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Biomass and energy production of eucalyptus clones in short-rotation systems

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Abstract

The use of energy forests using species of fast growth, high planting density, and conducted with short rotations to produce biomass in a shorter time scale has increased, generating demand for knowledge in its management. Thus, this study aimed to evaluate biomass production and the energy potential of eucalyptus clones grown with different spacing, at two years of age. A randomized block design in a 3 x 5 factorial scheme with three replications was used. Three eucalyptus clones (A217, AEC144, and H13), hybrids of Eucalyptus urophylla x Eucalyptus grandis, grown in five spacings, with useful areas of 1.6; 2.0; 3.0; 4.5, and 6.0 m², per plant were evaluated. At 24 months after planting, wood biomass, the basic density of wood, lower calorific value of wood, the energy density of wood, and energy were determined. The biomass production, basic density (D_b), energy density (D_e), lower calorific value (LCV), and energy generated by this biomass varied according to the clones and useful area occupied by plants. The biomass production per hectare and the energy generated by this biomass *decreased with the increase in the useful area per plant. For the two largest planting densities, clone H13 was more productive in biomass and energy. The highest values of D_b and D_e were found in the useful area of 4.6 and 4.7 m^2 per plant, respectively. The basic and energy densities were higher for clones H13 and A217.*

Keywords: Biomass energy, forest productivity, plantation density, energy forests, calorific power

INTRODUCTION

Given the growing concern with the environment and the need for a cleaner and renewable energy matrix, the search for alternative sources for energy production has increased (Pereira et al. 2015). For this reason, the use of forest biomass as a source of energy also grows, and, in this sense, the use of planted forests plays a fundamental role in mitigating problems related to the electricity supply (IEMA, 2018).

Biomass is one of the most important sources of renewable generation in Brazil in the Domestic Electricity Supply - all the energy needed to move the economy - with a record of 8.5% participation in 2018, a period that also showed an increase of 0.6% in the use of firewood and charcoal, as a renewable source, when compared to the previous year (MME 2019). Its use provides a destination for the by-products and residues of the industrial wood processes, transforming them into alternative and renewable sources of electricity supply (Blois et al. 2017), contributing to the strengthening of an economy with low environmental impact.

Besides the possibility of using these materials, the implantation of specific forests for this purpose has also grown. Energy forests are characterized using species of fast growth, high planting density, conducted by short rotations, allowing to produce biomass in a shorter time scale, using smaller areas when compared to conventional silvicultural systems (Machado 2014; Longue Júnior and Colodette 2013). Among the forest species that can be used, those of the genus *Eucalyptus* meet these requirements and have adequate bioenergetic use, making it an excellent alternative to native wood in timber production in Brazil (Ramos et al. 2011).

In general, in plantations with a higher population density, the highest values of total biomass and biomass of shoot are observed compared to lower population density (Caron et al. 2015; Lopes et al. 2017). However, over time, the amount of biomass stored in stands with different planting spacing tends to match. This is because, in denser plantations, the higher concentration of trees per unit area imposes stagnation in growth earlier, with the opposite occurring in areas with less planting density. As a result, it is necessary to know the dynamics of biomass production from the initial stages of growth to define the planting densities and select the genotypes most suitable to produce bioenergy (Müller et al. 2005).

In forests of shorter cycles, planting density is a factor of fundamental importance, since it affects, among others, the growth of trees, the production of biomass, and the quality of the wood formed, and may even affect the basic density of the wood, its calorific value, and energy density (Paulino 2012; Protásio et al. 2014).

In general, the density of the wood formed is related to the growth rate of the tree (Fernandes et al. 2011) and can affect the amount of energy produced per cubic meter of wood (Castro 2011; Jesus et al. 2017). Thus, low-density wood results in a quick-burning and less energy production; therefore, denser wood originates products with greater calorific power (Silva, Vale and Miguel 2015) and energy density (Jesus et al. 2017).

Thus, this study aimed to evaluate biomass production and the energy potential of eucalyptus clones grown with different spacing, at two years of age.

MATERIAL AND METHODS

The experiment was carried out at Jacuba farm, in an area of the Cerradinho Bioenergia Plant, in Serranópolis, GO, in December 2014. The region's climate, according to Köppen, is humid tropical (Aw), with a rainy season in summer and dry in winter, average annual rainfall of 1,579 mm, and average annual temperature ranging between 20ºC and 25ºC.

A randomized block design in a 3 x 5 factorial scheme with three replications was used. Three eucalyptus clones (A217, AEC144, and H13), hybrids of *Eucalyptus urophylla* x *E. grandis*, grown under five spacings (two spacings in double-row: 3, 0 x 1.0 x 0.8 m and 3.0 x 1.0 x 1.0 m and three spacings in single-row: 3.0 x 1.0 m; 3.0 x 1.5 m; 3.0 x 2.0 m, which result in useful areas of: 1.6, 2.0, 3.0, 4.5, and 6.0 m^2, respectively) were evaluated. The plots with double rows consisted of six rows with 12 plants each, and the plots with single rows, of four rows, the plots' useful area being the two central rows. At 24 months after planting, 45 trees were felled, one tree per plot, whose diameter represented the quadratic mean diameter of the sample unit. After cutting, each tree felled had its aerial part segmented into leaves, branches, and trunk with bark. For the present study, only the trunk was used.

The trunk of each tree was weighed, and then a disk of approximately 5.0 cm thick was removed in the positions: 0% (base of the tree); 1.30 m high from the ground (DBH); 25%; 50%; 75%, and 100% of the commercial height (height of the trunk whose diameter with bark was 3.0 cm).

The wooden disks with bark were weighed in the field, identified, and sent to the laboratory, where they were separated into wood and bark, and their fresh mass were obtained. Then, the samples were placed to dry in an oven at a temperature of 100 ± 5ºC to determine their dry mass.

The basic density (D_b) was determined using the recommendations described in the standard NBR 11941 (ABNT, 2003) and, the superior calorific value of the wood was determined according to the methodology described by the standard NBR 11956 (ABNT, 1990), using an adiabatic calorimeter. The amount of energy needed to remove hydrogen from the wood (around 6%) was discounted to determine the lower calorific value (LCV), according to Equation 1 (Moreira, Lima, and Goulart 2012).

$$LCV = GCV - 324 \qquad (Eq.\ 1)$$

Where: LCV is the lower calorific value (kcal kg^{-1}); GCV is the gross calorific value (kcal kg^{-1}).

The energy density (D_e, in Mcal m-3) was obtained according to Equation 2.

$$D_e = D_b.LCV/100 \qquad (Eq.\ 2)$$

Where: De is the energy density (Mcal m^{-3}); Db is the basic energy (g cm^{-3}); LCV is the lower calorific value (kcal kg^{-1}).

To calculate the amount of energy per hectare, expressed in kW ha^{-1} $year^{-1}$, the methodology used was adapted from Santos (2010), which was obtained by multiplying the dry mass without bark (Mg ha^{-1} $year^{-1}$) by its lower calorific value (kcal kg^{-1}).

The wood dry mass without bark per hectare per year was obtained by dividing the wood biomass per hectare, expressed in (Mg ha^{-1}), by the age, in years, of the stand.

The data were subjected to the analysis of variance and F-test. The means from the qualitative factor were compared by the Tukey test at the 5% significance level. The means from the quantitative factor were adjusted to the regression equation at the 5% significance level.

RESULTS AND DISCUSSION

The biomass per hectare, the lower calorific value of the wood (LCV), and the energy generated were influenced by the interaction between the useful area per plant and the eucalyptus clone. The basic density (D_b) and energy density (D_e) were influenced only by the factors studied in isolation (Table 1).

Table 1. Summary of the analysis of variance for the variables evaluated in the clones of *Eucalyptus urophylla* x *Eucalyptus grandis* hybrids, at 24 months of age, in Serranópolis, GO.

Source of Variation	D.F.	Mean square				
		Biomass	D_b	LCV	D_e	Energy
Block	2	1.822	0.000061	395.606	694.079	3.18 x 10^6
Area (A)	4	214.445**	0.002476**	3587.519*	42618.618**	4.02 x 10^{9**}
Clone (C)	2	74.995**	0.003553**	2294.156^{ns}	57620.860**	1.43 x 10^{9**}
A*C	8	17.72**	0.000126^{ns}	5245.586**	2173.376^{ns}	3.73 x 10^{8**}
Error	28	2.604	0.000209	650.987	3889.018	4.98 x 10^7
CV (%)		6.64	3.64	0.59	3.63	6.7
Overall average:		24.311	0.397	4331.344	1720.288	105321.3

D_b: basic density of wood (g cm^{-3}); LCV: lower calorific value of wood (kcal kg^{-1}); Energy (KWh ha^{-1} year^{-1}). *, **, and ^{ns}: significant at 5%, 1%, and not significant, respectively, by the F-test.

The wood biomass per unit area (Figure 1), in general, decreased with the increase of the useful area per plant for the three clones evaluated. A reduction of the biomass of 49.9, 34.9, and 30.3% for clones H13, AEC144, and A217, respectively, from the smallest to the largest useful area was observed. This result demonstrates that productivity in response to the planting density ranges with the choice of genetic material.

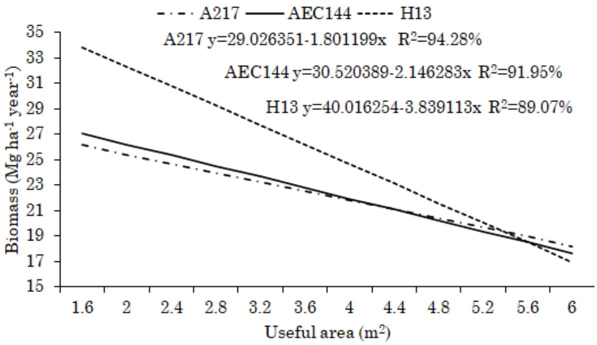

Figure 1. Average wood biomass production of three *Eucalyptus* clones according to the useful areas of planting, at 24 months of age, in Serranópolis, GO.

In the useful areas of 1.6 and 2.0 m^2, the biomass production of clone H13 was higher than the others (Table 2), with a gain of 31.4 and 30.6%, respectively, compared to the average biomass produced by clones AEC144 and A217. In the useful areas over 3.0 m^2, the productivity of the three clones was statistically similar.

Table 2. Average production of wood biomass, lower calorific value, and energy of three Eucalyptus clones, in different useful areas, at 24 months of age, in Serranópolis, GO.

Clones	Useful area				
	1.6	2.0	3.0	4.5	6.0
			Biomass (Mg ha^{-1} year^{-1})		
A217	26.18 b	25.50 b	24.15 a	19.57 a	18.93 a
AEC144	28.79 b	25.13 b	23.05 a	20.84 a	18.09 a
H13	36.12 a	33.07 a	24.88 a	21.44 a	18.92 a
			Lower calorific value (kcal kg^{-1})		
A217	4216 b	4382 a	4320 a	4316 a	4360 a
AEC144	4365 a	4338 a	4357 a	4320 a	4339 a
H13	4344 a	4352 a	4332 a	4307 a	4320 a
			Energy (kw ha^{-1} year^{-1}) x 1000		
A217	110.34 c	111.74 b	104.35 a	84.45 a	82.58 a
AEC144	125.68 b	109.02 b	100.45 a	90.02 a	78.47 a
H13	156.92 a	143.93 a	107.82 a	92.28 a	81.75 a

Means followed by the same lower-case letters in the column do not differ statistically from each other, by the Tukey test, at 5% probability.

Working with biomass production and distribution in eucalyptus plantations, Oliveira Neto et al. (2003) found that in wider spacings, which provide a larger useful area, the production of the aerial part and, in particular, of the wood, per tree, is high due to its greater growth in diameter, while in smaller spacing it occurs greater biomass production per unit area, due to the greater number of individuals per hectare. However, this result depends on factors such as population age, quality of the site, and genetic material (Hoppe et al. 2006).
This response of biomass production according to the useful area per plant is more observed at younger ages because, as the occupation of the site occurs, this difference is minimized by the increased competition between plants, earlier, in smaller spacing. Thus, for Fernandes et al. (2019), in longer rotations, there may be a change in the production of biomass with even higher productivity in less densely populated areas compared to those more densely populated.

At two years of age, the basic density of the wood varied with the clone and the useful area (Figure 2). Clones A217 and H13 showed D$_b$, on average, 6.6% higher than that observed for clone AEC144 (Figure 2a). The basic density of the wood is a factor of great relevance for the choice of the genetic material to be planted, especially in plantations that aim at the production of energy from the direct burning of the wood, since the greater the density, the greater the amount of energy stored per cubic meter of wood (Kumar et al. 2011).

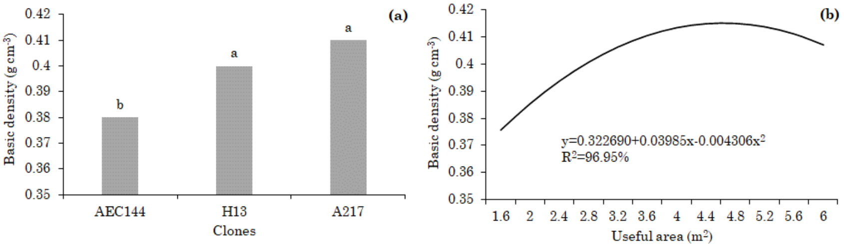

Figure 2. Basic density of wood, at 1.30 m, of three *Eucalyptus* clones (a), grown with different useful areas (b), at 24 months of age, in Serranópolis, GO. Lower-case letters, equal, on the bars, do not differ from each other, by the Tukey test, at 5% probability.

As for the effect of the useful area on the basic density of the wood (Figure 2 b), there was an increase in D_b up to the area of 4.6 m^2 (0.415 g cm^{-3}). However, in general, in larger useful areas, higher D_b values were observed when compared to those found in denser spacing, especially with plantings established in double rows.

Researchers have found controversial results regarding the influence of the useful area on the basic density of the wood. Goulart et al. (2003), working with seminal stands of *Eucalyptus grandis*, observed that larger spacing did not influence D_b. However, Castelo (2007) reported a decrease in the basic density of eucalyptus wood with increased planting spacing. On the other hand, Teixeira et al. (2020) and Magalhães et al. (2020), working with eucalyptus clones planted in denser spacing, found an increase in D_b, in ages ranging from 32 to 35 months, corroborating the results of this research. For Sereghetti et al. (2015) and Moulin et al. (2017), less competition for growth factors lead trees to produce mature wood earlier, causing them to reach higher D_b values more quickly.

For the lower calorific value of the wood (Table 2), only in the useful area of 1.6 m^2, there was a statistical difference between the clones. On average, clones H13 and AEC144 were 3.3% higher than clone A217.

There was a reduction in the LCV with an increase in the useful area (Figure 3), with the lowest value observed in the useful area of 5.0 m^2 for clone H13 and 4.8 m^2 for clone AEC144. The opposite result to that found for the basic density of the wood (Figure 2b). These results were similar to those found by Teixeira et al. (2020), at 32 months, for one of the *E. urophylla* x *E. grandis* clones grown in different spacing. According to the authors, this may indicate that, besides density, other factors may be related to the calorific value of wood.

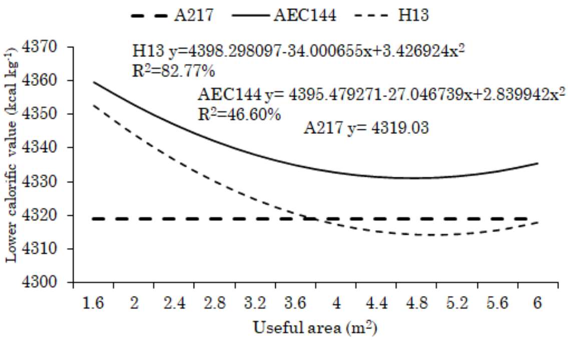

Figure 3. Lower calorific value of wood of three *Eucalyptus* clones according to the useful areas of planting, at 24 months of age, in Serranópolis, GO.

The energy density of wood (D_e) showed similar behavior to that of D_b, varying according to the clone and the useful area (Figure 4). The AEC144 clone showed a D_e, on average, 5.8% lower than that achieved for the other clones (Figure 4a). Protásio et al. (2014), when evaluating two commercial clones of *Eucalyptus* spp., found a reduction of 13% for this same variable. As discussed by Protásio et al. (2014), this variation in wood density among Eucalyptus clones demonstrates the need to continue investing in the genetic improvement of this genus in order to obtain materials that express better dendroenergetic traits.

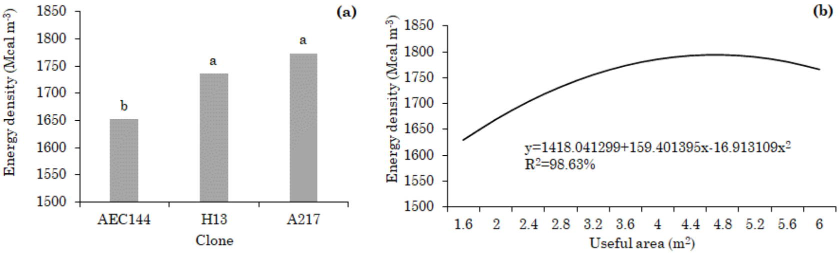

Figure 4. Energy density of the wood of three *Eucalyptus* clones (a), grown with different useful areas (b), at 24 months of age, in Serranópolis, GO. Lower-case letters, equal, on the bars, do not differ from each other, by the Tukey test, at 5% probability.

Regarding the effect of the useful area on D_e (Figure 4b), an increase in D_e was observed up to an area of 4.7 m^2 (1,793.62 Mcal m^{-3}) and, similarly to what was found for D_b, the values of energy density were higher in the larger useful areas than in the smaller ones.

Energy density is an important parameter when it is desired to produce wood for energy. It reflects the energy potential of the combustible material, for which high value is desired (Souza, 2018). However, it is important to correlate this variable with biometric traits, such as biomass production per hectare.

Regarding energy production (Table 2), clone H13 was superior to the others in the useful areas of 1.6 and 2.0 m^2. In the smallest useful area, clone H13 produced 24.9% more energy than clone AEC144 and 42.2% more than clone A217. In the useful area of 2.0 m2, clone H13 produced 30.4% more energy than the average of the others.

The energy generated per unit area, as observed in the production of wood biomass, reduced as the useful area per plant increased (Figure 5). Comparing the values achieved in the smallest and largest useful areas per plant, this reduction was 29.1%, 35.3%, and 46.8% for clones A217, AEC144, and H13. Among the evaluated clones, H13 was the one that produced the greatest amount of energy per hectare. This result was observed for the two spacings in double rows, with the smallest useful areas per plant. For the spacing with useful areas above 3.0 m^2 $plant^{-1}$, which are equivalent to the spacing in simple lines, the energy generated by the three clones did not differ statistically.

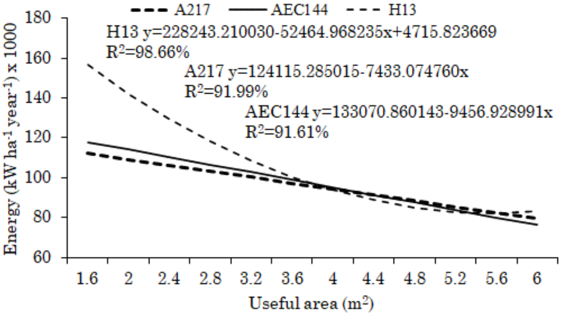

Figure 5. Energy produced (KWh ha^{-1} $year^{-1}$) by three *Eucalyptus* clones according to the useful areas of planting, at 24 months of age, in Serranópolis, GO.

Teixeira et al. (2020), evaluating the energy stored per cubic meter of wood from eucalyptus clones grown in different spacing, also found that the result varies according to the clone and spacing. Also, there was an increase in stored energy as the spacing between plants increased. According to Carneiro et al. (2014), wood density is directly related to the energy generation of this material. Thus, when the wood is used for direct burning, in the form of firewood, a wood of higher density results in fuel with greater concentrated energy (Frederico, 2009). In the present study, a higher basic density (Figure 2) and energy density (Figure 3) was also observed with the increase of the useful area per plant. However, at 24 months of age, the wood biomass produced per hectare

(Figure 1) showed the opposite behavior, demonstrating the strong influence of productivity in biomass for the generation of energy per unit area. This productivity, which can be changed over time, as the competition between plants, in different spacing, becomes more intense.

CONCLUSIONS

The production of biomass, the basic and energy density of wood, the lower calorific value, and the energy generated by this biomass vary according to the clones and the useful area, at the age of 24 months.

The biomass production per hectare and the energy generated by this biomass decrease with the increase in the useful area per plant. For the two largest planting densities, clone H13 was more productive, both in biomass and energy.

The basic density of the wood and energy density increases with the increase of the useful area per plant. The highest values were found for the area of 4.6 m^2 per plant. Clones H13 and A217 have the highest basic and energetic densities of wood.

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