Floresta e Ambiente 2019; 26(4): e20160201
https://doi.org/10.1590/2179-8087.020116
ISSN 2179-8087 (online)

Original Article

Wood Science and Technology

Elemental Chemical Composition of Forest Biomass at Different Ages for Energy Purposes

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ABSTRACT

This work aimed to evaluate the elemental composition of different biomass components of the forest species *Acacia mearnsii* De Wild, *Eucalyptus grandis* W. Hill ex Maiden, *Mimosa scabrella* Benth and *Ateleia glazioviana* Baill, at their first, third and fifth year after planting, aiming at bioenergetic use. The biomass elemental composition was determined by quantifying the levels of carbon, hydrogen, nitrogen, sulfur and oxygen. The three ages, the four species, and the four compartments differ in relation to the elementary constituents. The use of trees at any age allows for energy use. The fifth year presents the best carbon and hydrogen values, being the best age for using the biomass energy of the different species. *A. mearnsii* presents the highest carbon values for the leaf and *A. glazioviana* presents the highest hydrogen values for all compartments. The leaf is the best compartment for energetic use.

Keywords: wood quality, growth, energy.

1. INTRODUCTION AND OBJECTIVES

The definition of evaluation criteria to measure biomass quality is gaining increasing importance, especially in fast-growing forests. In order to evaluate this quality to generate subsidies and to define better use of the biomass, it is essential to identify the chemical, physical and mechanical properties that knowingly alter the final product.

Wood is a heterogeneous material because it is formed by several cells capable of performing specific functions and because it consists of a series of organic and inorganic compounds (Botrel et al., 2010). Wood variability can be explained by several factors, such as the effect of the genetic material used, the planting site, interaction between genotype and environment, and age and spacing, which can significantly affect its chemical, physical, mechanical and anatomical composition, and consequently influence the material's quality for producing energy (Assis et al., 2012).

Age is a factor that changes the characteristics of the source material, mainly due to the marked changes in the woody tissue properties over time, directly reflecting the material's quality for producing energy (Eloy et al., 2017). The choice of the species, the planting site and the analysis of their interaction becomes of fundamental importance, since they reflect in modifying the elemental composition and the physical properties of the wood (Neves et al., 2011), affecting the production and the material's quality for generating energy.

Thus, the biomass use as fuel for energy supply requires characterizing elemental chemical components. The energy released during the combustion process is positively correlated with the carbon and hydrogen contents as a function of the energy value of these elements. In contrast, high oxygen and nitrogen values decrease the calorific value, decreasing the energy potential of the fuel material (Huang et al., 2009; Protásio et al., 2011). In addition, it is desirable that biomass presents low nitrogen and sulfur levels, as these result in increased environmental pollution (Bilgen & Kaygusuz, 2008; Kumar et al., 2010).

In this context, the present work aims to evaluate the variability of elemental chemical composition in the following different biomass compartments: wood, bark, branch and leaf, of the following forest species: *A. mearnsii* De Wild, *E. grandis* W. Hill ex Maiden, *M. scabrella* Benth and *A. glazioviana* Baill, in the first, third and fifth year after planting.

2. MATERIALS AND METHODS

2.1. Characterization of the study area

The work was carried out in an experimental area of the Federal University of Santa Maria, Campus of Frederico Westphalen, RS (UFSM/FW), under geographic coordinates of 27°22' S; 53°25' W, at an altitude of 480 m.

According to the Köppen climatic classification, the climate of the region is Cfa, which is subtropical humid with an average annual temperature of 19.1 °C, varying from a maximum of 38 °C and a minimum of 0 °C, presenting an average annual precipitation of 1,606 mm.

The experiment was carried out using a completely randomized block design. The blocks were characterized by a 4×4×3 factorial, which is the four forest species (*Acacia mearnsii* De Wild, *Eucalyptus grandis* W. Hill ex Maiden, *Mimosa scabrella* Benth and *Ateleia glazioviana* Baill), four compartments (wood, bark, branch and leaf) and three periods after planting (first, third and fifth year) in three replications in the subdivided plot scheme, where the plot was represented by the species and the subplot by the age of the data. The block contemplates 16 experimental units, each of which has 45 plants distributed in five rows. The experimental units were divided into three subplots, each consisting of three plants.

The soil of the area is classified as typical dystrophic Red Latosol with a well-drained clayey texture, belonging to the mapping unit of Passo Fundo (Embrapa, 2006). Subsoiling and harrowing operations were carried out in preparation for planting the seedlings. Planting was done manually with subsequent fertilization of 150 g per NPK seedling in the formulation 8-24-12, in September 2008.

2.2. Sampling

Destructive evaluations were carried out in the first year (2009), third year (2011) and fifth year (2013) after planting the experiment, where 144 trees per year of evaluation were selected, corresponding to 36 trees per spacing. From these, six discs approximately two centimeters thick were removed in the following positions along the trunk: 0% (base), 1.30 m (diameter at breast height – DBH), 25%, 50% 75% and 100% of the total height of the tree. The discs were subsequently packed in plastic bags and transported to the laboratory where they were marked, separated from the wood bark, and then two symmetrically opposite wedges of each disc were sectioned.

The samples of branch and leaf were collected stratified in the plant, that is, in the lower, middle and upper stratum of the tree canopy, in order to obtain a more representative material from the tree canopy. These were identified and taken to circulation drying in greenhouses and renewing the air to obtain the dry matter. The wood, bark, leaf and branch samples were dried at 103 ± 2 °C until constant mass.

Leaf sampling for the *A. glazioviana* species was not computed due to the senescence of the leaf having started prior to the period in which the evaluations were carried out in September.

2.3. Elemental analysis

The wood, bark, branch and leaf samples were ground and sieved using the fraction that passed through the 200-mesh sieve and was retained in the 270-mesh sieve. Quantification of the carbon (C), hydrogen (H), nitrogen (N) and sulfur (S) contents in relation to the dry biomass was performed in a duplicate elemental universal analyzer (Vario Micro Cube model). The 2 mg samples were packed in tin capsules and completely incinerated at 1,200 °C. The oxygen content (O) was obtained by the difference in relation to the other elementary components according to Equation 1, as proposed by Protásio et al. (2011).

$$O(\%) = 100\% - C(\%) - H(\%) - N(\%) - S(\%) - As(\%) \quad (1)$$

O: oxygen content (%); C: carbon content (%); H: hydrogen content (%); N: nitrogen content (%); S: sulfur content (%); As: ash content (%).

2.4. Data analysis

The data were submitted to statistical analysis through the “Statistical Analysis System” (Sas, 2003), in which the analysis of variance, regression analysis and the Tukey test averages at 5% probability of error were performed.

The estimated regression equations were elaborated from the statistical difference between the three evaluation periods for the specific biomass compartments in each elementary chemical constituent. The inferences were only generated for the means when this difference between the years did not occur.

3. RESULTS AND DISCUSSION

Analysis of variance revealed a significant difference for the elementary constituents among the four forest species, between the three evaluated periods and among the four biomass compartments studied. Likewise, this characteristic was observed for the species vs. compartment interactions and for year vs. compartment in the elementary constituents of carbon and oxygen. This also occurred for the triple interaction species × compartment × year for hydrogen, nitrogen and sulfur.

These differences observed in the interactions related to the chemical composition of the biomass within a single tree are related to age, genetic factors and ecological conditions of the environment, which provide variations in the response to the formation of young wood and adult wood. It is clear that chemical properties are subject to substantial initial variations in juvenile wood, but tend to stabilize as adult wood begins to form (Santana et al., 2012). For Eloy et al. (2014), factors related to the structural composition of wood influence its energy potential, mainly with respect to the chemical and elemental constitution.

In relation to the oxygen content, the highest values in the first evaluation year were reported for wood in the four species studied, reaching the mean value of 49.64% for *A. mearnsii*, which did not differ statistically from the other species; while *E. grandis* was superior to the other species for the bark and branch compartments (Table 1). This high value of oxygen content is not desired when the biomass is intended to be consumed for energy, because according to Protásio et al. (2011), an increase in oxygen content and a decrease in the hydrogen or carbon content tends to decrease the calorific value of the biomass. However, it is necessary to mention that oxygen is an essential element to promote material combustion.

Table 1. Mean values for the elementary constituents of wood, bark, branch and leaf of the four forest species in the first year after planting.

Elementary constituent	Species	Component			
		Wood	Bark	Branch	Leaf
Carbon	*A. mearnsii*	43.77 abB	47.39 aA	48.31 aA	47.92 aA
	M. scabrella	44.50 aC	44.93 bBC	46.17 bAB	46.75 abA
	E. grandis	44.05 abB	37.33 cC	44.12 cB	45.83 bA
	A. glazioviana	43.00 bB	44.13 bAB	44.97 cA	-
Hydrogen	*A. mearnsii*	5.74 bAB	5.29 bC	5.82 bA	5.63 aB
	M. scabrella	5.76 bA	5.43 bB	5.61 cA	5.78 aA
	E. grandis	5.73 bA	4.15 cC	5.25 dB	5.35 bB
	A. glazioviana	6.00 aA	5.93 aA	6.06 aA	-
Nitrogen	*A. mearnsii*	0.82 bD	2.04 cC	2.28 bB	3.01 aA
	M. scabrella	0.91 bD	2.28 bB	1.87 cC	2.97 aA
	E. grandis	0.69 cD	1.05 dC	1.33 dB	2.59 bA
	A. glazioviana	1.70 aC	3.96 aA	3.12 aB	-
Oxygen	*A. mearnsii*	49.64 aA	45.23 cB	43.52 cC	43.43 bC
	M. scabrella	48.78 aA	47.26 bAB	46.28 bB	44.36 abC
	E. grandis	49.49 aA	57.45 aB	49.26 aA	46.17 aC
	A. glazioviana	49.23 aA	45.88 bcB	45.74 bB	-
Sulfur	*A. mearnsii*	0.028 aA	0.046 bA	0.067 bA	0.013 bA
	M. scabrella	0.056 aB	0.100 aAB	0.071 bB	0.140 aA
	E. grandis	0.035 aA	0.028 bA	0.035 cA	0.075 abA
	A. glazioviana	0.087 aA	0.085 aA	0.111 aA	-

Means followed by the same lowercase letter in the column compare the species, and uppercase in the line compare the biomass compartments, they do not differ from each other at 5% probability of error, according to the Tukey test; -: not evaluated.

The highest average carbon values were generally observed for *A. mearnsii* in the branch compartment (48.31%), not differing from leaf and bark. This characteristic was verified for *A. glazioviana* for hydrogen and nitrogen contents, differing in all evaluated biomass compartments, as well as for the branch (6.06%) and bark (3.96%) compartments, respectively, which was higher in the other species for hydrogen, whereas it was different for nitrogen between compartments (bark>branch>wood) (Table 1). The elemental chemical composition values of the wood observed in this work are in accordance with those reported in the literature for the *Eucalyptus* genus, of approximately 48% carbon, 6% hydrogen, 45% oxygen, 0.15% nitrogen and 0.01% sulfur (Protásio et al., 2011; Neves et al., 2011).

When a high carbon-nitrogen relationship is observed, we conclude that these imply a smaller amount of nitrogen to be released into the environment after biomass combustion. The carbon dioxide (CO_2) fixed in the biomass and released into the atmosphere by the combustion process is dependent on external factors to the process, and the release rate is mainly determined by the temperature and humidity of the combustible material, and the carbon-nitrogen relationship of biomass (Schneider et al., 2005). Besides, the lower this relationship, the faster the CO_2 releases into the atmosphere during combustion; which is not desirable since this gas is one of the responsibles for potentiating the greenhouse effect (Sanquetta et al., 2014).

Variation of the elementary properties of the forest stand in the third year of age was very similar to the first year. *A. mearnsii* presented the highest carbon values for all compartments, ranging from 45.10% for wood to 49.40% for leaf, which showed the highest values for all species studied (Table 2). Thus, when considering using wood as an energy source, it should be noted that from the carbon percentage present in the wood, much of this element reacts with hydrogen and oxygen when subjected to the carbonization process, where it becomes volatile and consequent formation of non-condensable gases and condensable gases occurs (Santos et al., 2013). Thus, only a fraction can be considered as fixed carbon which is stable and does not decompose under inert atmospheres.

Furthermore, the hydrogen and nitrogen contents had the highest average values for *A. glazioviana* standing out in all compartments, with 5.94% for bark and branches, and 3.66% for bark, respectively. For oxygen, the highest mean values were reported for wood in the four species studied, with 48.93% for *M. scabrella*, and not differing from *A. mearnsii* and *E. grandis* (Table 2). When comparing these to the literature, in determining the variability in the characteristics of *E. grandis* and *E. urophylla* wood used as energy source, Santana et al. (2012) found higher average values for carbon (48.72%) and hydrogen (6.55%) than those observed in this work and lower nitrogen (0.12%) and oxygen (44.57%) values.

Considering the different compartments for the fifth year, it was observed that leaf generally presented higher carbon, hydrogen, nitrogen and sulfur values for all species except for *A. glazioviana,* as this compartment was not evaluated. This same behavior was reported for wood in relation to oxygen. Likewise, when comparing different species, the highest values of the wood, bark and branches were reported for *A. glazioviana* species regarding hydrogen and nitrogen elemental components, and *E. grandis* and *M. scabrella* in relation to the oxygen and sulfur, respectively (Table 3). This variability observed in forest biomass can be explained by several factors, such as species, development stage, nutritional status, edaphoclimatic conditions, and with the part of the plant considered, this can significantly affect its chemical composition and consequently influence the material's quality for producing energy (Ratuchne et al., 2016).

Table 2. Mean values for the elementary constituents of wood, bark, branch and leaf of the four forest species in the third year after planting.

Elementary constituent	Species	Component			
		Wood	Bark	Branch	Leaf
Carbon	*A. mearnsii*	45.10 aC	47.94 aB	47.39 aB	49.40 aA
	M. scabrella	44.72 aB	44.43 bB	46.62 aA	46.53 bA
	E. grandis	44.71 aB	38.23 cC	43.94 cB	47.08 bA
	A. glazioviana	45.04 aAB	43.65 bB	45.29 bA	-
Hydrogen	*A. mearnsii*	5.79 abB	5.49 bC	5.91 abB	6.28 aA
	M. scabrella	5.55 cBC	5.42 bC	5.73 bB	6.03 bA
	E. grandis	5.73 bA	4.45 cC	5.44 cB	5.88 bA
	A. glazioviana	5.92 aA	5.94 aA	5.94 aA	-
Nitrogen	*A. mearnsii*	0.80 bC	1.79 cB	1.62 cB	3.07 bA
	M. scabrella	0.74 bD	2.19 bB	1.85 bC	3.55 aA
	E. grandis	0.48 cD	1.09 dB	0.74 dC	2.72 bA
	A. glazioviana	2.07 aC	3.66 aA	2.44 aB	-
Oxygen	*A. mearnsii*	48.27 abA	44.74 cB	45.04 bB	41.14 bC
	M. scabrella	48.93 aA	47.77 bA	45.70 bB	43.54 aC
	E. grandis	48.92 aB	56.19 aA	49.86 aB	44.21 aC
	A. glazioviana	46.93 bA	46.67 bA	46.27 bA	-
Sulfur	*A. mearnsii*	0.037 bB	0.042 cB	0.041 cB	0.112 bA
	M. scabrella	0.060 bC	0.181 aB	0.103 aC	0.363 aA
	E. grandis	0.156 aA	0.046 cB	0.014 dB	0.118 bA
	A. glazioviana	0.036 bA	0.076 bA	0.059 bA	-

Means followed by the same lowercase letter in the column compare the species, and uppercase in the line compare the biomass compartments, they do not differ from each other at 5% probability of error, according to the Tukey test; -: not evaluated.

Table 3. Mean values for the elementary constituents of wood, bark, branch and leaf of the four forest species in the fifth year after planting.

Elementary constituent	Species	Component			
		Wood	Bark	Branch	Leaf
Carbon	*A. mearnsii*	45.32 aC	48.93 aB	46.79 aB	51.67 aA
	M. scabrella	45.62 aAB	44.60 bB	45.23 bB	46.73 bA
	E. grandis	45.26 aB	37.80 cD	43.38 cC	48.20 bA
	A. glazioviana	45.07 aB	43.69 bB	46.55 aA	-
Hydrogen	*A. mearnsii*	5.70 bB	5.29 bC	5.79 abB	6.92 aA
	M. scabrella	5.59 bB	5.50 bB	5.61 bB	6.07 bA
	E. grandis	5.67 bB	4.38 cD	5.32 cC	6.09 bA
	A. glazioviana	6.02 aA	6.00 aA	6.02 aA	-
Nitrogen	*A. mearnsii*	0.49 cD	1.67 cB	1.38 cC	2.81 bA
	M. scabrella	0.68 bD	2.08 bB	1.69 bC	3.77 aA
	E. grandis	0.29 dD	0.68 dC	0.96 dB	2.54 bA
	A. glazioviana	1.35 aC	3.77 aA	2.32 aB	-
Oxygen	*A. mearnsii*	48.49 aA	44.10 cC	46.02 bcB	38.48 bD
	M. scabrella	48.08 aA	47.67 bA	47.42 bA	43.18 aB
	E. grandis	48.77 aB	57.12 aA	50.34 aB	42.93 aC
	A. glazioviana	47.54 aA	46.48 bAB	45.06 cB	-
Sulfur	*A. mearnsii*	0.002 aB	0.014 cB	0.013 bB	0.125 bA
	M. scabrella	0.030 aC	0.143 aB	0.055 aC	0.249 aA
	E. grandis	0.004 aB	0.013 cB	0.012 bB	0.246 aA
	A. glazioviana	0.024 aA	0.057 bA	0.053 aA	-

Means followed by the same lowercase letter in the column compare the species, and uppercase in the line compare the biomass compartments, they do not differ from each other at 5% probability of error, according to the Tukey test; -: not evaluated.

The variability in the wood can be explained by several factors, such as the effect of the genetic material used, the planting site, interaction between genotype and environment, age and spacing, which can significantly affect its chemical, physical, mechanical and anatomical composition, and consequently influence the material's quality for producing energy (Assis et al., 2012).

The use of biomass as biofuel for energy supply requires its elementary characterization, mainly because when biomass is destined for producing energy, it must contain smaller amounts of oxygen and nitrogen and high carbon and hydrogen levels, since these elementary components have direct correlations with the gross calorific value (Obernberger et al., 2006; Huang et al., 2009, Protásio et al., 2011).

When analyzing the biomass components and their potential to be used as an energy source, and not only considering using the wood, but all the compartments, the *A. mearnsii* and *A. glazioviana* species generally presented the best carbon and hydrogen values, respectively, resulting in a greater potential for power generation. The *E. grandis* species was the least recommended species for this purpose, in view of the same criteria, since it generally presents the highest average oxygen values when compared to the other species, mainly in the bark and branch compartments.

For Protásio et al. (2011), an increase of approximately 515 kcal kg^{-1} in the biomass calorific value occurs for every 1% increase in the hydrogen content. They also observed that every 1% increase in the carbon content causes an increase of 64.14 kcal kg^{-1} in the biomass calorific value. For the same authors, low hydrogen values in the wood composition result in a high carbon-hydrogen relationship; which is undesirable when it is aimed for energy production, because small increases in the hydrogen content provide high gains in the biomass calorific value.

When the significant equations were analyzed over time for the fifth year after planting, there was an increasing tendency in the carbon content for the bark and the leaf of *A. mearnsii* (Figure 1A), for *E. grandis* leaf (Figure 1B) and for *A. glazioviana* wood (Figure 1C). Santana et al. (2012), who also found higher carbon values in older trees, suggested that carbon levels tend to increase as tree size increases, as well as being directly proportional to biomass production. For the same authors, this significant increase in the carbon content with the advancing age is much desired when the objective is to destine the biomass to produce energy, since it positively contributes to the calorific power.

Thus, it is observed that when the growth tendency of a certain element occurs, the others behave inversely proportionally. This corroborates Assis et al. (2012), who concluded that the increase in the carbon content of the fuel is associated with a decrease in the hydrogen, nitrogen and oxygen levels, since these elements combine and are volatilized, thus justifying the observed trends.

In the same way that increasing trends over time were observed for the carbon content in *A. mearnsii* (Figure 1A) and *E. grandis* (Figure 1B) leaf compartments, this characteristic was also observed for the hydrogen content in the *E. grandis* (Figure 1D), *A. mearnsii* (Figure 1E) and *M. scabrella* (Figure 1F) leafs. These positive trends over time are highly desired for an energetic material and corroborate with Santana et al. (2012) in working with trees between 34 and 48 months, who observed the best values of these elements which therefore suggested better energy values and less impact to the environment.

Although the hydrogen content presents statistical difference with the age of the trees only for the leaf, it is emphasized that it significantly contributes to the increase in the calorific value of the fuel (Demirbas & Demirbas, 2004; Huang et al., 2009; Protásio et al. al., 2011). Thus, it is recommended to consider the proportion of other elemental chemical constituents for selecting and evaluating wood in the considered ages, with a view toward its energetic use.

In general, it is expected that wood with higher carbon content has a positive relationship with higher thermal resistance, and consequently a longer energy supply, due to the chemical nature of this element. However, it must be emphasized that hydrogen is the chemical element with the greatest capacity to provide energy from wood combustion. The vast majority of fuels (other than nuclear fuels) depends on the thermal effect resulting from the combustion of carbon and hydrogen. On the other hand, the presence of oxygen in the wood offers the disadvantage of diminishing its value as a fuel (Santos et al., 2013).

In relation to the significant equations for the nitrogen content, there is a decreasing tendency in the wood, bark and branches of *A. mearnsii* (Figure 2A) and *M. scabrella* (Figure 2B), as well as in the wood and bark of *E. grandis* (Figure 2C) and the bark and branches of *A. glazioviana* (Figure 2D). Likewise, this trend was observed for the oxygen content in leaf from the *A. mearnsii* (Figure 2E), *M. scabrella* (Figure 2F) and *E. grandis* (Figure 2G) species. This variation found in the nitrogen content may be associated with physiological activity, since smaller trees have a higher percentage of sapwood, as it is through this active region that the necessary compounds for the survival of the trees are translocated, and therefore the physiological activities are more intense in these than older trees. The significant values found show that nitrogen levels tend to be higher in trees with lower ages.

This trend of decreasing the nitrogen content in the wood with the increase in age can occur due to the genetic and consequently physiological differences of the trees, as well as the aspects related to soil fertility and fertilization, which was also verified by Neves et al. (2011) when studying *Eucalyptus* clones. However, the nitrogen concentrations observed in this study were higher than those found in the literature.

Regarding the sulfur content, there is a decreasing trend of *A. mearnsii* (Figure 1G) and *M. scabrella* (Figure 1J), and the *E. grandis* branches (Figure 1I). For the bark and branches of *A. glazioviana* (Figure 1H), there was a growing trend up to the third year, and a subsequent decrease in the sulfur content. Although they did not verify a significant difference for the sulfur content due to the size of the trees, Santana et al. (2012) concluded that the levels are conditioned to the type of species and the conditions of each planting site. These sulfur values are in agreement with those acceptable by the steel industry, which are all below 0.5% (Assis et al., 2012).

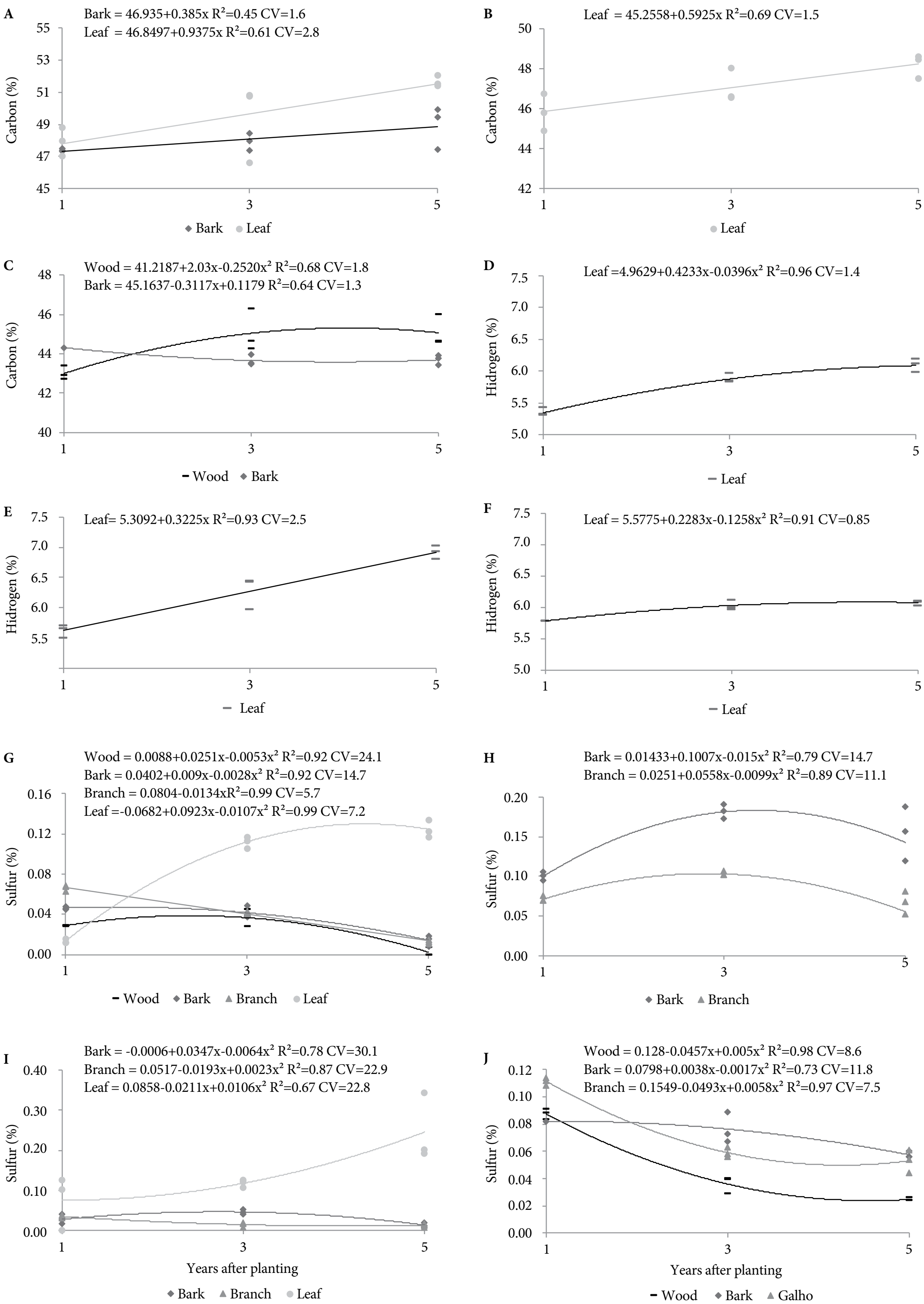

Figure 1. Estimated regression equations (*) for the carbon content of the different biomass compartments of the species *A. mearnsii* (A), *E. grandis* (B), *A. glazioviana* (C), for the hydrogen content in the leaf of *E. grandis* (D), *A. mearnsii* (E) and *M. scabrella* (F) and for the sulfur content in the four biomass compartments of *A. mearnsii* (G), *A. glazioviana* (H), *E. grandis* (I) and *M. scabrella* (J) in the first, third and fifth year after planting.

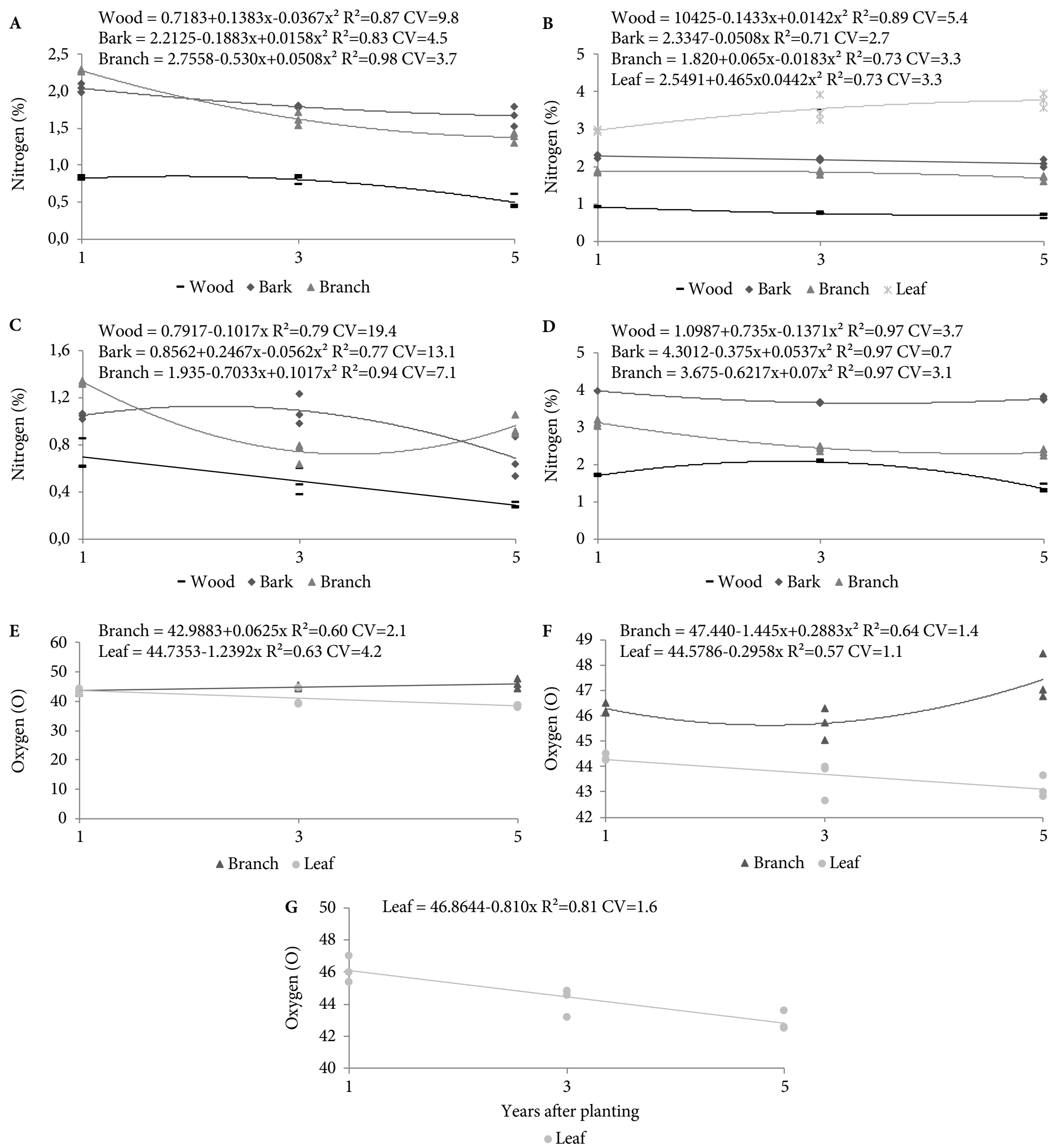

Figure 2. Estimated regression equations (*) for the nitrogen content in the different biomass compartments of the species *A. mearnsii* (A), *M. scabrella* (B), *E. grandis* (C) and *A. glazioviana* (D); and for the oxygen content in the branch and leaf compartments of the species *A. mearnsii* (E), *M. scabrella* (F), and leaf for *E. grandis* (G) in the first, third and fifth year after planting.

The sulfur and nitrogen elements contribute relatively little to the energy release of a fuel (Bilgen & Kaygusuz, 2008), showing a negative correlation with the calorific value (Bilang & Kaygusuz, 2008; Huang et al., 2009; Kumar et al., 2010), while high levels can cause environmental pollution when released into the atmosphere after the complete combustion of the fuel. Even though wood is a low-sulfur fuel, smaller percentages are always desired, thus avoiding the formation and emission of sulfur gases into the atmosphere.

This study corroborates the results of Santana et al. (2012), who found lower nitrogen concentrations at a more advanced age, together with minimum sulfur concentrations, indicating that the studied species can be used for energy production. The use of wood as fuel for energy supply requires elementary characterization, in particular to determine the amounts of nitrogen and sulfur.

The high concentrations of these two elements have a negative impact on the environment and human health. Nitrogen is directly related to the emission of NOx components (toxic nitrogen oxides), corrosion and ash deposition (Assis et al., 2018). In contrast, sulfur is related to the emission of sulfur dioxide (SO_2) and formation of acid rain, and consequently corrosion (Bilgen & Kaygusuz, 2008). In addition, when sulfur is present in high concentrations it can cause the formation of $FeCl_2$ and $ZnCl_2$, which are corrosive components in boilers (Telmo et al., 2010).

As it can be observed in most woods, low sulfur concentrations do not impede their energy use, similar to other biomasses reported in the literature (Neves et al., 2011; Bufalino et al., 2012). Thus, low proportions of this component suggest that the biomass compartments studied are environmentally adequate for energy production (Pattiya, 2011).

Age was a factor that influenced the characteristics of the source material. This change over time is mainly motivated by the marked modifications in the woody tissue characteristics, reflecting in the material's quality for producing energy. Thus, it is of fundamental importance to choose the species and the planting site, as well as the analysis of their interaction, as these reflect in changes in the elemental composition influencing the production and quality of the material for producing energy.

4. CONCLUSIONS

The three ages induced a significant effect on the elemental constituents of biomass, generating:

- Increased distribution of the hydrogen content of *A. mearnsii*, *M. scabrella* and *E. grandis* leaf, and for the carbon content of *A. mearnsii* bark and leaf, and for *E. grandis* and *A. glazioviana* leaf.
- A decreased distribution of the nitrogen content in the wood, bark and branches of *A. mearnsii* and *M. scabrella*, in the wood and bark of *E. grandis* and in the branches of *A. glazioviana*. For the oxygen content in the leaf of *A. mearnsii*, *M. scabrella* and *E. grandis*, and for the sulfur content in the wood, bark and branches of *A. mearnsii* and *A. glazioviana*, and for *E. grandis* branches.
- The use of trees at any age enables energetic use; however, the fifth year presents the best carbon and hydrogen values, being the best age for the energetic use of the biomass of these different species.

The four forest species and the four compartments of the biomass differ in relation to the elementary constituents.

In general, the higher values of the elemental constituents of hydrogen and nitrogen were verified for *A. glazioviana*, those of carbon in general for *A. mearnsii*, those of sulfur for *M. scabrella* and the highest oxygen values were reported for *E. grandis*.

The biomass of the *A. mearnsii* and *A. glazioviana* species generally has greater potential for energy purposes, considering the carbon and hydrogen values. The *E. grandis* species is less recommended for this purpose, considering the same criteria.

SUBMISSION STATUS

Received: 19 Apr., 2016
Accepted: 12 Sept., 2018

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FINANCIAL SUPPORT

National Council for Scientific and Technological Development (CNPq – Brazil).

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