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Age and tree spacing and their effects on energy properties of *Ateleia glazioviana*

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ABSTRACT: The use of wood for energy purposes is common in Brazil, motivated mainly by the diversity of species that present a potential for energy production. The objective of this study was to determine the effects of tree age and spacing on the energy properties of different components of the biomass: wood, bark, and branch of the species *Ateleia glazioviana* Baill, distributed at different spacings: $2.0 \times 1.0\text{m}$, $2.0 \times 1.5\text{m}$, $3.0 \times 1.0\text{m}$, and $3.0 \times 1.5\text{m}$ in the 1st, 3rd, and 5th year after the planting. The experiment was carried out in a randomized complete block design with three replications. The following variables were determined: biomass (BIO), gross calorific power (GCV), basic density (BD), energy productivity (EP), energy density (ED), fixed carbon content (FCC), volatile material content (VMC), and ash content (AC). Different tree ages significantly affected all analyzed variables, increasing the distribution of BIO, EP, AC, BD, and ED with no tendency to stabilize over time. The four tree spacings induced different levels of BIO and EP, with a trend toward lower values with increasing tree spacing for all assessed periods. The four components of the trees had a significant effect on the variables BIO, EP, GCV, FCC, VMC, and AC.

Key words: Timbó, biomass, gross calorific power, energy productivity.

A idade e o espaçamento de plantio e suas influências nas propriedades energéticas da *Ateleia glazioviana*

RESUMO: A utilização da madeira para fins energéticos é elevada no país, motivada principalmente pela diversidade de espécies que apresentam potencialidade de geração de energia. Esse trabalho teve como objetivo determinar o efeito da idade e do espaçamento de plantio nas propriedades energéticas em diferentes compartimentos da biomassa: madeira, casca e galho da espécie *Ateleia glazioviana* Baill, distribuída em diferentes espaçamentos: $2,0 \times 1,0\text{m}$, $2,0 \times 1,5\text{m}$, $3,0 \times 1,0\text{m}$ e $3,0 \times 1,5\text{m}$, no 1^o, 3^o e 5^o ano após o plantio. O presente trabalho foi realizado em um experimento instalado em delineamento experimental de blocos completos casualizados em três repetições. Foram determinadas as variáveis biomassa (BIO), poder calorífico superior (PCS), massa específica básica (ME), produtividade energética (PE), densidade energética (DE), teor de carbono fixo (CF), teor de material volátil (MV) e teor de cinzas (CZ). Concluiu-se que as diferentes idades das árvores influenciam significativamente todas as variáveis analisadas, proporcionando uma distribuição crescente da BIO, PE, CF, ME e DE, sem tendência a estabilização ao longo do tempo. Os quatro espaçamentos de plantio induzem a diferentes produções de BIO e PE, com uma tendência de redução dos seus valores com o aumento do espaçamento, em todos os períodos avaliados. Os quatro compartimentos das árvores induzem a um efeito significativo das variáveis BIO, PE, PCS, CF, MV e CZ.

Palavras-chave: timbó, biomassa, poder calorífico superior, produtividade energética.

INTRODUCTION

Proper use of any material requires the knowledge of its characteristics, especially those related to its applicability. This is not different with the forest biomass, with the characterization of its properties being necessary to determine

its final use. Each species presents different characteristics, and thus verification of different factors that can intrinsically affect its quality and use is recommended.

The choice of the genetic material to be used in the plantation of forest stands from both native and exotic species is extremely important for

use as an alternative source of energy. However, for this to become feasible, it is necessary to know the essential characteristics of forest and its use, with respect to the ecological and silvicultural factors, and those related to the energy potential. These factors support the decision making for the implantation of forest stands (ELOY et al., 2015).

With the increasing demand for renewable energy sources, studies about the potential of energy generation from forest biomass have been conducted in Brazil and worldwide. Studies reported biomass capacity for clean energy production, such as the research performed by LIMA et al. (2011), VIDAURRE et al. (2012), PROTÁSIO et al. (2013), CARON et al. (2015), and ELOY et al. (2016a). However, to increase the efficiency of the conversion of wood into energy, it is necessary to use appropriate technologies to assess its true potential in carbonization, heat production, and cogeneration. In this context, the expectations about the use of forest biomass as a raw material for energy generation are promising.

In a forest production system, wood production as energy resources aim greater biomass production per unit area over a short time. In this way, together with exploration in a dense system, with the objective of producing biomass, the concept of short rotation plantations arises (CARON et al., 2015). Within this context, for Brazil to increase the participation of biomass and wood products in its energy matrix, improvements in access to forestry technologies are required for small and medium-sized producers, both for forestry management and conversion of wood to energy, increasing the generation potential of future forest plantations.

Tree spacing is one of the main factors that affect the establishment of forests, because it has silvicultural, technological, and economic implications, affecting the tree growth rate, age at cutting, wood quality, forest practices employed, and consequently production costs (LELES et al., 2011). Thus, when targeting timber production for energy purposes, denser spacing is usually recommended to produce a larger volume of biomass per unit area in the shortest possible time (ELOY, 2015).

The use of wood for energy purposes is common in Brazil, motivated mainly by the diversity of species that have the energy properties. Currently, 8.2% of the energy produced domestically comes from firewood and charcoal, according to official sources linked to the energy area (MME, 2016). Thus, it is essential to establish

forest experiments in which the original conditions of site, planting, and the ages of the trees are known. This would support the generation of new information regarding the qualification of species destined for the generation of energy, and thus with the goal of establishing forest masses destined to produce wood for energy.

In this context, the present study aimed to determine the effects of planting age and spacing on energy properties of different components of the biomass of *Ateleia glazioviana* Baill.

MATERIALS AND METHODS

Study area

The experiment was carried out in an area belonging to the Universidade Federal de Santa Maria (UFSM), under geographic coordinates of 27°22'S; 53°25'W, at 480m altitude, in the city of Frederico Westphalen, Rio Grande do Sul.

According to the Köppen climate classification, the climate in this region is Cfa, i.e., humid subtropical climate, with an average annual temperature of 19.1°C, varying with a maximum of 38°C and a minimum of 0°C, and an average annual rainfall of 1606mm. The experimental area is approximately 30km from Iraí, which is the city taken as reference for the climate classification data. As proposed by MALUF (2000), Iraí has an average annual temperature of 18.8°C and average temperature of 13.3°C in the coldest month.

The experiment was arranged in a randomized complete block design. It was a $3 \times 4 \times 3$ factorial experiment, i.e., three time periods (1st, 3rd, and 5th year after planting), four tree spacings ($2.0 \times 1.0\text{m}$, $2.0 \times 1.5\text{m}$, $3.0 \times 1.0\text{m}$, and $3.0 \times 1.5\text{m}$), and three tree components (wood, bark, and branch) with three replicates.

The block had four experimental units, which allocated the four levels of planting spacings. Plots were divided into sub-plots for the different evaluation stages over time, and three trees were collected per evaluation period for each planting spacing. Thus, for each evaluation period, 36 trees were collected and evaluated, totaling 108 trees in all periods.

The soil of the area is classified as typical dystrophic red latosol, clayey texture, belonging to the mapping unit of Passo Fundo (EMBRAPA, 2006).

Tree sampling

Destructive assessments of the trees were carried out during three different time

periods: in the 1st year (2009), 3rd year (2011), and 5th year (2013) after planting the experiment, and 36 trees were assessed during each period. For tree sampling, six discs approximately 2cm thick were taken along the stem at the following positions: 0% (base), 1.30m (diameter at breast height - DBH), 25%, 50%, 75%, and 100% of the total height of the tree, and two symmetrically opposite wedges of each disk were sectioned.

Tree samples were collected in a stratified manner, i.e., the lower, middle, and upper stratum of the tree canopy, to obtain a homogeneous material that represents the entire canopy length. These were identified and taken for drying in a circulation and renewal oven, to obtain the dry product. Samples of wood, bark, and branch were dried at 103°C at 0% moisture, to determine the respective humidity content.

The data for the sampled leaves were not computed, because senescence started prior to the period when the evaluations were carried out, that is, in the month of September.

Characterization of the evaluated properties

To determine the biomass (BIO), the direct method was used, which consisted of cutting and weighing of the different components of trees (SANQUETTA, 2002). Total fresh masses of the sampled trees were determined under field condition, and samples were taken from each component to obtain its moisture content in the laboratory.

Regarding the determination of the gross calorific value (GCV) and the immediate chemical analysis (ICA), samples taken from the trees were ground in a slicer with a 40-mesh sieve to obtain a thinner and more uniform material. Evaluation for GCV was performed using a digital bomb calorimeter, C5000 Cooling System model, IKA Werke, with adiabatic operating principle, according to the technical standard NBR 8633 (ABNT, 1984), and, in the case of the ICA, the technical standard NBR 8112 (ABNT, 1986) was used, from which the concentrations of volatile compounds, ash, and fixed carbon compounds were determined.

To determine the basic density (BD), the materials obtained in the sampling were used. The procedures were performed according to the technical standard NBR 11941 (ABNT, 2003). Regarding the determination of energy productivity (EP), the BIO values with their respective GCV were multiplied according to the following equation:

$$EP = BIO \times GCV \quad (1)$$

where: EP = Energy productivity (Gcal ha⁻¹); BIO = Dry biomass of each component (ton ha⁻¹), and GCV = Gross calorific value (kcal kg⁻¹).

To determine the energy density (ED), BD and GCV values were multiplied according to the following equation:

$$ED = BD \times GCV \quad (2)$$

where: ED = Energy density (kcal m⁻³); BD = Basic density of the wood according to the volume of the tree (kg m⁻³), and GCV = Gross calorific value of the wood (kcal kg⁻¹).

Data analysis

The data obtained were subjected to statistical analysis, which proceeded with the test assumption of homogeneity of variances, analysis of variance, regression analysis, F-test, and Tukey test at 5% probability of error.

RESULTS AND DISCUSSION

Analysis of variance revealed significant effects of the three periods studied and for all tree components, on all variables analyzed. Likewise, significant effects of the four tree spacings on the biomass (BIO) and energy productivity (EP) variables were observed. When the effect of interactions between the three factors was tested, significant differences were observed for BIO, EP, Gross calorific power (GCP), fixed carbon content (FCC), and volatile material content (VMC). Significant interaction effect between year and the components was verified only for ash content (AC). Thus, we reported that there is dependence between the evaluated effects and, by doing so, the evaluation of one factor within the other was carried out.

In the 1st year of evaluation, BIO and EP did not present significant differences between the different components of trees. For GCV and AC, significant differences were observed, with branch and bark components presenting the highest average values. Similarly, significant differences were observed for FCC with higher average values in the wood and bark components with the smaller tree spacing. This characteristic was also observed for the VMC in the branch component (Table 1).

In the 3rd year of evaluation, the highest values of BIO and EP were reported in the wood and branch components. For the AC, the bark had the highest average value of 4.0%. As for GCV, although it was not affected by the spacing, it had the highest values in the bark component (Table 2).

Table 1 - Average test for biomass (BIO), in ton ha^{-1} , energy productivity (EP), in Gcal ha^{-1} , gross calorific value (GCV), in kcal kg^{-1} , fixed carbon content (FCC), in %, volatile material content (VMC), in %, ash content (AC), in %, basic density (BD), in g cm^{-3} and energy density (ED), in Gcal m^{-3} , for the different compartments (Comp.) of *Ateleia glazioviana*, distributed in different planting spacing, in the 1st year after planting.

Variable	Comp.	-----Spacing (m)-----			
		2.0 × 1.0	2.0 × 1.5	3.0 × 1.0	3.0 × 1.5
BIO	Wood	0.256 aA	0.179 aA	0.165 aA	0.140 aA
	Bark	0.044 aA	0.032 aA	0.027 aA	0.027 aA
	Branch	0.017 aA	0.013 aA	0.010 aA	0.006 aA
	Total	0.317 A	0.224 A	0.202 A	0.173 A
EP	Wood	1.172 aA	0.806 aA	0.735 aA	0.629 aA
	Bark	0.204 aA	0.148 aA	0.122 aA	0.126 aA
	Branch	0.078 aA	0.062 aA	0.047 aA	0.027 aA
GCV	Wood	4578 a	4502 b	4455 b	4492 b
	Bark	4626 a	4613 ab	4521 b	4674 a
	Branch	4576 a	4748 a	4704 a	4483 b
FCC	Wood	20.81 a	19.31 a	17.95 a	18.35 a
	Bark	22.29 a	17.45 a	16.50 a	14.92 b
	Branch	13.01 b	16.02 a	15.72 a	17.11 ab
VMC	Wood	77.21 b	78.90 a	80.38 a	80.09 a
	Bark	74.98 b	80.04 a	80.42 a	81.43 a
	Branch	83.57 a	80.71 a	81.02 a	78.92 a
AC	Wood	1.99 b	1.78 b	1.67 b	1.57 b
	Bark	2.74 ab	2.84 a	3.08 a	3.64 a
	Branch	3.41 a	3.27 a	3.25 a	3.93 a
BD	Wood	0.417	0.423	0.440	0.399
ED	Wood	1.909	1.904	1.960	1.792

Where: Means followed by lower case letters in the column do not differ between species; Means followed by uppercase letters in the line do not differ between 5% error probability spacing according to Tukey test.

For the 5th year of evaluation, the BIO production and EP of the wood were significantly greater than the other components of the trees, reaching $24.712 \text{ ton ha}^{-1}$ and $111.797 \text{ Gcal ha}^{-1}$, respectively. In general, for FCC and VMC, it was reported that the highest mean values were present in the wood and branch components. In contrast, for AC, the highest value was reported for the bark. Although, not affected by tree spacing, the highest mean values of 0.519 g cm^{-3} and $2.347 \text{ Gcal m}^{-3}$ were reported for basic density (BD) and energy density (ED), respectively (Table 3).

We observed that the four tree spacings tested led to different BIO and EP production of the three different components of the aerial parts of the trees during the three time periods after planting. A direct relationship between tree spacing and distribution of each component was observed, i.e., in the treatment with higher density ($2.0 \times 1.0 \text{ m}$), the higher average values of BIO were observed

when compared to the less dense spaces. According to NETO et al. (2003), there is a higher production of BIO per unit area with high tree density, mainly owing to the greater number of individuals. This justifies the decreasing trends of BIO production in the different components of the tree due to the increase in tree spacing.

However, CARON et al. (2015) pointed out that, over time, the amount of wood stored in a site tends to equalize at different spacings, and in denser plantations, there is stagnation of growth at younger ages, and that in plantings with wider spacing, the stagnation of growth appears at more advanced ages.

Figure 1 shows the significant regression equations of different components, over the three periods, for all variables evaluated. In general, there is an increasing tendency of the components, mainly wood, in the variables BIO, EP, FCC, BD, and ED, in relation to the different evaluation years, with no tendency to stabilize, because the different years

Table 2 - Average test for biomass (BIO), in ton ha⁻¹, energy productivity (EP), in Gcal ha⁻¹, gross calorific value (GCV), in kcal kg⁻¹, fixed carbon content (FCC), in %, volatile material content (VMC), in %, ash content (AC), in %, basic density (BD), in g cm⁻³ and energy density (ED), in Gcal m⁻³, for the different compartments (Comp.) of *Ateleia glazioviana*, distributed in different planting spacings, in the 3rd year after planting.

Variable	Comp.	Spacing (m)			
		2.0 × 1.0	2.0 × 1.5	3.0 × 1.0	3.0 × 1.5
BIO	Wood	12.656 aA	7.116 aB	6.591 bB	4.111 bC
	Bark	1.977 cA	1.484 bB	0.939 cC	0.662 cC
	Branch	9.543 bA	7.142 aB	7.839 aB	5.005 aC
	Total	24.176 A	15.742 B	15.369 B	9.778 C
EP	Wood	55.775 aA	31.204 aB	29.099 bB	18.064 bB
	Bark	9.211 cA	6.751 bA	3.925 cB	2.982 cB
	Branch	42.562 bA	31.960 aB	35.197 aB	22.317 aC
GCV	Wood	4405 b	4385 b	4415 a	4394 a
	Bark	4659 a	4549 a	4180 b	4504 a
	Branch	4460 b	4475 ab	4490 a	4459 a
FCC	Wood	17.46 ab	17.31 a	19.19 a	18.70 a
	Bark	14.85 b	19.55 a	18.92 a	14.99 a
	Branch	18.42 a	15.94 a	15.44 b	16.67 a
VMC	Wood	81.02 a	81.10 a	79.40 ab	79.62 a
	Bark	81.72 a	76.44 b	77.75 b	81.05 a
	Branch	79.60 a	81.87 a	82.25 a	81.11 a
AC	Wood	1.52 b	1.59 b	1.41 c	1.65 b
	Bark	3.43 a	4.00 a	3.34 a	3.96 a
	Branch	1.99 b	2.19 b	2.30 b	2.21 b
BD	Wood	0.472	0.468	0.489	0.486
ED	Wood	2.079	2.052	2.159	2.135

Where: Means followed by lower case letters in the column do not differ between species; Means followed by uppercase letters in the line do not differ between 5% error probability spacing according to Tukey test.

evaluated had a significant effect on the different tree components.

This difference in the distribution of BIO between different species, and for the same species, is mainly motivated by factors such as tree spacing, population age, and site quality (LADEIRA et al., 2001). This is corroborated by authors who carried out their research related to the effects of density and age of planting on the production of forest stands, such as LELES et al. (2001) and MÜLLER et al. (2005).

We observed that the age had a significant effect on GCV, which corroborated the research done by LEMENIH & BEKELE (2004) evaluated the effect of age on wood GCV of species of the genus *Eucalyptus* and observed a negative relationship with tree age, with a small difference between the ages of 11 and 21 years. VIDAURRE et al. (2012) reported similar results with *Schizolobium amazonicum*, reporting that the younger age presented the highest GCV values, with a tendency to decrease with increasing tree age.

The mean GCV values for *A. glazioviana* reported by MATTOS et al. (2000) and SILVA et al. (2012) were 4637 and 4492 kcal kg⁻¹, respectively. These are lower than those described by QUIRINO et al. (2005), in which the average value of 4710 kcal kg⁻¹ was observed when they carried out a literature review concerning wood GCV of 258 exotic and native tropical forest species.

Results of BD observed in this study are within the range that QUIRINO et al. (2005) reported for 108 forest species, ranging from 0.200 to 1.080 g cm⁻³. The average values of BD increased with age, with the highest values for *A. glazioviana*, observed in the 5th year after planting. The differences in BD observed among the time periods is corroborated by a series of authors who studied this technological feature. TREVISAN et al. (2012) studied the effect of thinning on *Eucalyptus grandis* central trees with ages ranging from 4 to 18 years and reported a variation in the mean BD values of 0.390 to 0.462 g cm⁻³, confirming the existence of variability within the species and between the different ages of the stands.

Table 3 - Average test for biomass (BIO), in ton ha^{-1} , energy productivity (EP), in Gcal ha^{-1} , gross calorific value (GCV), in kcal kg^{-1} , fixed carbon content (FCC), in %, volatile material content (VMC), in %, ash content (AC), in %, basic density (BD), in g cm^{-3} and energy density (ED), in Gcal m^{-3} , for the different compartments (Comp.) of *Ateleia glazioviana*, distributed in different planting spacings, in the 5th year after planting.

Variable	Comp.	-----Spacing (m) -----			
		2.0 × 1.0	2.0 × 1.5	3.0 × 1.0	3.0 × 1.5
BIO	Wood	24.712 aA	15.498 aAB	22.041 aA	13.356 aAB
	Bark	1.818 cA	1.148 cBC	1.738 cAB	1.017 cC
	Branch	5.556 bA	7.242 bA	6.585 bA	5.572 bA
	Total	32.086 A	23.888 AB	30.364 A	19.945 B
EP	Wood	111.797 aA	68.765 aB	99.691 aA	59.554 aB
	Bark	8.343 cA	5.200 cAB	8.059 cA	4.683 cB
	Branch	24.219 bB	32.654 bA	29.988 bAB	25.269 bB
GCV	Wood	4524 a	4437 a	4523 a	4459 a
	Bark	4589 a	4530 a	4637 a	4605 a
	Branch	4539 a	4509 a	4554 a	4535 a
FCC	Wood	20.54 a	20.92 a	20.94 a	20.86 a
	Bark	19.77 a	19.17 a	19.98 ab	20.03 a
	Branch	20.97 a	21.61 a	17.33 b	21.80 a
VMC	Wood	78.44 a	77.85 a	77.82 ab	77.96 a
	Bark	76.32 a	76.95 a	76.03 b	76.03 a
	Branch	76.65 a	76.33 a	80.67 a	76.04 a
AC	Wood	1.02 c	1.23 c	1.24 b	1.17 c
	Bark	3.91 a	3.88 a	3.99 a	3.94 a
	Branch	2.37 b	2.07 b	2.00 b	2.17 b
BD	Wood	0.510	0.516	0.519	0.502
ED	Wood	2.317	2.290	2.347	2.238

Where: Means followed by lower case letters in the column do not differ between species; Means followed by uppercase letters in the line do not differ between 5% error probability spacing according to Tukey test.

The different tree densities did not significantly affect the BD of the wood. This result corroborated ELOY et al. (2013). These results can be attributed to several factors, such as the genetic variability of the stands and different environmental conditions, according to different ages (ELOY et al., 2014).

Our results of the VMC and FCC contents in the wood are in agreement with BRITO & BARRICHELLO (1982). Generally, VMC ranged from 75% to 85% and FCC ranged between 15% and 25%. As reported by ELOY et al. (2016b), fuels with a high FCC are desirable, because they present slower burning, implying a longer residence time within the appliances. VIEIRA et al. (2013) concluded that the VMC content positively interferes with the ignition, facilitating combustion; and although, the combustion process is rapid, it can contribute to a low energy efficiency. The same authors reported that AC is undesirable for an energetic product considering that it decreases the GCV, resulting in loss of efficiency because it corresponds to non-combustible substances that are in solid form.

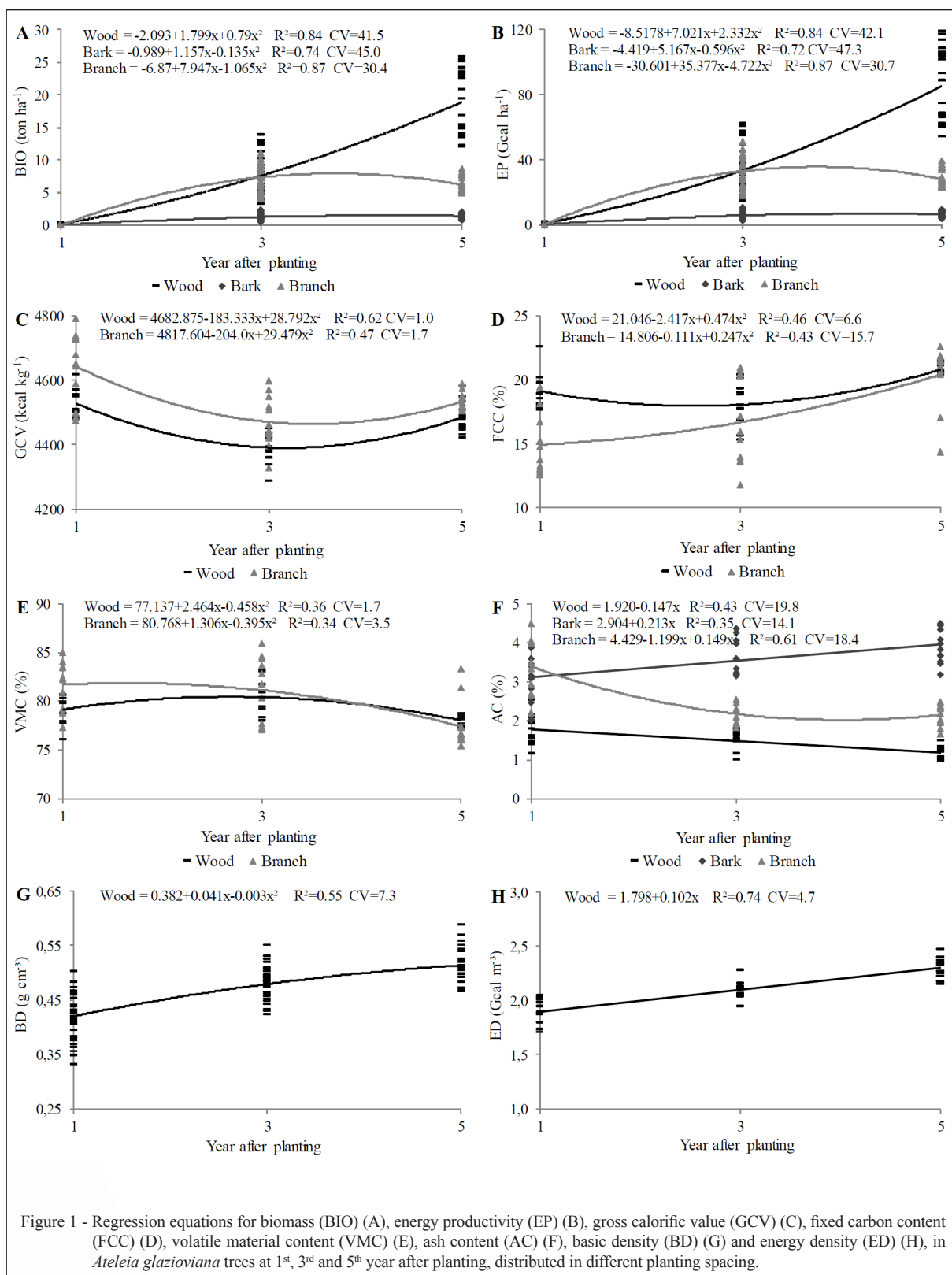
CONCLUSION

Age affected the energy properties of the biomass of the different components of the trees. In the 5th year after planting, the highest values of biomass, energy productivity, basic density, energy density, and fixed carbon content were obtained.

The four tree spacings (2.0 × 1.0m, 2.0 × 1.5m, 3.0 × 1.0m, and 3.0 × 1.5m) provided different biomass yield and energy productivities, with a tendency to reduce their values with increasing tree spacing in all evaluated periods.

The three components of the trees (wood, bark, and branch) induced significant effects on the variables biomass, gross calorific power, energy productivity, fixed carbon content, volatile material content, and ash content.

From the energy perspective, increased age and less tree spacing resulted in better energy properties of *A. glazioviana* biomass.



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