the two species was of 528, 305, 200, 128 and 30 kg ha^{-1}.
Keywords: forest inventory; nitrogen; phosphorous, potassium; trees compartment.

Produção de biomassa aérea e acúmulo de nutrientes em plantação de *Eucalyptus grandise* e *E. urophylla* com cinco anos de idade

Resumo

As concentrações de nutrientes nos componentes da biomassa arbórea podem variar em função do componente, da idade da plantação e o material genético, e sua mensuração é importante para entender o manejo florestal de nutrientes do solo. A produção de biomassa da parte aérea, o acúmulo de nutrientes e o seu potencial de remoção em duas espécies de *Eucalyptus* com cinco anos de idade foram avaliados no sul do Brasil. Os tratamentos foram dispostos em delineamento de blocos casualizados com três repetições, em esquema fatorial 2 x 4, sendo duas espécies (*E. grandis* e *E. urophylla*) e quatro classes diamétricas (C1: 3,0 - 8,8; C2: 8,9 - 14,7; C3: 14,8 - 20,6; C4: 20,7 - 26,5 cm). O acúmulo médio anual de matéria seca em ambas as espécies foi de 16,9 Mg ha^{-1}. A biomassa foi alocada principalmente no caule (madeira e casca). O dossel das árvores (ramos e folhas) representa as menores frações, com apenas 14,3% da biomassa total. *E. grandis* apresentou maiores valores de madeira e compartimentos foliares. Os maiores teores de N e K foram encontrados nas folhas, com níveis de N de 33,2 e 30,5 g.Kg^{-1}, respectivamente, para *E. grandis* e *E. urophylla*. A casca das árvores representa uma importante reserva de Ca e Mg para o desenvolvimento da planta, com valores de 18,02 e 3,24 g.kg^{-1}, respectivamente. As concentrações médias de Ca, N, K, Mg e P na biomassa total das duas espécies foram de 528, 305, 200, 128 e 30 kg ha^{-1}.
Palavras-chave: inventário florestal; nitrogênio; fósforo, potássio; componente arbóreo;

Introduction

Men see Forest as a scarce resource with aggregated value, from economic, ecological and social aspects. Brazilian planted forests occupy approximately 6.9 million hectares from which 4.9 million hectares is planted with *Eucalyptus* (around 25% of world plantation). Moreover, the country has shown a steady increase in productivity; in the 1970s, the average yield was 13 m^3 ha^1 yr^1, and it currently exceeds 40 m^3 ha^1 yr^1 (GONÇALVES *et al.*, 2013).

Trees growth in a forest depends on both biotic and abiotic factors. According to Soalleiro *et al.* (2018), biomass production may vary intensely according to resources (water and nutrients) availability in the forest site, which influences photosynthesis and trees production (RYAN *et al.*, 2010).

Beyond it biomass accumulation and distribution on trees components, its nutrient content and potential of removal from the area are important data to help understand and improve forestry management.

Short rotations without nutrients reposition after harvesting are the main responsible for soil exhaustion in *Eucalyptus* farming, since there are high amounts of nutrients in branches, leaves, and bark (BELLOTE *et al.*, 2008). Therefore, understanding the accumulation of nutrients and total aboveground biomass in plants, including woody parts, require additional research.

Both N and P are major nutrients for tree growth, however, they differ in their sources, site availability (CHAPIN *et al.*, 2011) and degrees of translocation in plant organs (INAGAKI *et al.*, 2011). Measuring the aboveground biomass and accumulated nutrients of entire trees is difficult because it requires destructive measurements. Until recently, very limited information on the aboveground biomass of tropical trees has been available.

The aim of this study was to evaluate the accumulation and distribution (leaf, branch, stem, and bark) of aboveground biomass and nutrients in a five-years-old plantation of *Eucalyptus grandis* and *E. urophylla* planted in the Southwest region of Parana state, Brazil.

Materials and Methods

The experiment was conducted in a commercial stand in Salto do Lontra, province of Paraná, Brazil (25º46'S, 53º12'W; 510 m elevation). The site has a warm subtropical climate (ALVARES *et al.*, 2013), with a mean annual rainfall of 2044 mm (POSSENTI *et al.*, 2007). The soil of the study site is classified as an oxisoil and soil chemical analyses (0 to 20-cm depth), were: pH (CaCl2) 5.2; P=10.28 mg dm^{-3}; K=0.23 $cmol_c dm^{-3}$; organic matter=3.6 $g.kg^{-1}$, Ca=6.2 $cmol_c dm^{-3}$; base saturation=64% and CEC of 13%.

Trees were planted using a 3 x 2 m row and intra-row spacing with a stand density was 1,666 trees ha^{-1}. This study was undertaken with two species; *Eucalyptus grandis and Eucalyptus urophylla*, both from seminal origin with 60 months old.

Treatments were arranged in a randomized block design with three replications in a 2 x 4 factorial scheme, being 2 species (*E. grandis* and *E. urophylla)* and four diametric classes (C1: 3.0 - 8.8; C2: 8.9 - 14.7; C3: 14.8 - 20.6; C4: 20.7 -26.5 cm).

In order to get biomass production data, a forest inventory was carried out and the diametric classes were gotten from it, which determined the choice of sample-trees that were cut to obtain biomass production data and samples collection from the different fractions. Three trees were selected in each diametric class, where for each studied species, four classes of diameter were classified, being: C1; 3.0-8.8; C2: 8.9-14.7; C3: 14.8-20.6; C4: 20.7-26.5 cm. Twelve trees were evaluated for each species.

The establishment of each sample-tree's volume was undertaken by Smalian methodology (CAMPOS; LEITE, 2013). Total nutrient accumulations in harvested aboveground biomass for leaf, branches, bark and tree trunk wood at the end of five-year rotations were then estimated. The density determination method followed the immersion in water as described by Rezende (1997).

Samples of 200 g of dried material were taken out from each component, were dried in a forced-air oven at 60 ºC until constant weight to determine the dry matter (DM). A fraction of the samples was dried in a forced-air oven at 105°C until they reached constant weight for dry matter establishment.

After the DM weight determination, the remaining biomass was ground in a knife mill type Willey (<40 mesh) and held sulfuric digestion being the total N determined by the Kjeldahl method (TEDESCO *et al.*, 1995). After it, using a sub-sample obtained in the digestion, the total levels of P, K and Ca were determined by spectrophotometry, flame spectrophotometry and atomic absorption spectrophotometry respectively.

To evaluate the biomass allocation and nutrient accumulation in an entire tree and in each component unit (leaves, branches, bark, and trees trunk wood) of two different *Eucalyptus* species, we compared total aboveground biomass and biomass of each component as well as nutrient accumulation using Assistat free software, version 7.7 at 5% level of probability error.

Results and Discussions

Biomass volume in the commercial wood + bark component for *E. grandis* and *E. urophylla* with 60 months old was of 163.32 and 176.40 m^3 ha^{-1} respectively. The mean annual volume increments (MAI) of biomass of *E. grandis* and *E. urophylla* with and without bark were of 32.66 and 27.03 $m^3.ha^{-1}.year^{-1}$ and 35.28 and 26.72 $m^3.ha^{-1}.year^{-1}$ respectively (Table 1). *E. urophylla* showed a higher percentage of bark (24.75%) when compared with *E. grandis.*

Table 1. Dendrometric parameters of diameter at breast height (DBH), total height (Th), volume with bark (Vw/b) and without bark (V w/b), form factor with bark (ff w/b) and without bark (ff w/b) and bark volume (BV %) of *E. grandis and E. urophylla*.

Variables	DBH w/b (cm)	Th (m)	V w/b ($m^3.ha^{-1}$)	V w/b ($m^3.ha^{-1}$)	ff w/b	ff w/b	Bv %
E. grandis	12.63^{ns}	20.42^{ns}	163.32^{ns}	135.16^{ns}	0.43^{ns}	0.43^{ns}	18,77 b
E. urophylla	13.01^{ns}	19.70^{ns}	176.40^{ns}	133.58^{ns}	0.42^{ns}	0.42^{ns}	24.75 a
Average	12.82	20.06	169.86	134.37	0.43	0.43	21.76

Averages followed by the same letter do not statistically differ among themselves. The Tukey Test was applied at 5% level of probability.

Considering dry matter content biomass and its densities, biomass accumulation was estimated both for *E. grandis* and *E. urophylla* being most of it represented by the trees trunk wood component, followed by bark, branches, and leaves, which showed the lowest values. *E. grandis* and *E urophylla* wood production differed with values of 66.77 and 64.30 Mg DM ha^{-1}, respectively (Table 2).

Table 2. Biomass amount aboveground ($Mg.MS.ha^{-1}$) and percentage in each fraction for populating of *E. grandis and E. urophylla*.

	$Mg.MS.ha^{-1}$				
	Wood	**Bark**	**Branches**	**Leaves**	**Total**
E. grandis	66.77 a	7.49 b	7.22 b	2.20 a	83.68
-------%------	79.79	8.95	8.63	2.63	100.00
E. urophylla	64.30 b	11.55 a	7.56 a	2.10 b	85.51
-------%------	75.20	13.51	8.84	2.46	100.00
Average	65.54 A	9.52 B	7.39 C	2.15 D	84.59

Averages followed by the same letter do not statistically differ among themselves. The Tukey Test was applied at 5% level of probability. For classification Columns with lowercase letter, for classification rows with uppercase letters.

The annual aboveground biomass accumulation for *E. grandis* and *E. urophylla* was of 16.74 and 17.10 Mg ha^{-1} $year^{-1}$ respectively. *E. grandis* total aboveground biomass accumulation (83.68 Mg DM ha^{-1}), was most present into the trees trunk wood component (79.79%), followed by bark (8.95%), branches (8.63%), and leaves (2.63%). *E. urophylla* showed a similar distribution in its components, as followed: wood (75.20%), bark (7.56%), branches (8.84%) and leaves (2.46%).

E. grandis showed higher biomass allocated in wood and leaves than *E. urophylla,* however*, E. urophylla* showed higher biomass allocated into bark and branches components. Souza and Fiorentin (2013), assessing the percentage of dried weight for each compartment of *E. grandis*, found that most of the aerial biomass (72.02%) was allocated into wood fraction, equivalent to 80.49% of total aerial biomass, with only 8.47% in bark fraction.

Paixão *et al.* (2006) carried out a forest inventory in a *E. grandis* plantation with 6 yr. old and after analyses, they reported that the trees trunk was the component that most contributed for the above ground biomass (81.84%), followed by bark (8.05%), branches (7.74%), and leaves (2.57%). These results are similar to those found for *E. grandis* tree in this study.

Silva (2005), studying the effect of tree density on the trees trunk biomass of a clone hybrid (*Eucalyptus grandis* x *Eucalyptus urophylla*) six years old, found average values of 86.5% for wood, 7.6% for bark, 3.4% for branches, and 2.4% for leaves.

Regarding to nutrient content and potential of trees components removal and in accordance with Schneider (2008), trees trunk wood showed the lowest nutrient contents when compared to the other trees components. On the other hand, leaf fraction showed the highest contents of N, P, and K, while the bark showed the highest contents of Ca and Mg (Table 3). Considering this fact, it is possible to infer that trees leaves should stay in the field, after harvesting, once export high amounts of nutrients. (moreover, there is ahead in the text a discussion about this subject).

Table 3. Comparison of average nutrients contents (N, P, K, Ca, and Mg) in the different fractions of the tree, for species *E. grandis and E. urophylla* with 60 months old.

		g kg^{-1}					
Fraction	**Specie**	**N**	**P**	**K**	**Ca**	**Mg**	**Sum**
Wood	***E. grandis***	2.22a*	0.29a	1.39a	5.07a	1.2a	10.25a
	E. urophylla	1.72b	0.21a	1.31a	3.06b	1.06a	7.36b
	Average	1.97	0.25	1.35	4.06	1.17	8.81
Bark	***E. grandis***	6.19a	0.86a	5.69a	18.21a	3.03a	33.98 a
	E. urophylla	5.63a	0.86a	5.21a	17.82a	3.45a	32.99 a
	Average	5.91	0.87	5.45	18.02	3.24	33.49
Branch	***E. grandis***	8.66a	0.41a	5.90a	10.39a	1.75b	27.11a
	E. urophylla	5.41b	0.41a	4.66b	8.33a	2.66a	21.4b
	Average	7.04	0.41	5.28	9.36	2.21	24.29
Leaf	***E. grandis***	33.18a	1.44a	10.46a	10.91a	1.48a	55.74a
	E. urophylla	30.50a	1.37a	9.60a	7.82b	1.67a	50.96a
	Average	31.84	1.41	10.03	9.37	1.58	53.22

* To the each nutrient, averages followed by the same letter do not statistically differ among themselves. The Tukey Test was applied at 5% level of probability.

Silva (2015) studying a 6 yr. old *E. benthamii* plantation, reported similar values as this study, with total nutrients (N, P, K, Ca, and Mg) content of 7.18 g Kg^{-1}.

Among the trees components, bark showed 18.02 and 3.24 g kg^{-1} of Ca and Mg, being these values the highest content among the other trees components. Leaves showed the highest nutrient contents. Regarding to N, there were 33.18 and 30.50 g.kg^{-1} in *E. grandis* in *E. urophylla* (Table 4). These values are greater than those reported by Assis *et al.* (2006), in leaves of *E. urophylla*.

Table 4. Nutrients amounts in different components setting up the biomass of *E. grandis* and *E. urophylla* with 60 months old.

Components		Biomass (Mg ha^{-1})	N	P	K	Ca	Mg	Total
			kg ha^{-1}					
Wood	***E. grandis***	66.77	148,23a*	19.36a	82,81a	338.52a	85.47a	684.39a
	E. urophylla	64.30	110.60b	13.50b	84.23b	196.76b	68.16b	473.25b
	Average	65.54	129.41	16.43	88.52	267.64	76.81	578.81
Bark	***E. grandis***	7.49	46.36b	6.44b	42.62b	136.39b	22.69b	254.50b
	E. urophylla	11.55	65.03a	10.15a	60.18a	205.82a	39.85a	381.04a
	Average	9.52	55.69	8.30	51.40	171.11	31.27	317.77
Branches	***E. grandis***	7.22	62.53a	2.96a	42.60a	75.02a	12.64b	195.75a
	E. urophylla	7.56	40.96b	3.10a	35.23b	62.97b	20.11a	162.31b
	Average	7.39	51.71	3.03	38.91	69.00	16.37	179.02
Leaves	***E. grandis***	2.20	73.00a	3.17a	23.01a	24.00a	3.26b	126.44a
	E. urophylla	2.10	64.05b	2.88b	20.16b	16.42b	3.51a	107.02b
	Average	2.15	68.52	3.02	21.59	20.21	3.38	116.72
Total		84.60	305.33	30.78	200.42	527.96	127.83	-----

* To the each nutrient, averages followed by the same letter do not statistically differ among themselves. The Tukey Test was applied at 5% level of probability.

Considering that, the stand was established from seminal seedlings, biomass accumulation can be considered satisfactory for the studied region. Viera (2012) evaluating a hybrid populations of 10 yr. old (*Eucalyptus urophylla* x *Eucalyptus globulus)* reported similar values, with total aboveground biomass of 198.5 Mg ha^{-1}, equivalent to 19.85 Mg ha^{-1} year^{-1}, presenting greater stock of wood (84.2%), followed by bark (9.5%), branches (4.5%), and leaves (1.8%). According to Schneider (2008), biomass fraction on tree trunk wood biomass tends to increase as trees gets older.

Santana *et al.* (1999), evaluating 15 areas with *Eucalyptus grandis* and *Eucalyptus saligna*, with 6.5 yr. old reported average biomass accumulation values of 18.5 and 18.3 Mg ha^{-1} year^{-1}, respectively. Means showed a great variability between the same specie an between areas and varied from 14.6 and 12.3 Mg ha^{-1} year^{-1} to 31.7 and 32.92 Mg ha^{-1} year^{-1}, respectively.

Schumacher and Caldeira (2001) evaluating *Eucalyptus globulus* with 4 yr. old reported a total aboveground biomass of 83.2 Mg ha^{-1}, which is equivalent to 20.8 Mg ha^{-1} year^{-1}. The trees trunk wood component accumulated the higher biomass amount (57.5 Mg ha^{-1}) corresponding to 69% of the aerial total portion, followed by leaves, branches, and bark.

Beyond it biomass accumulation and distribution on trees components, its nutrient content and potential of removal from the area are important data to help understand and improve forestry management. Nutrients are distributed among the several trees components in different proportion. Whereas, leaves and growing tissues present the greatest concentrations, mature structures such as wood tends to have lower levels of nutrients (SCHNEIDER, 2008),

Among trees compartments, *Eucalyptus* trees barks are important nutrient source for plant development (CARVALHO, 2010). High Ca content in the bark can be explained by presence of Calcium oxalate in the phloem, component that along with the periderm comprises the bark (PATRÍCIO, 2014). Vieira (2012) describes that Ca immobility in plants phloem could explains its high content in the bark fraction, as well as the fact of the element is a structural component, part of the medium lamella of the cell membrane. These results are similar to the results reported by Viera (2012).

According to Gonçalves (1995), suitable N content would be between 13.5 and 18 g kg^{-1}, considering the average data for the most cultivated Eucalyptus species in Brazil. Malavolta *et al.* (1997), studying *Eucalyptus grandis* plantations with high wood yield reported N values ranging from 21 to 23 g kg^{-1}. These values were below the data reported at Table 4, showing good plant nitrogen status at the experimental site. Different time of the year that sample is collected may help explain these differences.

Regarding to the amount of nutrients on trees components, tree trunk wood showed higher amounts followed by bark and branches. As previously discussed, tree trunk wood showed the lowest nutrients content per kilogram of dried matter; however, due to its greater biomass volume, it has greater nutrient accumulation that the other trees components (Table 4).

The magnitude of nutrients accumulation allocated in total biomass showed the following decreasing order: Ca > N > Mg > P. This macronutrients sequence was also reported by other authors (SCHNEIDER, 2008; VIERA, 2012; VIERA *et al.*, 2012). Beulch (2013), reported higher levels of K than N, differing form this study.

When comparing biomass production and plant nutrients (N, P, K, Ca, and Mg) content, it is possible to observe absorption of 8.83 kg of these nutrients for each ton of produced tree trunk wood, which allow to emphasize that this tree component is the one that exports the least nutrients. Branches come in second with 24.22 kg of biomass, bark in third with 33.38 and leaves in fourth place with 54.29 kg on nutrients per ton of produced biomass.

Following the definition of nutrient use efficiency as the net primary production per amount of nutrients taken up, it is possible to observe that tree trunk wood (without bark) stands out as the most efficient nutrient user per ton of produced biomass. When analyzing biomass harvest, wood will be exporting 48.54% of total nutrients. In this way, it is interesting to leave the other aboveground tree biomass components to be recycled and return to the system reducing thus over 50% the need of nutrients fertilizers reposition for future cycles.

Similarly reported by Carneiro *et al.* (2008), keeping as much biomass as possible at the site could be important to sustain the productivity. As the result indicates, keeping leaves and branches in the area may return over 50% of the absorbed nutrients. In the other hand, if all the biomass is harvest, large amounts of nutrients are removed from the ecosystem and depletion of nutrients in the soil could be expected.

According to the data observed, it is possible to conclude that *Eucalyptus* aboveground biomass is mainly allocated on the tree trunk, which is followed by bark > branches > leaves. Comparing the two species, *E. grandis* showed higher biomass allocated on the tree trunk (without bark) and on tree leaves while *E. urophylla* showed greater biomass on bark and branches compartments.

Furthermore, tree trunk wood has the lowest nutrients content per kg of dry matter, with 10.25 and 7.36 g kg^{-1} of total nutrient (N, P, K, Ca, and Mg) respectively for *E. grandis* and for *E. urophylla*. On the other hand, leaves showed the highest content of N, P, and K, except for Ca and Mg that are allocated in greater amounts in the eucalyptus' bark. Moreover, If only tree trunk wood is harvested, only 48.54% of absorbed nutrients will be exported, decreasing the need for nutrients reposition for the next crop.

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