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Production of biomass and energy stock for five *Eucalyptus* species

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ABSTRACT This study assessed the energy quality of different tree compartments (wood, bark, branches and leaves) for bioenergy use. Five species of the genus *Eucalyptus* were used, in which high heating value, contents of fixed carbon, volatile materials and ash, as well as the production of dry biomass and the amount of energy stored in each of the evaluated compartments, were measured. All evaluated species were able to produce energy, with no significant differences among species. In relation to the compartments, leaves and bark had higher heating value and ash content, respectively. The energy stock per unit area of all species had similar values.
Keywords: bioenergy; combustion; heating value.

Produção de biomassa e estoque de energia para cinco espécies de *Eucalyptus*

RESUMO O presente trabalho avaliou a qualidade energética dos diferentes compartimentos da árvore (madeira, casca, galhos e folhas) para utilização bioenergética. Foram utilizadas cinco espécies do gênero *Eucalyptus*, nas quais foram mensurados poder calorifico superior, teor de carbono fixo, materiais voláteis e cinzas, além da produção de biomassa seca e a quantidade de energia estocada em cada um dos compartimentos avaliados. Todas as espécies avaliadas mostraram ser aptas para produção de energia, não havendo diferenças significativas entre as espécies. Em relação aos compartimentos, folhas e casca apresentaram maior poder calorifico superior e maior teor de cinzas, respectivamente. O estoque de energia por unidade de área todas as espécies apresentaram valores semelhantes.
Palavras-chave: bioenergia, combustão, poder calorifico.

Introduction

The global demand for energy has grown more than 50% in the last decade and the tendency is that there will be an increase in this demand over time. Wood accounted for 6.3% of the energy consumed in Brazil in 2014; although the relative wood consumption has declined since the 1970s, total consumption increased (EPE, 2014).

However, the use of wood on a large scale as an energy source requires planting for this specific purpose. In Brazil, several studies have been conducted to make plantations feasible for energy purposes (ELOY et al., 2015a, 2015b). It is essential that forest experiments be carried out to understand the relation of biomass and energy production of different species, in order to obtain information that enables the production of wood material.

Eucalyptus plantations stand out among planted forests due to their rapid growth and, therefore, high volumetric productivity, besides being a homogeneous material that is available as an alternative to the use of native wood (RAMOS et al., 2011). The area planted with the genus *Eucalyptus* in Brazil corresponds to 5.47 million hectares, and it is the most planted forest species, representing 72% of the total area for

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this purpose (IBÁ, 2015). Of commercial plantations, the biomass left in the field after harvest represents values of 4 to 20% of the biomass above the soil, depending on several factors such as species, clone, spacing, silvicultural care, environment and site management. This biomass corresponds to tree compartments such as bark, branches and leaves.

Dry biomass, energy stock, high heating value and proximate chemical composition are important properties in evaluation of biomass as fuel. It is necessary to understand how these properties vary between forest species and their compartments. Therefore, this study aims to analyze the effect of the different tree compartments on the energy quality of forest biomass.

Material and Methods

Study area and sample collection

The study was conducted on three farms belonging to StoraEnso Florestal – Rio Grande do Sul, located in the municipalities of Alegrete and São Francisco de Assis. The climate of the region is classified as Cfah "Subtropical Mesothermic", constantly humid, according to the Koppen classification, with months of cold weather, frost from May to August, intense heat predominant in January and February. The average temperature of the hottest month is above 22°C and the annual average is above 18°C. Rainfall ranges from 1250 mm to 1500 mm, with no dry season defined (MALUF, 2000). The soil of the study area is classified as dystrophic red argisol (EMBRAPA, 2006).

Six discs, with approximately 10 cm height, were taken from the samples: 0% (10cm of the soil), DAP (1.30m of the soil), 25%, 50%, 75% and 100% with respect to the commercial height of the sample, considered up to the diameter of 6 cm with bark. At the time of collection, the plants were seven years old

In order to determine the biomass of wood, bark, branch and leaf, the direct method was used, in which clearing and weighing of the different tree compartments are carried out in the field (SANQUETTA, 2002).

Bark and wood were weighed together in the field, and then separated in the laboratory. From each compartment, samples were taken for the determination of moisture content, where the samples were dried in an oven at 103 ± 2 °C.

For the calculation of biomass per area, the methodology proposed by Santana et al. (2008) was used, in which the average dry biomass of each compartment of the nine trees sampled per species is multiplied by the number of samples per hectare.

Analysis procedure

The material dried in an oven for 24 h at 103ºC was sent for determination of high heating value, according to NBR 8633 (ABNT, 1984), in an adiabatic calorimeter pump (IKA WERKE C5000); and determination of proximate chemical composition, according to NBR 8112 (ABNT, 1986), in which the contents of fixed carbon, volatile materials and ash are determined.

The energy stock (ES), in Mcal, was calculated for each compartment by Equation 1:

$$ES = BIO * HHV * 10^3 \quad (1)$$

Where, ES = Energy stock (Mcal); BIO = Dry biomass of the compartment (kg); HHV = High heating value of the compartment (kcal kg^{-1}).

As for the biomass estimate per area, the energy stock per hectare was calculated by multiplying the average of the nine trees sampled by the number of samples per hectare.

In the evaluation of the experiment, a completely randomized design was used, in a 5x4 factorial scheme, with five species (*Eucalyptus benthamii*, *Eucalyptus dunnii*, *Eucalyptus* *grandis*, *Eucalyptus saligna* and *Eucalyptus urophylla x Eucalyptus grandis*) and four tree compartments (wood, bark, branches and leaves), with nine replicates (trees).

Data were submitted to analysis of variance, with a significant effect of the Tukey test, both at 5% probability, using the software R 3.1.2 (R CORE TEAM, 2014), with the stats package.

Results and Discussion

In the assessment of high heating value, there was no significant difference for the compartments wood and branches, while bark and leaves showed differences for the factor species. Regarding compartment, the highest average values were found in the leaves, followed by wood and branches, which formed an intermediate group, and the bark was the compartment with the lowest results (Table1).

The mean high heating values observed in wood are higher that reported by Eloy et al. (2015a, 2015b, 2016), but for the bark the mean values are lower. Ash content reduces the calorific value of the fuel and causes reduction on efficiency of burning (VIEIRA et al., 2013). For wood *Eucalyptus* clones, Botrel et al. (2010) reported ash content 0,11 – 0,25% and Dias Junior et al. (2016) reported 1,67 – 2,50 % for *E. grandis* and *E. saligna*.

Table 1. High heating value and proximate chemical composition of the species in the different tree compartments.
Tabela 1. Poder calorifico superior e composição química imediata das espécies nos diferentes compartimentos da árvore

Variable		Species				
		E. benthamii	*E. dunnii*	*E. grandis*	*E. saligna*	*E. urograndis*
HHV (kcal kg^{-1})	Wood^{ns}	4626 aB	4660 aB	4532 aB	4661 aB	4585 aB
	Bark	4151 aC	3986 abC	3620 cC	3838 bcC	3672 cC
	Leaves	5394 bA	5652 aA	5206 bcA	5081 cA	5074 cA
	Branches^{ns}	4536 aB	4566 aB	4562 aB	4561 aB	4504 aB
FC (%)	Wood^{ns}	15.56 aC	14.80 aB	14.59 aC	15.67 aC	15.14 aC
	Bark	21.83 aA	19.95 bA	17.65 cB	17.12 cC	20.86 abB
	Leaves	20.55 cB	20.21 cA	20.73 bcA	23.65 aA	22.21 abA
	Branches^{ns}	20.99 aAB	20.12 aA	20.23 aA	20.89 aB	20.74 aB
VM (%)	Wood^{ns}	84.05 aA	84.81 aA	85.11 aA	84.06 aA	84.52 aA
	Bark	71.76 cD	74.78 abC	73.47 bcC	75.88 aB	69.35 dD
	Leaves	75.60 aC	75.74 aC	74.75 abC	71.51 cC	73.34 bC
	Branches^{ns}	77.45 aB	78.19 aB	78.17 aB	76.89 aB	77.77 aB
Ash (%)	Wood	0.38 aD	0.38 aD	0.29 abD	0.27 bD	0.34 abD
	Bark	6.32 bcA	5.26 cA	8.86 aA	6.98 bA	9.78 aA
	Leaves^{ns}	4.17 aB	4.04 aB	4.51 aB	4.83 aB	4.44 aB
	Branches^{ns}	1.55 aC	1.68 aC	1.59 aC	2.20 aC	1.70 aC

HHV: High heating value, FC: Fixed carbon content, VM: Volatile material content, Ash: Ash content, ^{ns}: Not significant at 5% probability. Same lowercase letters in the same row do not differ between species for the same compartment, same uppercase letters in the same column do not differ statistically between compartments for the same species.

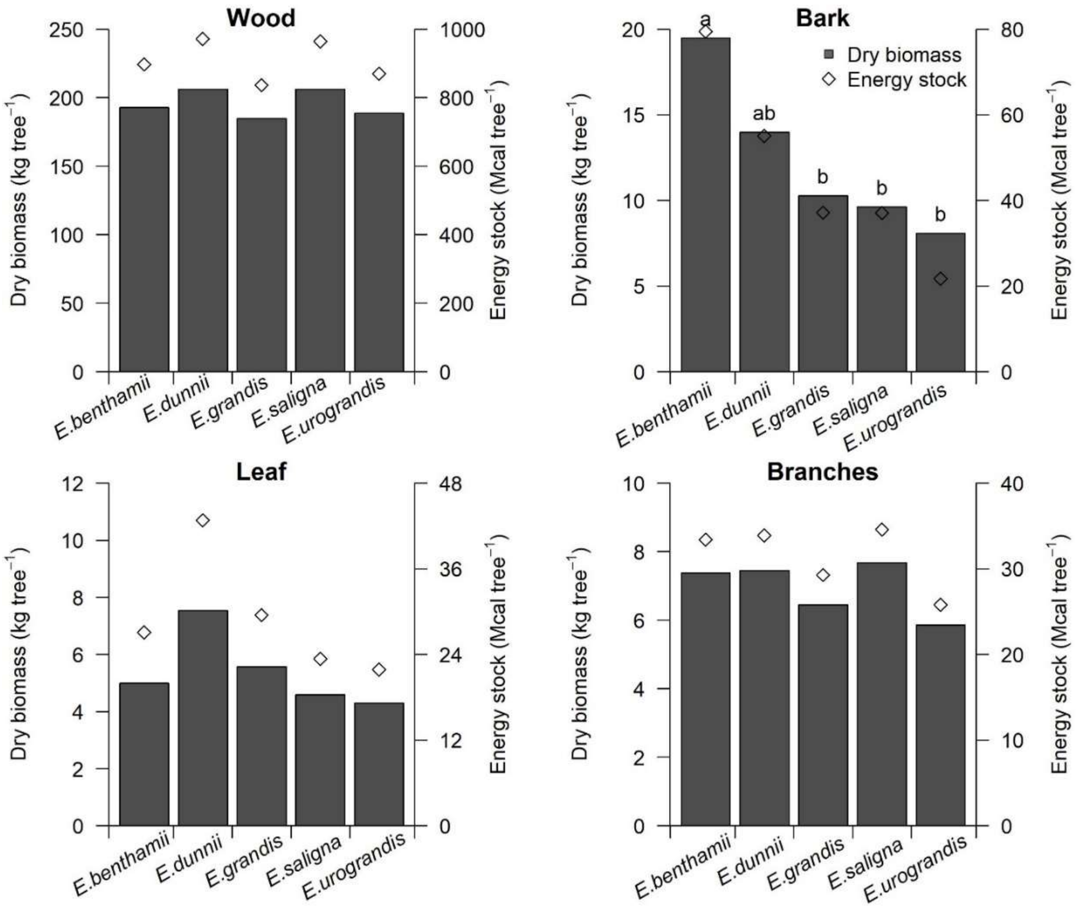

Figure 1. Dry biomass and energy stock in the different tree compartments.
Figura 1. Biomassa seca e estoque de energia nos diferentes compartimentos da árvore.

Materials with higher ash contents, such as bark and leaves, are not recommended for combustion in conventional boilers, since they can cause emissions of particulate matter in chimneys during the combustion process (BARRON, 1970; BRITO; BARRICHELO, 1978). In addition, slag and scale can be formed in burners and heat exchangers (PELANDA et al., 2015). The results found in this study corroborate the literature regarding the average values for fixed carbon and ash contents, so that the bark has values higher than those found for wood (BRITO; BARRICHELO, 1978; ELOY et al., 2015a, 2015b, VALE et al., 2002).

Volatile materials content affects positively in the ignition of solid fuels, facilitating the beginning of the process, however the burning is faster than fixed carbon (VIEIRA et al., 2013). The average for volatile materials are in accordance with those reported by Eloy et al (2016).

Regarding biomass production and energy stock per sample, there was no significant difference among species, except for the bark compartment. The species *Eucalyptus benthamii* presented the highest values for energy stock and biomass production in the bark compartment; however, the mean values for the species *Eucalyptus dunnii* did not differ statistically from the former or any other species (Figure 1).

In the evaluation of dry biomass production per hectare, *Eucalyptus saligna* and *Eucalyptus dunnii* stand out with a production of 219 Mg ha^{-1} and 225 Mg ha^{-1} for wood, which also present the highest values for energy stock, 1035 Gcal ha^{-1} and 1053 Gcal ha^{-1}. In the bark, the highest values of dry biomass production and energy stock were observed for *Eucalyptus benthamii*, with 20.77 Mg ha^{-1} and 84.75 Gcal ha^{-1}, respectively. This is due to the high percentage of bark in this species in relation to the others. For the compartment leaves, the highest values were observed in *Eucalyptus dunni*, with 8.03 Mg ha^{-1} and 45.62 Gcal ha^{-1}. In the compartment branches, species *Eucalyptus dunnii*, *Eucalyptus grandis* and *Eucalyptus saligna* presented the highest values for biomass in the range of 7.51 to 8.38 Mg ha^{-1}; for energy stock, the values were between 34.13 and 37.78 Gcal ha^{-1} (Table 2).

In an experiment using *Eucalyptus benthamii* at one, two, three and four years of age, Silva et al. (2004) observed an increase in biomass allocation in the compartments wood and bark and, consequently, a decrease in the other two compartments (branches and leaves), with increasing age; the authors observed values of 70.4%, 7.3%, 15.2% and 7.1% for wood, bark, branches and leaves at four years of age, respectively.

The species *Eucalyptus dunnii* and *Eucalyptus saligna* presented superior results in relation to energy stock; they were the only ones among the studied species with an energy stock higher than 1000 Gcal ha^{-1} in the shaft, which is the most used compartment for power generation, since the compartments branches and leaves tend to be left in the field for nutrient cycling during forest harvest.

Table 2. Dry biomass and energy stock in the different tree compartments per hectare.
Tabela 2. Biomassa seca e estoque de energia nos diferentes compartimentos da árvore por hectare.

	Variable	Species				
		E. benthamii	*E. dunnii*	*E. grandis*	*E. saligna*	*E. urograndis*
BIO (Mg ha^{-1})	Wood	205.8	219.89	215.28	225.23	205.06
		(85.8)	(87.7)	(89.2)	(90.4)	(91.9)
	Bark	20.77	14.91	11.96	10.51	8.77
		(8.7)	(5.9)	(5.0)	(4.2)	(3.9)
	Leaves	5.33	8.03	6.48	5.01	3.91
		(2.2)	(3.2)	(2.7)	(2.0)	(1.8)
	Branches	7.86	7.94	7.51	8.38	5.38
		(3.3)	(3.2)	(3.1)	(3.4)	(2.4)
	TOTAL	**239.73**	**250.78**	**241.24**	**249.15**	**223.12**
ES (Gcal ha^{-1})	Wood	956.73	1035.41	974.75	1053.33	944.71
		(86.5)	(88.1)	(89.7)	(91.0)	(93.4)
	Bark	84.75	58.73	43.33	40.51	23.56
		(7.7)	(5.0)	(4.0)	(3.5)	(2.3)
	Leaves	28.88	45.62	34.36	25.55	19.95
		(2.6)	(3.9)	(3.2)	(2.2)	(2.0)
	Branches	35.60	36.13	34.13	37.78	23.50
		(3.2)	(3.1)	(3.1)	(3.3)	(2.3)
	TOTAL	**1105.98**	**1175.90**	**1086.59**	**1157.19**	**1011.73**

BIO: Dry biomass, ES: Energy stock, Values in parentheses represent the percentage participation of the compartment in the total of the tree.

Conclusions

Based on the results, it was possible to conclude that:

The different tree compartments presented characteristics that enable their energy use; however, this must be done carefully for bark and leaves, due to their high ash content;

Regarding biomass production and energy stock per species, there was no significant difference among species, except for the bark compartment;

More than 85% of the dry biomass and 86% of the energy stock of the tree are in the shaft; wood and bark are, respectively, the compartments with the greatest energy stock;

All species evaluated have a total energy stock higher than 1000 Gcal.ha^{-1};

The wood of the shaft and branches does not present differences in relation to high heating value in the studied species.

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