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Energy potential of wood from clones of *Eucalyptus* and *Corymbia* in different spacings

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ABSTRACT: This study aimed to determine the influence of spacing and different genetic materials of *Eucalyptus* and *Corymbia* on wood production for energy purposes. At 24 months, two *Eucalyptus* clones (C1 and C2) and two *Corymbia* clones (C3 and C4) implanted in three different spacings (3.0 × 3.0, 3.0 × 1.5, and 3.0 × 1.0 m) were evaluated, totaling 12 treatments. In each treatment, 4 trees were selected, and 5 disks were removed from each tree, which were used to determine the basic density, the higher calorific value and to quantify the elemental carbon in the wood. Based on these characteristics, it was possible to estimate the dry mass, the carbon mass, and the amount of energy per hectare. It was observed that there was an effect of spacing, clone and interaction for the basic density of wood, being observed in clone C3 (*C. citriodora* × *C. torelliana*) the highest values of this property. As for the higher calorific value and the carbon content, no significant effect was found. It was also verified that the production of dry mass, carbon mass, and the amount of energy available per hectare increased with the densification of the spacings for all clones studied. The highest values of the amount of energy per hectare, in the different spacings, were attributed to clones C2 and C3 (3.0 × 3.0 m), clone C3 (3.0 × 1.5 m), and clones C1 and C3 (3.0 × 1.0 m). The C3 clone (*Corymbia* hybrid) can be a good alternative for energy use, due to its wood quality and productivity similar, or even superior, to *Eucalyptus* clones already used for this purpose.

Key words: bioenergy; biomass; energy forests

Potencial energético da madeira de clones de *Eucalyptus* e *Corymbia* em diferentes espaçamentos

RESUMO: Este estudo teve como objetivo determinar a influência do espaçamento e de diferentes materiais genéticos de *Eucalyptus* e *Corymbia* na produção de madeira para fins energéticos. Foram avaliados, aos 24 meses, dois clones *Eucalyptus* (C1 e C2) e dois clones de *Corymbia* (C3 e C4) implantados em três diferentes espaçamentos (3,0 × 3,0, 3,0 × 1,5 e 3,0 × 1,0 m), totalizando 12 tratamentos. Em cada tratamento foram selecionadas 4 árvores, e de cada árvore foram retirados 5 discos que foram utilizados para a determinação da densidade básica, do poder calorífico superior e para a quantificação do carbono elementar da madeira. Com base nessas características foi possível estimar a massa seca, a massa de carbono e a quantidade de energia por hectare. Observou-se que houve efeito do espaçamento, de clone e da interação para a densidade básica da madeira, sendo observado no clone C3 (*C. citriodora* × *C. torelliana*) os maiores valores dessa propriedade. Já para o poder calorífico superior e para o teor de carbono não foi constatado nenhum efeito significativo. Verificou-se ainda que a produção de massa seca, massa de carbono e a quantidade de energia disponível por hectare aumentou com o adensamento dos espaçamentos para todos os clones estudados. Os maiores valores da quantidade de energia por hectare, nos diferentes espaçamentos, foram atribuídos aos clones C2 e C3 (3,0 × 3,0 m), clone C3 (3,0 × 1,5 m) e clones C1 e C3 (3,0 × 1,0 m). O clone C3 (híbrido de *Corymbia*), pode ser uma boa alternativa para o uso energético, em razão da sua qualidade da madeira e produtividade semelhante, ou até mesmo superior, aos clones de *Eucalyptus* já utilizados para essa finalidade.

Palavras-chave: bioenergia; biomassa; florestas energéticas

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Introduction

Brazil is one of the largest producers and consumers of wood for energy use in the world with potential to increase productivity and the participation of this biomass in the national energy matrix (Neves et al., 2013). Compared to fossil fuels, the use of wood for energy production occupies a strategic position in the national scenario, since it is a renewable raw material (Eloy et al., 2014) and less polluting, thus contributing to the reduction of greenhouse gases (Carneiro et al., 2014).

The genus *Eucalyptus* is the most used for the formation of forest stands by the Brazilian forest sector, and the wood from these stands is directed to the production of pulp and paper, solid wood products, among other products (Figueiró et al., 2020). Another important use of *Eucalyptus* wood is the generation of energy, either for direct burning of firewood or for its conversion into materials of higher energy value, such as charcoal (Santos et al., 2012). However, *Eucalyptus* species and their clones, commonly used for energy purposes in Brazil, have low wood density (Loureiro et al., 2021). Values of wood basic density for species and clones of the *Eucalyptus* genus close to 500 kg m^{-3} are reported in the literature (Santos et al., 2012; Neves et al., 2013; Hsing et al., 2016; Carneiro et al., 2017), values that are considered low, thus possibly compromising the quality of the energy biomass.

The energy potential of a genetic material can be influenced by different factors, such as genetic makeup, responses to silvicultural treatments, planting site, and various genotype × environment interactions (Protásio et al., 2014). These factors can compromise forest productivity and also wood properties, thus justifying the need to search for new genetic materials aimed at energy use.

The establishment of forests for energy production should prioritize productive genetic materials with the desired quality for this purpose (Carneiro et al., 2017). In this context, companies and researchers in the forestry sector have been looking to some species and hybrids of the genus *Corymbia* for the production of new clones that have high volumetric increment associated with a higher basic density of the wood, which favors a better energy potential (Lee et al., 2009; Segura & Silva Junior, 2016; Loureiro et al., 2019).

For a better use of new clones in the formation of energy forests it is of fundamental importance to characterize the physical and chemical properties of forest biomass, because such properties influence the quality of the material, directly affecting its yield, conversion and its energy quality (Santos et al., 2012). In addition, it is important to know if there are dependencies between clones and planting spacings in determining biomass characteristics and how these interactions can influence the use of forest stands (Araujo et al., 2019).

Trees grown for bioenergy use have, over time, had their cutting cycle reduced from seven to five or four years due to successful breeding programs and changes in silvicultural treatments (Carneiro et al., 2014). In this context, it is essential that the studies of productivity and wood quality be carried out with the necessary anticipation, aiming at an early knowledge of the wood properties and their variation according to different possibilities of planting spacing, in order to promote the best energy use of the wood produced.

Therefore, the objective of this study was to evaluate the influence of different planting spacing on the energy properties of two Eucalyptus spp. and two Corymbia spp. hybrid clones.

Materials and Methods

Biological material

Four clones were used, being two commercially planted Eucalyptus clones and two new *Corymbia* hybrid clones: spontaneous hybrid of *Eucalyptus urophylla* S. T. Blake (C1); controlled pollination hybrid of *E. urophylla* S. T. Blake × (*E. camaldulensis* Dehnh × *E. grandis* W. Hill ex Maiden) (C2); spontaneous hybrid of *Corymbia citriodora* (Hook.) KD Hill & LAS Johnson × *C. torelliana* (F. Muell.) KD Hill & LAS Johnson (C3); spontaneous hybrid of *C. torelliana* (F. Muell.) KD Hill & LAS Johnson × *C. citriodora* (Hook.) KD Hill & LAS Johnson (C4).

The four clones were evaluated at three different planting spacings, with different planting densities and growth spacing: 3.0 × 3.0 m (1,111 plants ha^{-1} and 9.0 m^2 $plant^{-1}$), 3.0 × 1.5 m (2,222 plants ha^{-1} and 4.5 m^2 $plant^{-1}$), and 3.0 × 1.0 m (3,333 plants ha^{-1} and 3.0 m^2 $plant^{-1}$). For each of the treatments, four repetitions were established with 30.0 × 15.0 m (450.0 m^2) plots containing 50, 100, and 150 plants for the 3.0 × 3.0, 3.0 × 1.5, and 3.0 × 1.0 m spacings, respectively. In each experimental plot a tree of average diameter at 1.30 m from the ground (DBH) was selected and used for the physical and chemical evaluations of the wood.

The experimental area is located in Itamarandiba, in the Vale do Jequitinhonha region, Minas Gerais State, Brazil, with geographical coordinates 17° 46’ 22” S, 42° 54’ 12” W, and 946 m of altitude. The region climate is defined as high-altitude tropical, humid temperate, with two well-defined seasons, hot and humid summers and dry winters, according to the Köppen and Geiger classification of Cwa. The average temperature of the region is 21.2 °C, the annual relative air humidity varies between 60 and 70%, and the average annual precipitation is 1,132 mm (INMET, 2021). The installation of the experiment took place in the month of September 2015.

Sample preparation

At 24 months of age, four trees of average diameter at breast height (DBH) were selected for each clone at the three planting spacings, totaling 48 samples throughout the experimental plot. The 48 trees were cut to remove 2.5 cm thick discs at the positions 0, 25, 50, and 75% of the total height of each tree, plus an extra disc at DBH. Discs taken at different longitudinal positions (0, 25, 50, and 75% of the total height of the tree) were used to determine the basic density of the wood. To determine the carbon content and the calorific value of the wood, the discs taken from DBH and other positions were used to obtain a composite sample, with each tree being considered a repetition.

Determination of basic density

From each disc, at the different sampled heights, two opposite wedges were removed and used for the determination of the basic density of the wood, according to NBR 11.941 (ABNT, 2003). The basic density of the wood (BD) was considered to be the arithmetic average of the longitudinal sampling points on the trunk of the trees, without considering the DBH position, according to guidelines by Protásio et al. (2014).

Determination of carbon content

To determine the carbon content, samples were taken from all the discs in the longitudinal positions, in addition to the disc taken from DBH, in order to obtain a composite sample per tree. Subsequently, the samples were ground in a Wiley type mill. The carbon content was calculated by measuring a mass equivalent to 2.0 mg (± 0.5) of sawdust from wood dried at a temperature of 105 ± 2 °C, previously selected on overlapping sieves, granulometry of 200 and 270 mesh, using the fraction retained on the 270 mesh sieve. Then, the samples were placed in the carousel of the equipment brand LECO®, model TruSpec Micro CHNS/O. The analysis was performed on one sample at a time. The gases required for the operation were helium, which is the carrier gas, and oxygen, the ignition gas. The temperature of the combustion tube, located inside the equipment, at the moment the sample was dropped from the carousel, was 1,075 °C. After combustion, the gases were carried by dragging to the reduction pipe and from there to the detection column. The chemical elements are individualized in an induced sequence, according to the molecular mass of each one, and quantified using the TruSpec Micro software, which calculates the percentage of each element, considering, in this study, only the carbon content.

Determination of the gross calorific value (GCV)

For the determination of the superior calorific value of the wood of the different clones, the samples were sieved and the fraction that passed through the 40 mesh sieve and was retained on the 60 mesh sieve was used. Subsequently, the samples were dried in a conventional oven at 103 ± 2 °C to constant mass. The gross calorific value was determined in an adiabatic calorimeter, according to NBR 8.633 (ABNT, 1984).

Estimates of dry mass, carbon mass, and the amount of available energy

The dry mass of debarked wood per hectare was obtained by multiplying the volume of debarked wood ($m^3\ ha^{-1}$) by the basic density of the wood ($kg\ m^{-3}$), according to Equation 1:

$$\mathrm{DM} = \mathrm{Vol} \times \mathrm{BD} \tag{1}$$

where: DM - dry mass of the wood ($t\ ha^{-1}$); Vol - volume of debarked wood ($m^3\ ha^{-1}$); and, BD - basic density of the wood ($kg\ m^{-3}$).

For volume determination, the sampled trees were rigorously cubed using the Smalian method. Subsequently, the averages of the individual volumes obtained in each treatment were multiplied by the planting densities at the different spacings.

The carbon mass per hectare was obtained by multiplying the wood dry mass by the carbon content in the wood, according to Equation 2:

$$\mathrm{CM} = \mathrm{DM} \times \mathrm{C} \tag{2}$$

where: CM - carbon mass of the wood ($t\ ha^{-1}$); DM - dry mass of the wood ($t\ ha^{-1}$); and, C (%) - percentage of carbon of the wood/100.

To calculate the amount of energy available per hectare (AEA), the dry matter mass was multiplied by the superior calorific value of the wood of the *Eucalyptus* and *Corymbia* clones, making the equivalence of 1.0 kW h for each 859.85 kcal, calculated by Equation 3:

$$\mathrm{AEA} = \mathrm{DM} \times \mathrm{SCV} \tag{3}$$

where: AEA - amount of energy available per hectare ($kW\ h\ ha^{-1}$); DM - dry mass of the wood ($t\ ha^{-1}$); and, SCV - superior calorific value of the wood ($kcal\ kg^{-1}$).

Statistical analysis of the data

To evaluate the effect of different spacings and clones on wood properties and mass and energy estimates, a complete factorial design was set up in an entirely randomized design, in which three spacings and four clones were compared, with four repetitions (trees), totaling 12 treatments and 48 observations.

The data of the evaluated characteristics were submitted to analysis of variance (ANOVA) and the F test ($p < 0.05$). Once significant differences were established, the treatments were compared with each other using the Tukey test at 95% probability.

Results and Discussion

Table 1 shows the yield data of the four clones at the three different spacings tested.

The yields observed in the study were lower than expected, a fact that can be explained by the low average annual

Table 1. Volume per hectare (V), in $m^3\ ha^{-1}$, and average annual increment (AAI), in $m^3\ ha^{-1}\ year^{-1}$, of the four clones at the three different planting spacings, considering wood without bark.

Clones	Spacing (m)					
	3.0 × 3.0		3.0 × 1.5		3.0 × 1.0	
	V	AAI	V	AAI	V	AAI
C1	30.5	15.2	46.4	23.2	61.8	30.9
C2	37.7	18.8	48.4	24.2	58.4	29.2
C3	28.4	14.2	42.7	21.3	56.3	28.1
C4	21.8	10.9	31.0	15.5	42.4	21.2

precipitation (783 mm year^{-1}) observed during the evaluation period of the study (INMET, 2021). Another factor that must be considered is the age at which the study was evaluated (24 months). In the early years, plants are still contributing energy to the production of leaves, roots, and branches, which reduces the amount of biomass present in the wood (Hsing et al., 2016). In the same region as the present study, Oliveira et al. (2021), studying the productivity and adaptability of different genetic materials at different planting densities, observed a average annual increment of 45.6 and 35.3 m^3 ha^{-1} year^{-1}, for clones of *Eucalyptus* spp. and *Corymbia* spp., respectively.

It was observed that the *Eucalyptus* clones obtained higher volumetric productivity than the *Corymbia* clones, at the three spacings evaluated. The highest average volumetric yields were observed for the four clones evaluated at the 3.0 × 1.0 m spacing, a result that was expected due to the higher density of plants per hectare at this spacing. This higher productivity at denser spacings is also reported by other authors (Ferreira et al., 2014; Sereghetti et al., 2015; Eloy et al., 2016).

Table 2 shows the summary of the analysis of variance (ANOVA) for wood basic density, carbon content, gross calorific value (GCV), dry mass, carbon mass, and amount of energy per hectare.

There was a significant effect of the clone × spacing interaction for wood basic density, dry mass, carbon mass, and for the amount of available energy per hectare. This significant interaction effect indicates the existence of dependence between the factors clones and planting spacing. Thus, it was decided to unfold them and evaluate the effect of clone within spacing and vice versa. For the carbon content and the calorific value of the wood, no significant effect was observed for clone, spacing or the interaction between the factors.

Basic density, carbon content, and gross calorific value

Table 3 shows the average values of basic density, carbon content, and PCS of the wood. The breakdown of the clone within spacing and spacing within clone factors for the significant interactions are presented.

Clone C3 showed the highest average wood basic density at the three spacings, and clones C1 and C2 showed the lowest averages in the study. No influence of spacing was observed on the basic density for clones C1, C2, and C4. For clone C3, the average of this variable was lower at the 3.0 × 1.0 m spacing.

Table 3. Average values and multiple comparison test for basic density, gross calorific value, and carbon content of wood.

Variables	Clones	Spacing (m)		
		3.0 × 3.0	3.0 × 1.5	3.0 × 1.0
Basic density (kg m^{-3})	C1	466.8 cA	473.2 cA	470.2 cA
	C2	445.1 cA	448.7 cA	452.8 cA
	C3	619.5 aA	599.8 aA	576.6 aB
	C4	519.9 bA	499.7 bA	500.5 bA
Carbon (%)	C1	47.1	47.1	46.0
	C2	46.6	46.5	45.9
	C3	45.8	45.8	45.8
	C4	45.7	46.9	45.8
Gross calorific value (kcal kg^{-1})	C1	4,441.3	4,498.5	4,492.5
	C2	4,465.3	4,499.6	4,514.1
	C3	4,536.1	4,539.5	4,442.6
	C4	4,350.8	4,327.5	4,417.3

Averages followed by the same lower case letter in the column and capital in the row do not differ by Tukey test at 5% significance level.

The planting densification factor may have been the possible cause of the variation in the basic density of the wood for clone C3, at the different planting spacings. This result indicates that at the 3.0 × 1.0 m spacing there was a 6.9 and 3.9% reduction in wood density for clone C3 compared to the 3.0 × 3.0 and 3.0 × 1.5 m spacings, respectively. Thus, it can be inferred that denser spacing for this genetic material may not be the most appropriate for energy wood production, since there was a significant reduction in the basic density of the wood.

The results found in the literature are divergent regarding the influence of spacing on the basic density of wood. Sereghetti et al. (2015) observed no differences in the basic density of the wood of a hybrid of *E. urophylla* × *E. grandis* at different spacings. Eloy et al. (2014), studying the influence of spacing on the wood density of *E. grandis* at 12 months of age, found higher basic density of the wood in more open spacings. Therefore, for the implementation of forests for energy purposes, it is important to evaluate the most adequate spacing for each new genetic material, so that the wood can meet the demands required in quantity and quality by the consumer market.

The basic density values of the *Corymbia* clones were significantly higher than those of the *Eucalyptus* clones. Similar results were observed by Medeiros et al. (2016) who observed, at 48 months of age, higher wood density of *C. citriodora* (570 kg m^{-3}) compared to a hybrid of *E. urophylla* × *E. grandis* (460 kg m^{-3}), and by Segura & Silva Júnior (2016), who also found average values of basic density of the wood

Table 2. Summary of the analysis of variance of the data concerning the basic density of wood, carbon content and higher calorific value, dry mass, carbon mass, and amount of energy per hectare.

Variation factor	Degrees of freedom	Mean square					
		BD	C%	GCV	DM	CM	AEA
Clone	3	0.05254*	1.41^{ns}	37,484.76^{ns}	101.00*	21.41*	122,084,684*
Spacing	2	0.00066*	1.51^{ns}	1,290.19^{ns}	427.97*	87.96*	169,332,429*
Clone × Spacing	6	0.00060*	0.48^{ns}	6,380.04^{ns}	6.39*	1.40*	6,447,924*
Error	36	0.00017	2.05	9,515.47	0.239	0.051	675,634

BD - wood basic density; C (%) - percentage of carbon in wood; GCV - gross calorific value; DM - wood dry mass; CM - wood carbon mass; AEA - amount of energy available per hectare; * Significant at 5% by F test; ^{ns} not significant at 5% by the F test.

of a hybrid of *C. citriodora* (568 kg m^{-3}) higher than a hybrid of *E. grandis* × *E. urophylla* (451 kg m^{-3}). The highest values of wood basic density were observed in the genetic materials with the lowest volumetric increments. Presumably, clones with higher densities focused their energies on reaction wood formation in response to environmental conditions (Vidaurre et al., 2013), to the detriment of favoring volumetric growth (Lima et al., 2020).

For energy use, it is desirable that the wood presents high basic density values, because this characteristic is directly related to energy production by volume, being one of the main criteria for selection of genetic materials for energy use (Carneiro et al., 2014). When using genetic materials intended for energy production that have low basic density, burning will be fast, providing lower energy production per unit volume, contrary to what occurs with materials with higher values of basic density of the wood (Santos et al., 2012). However, it should be noted that this is not the only parameter for evaluating the potential of a given clone for energy use.

The wood carbon content values of the different clones were close to each other, ranging from 45.7 to 47.1%, and the effect of spacing on the determination of this characteristic was not significant.

For bioenergy production, it is desirable for wood to have high carbon contents, due to the existing correlation between this chemical component and calorific value (Santos et al., 2012). Thus, quantification of carbon content is important in the energy assessment of forest biomass because the energy released during the combustion process is positively correlated with the contents of this element due to its high energy value (Silva et al., 2019). According to Carneiro et al. (2014), in direct burning of forest biomass, the carbon is fully consumed, while for charcoal production part of the carbon is converted into fixed carbon, which is the main responsible for the stored energy.

No significant differences were observed for the GCV among the clones, the average value found being 4,460.40 kcal kg^{-1}. GCV is one of the main characteristics for the selection of the best genetic materials for bioenergy, because it is related to the amount of energy released by the wood during its burning (Carneiro et al., 2014). The GCV values found are consistent with that reported in several studies that evaluated this characteristic in different species and clones of the *Eucalyptus* and *Corymbia* genera (Loureiro et al., 2019; Protásio et al., 2014; Santos et al., 2012).

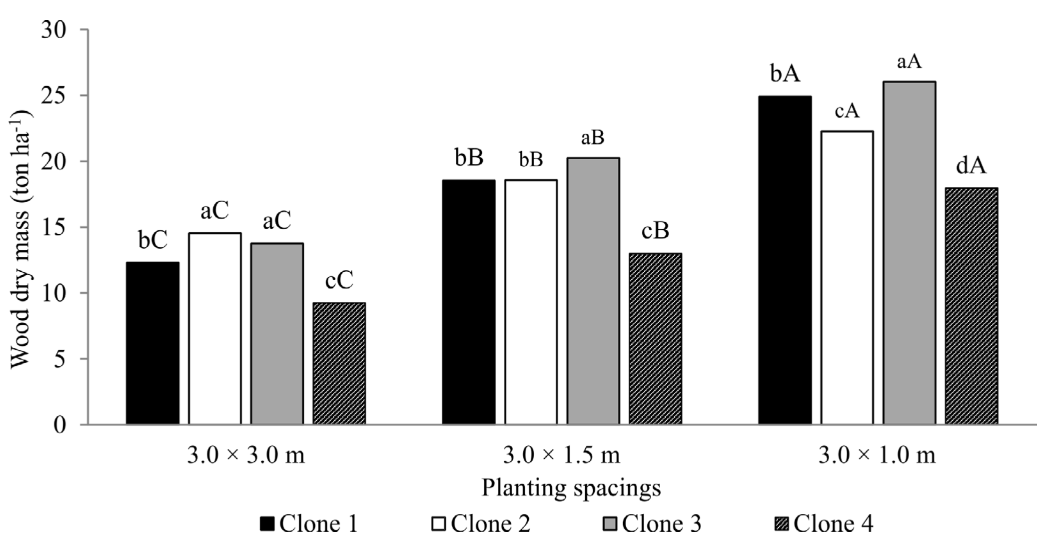
It was found that planting spacing had no influence on the GCV of the wood for the evaluated clones. One hypothesis to explain these non-discrepant values is that the GCV is a characteristic closely related to the elemental chemical composition, especially regarding carbon contents, which did not show significant differences among the clones in the present study. Eloy et al. (2014), studying the influence on energy characteristics of four forest species as a function of different spacings in short rotation plantings, also found no variation in GCV in relation to the evaluated living spaces.

Dry mass and carbon mass estimates

Figure 1 shows the average dry mass values for the four clones at three planting spacings considering the unfolding of the factors clone within spacing and vice versa.

Evaluating the dry mass of the wood of the clones in the spacing, it was observed in the 3.0 × 3.0 m spacing, the highest values of this variable in clones C2 (14.5 t ha^{-1}) and C3 (13.7 t ha^{-1}). In the 3.0 × 1.5 and 3.0 × 1.0 m spacing, clone C3 showed the highest averages for dry mass (20.2 and 26.0 t ha^{-1}, respectively).

In general, for all clones studied, the highest values of wood dry mass were found at the 3.0 × 1.0 m spacing (24.9, 22.2, 26.0, and 17.9 t ha^{-1} for clones C1, C2, C3, and C4, respectively). Thus, in the spacings with higher plant densities per hectare the highest values of wood dry mass were also observed. These results are corroborated by other studies on the influence of planting spacings on biomass production in forest plantations (Müller et al., 2005; Eloy et al., 2016; Tun et



Averages followed by the same lower case letter between clones and upper case between spacings, do not differ by the Tukey test at 5% significance level.

Figure 1. Averages values and multiple comparison test for wood dry mass of the four clones at the three planting spacings.

al., 2018). The definition of which spacing should be used for each genetic material is a primary evaluation to minimize the possibility of error in the implementation of a forest stand, because different genotypes can respond differently to the reduction or expansion of planting density (Ferreira et al., 2014).

It is noteworthy that although the clone C3, which is a hybrid of *C. citriodora* × *C. torelliana*, did not show the highest volumetric productivity in the three spacings evaluated, this clone had the highest values of basic density of the wood, which directly reflected in the highest production of dry mass of wood. This result highlights the good potential of this clone to be used in the production of wood for bioenergy. Lee et al. (2009), also observed that interspecific hybrids of species of the genus Corymbia are promising genetic materials because they show good growth and high biomass production due to their higher basic density of wood.

Dry matter production correlates directly with volume production and the basic density of the wood, and these factors are under strong genetic control (Trugilho et al., 2010). Thus, the determination of dry matter mass is more important than the isolated use of productivity and wood density variables for the selection of the most promising genetic materials for energy production. Another factor related to the dry mass productivity of forest stands is planting density. According to Ara et al. (2021), the definition of initial spacing in the establishment of a forest stand determines the number of trees per unit area and directly influences the quality of the future stand and forest productivity. In forest stands with low plant density per area, the full potential of the site may not be used, and conversely, stands with high plant density per area may not have sufficient environmental resources to ensure good tree growth. For the age of evaluation of the present study, there was no limitation of the environmental resources of the site since the production of dry mass increased with increasing planting density for all clones evaluated.

Figure 2 shows the average values for carbon mass for the four clones at three planting spacings, considering the unfolding of the factors clone within spacing and vice versa.

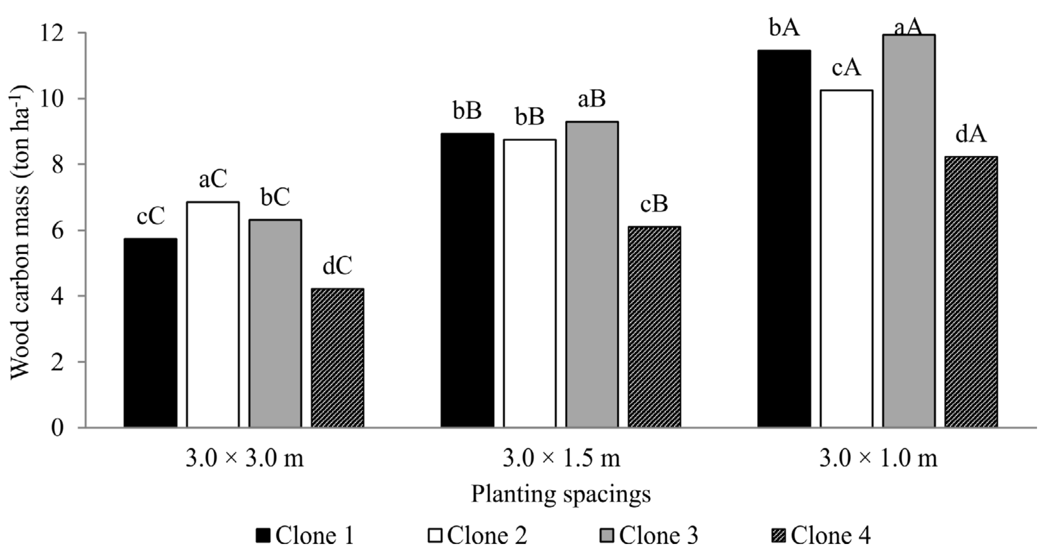
Comparing the wood carbon mass of the clones within each spacing, it was observed in the 3.0 × 3.0 m spacing the highest values of this variable in clone C2 (6.8 t ha^{-1}). At the 3.0 × 1.5 and 3.0 × 1.0 m spacings, the highest carbon mass values were seen in clone C3 (9.2 and 11.9 t ha^{-1}, respectively). Evaluating the different spacings within each clone studied, the 3.0 × 1.0 m spacing had the highest average carbon mass in the wood, a result that was already expected, since the carbon contents did not vary between the spacings and the highest values of dry matter mass in the wood were observed at this spacing.

The observed values for carbon mass in the present study ranged from 4.8 to 7.5, 6.9 to 10.8, and 9.2 to 13.9 t ha^{-1}, at the 3.0 × 3.0, 3.0 × 1.5, and 3.0 × 1.0 m spacings, respectively. Since there were no significant differences in carbon content between the clones and spacings evaluated, the dry mass of the wood had the greatest contribution to the determination of the carbon mass. Thus, the clones and spacings with the highest dry mass production also showed the highest carbon masses.

It is noteworthy that the clone C3 showed the highest values of carbon mass, in the three spacings evaluated, and the clone C4 has the lowest values of this variable. The estimate of carbon mass per area of a given genetic material is a relevant information for the quantification of carbon fixed in biomass, and this information is essential for decision making of the correct selection of the best clones in terms of energy production and for a possible obtaining of carbon credits from forest planting (Trugilho et al., 2010).

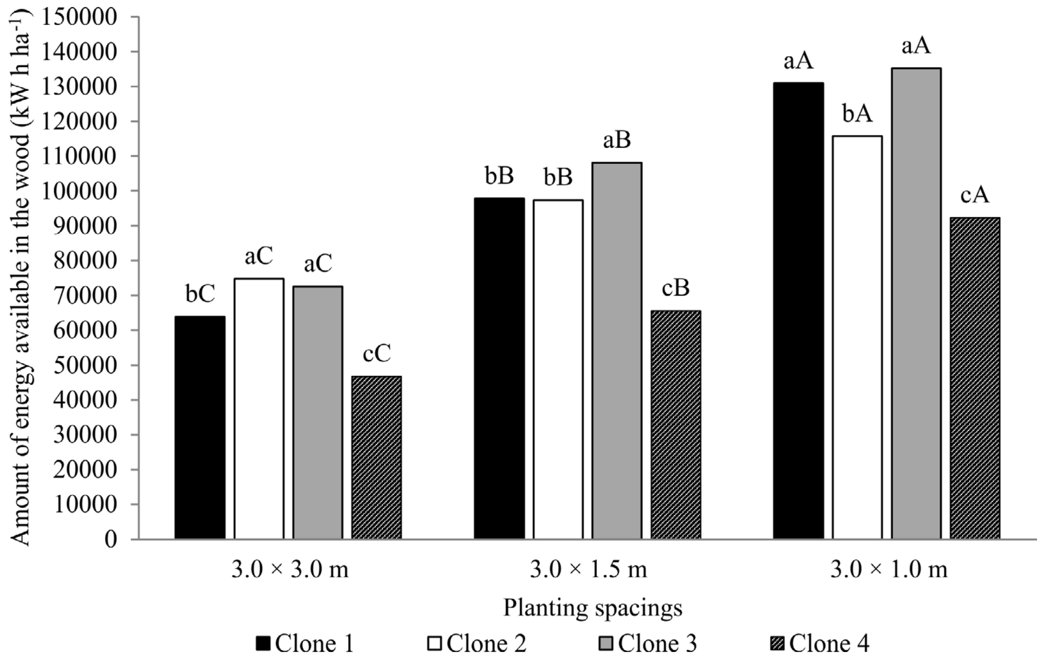
Amount of energy available

Figure 3 shows the average values of the amount of energy available from the wood of the four clones at the three planting spacings, considering the unfolding of the factors clone within



Averages followed by the same lower case letter between clones and upper case between spacings, do not differ by the Tukey test at 5% significance level.

Figure 2. Averages values and multiple comparison test for wood carbon mass of the four clones at the three planting spacings.



Averages followed by the same lower case letter between clones and upper case between spacings, do not differ by the Tukey test at 5% significance level.

Figure 3. Averages values and multiple comparison test for the amount of energy available in the wood of the four clones at the three planting spacings.

spacing and spacing within clone, with the respective multiple comparison test.

The clones C2 and C3 at the 3.0 × 3.0 m spacing, obtained the highest values of the amount of energy per hectare. At 3.0 × 1.5 m spacing, the highest values of this variable were observed in clone C3, and at 3.0 × 1.0 m spacing in clones C1 and C3. These higher energy values corroborate with the dry mass results of the best clones at each spacing.

It was observed that the total amount of available energy per hectare increased with planting densification. This is presumably due to the greater amount of dry mass produced by the clones at the spacing with the higher number of plants per hectare. Müller et al. (2005), evaluating a hybrid clone of *E. grandis* × *E. camaldulensis*, in Itamarandiba, MG, Brazil, at 24 months of age, also found a strong tendency for the amount of energy to increase with increasing planting density.

Clone C4 showed the lowest values for this variable, with a range of 46,761 to 92,344 kW h ha^{-1}, while clone C3 showed the best performance for this variable with average values ranging from 72,613 to 135,215 kW h ha^{-1}. The other two clones obtained intermediate values with average values for clone C1 ranging between 63,854 and 130,943 kW h ha^{-1}, and clone C2 between 74,748 and 115,722 kW h ha^{-1}.

It was found that the GCV did not influence the estimation of the amount of energy available per hectare since no significant differences were observed for the GCV, leaving the amount of energy available per hectare dependent on the dry masses of wood observed in this study. Thus, the clones that obtained the highest dry mass values per hectare also had the highest energy quantity values.

The evaluation of the amount of energy allows a better perception of the energy potential of the genetic material, and this characteristic is directly related to the dry mass production of forest species (Eloy et al., 2014). Thus, in the present study, clones C2 and C3 showed the highest values for dry mass and the amount of available energy per hectare at the 3.0 × 3.0 m spacing. In the 3.0 × 1.5 and 3.0 × 1.0 m spacings, the highest values of dry mass and amount of available energy were observed in clone C3.

Conclusions

The basic density of the wood observed in the *Corymbia* clones was higher than that of the *Eucalyptus* clones. A direct influence of genetic material and spacing was observed on the determination of dry mass, carbon mass, and the amount of available energy in the wood. The increase in planting density showed a direct relationship with these variables, and these observations are a valuable tool for selecting genetic materials with better aptitude for higher energy production.

Although it is still a young plantation, it can be inferred that the C3 clone, due to its outstanding performance in the evaluations of the study, presents a good potential for energy utilization, due to its wood quality and productivity, similar or even higher than the *Eucalyptus* clones already used for this purpose.

The results of this study can contribute to guide silvicultural decisions, especially regarding the choice of the best spatial arrangement for each genetic material (clone), in order to maximize the energy production of the plantation site. We also emphasize the importance of evaluating these clones at ages closer to the rotation, in order to have a better definition for the energy use of the different genetic materials studied.

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Compliance with Ethical Standards

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