Alves de Magalhães, Mateus; de Cássia Oliveira Carneiro, Angélica; Rocha Vital, Benedito; Simões da Silva, Carlos Miguel; Moura de Souza, Marina; de Freitas Fialho, Lucas

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ESTIMATES OF MASS AND ENERGY OF DIFFERENT GENETIC MATERIAL EUCALYPTUS[1]

Mateus Alves de Magalhães[2*], Angélica de Cássia Oliveira Carneiro[3], Benedito Rocha Vital[3], Carlos Miguel Simões da Silva[2], Marina Moura de Souza[2] and Lucas de Freitas Fialho[2]

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[2] Universidade Federal de Viçosa, Programa de Pós-Graduação em Ciência Florestal. E-mail: <mateusmagalhaes91@gmail.com>, <karmiguel@yahoo.com.br>, <mourasouzam@gmail.com> and <l.freitasfialho@gmail.com>.
[3] Univercidade Federal de Viçosa, Departamento de Engenharia Florestal. E-mail: <cassiacarneiro@ufv.br> and <bvital@ufv.br>.
*Corresponding author.

ABSTRACT – The use of forest biomass or its derived charcoal as firewood can generate environmental and economic advantages for the Brazilian energy matrix. In this context, the main objective was to evaluate the energy potential of certain *eucalyptus* genetic materials, which are used by the charcoal production sector. We have evaluated six materials of *Eucalyptus* ssp. at the age of seven years from commercial plantations, spaced 3 x 3m, grown in the Alto Vale do Jequitinhonha, in Minas Gerais. Based on the production data, the average annual increment and the physical and chemical analyzes of the wood and the charcoal produced with it, we have estimated parameters to compare the potential of each genetic material, such as mass and energy of wood and charcoal per hectare, as well as the energy density. The results show that a material of *Eucalyptus urophylla* has greater energetic potential in relation to the others because it presents higher energy/hectare estimated for its wood and consequently for charcoal produced with it. However, a material of *Eucalyptus cloeziana* presented a higher energetic density of the wood and its charcoal, showing advantages mainly in the transport.

Keywords: Charcoal; Wood; Energetic potential.

ESTIMATIVAS DE MASSA E ENERGIA DE DIFERENTES MATERIAIS GENÉTICOS DE EUCALIPTO

RESUMO – O uso da biomassa florestal como lenha ou seu derivado carvão vegetal, pode gerar vantagens ambientais e econômicas para a matriz energética brasileira. Nesse contexto, o objetivo principal foi avaliar o potencial energético de alguns materiais genéticos de eucalipto, que são utilizados no setor de produção de carvão vegetal. Foram analisados seis materiais de ***Eucalyptus*** *ssp. na idade de sete anos provenientes de plantios comerciais, com espaçamento 3 x 3 m, cultivados no Alto Vale do Jequitinhonha, em Minas Gerais. Baseando-se nos dados de produção, no incremento médio anual e nas análises físicas e químicas da madeira e do carvão com ela produzidos, foram estimados parâmetros para se comparar o potencial de cada material genético, como a massa e a energia da madeira e do carvão por hectare, além da densidade energética. Os resultados demonstram que um material de* ***Eucalyptus urophylla*** *possui maior potencial energético em relação aos demais, por apresentar maior energia/hectare estimada para sua madeira e consequentemente para seu carvão produzido. Mas um material de* ***Eucalyptus cloeziana*** *apresentou maior densidade energética da madeira e de seu carvão, mostrando vantagens principalmente no transporte.*

Palavras-Chave: Carvão; Madeira; Potencial energético

1. INTRODUCTION

The Brazilian energy matrix for the year 2015 was based on petroleum and its derivatives with 37.3%, mineral coal with 5.9%, natural gas with 13.7%, nuclear energy with 1.3% and others with 0.6%, adding up to a total of 58.8% for non-renewable sources. Renewable sources accounted for 41.2% of the matrix, and are subdivided into hydro power with 11.3%, sugarcane products with 16.9%, wood and charcoal with 8.2%, and others with 4.7% (EPE, 2016).

Wood and charcoal, which accounted for 44 percent of the Brazilian energy matrix in the 1970s, now account for less than ten percent. This decrease is justified by the introduction of more efficient energy resources, replacing a significant percentage of renewable energy sources predominantly based on forest biomass, by non-renewable sources such as oil and its derivatives (Tolmasquim et al., 2007). Prospects for 2020 and 2030 show the continuity of this decrease (Rodrigues and Halmeman, 2012).

For Brito (2007), these energies of fossil origin, in addition to being non-renewable sources which make the energy matrix somewhat uncertain for the future, they also have negative effects over the environment. In this context, study and investment are justified in order to develop alternative sources and improve existing ones, such as those of forest biomass that have lost part of their relevance over the last decades. It is worth emphasizing the importance of using wood from reforestation areas to produce "clean" energy, following environmental and social precepts.

One of the focuses for the improvement of biomass characteristics is through forest improvement. Nowadays, we have sought the development of genetic materials with a higher energy vocation in order to present features exclusively geared to this sector. In Brazil, the genetic improvements applied to the genus *Eucalyptus* are a potential option for the increase in production of this wood (Botrel et al., 2007). The genus *Eucalyptus* represents a large part of the forests planted for energetic purposes due to the adaptation of this genus to the edaphoclimatic conditions and its rapid growth, in addition to Brazil already holding high scientific and technological level for procedures in the several areas of eucalyptus culture (Alzate et al., 2005).

Thus, the main objective of this work was to evaluate the energy potential of certain genetic materials from eucalyptus which are used by the charcoal production sector. The specific objectives were to determine the density, higher calorific value, dry mass, energy/hectare and energy density of these different genetic materials and of the charcoal produced with them, in order to classify them in relation to their energy potential.

2. MATERIAL AND METHODS

2.1 Materials used

In order to carry out this work, we have used six genetic materials of eucalyptus (Table 1), all at the age of 7 years, collected from commercial plantations belonging to Arcelor Mittal BioEnergia LTDA, located in the municipality of Itamarandiba. The planting site is located at 1,056 meters altitude, with average rainfall of 1,164.56mm, temperature ranging between 16.8 and 26.8ºC and an average relative humidity of 69%.

Six trees of medium diameter were selected for each of the genetic materials, totaling thirty-six trees (samples). The trees were collected from commercial plantations with average spacing of 3m x 3m.

2.2 Sample preparation

We have removed disks from the trees at 0, 25, 50, 75 and 100% of the commercial height of the trunk. From these, two opposite wedges were passed through the medulla, which were used to determine the basic density of the wood. The rest of the disk samples were taken for the production of charcoal and for determining the higher calorific value of the wood.

2.3 Determination of basic wood density

The analysis was done following the procedures of the water immersion method described by (Vital, 1984). The wedge-shaped samples were kept submerged in water in order to create saturation of the wood, after which their volume was measured in water by means of a scale. They were dried in an oven at 103 ± 2°C until constant weight, so the anhydrous wood mass was obtained. The basic density of the wood was calculated by dividing the dry wood mass by its saturated volume and the value for each disk was obtained from the arithmetic mean of its respective wedges.

Table 1 – General information about the genetic materials used in the study.
Tabela 1 – Informações gerais sobre os materiais genéticos utilizados no estudo.

	1	*Eucalyptus cloeziana*
Genetic material	2	Spontaneous hybrid of *Eucalyptus urophylla*
	3	*Eucalyptus urophylla* x *Eucalyptus grandis*
	4	Spontaneous hybrid of *Eucalyptus urophylla*
	5	Spontaneous hybrid of *Eucalyptus urophylla*
	6	Spontaneous hybrid of *Eucalyptus urophylla*

2.4 Determination of the higher calorific value

The higher calorific value of the wood, as well as of its charcoal was determined according to the methodology described by ABNT NBR 8633 (ABNT, 1984), using an adiabatic calorimetric pump.

2.5 Carbonization and gravimetric yields

The samples for carbonization were taken from the rest of the disks used to determine the basic density of the wood; these were mixed together and we have obtained a composite sample. The composite sample was then oven dried at 103 ± 2°C until constant weight.

The carbonizations were carried out in a laboratory furnace with electric heating, using about 250g of wood which were inserted in a metallic container with nominal dimensions of 30cm in length and 12cm in diameter.

The total carbonization time of the wood was five hours, with an average heating rate of 1.56°C/minute, the initial temperature being 30°C and the final temperature, 450°C. After carbonization, we have determined the gravimetric charcoal yield based on the dry mass of the wood.

2.6 Apparent relative density

The apparent relative density of the charcoal was determined according to the method proposed by Vital (1984), using a hydrostatic balance to determine the displaced volume. Samples of approximately 5g of charcoal were weighed to obtain the mass and subsequently immersed in mercury to determine the displaced volume.

2.7 Estimates for dry mass, energy per hectare and energy density

The dry mass of shelled wood expressed in (t/ha.year) was obtained by multiplying the average annual increment (m^3/ha.year) by the basic density of the wood (kg/m^3).

The charcoal mass in (t/ha.year) was determined by multiplying the dry mass of wood by the gravimetric yield of the charcoal.

In order to calculate the amount of energy per hectare of wood and charcoal expressed in (kwh/ha.year), their respective mass (kg/ha.year) was multiplied by their corresponding higher calorific value (kcal/kg).

In order to calculate the energy density of wood as well as that of charcoal, expressed in (kwh/m^3), we have multiplied the corresponding density (kg/m^3) by its respective higher calorific value (kcal/kg).

It was assumed that, 1 kWh corresponds to 859.18 kcal.

2.8 Statistical analysis of the experiment

The experiment was analyzed according to a completely randomized design, with six genetic materials of eucalyptus and six replicates, totaling 36 trees.

All data were submitted to the Cochran and Bartlett (normality variance homogeneity) and Lilliefors (normality) tests.

The data were submitted to analysis of variance (ANOVA) and whenever significant differences were established, the treatments were compared by means of the Tukey test at 5% probability.

3. RESULTS

3.1 Properties and mass and energy estimates for wood

It can be observed that the value obtained for the annual average increment (AAI) without peel was statistically higher for genetic material 5 *(Eucalyptus urophylla* spontaneous hybrid), and genetic material 1 (*Eucalyptus cloeziana*) had a lower AAI value.

In regards to the basic density, we have verified that the genetic material 1 presented the highest average value, and this one was significantly different from the others. In contrast, materials 2 and 5 (spontaneous hybrids of *Eucalyptus urophylla*) presented the lowest values for this particular property.

Genetic materials 4 and 5 (spontaneous hybrids of *Eucalyptus urophylla*) presented higher average values of dry mass, and were statistically different from the others which can be explained by the fact that both presented the highest average annual increments, even if they were not the ones with the highest densities. The genetic materials 1 and 6 (spontaneous hybrid of *Eucalyptus urophylla*) were the ones with the lowest values for this variable.

It is observed a superior average for the higher calorific value of the wood of genetic material 3 (*Eucalyptus grandis* x *Eucalyptus urophylla*), while genetic materials 2 and 5 presented the smallest average values for this property.

From an energetic point of view, it can be observed that the most interesting genetic materials are 4 and 5, since they had the highest average values of energy/ hectare, provided they obtained the highest amount of dry mass per hectare/year. Materials 1 and 6 are the least indicated for energy production, since they have the lowest average values among the materials we have analyzed.

The genetic material that presented the highest energy density was 1, showing that its wood produces more energy for the same unit of volume. In contrast, genetic material 2 had the lowest energy density.

3.2 Properties and mass and energy estimates for the charcoal

Regarding the gravimetric yield, genetic material 1 (*Eucalyptus cloeziana*) presented the highest average value for gravimetric charcoal yield and was statistically different from the others; genetic material 3 (*Eucalyptus urophylla* x *Eucalyptus grandis*) presented the lowest value.

Genetic materials 4 and 5 (both spontaneous hybrids of *Eucalyptus urophylla*) showed, in a statistically significant way, the highest values of mass for charcoal, namely 7.9 and 8.2t/ha.year respectively.

As for the higher calorific value of the charcoal, the highest average values were observed in genetic materials 3, 4, 5 and 6 (spontaneous *Eucalyptus urophylla* hybrids), showing no statistical difference among them but differing significantly from materials 1 and 2 (spontaneous hybrids of *Eucalyptus urophylla*), which presented the lowest average values for this particular property.

When it comes to the amount of energy stored per hectare/year estimated for charcoal, genetic materials 4 and 5 presented the highest values, and we have observed the lowest values for this variable in materials 1 and 6.

The charcoal produced from genetic material 1 presented the highest average value for apparent density, differing significantly from the others. Contrariwise, genetic materials 2 and 5 showed the lowest values, although these values have not differed statistically. This result presented by genetic material 1 can be explained by the wood that gave rise to it having the highest basic density in relation to the studied materials, since the higher the basic density of the wood, the greater the density of the charcoal produced by it.

The energy density of the charcoal followed patterns similar to the energy density of the corresponding wood, where genetic materials 1 and 2 presented respectively the highest and lowest values.

4. DISCUSSION

4.1 Properties and mass and energy estimates for wood

The average annual increment obtained by forest-based companies in the year 2015 for eucalyptus plantations was 36m³/ha.year (IBÁ, 2016). Only genetic materials 2, 4 and 5 presented higher AAI than those observed in forestry companies. The observed differences between the materials of this work can be attributed to the species and also to the different conditions of site, climate, silvicultural management, etc. A higher average annual increment associated with a higher wood density contributes to a higher dry mass production for a given genetic material, and the AAI also has a greater influence when compared to the density of the wood.

The basic density results found in the present study, 0.49 to 0.64g/cm³, cover a larger range than those observed by certain authors, possibly reflecting mass and energy estimates. Santos et al. (2011) reported that denser woods are interesting for the production of charcoal, since thermal degradation of the wood

Table 2 – Average values for the average annual increment without bark, basic density, dry mass, higher calorific value, energy and energetic density for wood of different clones of eucalyptus.

Tabela 2 – Valores médios de incremento médio anual sem casca, densidade básica, massa seca, poder calorífico superior, energia e densidade energética para a madeira dos diferentes materiais genéticos de eucalipto.

Genetic	Wood					
material	IMAsc(m³/ha.year)	DB (g/cm³)	MS (t/ha.year)	PCS (kcal/kg)	EM (kwh/ha.year)	DEM(kwh/m³)
1	24.8 d	0.64 a	15.9 d	4539.3 ab	83937.3 d	3387.8 a
2	38.8 b	0.49 e	18.9 b	4466.8 b	98410.8 b	2534.7 e
3	34.2 c	0.52 c	17.8 c	4577.3 a	94608.9 c	2763.0 c
4	40.4 b	0.56 b	22.8 a	4494.5 ab	119062.4a	2950.1 b
5	46.9 a	0.49 e	23.1 a	4450.1 b	119496.2 a	2547.8 de
6	31.0 c	0.50 d	15.6 d	4493.1 ab	81783.3 d	2634.8 d

IMAsc = average annual increment without bark; DB = basic density; MS = dry mass; PCS = higher calorific value; EM = estimated energy per hectare; DEM = energy density. Averages followed by the same lowercase letter across the column do not differ from each other at 5% significance by the Tukey test.

Table 3 – Displays values of gravimetric yield, higher calorific value, apparent density, mass and energy estimates for charcoal produced from different clones of eucalyptus.

Tabela 3 – *Apresenta valores médios de rendimento gravimétrico, poder calorifico superior, densidade aparente, estimativas de massa e energia para o carvão produzido a partir do diferentes materiais genéticos de eucalipto.*

Genetic	Charcoal					
material	RGCV (%)	MCV (t/ha.year)	PCS (kcal/kg)	ECV (kwh/ha.year)	DRA (g/cm³)	DECV (kwh/m³)
1	36.6 a	5.8 d	7306.6 b	49426.2 d	0.48 a	4083.9 a
2	36.0 ab	6.8 b	7309.3 b	57915.6 b	0.33 c	2784.2 d
3	34.6 c	6.1 c	7539.6 a	53838.9 c	0.38 b	3342.1 b
4	34.8 bc	7.9 a	7562.2 a	69663.0 a	0.39 b	3443.1 b
5	35.4 abc	8.2 a	7546.8 a	71832.6 a	0.33 c	2909.3 cd
6	35.3 abc	5.5 d	7508.8 a	48257.8 d	0.37 bc	3234.9 bc

RGCV = gravimetric yield for charcoal; MCV = estimated mass of charcoal per hectare; PCS = higher calorific value; ECV = estimated energy for charcoal per hectare; DRA = apparent relative density; DECV = energy density of charcoal. Averages followed by the same lowercase letter across the column do not differ from each other at 5% significance by the Tukey test.

occurs during the carbonization process and about 60% of its mass is lost. In light of this, the higher the wood density, the greater the mass of charcoal produced for a given volume. Castro (2011) observed values ranging from 0.52 to 0.56g/cm³ for eucalyptus clones also at 7 years of age. Alzate et al. (2005) evaluated a clone of *Eucalyptus urophylla x Eucalyptus grandis* at the age of 8 years, and obtained an average basic density value of 0.49g/cm³; the same authors reported that according to literature, the basic density of wood varies in function of certain factors such as: tree growth rate, climate, silvicultural treatments, age, whether within the same species or across different species. The species factor can be explained by the higher density value presented by genetic material 1, since *Eucalyptus cloeziana* is cited in literature as one of the species with the highest density among the genus *Eucalyptus*.

The dry mass estimates varied between 15.6 and 23.1t/ha.year. The values are slightly different from those observed in literature, due to differences in productivity and basic density of the materials used by other authors. Santos (2010) studied different genetic materials of eucalyptus at 7 years of age, and observed an average dry mass of wood ranging from 21.9 to 26.9t/ha.year. Rocha (2011) obtained an average value of 17.23t/ha.year for *Eucalyptus grandis x Eucalyptus camaldulensis* at 7 years of age, at spacing of 3 x 3 meters. The highest values of dry mass for wood that were found, were largely influenced by the AAIs of their respective materials. As a consequence, these higher values contributed considerably to energy production/hectare, since the calorific value of the wood did not present great statistical differences to the materials used.

The figures for the higher calorific value observed in this work varied between 4,450.08 and 4,577.33kcal/kg and are very similar to the values found by the authors mentioned below. Castro (2011) evaluated eucalyptus clones at 7 years of age and found average values for the higher calorific value ranging from 4,481.65 to

4,617.17kcal/kg. In a study, Quirino et al. (2005) found higher calorific values of *Eucalyptus urophylla* wood to be between 4,422.0 and 4,595.0kcal/kg. Santos et al. (2011) reported that, according to literature, certain factors such as the chemical composition of the wood can influence its calorific value, mainly by means of the extractive and lignin contents, which are also variable across different species.

The estimated energy for the materials ranged from 81,783.3 to 11,9496.2kwh/ha.year, with these results being lower than those observed by Santos (2010), from 111,388.4 to 143,678.9kwh/ha.year but higher than those found by Rocha (2011), with an average value of 76,223.63kwh/ha.year.

The average values of energy density observed for the genetic material used in the present work are between 2,534.7 and 3,387.8kwh/m³, showing greater variation than those observed by Castro (2011) when evaluating eucalyptus clones, who found energy density ranging from 2,801.0 to 2,943.0kwh/m³ for materials at 7 years of age. These results are influenced by the basic density and the higher calorific value of the wood. Therewith, the result presented by the genetic material 1 is explained. The energy density must be taken into account for the transportation, since the amount of energy transported per unit of volume is higher for wood that has higher energy density, thus reducing transport costs for a given energy content.

4.2 Properties, and mass and energy estimates for charcoal

The charcoal yield values observed in this study, which ranged from 34.6 to 36.6%, can be considered satisfactory since Arantes (2009), when evaluating a hybrid clone of *Eucalyptus urophylla* and *Eucalyptus grandis* at six years of age, found yields varying from 33.68 to 35.07%, using final carbonization temperature of 450°C and heating rate of 1.67°C. Santiago and Andrade (2005) found an average carbonization yield of 26.91% for *Eucalyptus urophylla* wood, using a final temperature of 400°C and a heating rate of 11.98°C/min, this low yield can be explained by the high heating rate used by the authors. According to Pinheiro et al. (2005) the higher this rate, the lower the charcoal yield.

The results of mass of charcoal were higher than those found by Rocha (2011), which ranged from 5.11 to 6.16t/ha.year. Santos (2010) obtained average values between 6.2 and 8.1t/ha.year. We have observed the lowest values for charcoal mass in the genetic materials 1 and 6. The highest values were observed due to the high dry mass values of the wood. Thus, the ability to produce more dry wood mass may indicate which genetic materials will present higher mass values of charcoal produced with them.

Rocha (2011) obtained higher calorific values, similar to those observed in the present study, for a hybrid clone of *Eucalyptus grandis x Eucalyptus camaldulensis* at seven years of age, which ranged from 7,834kcal/kg to 7,900kcal/kg. Oliveira et al. (2010) observed average values for the higher calorific value of charcoal ranging from 8,023kcal/kg to 8,339kcal/kg for *Eucalyptus pellita* at five years of age. The differences found in these results may be related to the use of different carbonization steps. The calorific value of charcoal is related to its fixed carbon content, which in turn increases with the degradation of the wood. However, the wood exposed to higher carbonization temperatures and for a longer time, suffers greater degradation and consequent losses in the apparent density and resistance of the charcoal (Castro, 2011).

The best energy/hectare results in materials 4 and 5 are the consequence of having a higher charcoal mass than the others, and the higher calorific value of the charcoal did not significantly influence these results since it did not show large statistical differences.

The average values of apparent density for the charcoal observed in this study ranged from 0.33 to 0.48g/cm³. These are similar to those found by Oliveira et al. (2010), which varied between 0.35g/cm³ and 0.39g/cm³ and those of Frederico (2009), who obtained average values of apparent density ranging from 0.27 to 0.33g/cm³ for charcoal produced from the clones of *Eucalyptus* sp. According to Santos (2010), the higher the wood density, the greater the density of the charcoal produced from it, and this is an important parameter to be considered when the charcoal is destined for steel use.

The high apparent density observed for the charcoal from genetic material 1 have contributed significantly to its higher energy density in relation to the others, since the calorific value of its charcoal was the lowest among the studied materials. It is also observed a higher value for the energy density of the charcoal in relation to the wood that gave rise to it; this can be explained because carbon fixation occurs in the charcoal during the carbonization process, contributing to the increase of its higher calorific value than that of its wood. Considering that the energy density of charcoal is greater than the wood it was made from, it is possible to transport the charcoal to greater distances in relation to wood.

5. CONCLUSIONS

Genetic materials 4 and 5 (both spontaneous hybrids of *Eucalyptus urophylla*) stood out in relation to the others for energetic purposes.

Genetic material 1 (*Eucalyptus cloeziana*) presented higher energetic density for wood and charcoal, showing advantages mainly at the time of transportation.

When choosing genetic materials for energy production it is recommended that one uses those with higher volumetric productivity, higher basic wood density and the calorific value of both wood and charcoal.

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