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FUEL PROPERTIES OF FOREST RESIDUES RECOVERED FROM FULL EUCALYPTUS TREE HARVESTING IN DIFFERENT CHIP PRODUCTION SCENARIOS

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Resumo

Propriedades combustíveis de resíduos florestais recuperados da colheita de árvores de eucalipto em diferentes cenários de produção de cavacos. Este estudo tem como objetivo avaliar as propriedades combustíveis de resíduos florestais recuperados de povoamentos de *Eucalyptus saligna* e *E. urophylla* × *E. grandis* aos sete anos de idade e em cinco cenários de produção de cavacos. Para isso, um inventário florestal foi realizado para estimar a biomassa seca, seguido da colheita de árvores inteiras com diâmetros mínimos de fuste iguais a 8, 10, 12 e 14 cm para madeira para celulose e árvores inteiras para energia (tratamentos). Foram avaliados os teores de umidade, material volátil, carbono fixo e cinzas, bem como o poder calorífico superior e inferior dos cavacos. A quantidade de biomassa seca foi comparada entre os povoamentos pelo teste t ($\alpha = 0{,}05$) e as propriedades do combustível foram avaliadas entre os diâmetros mínimos do fuste, no mesmo povoamento, pelo teste de Tukey ($\alpha = 0{,}05$). Os maiores valores de umidade dos cavacos foram obtidos nos maiores diâmetros mínimos do fuste, uma vez que apresentou aumento de até 88% na umidade para o povoamento de *E. urophylla* × *E. grandis*. Os resultados dos teores de material volátil, carbono fixo e cinzas mostraram que os resíduos recuperados de *E. saligna* foram mais suscetíveis a variações nos diâmetros mínimos do fuste, com redução de até 53% no teor de cinzas entre o menor diâmetro e as árvores inteiras. Os valores de poder calorífico superior e inferior não mostraram diferenças estatísticas entre os diâmetros mínimos do fuste em povoamentos de eucalipto.

Palavras-chave: Teor de cinzas; biomassa; poder calorífico superior; compartimentos das árvores.

Abstract

This study aims to evaluate the fuel properties of forest residues recovered from *Eucalyptus saligna* and *E. urophylla* × *E. grandis* stands at seven years old in five chip production scenarios. A forest inventory was conducted to estimate the dry biomass, followed by full-tree harvesting with minimum stem diameters equal to 8, 10, 12, and 14 cm for pulpwood, as well as the full trees for energy purposes (treatments). Moisture, volatile matter, fixed carbon, ash contents, and higher and lower heating values of chips were evaluated. The dry biomass was compared between stands by the t-test ($\alpha = 0.05$) and the fuel properties were assessed between minimum stem diameters in the same forest stand by the Tukey's test ($\alpha = 0.05$). Higher chip moisture was obtained in the larger minimum stem diameter, since it showed an increased up to 88% in moisture for the *E. urophylla* × *E. grandis* stand. Volatile matter, fixed carbon, and ash results showed that the recovered residues of *E. saligna* were more susceptible to variations in minimum stem diameters, with up to 53% reduction in ash content between the smallest diameter and full trees. Higher and lower heating values showed non-statistical differences between the minimum stem diameters in *Eucalyptus* stands.

Keywords: Ash content; biomass; higher heating value; tree compartments.

INTRODUCTION

The energy demand for renewable sources in Brazil and world has been growing significantly in recent years due to the need to reduce greenhouse gas emissions (BAIS *et al.*, 2015; WELFLE, 2017). In this context, forest biomass has many advantages as an essentially carbon neutral energy source (DEMIRBAS, 2004; WELFLE *et al.*, 2017). This biomass can come from solid wood, sawmill residues, and forest residues recovered from wood harvesting that are not used in solid wood market, in the pulp and paper industry and other segments.

Cultivated forest stands can be harvested according to two main systems (MACHADO *et al.*, 2014): cut-to-length harvesting (CTL) and full-tree harvesting (FTH). The first processes trees on the stump and transports the logs to the roadside, while the second is based on extracting unprocessed full trees to the roadside, where they are processed in commercial assortments with the residue disposal occurring at this place. FTH in Brazil enables the use of forest residues recovered from wood harvesting as a renewable energy source by means of feller-bunchers, grapple-skidders, harvesters, and grinders.

The use of forest residues recovered from FTH facilitates subsequent forestry operations, is considered a renewable energy source and is carbon neutral (WELFLE, 2017). Its use as an energy source makes it necessary to understand their fuel properties and its composition in detail (wood, bark, branches, and leaves). This need arises from interlocking problems in the boiler feed system caused by fine dust, material compressibility, and moisture (DAI *et al.*, 2012; RACKL; GÜNTHNER, 2016). Furthermore, these problems depend on the harvester's technology, the timing to drag and stack the residues, as well as the choice of chip size at the output of the grinder. Thus, increasing the amount of wood from full trees with fine particle residues combined with adequate moisture can ensure continuous flow to the reactor.

Higher and lower heating values, moisture, volatile matter, fixed carbon, and ash contents are the main fuel properties to be assessed. These fuel properties of the recovered forest residues may be variable according to the minimum stem diameters of the trees for pulpwood, as well as from the use of full trees for energy. Thus, alternative chip production scenarios may provide different wood, bark, branch, and leaf percentages in the recovered forest residues.

Therefore, this study was motivated by problems which occur in the boiler feeders of a pulp and paper company in the South of Brazil. Since the literature describes that screw feeder locks are caused by very fine materials, ashes, and moisture, including other properties such as granulometry and the wood, bark, branch, and leaves percentages (DAI *et al.*, 2012; RACKL; GÜNTHNER, 2016), our goal is to solve this problem by improving the quality of forest *Eucalyptus* residues recovered from wood harvesting by increasing the minimum stem diameter for pulpwood, or even using full trees for energy.

Decisions to change the minimum tree stem diameter for pulpwood and the use of full trees for energy should be planned, in which the fuel properties of recovered forest residues in different chip production scenarios should be known to assist managers in their decision-making. Thus, this study aims to evaluate the fuel properties of forest residues recovered from different *Eucalyptus* clone stands at seven years old in five chip production scenarios obtained with 8, 10, 12 and 14 cm of minimum tree stem diameters for pulpwood and full trees for energy purposes.

MATERIAL AND METHODS

This study was carried out in seven-year-old *Eucalyptus saligna* Smith and hybrid *Eucalyptus urophylla* S. T. Blake and *Eucalyptus grandis* W Hill ex Maiden clone stands located in Paraná State, Southern Brazil (coordinates: 24°26' S and 50°45' W). These clone stands had an initial spacing of 3.75 m × 2.40 m and established in the same site class (Table 1).

Table 1. Characteristics of *E. saligna* and *E. urophylla* × *E. grandis* stands.
Tabela 1. Características dos povoamentos de *E. saligna* and *E. urophylla* × *E. grandis.*

Characteristics	*E. saligna*	*E. urophylla* × *E. grandis*
Age (years)	7	7
Diameter at breast height (cm)	18.7 ± 2.6	18.2 ± 3.0
Total height (m)	31.4 ± 3.1	31.7 ± 3.0
Dominant height (m)	34.1 ± 0.4	34.1 ± 0.8

A forest inventory was initially carried out to measure the diameter at breast height and total height of the trees. The required sample plots (*n*) were determined by the coefficient of variation (*cv*) of diameter at breast height for finite population (equation. 1), according to Kershaw *et al.* (2017).

$$n = \frac{N \times t^2 \times cv^2}{N \times LE^2 + t^2 \times cv^2} \quad (1)$$

In which: *n* is required sample plots, *N* is total plots in the population, *cv* is coefficient of variation (%), *LE* is allowable limit of error equal to 10%, and *t* value (α = 0.05).

Sample plots were randomly allocated with average dimensions of 37.1 m × 23.3 m and 30.5 m × 24.9 m in *E. saligna* and *E. urophylla* × *E. grandis* stands, respectively, due to the applied topographic slope corrections. A total of 8 and 12 plots were respectively allocated in the stands, considering 7 and 9 sampling plots required for an allowable limit of error equal to 10%. Thus, five diameter-at-breast-height classes were obtained, which made it possible to define the sample trees for green biomass quantification (Table 2).

Table 2. Diameter tree distribution and sampling in the *E. saligna* and *E. urophylla* × *E. grandis* stands.
Tabela 2. Distribuição diamétrica das árvores e amostragens nos povoamentos de *E. saligna* and *E. urophylla* × *E. grandis*.

Diameter class	Lower limit	Midpoint	Upper limit	*f*	Number of sampled trees	
		(cm)			*E. saligna*	*E. urophylla*×*E. grandis*
1	7.0	9.0	10.9	35	2	2
2	11.0	13.0	14.9	186	5	5
3	15.0	17.0	18.9	885	11	11
4	19.0	21.0	22.9	914	10	10
5	23.0	25.0	27.5	51	2	2
Total				2,071	30	30

Legend: *f* is frequency of trees per hectare.

The green biomass of trees was quantified in the field by the destructive method, in which tree compartments (wood, bark, branches, and leaves) were partitioned and weighed using a 0.01 g precision digital winch scale with a capacity of 500 kg. Subsamples were obtained to assess moisture and dry biomass, in which 3 cm thick disks were sampled at 0%, 25%, 50%, and 75% of the tree stems for wood and bark compartments, and subsamples were collected at the top, middle, and base of stems for branches and leaves.

Biomass samples were dried in an oven with cross-air circulation at 105ºC until constant weight and moisture determined by equation 2 (TELMO; LOUSADA, 2011). The values were used to determine the dry weight of the sampled components. Dry biomass estimates were subsequently performed by multiplying the absolute frequency of trees in each diameter class per plot.

$$w = \frac{(m_2 - m_3)}{(m_2 - m_1)} \times 100 \quad (2)$$

In which: w is moisture (%), m_1 is empty weight dish mass (g); m_2 is empty weight dish mass plus sample before drying (g); m_3 is empty weight dish mass plus sample after drying (g).

Forest stands were harvested by the full-tree harvesting system (FTH), with minimum stem diameters for pulpwood equal to 8, 10, 12, and 14 cm, as well as full trees for energy purposes corresponding to the treatments of this study (T1-8, T2-10, T3-12, T4-14 e T5-FT), totaling 1,000 trees per treatment. Fresh trees were extracted and the residues remained at the roadside. After 60 days of storage in the field, the recovered forest residue was ground by a CBI 6,400 horizontal grinder.

Grinding was performed on the ground homogeneously and it was continuously carried out along the wood pile, in which five samples were randomly collected in each treatment. Samples with approximately 1 kg of wet material were packed in plastic bags and sent to the laboratory.

The treatments called T1-8, T2-10, T3-12, T4-14, and T5-FT refer to the amount of forest residues recovered after the pulpwood processing, which are composed by the end section of the stems, bark, branches, and leaves. For pulpwood, stems with bark were sectioned in 7.2 m logs, in addition to a log in the final section of the stems with a length greater than 2.40 m, up the minimum diameters of 8, 10, 12 and 14 cm. The end section of the stems below the minimum diameters mentioned above, bark, branches, leaves, and full trees were used for energy. These treatments provided a different dry biomass percentage per hectare between pulpwood and residue recovered for energy (Table 3).

Table 3. Dry biomass percentage per hectare between pulpwood and residue recovered for energy in the evaluated treatments.
Tabela 3. Percentual de biomassa seca por hectare entre madeira para celulose e resíduo recuperado para energia nos tratamentos avaliados.

Treatments	*E. saligna*		*E. urophylla*×*E. grandis*	
	Pulpwood (%)	Energy (%)	Pulpwood (%)	Energy (%)
T1-8	91	9	93	7
T2-10	84	16	87	13
T3-12	75	25	78	22
T4-14	59	41	64	36
T5-FT	0	100	0	100

NBR 14929-17 of the Brazilian Association of Technical Standards (ABNT, 2017) was used to determine moisture and D1762-84 of the American Society for Testing and Materials (ASTM, 2007) was applied to quantify volatile matter, fixed carbon, and ash contents. Higher heating value (*HHV*) was performed according to D 5865-13 of the American Society for Testing and Materials (ASTM, 2017) in a calorimetric pump, while the lower heating values (*LHV*) was calculated using equation 3 (DOAT, 1977).

$$LHV = HHV - \left(600 \times 9 \times \frac{H\%}{100}\right) \quad (3)$$

In which: *LHV* is the lower heating value (kcal kg^{-1}), *HHV* is the higher heating value (kcal kg^{-1}), and *H*% is average hydrogen content of forest biomass, being 6% for *Eucalyptus* sp. (SILVA *et al.* 2015, BRUN *et al.* 2018).

The Student's t-test was applied to compare dry biomass per hectare between stands (*E. saligna* and *E. urophylla* × *E. grandis*), considering the inventory plots as repetitions ($\alpha \leq 0.05$). In addition, a completely randomized design with four minimum stem diameters for pulpwood (8, 10, 12, and 14 cm) and full trees for energy was considered in this study for fuel evaluation, assuming the chip samples as repetitions. This experiment was evaluated by analysis of variance and Tukey's test ($\alpha \leq 0.05$), in which the data had normality by Shapiro-Wilk's test and homogeneity by Bartlett's test ($\alpha \leq 0.05$).

The analysis of the relationship between tree compartments and ash content (Figure 4) was carried out using the values of wood, bark, branches and leaves present in the recovered forest residue estimated by the forest inventory, while the ash content data were obtained by the chip analysis.

RESULTS

The recovered forest residue treatments with minimum stem diameters for pulpwood (T1-8 to T4-14) and full trees for energy (T5-FT) showed an increase of dry biomass per hectare with the increase in stem diameter (Table 4). However, these values did not present statistical differences between stands, except for T5-FT with higher dry biomass in the *E. grandis* × *E. urophylla* stand ($\alpha \leq 0.05$).

Table 4. Dry biomass of forest residue recovered from *E. saligna* and *E. urophylla* × *E. grandis* stands.
Tabela 4. Biomassa seca dos resíduos florestais recuperados oriundos dos povoamentos de *E. saligna* and *E. urophylla* × *E. grandis.*

Treatments	*E. saligna* (t ha^{-1})	*E. urophylla* × *E grandis.* (t ha^{-1})	Statistical significance
T1-8	18.3	17.9	ns
T2-10	33.7	32.0	ns
T3-12	52.0	54.9	ns
T4-14	84.4	90.1	ns
T5-FT	210.0	249.5	*

Legend: ns is non-significance between *Eucalyptus* stands, and * is significance between *Eucalyptus* stands ($\alpha \leq 0.05$).

The average chip moisture contents showed a statistical difference ($\alpha \leq 0.05$) between residues from minimum stem diameters for pulpwood after 60 days stored in the field (Figure 1), with higher moisture contents in T4-14 and T5-FT. In addition, the *E. saligna* stand had difficulty from losing moisture, since it showed a tendency of higher values than the *E. urophylla* × *E. grandis* stand.

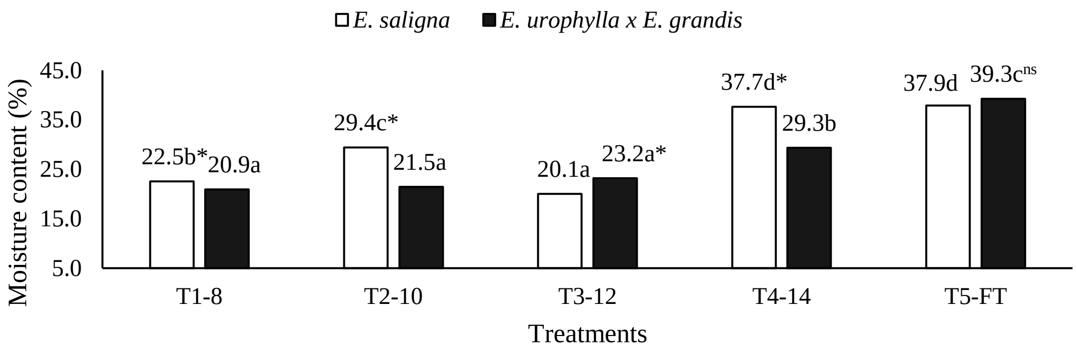

Figure 1. Moisture content of recovered forest residues. Average values followed by the same letters do not differ between treatments in the same *Eucalyptus* stand by the Tukey's test ($\alpha \leq 0.05$). Average values

followed by ns do not differ between *Eucalyptus* stands in the same treatment, and * differ between *Eucalyptus* stands in the same treatment by the t-test ($\alpha \leq 0.05$).

Figura 1. Umidade dos resíduos florestais recuperados. Os valores médios seguidos das mesmas letras não diferem entre os tratamentos em um mesmo povoamento de eucalipto pelo teste de Tukey ($\alpha \leq 0,05$). Os valores médios seguidos por ns não diferem entre povoamentos de *Eucalyptus* em um mesmo tratamento, e * diferem entre povoamentos de *Eucalyptus* em um mesmo tratamento pelo teste t ($\alpha \leq 0,05$).

Volatile matter contents increased with the largest minimum stem diameters (Figure 2a), while the opposite behavior was observed for fixed carbon contents (Figure 2b) and ash (Figure 2c). Volatile matter showed an increase in the *E. saligna* stand, changing from 79.6% to 81.7% between T1-8 to T5-FT treatments, respectively (Figure 2a). On the other hand, this variable did not show statistical difference between T1-8 and T4-14 in the *E. urophylla* × *E. grandis* stand (Figure 2a).

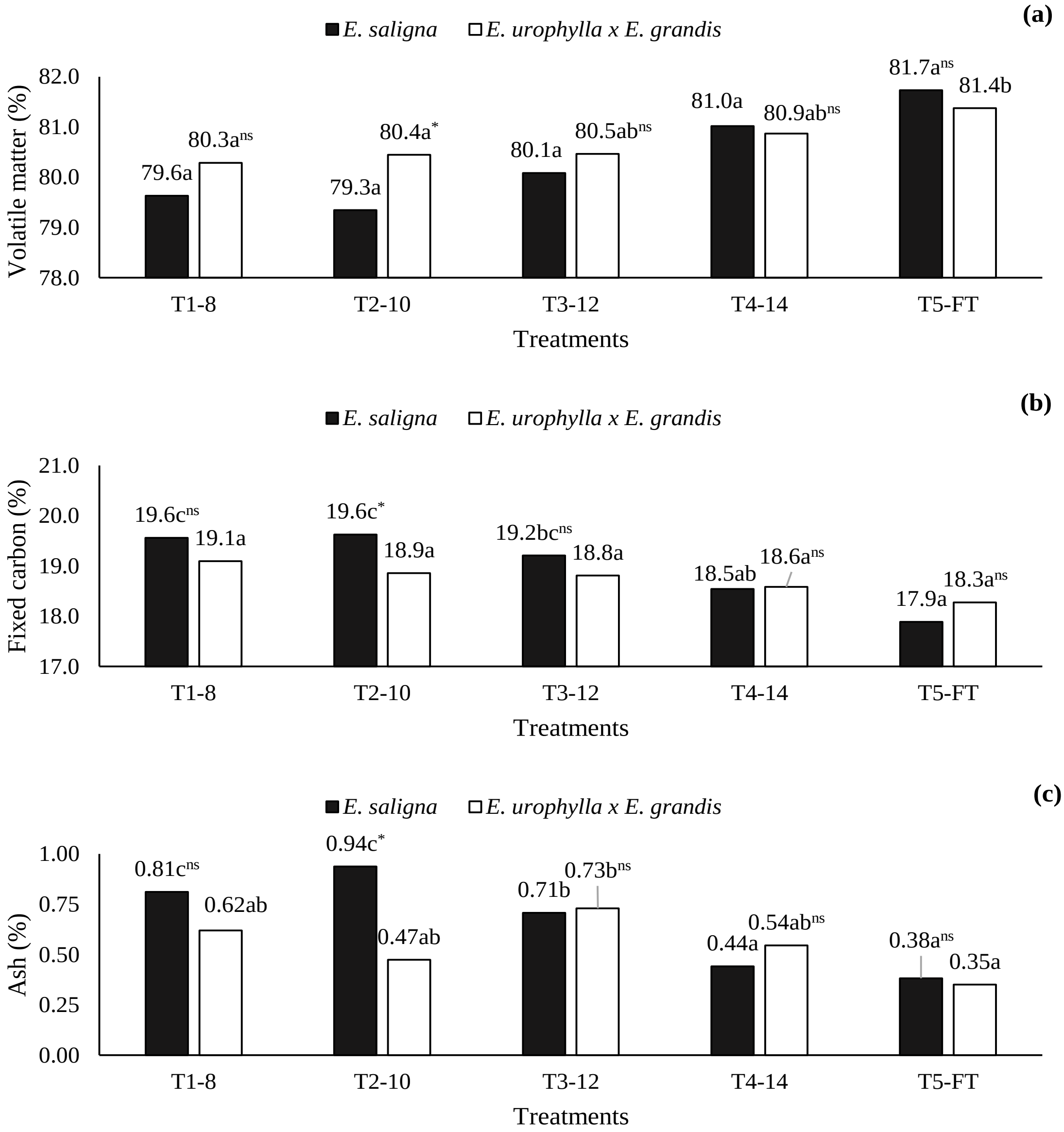

Figure 2. Volatile matter (a), fixed carbon (b), and ash (c) contents of recovered forest residues. Average values followed by the same letters do not differ between treatments in the same *Eucalyptus* stand by the Tukey's test ($\alpha = 0.05$). Average values followed by ns do not differ between *Eucalyptus* stands in the same treatment, and * differ between *Eucalyptus* stands in the same treatment by the t-test ($\alpha = 0.05$).

Figura 2. Teores de material volátil (a), carbono fixo (b) e cinzas (c) dos resíduos florestais recuperados. Os valores médios seguidos pelas mesmas letras não diferem entre os tratamentos em um mesmo eucalipto pelo teste de Tukey ($\alpha \leq 0,05$). Os valores médios seguidos por ns não diferem entre povoamentos de eucalipto em um mesmo tratamento, e * diferem entre povoamentos de eucalipto em um mesmo tratamento pelo teste t (α = 0,05).

Wood proportions in forest residues recovered from the *E. urophylla* × *E. grandis* stand (Figure 3b) were more constant than the *E. saligna* stand (Figure 3a), mainly at T3-12 to T5-FT. These results possibly affected the fuel properties, in which *E. saligna* was more susceptible to the evaluated treatments, since the wood proportion in the forest residues varied from 48% to 85% (Figure 3a), and between 66% and 87% for *E. urophylla* × *E. grandis* (Figure 3b).

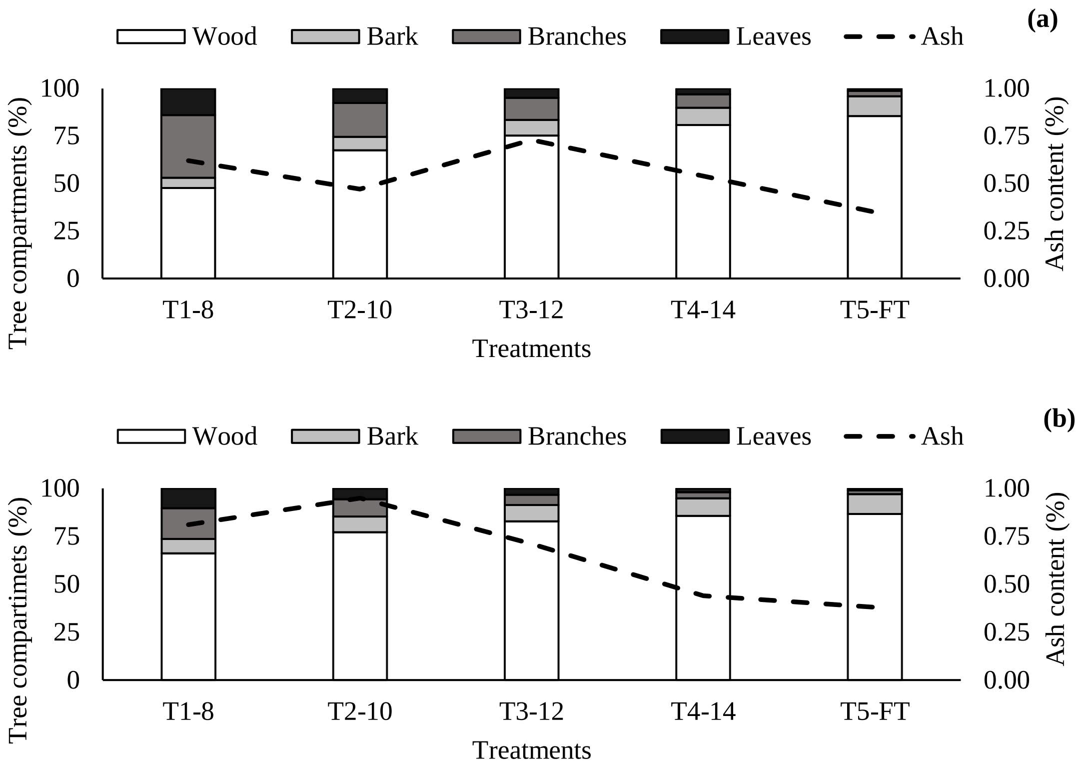

Figure 3. Tree compartments and ash content of forest residues recovered from *Eucalyptus saligna* (a) and *Eucalyptus urophylla* × *Eucalyptus grandis* (b) stands.
Figura 3. Compartimentos de árvores e teores de cinzas de resíduos florestais recuperados de povoamentos de *Eucalyptus saligna* (a) e *Eucalyptus urophylla* × *Eucalyptus grandis* (b).

The bark proportion for *E. saligna* tended to increase with increasing minimum stem diameter (Figure 3a) and then remained constant for *E. urophylla* × *E. grandis* (Figure 3b). On the other hand, branch and leaf proportions decreased with the increase in minimum stem diameter for both stands, while the ash content oscillated within a small range of values less than 1%.

Higher and lower heating values of *E. saligna* and *E. urophylla* × *E. grandis* did not present statistical differences (α ≤ 0.05) between the minimum stem diameters and full trees (Figure 4a and 4b). In addition, the higher and lower heating values for full trees (T5-FT) were higher for *E. urophylla* × *E. grandis* than for *E. saligna*, in which an opposite behavior was observed for T4-14, as well as more similarity among other treatments between stands.

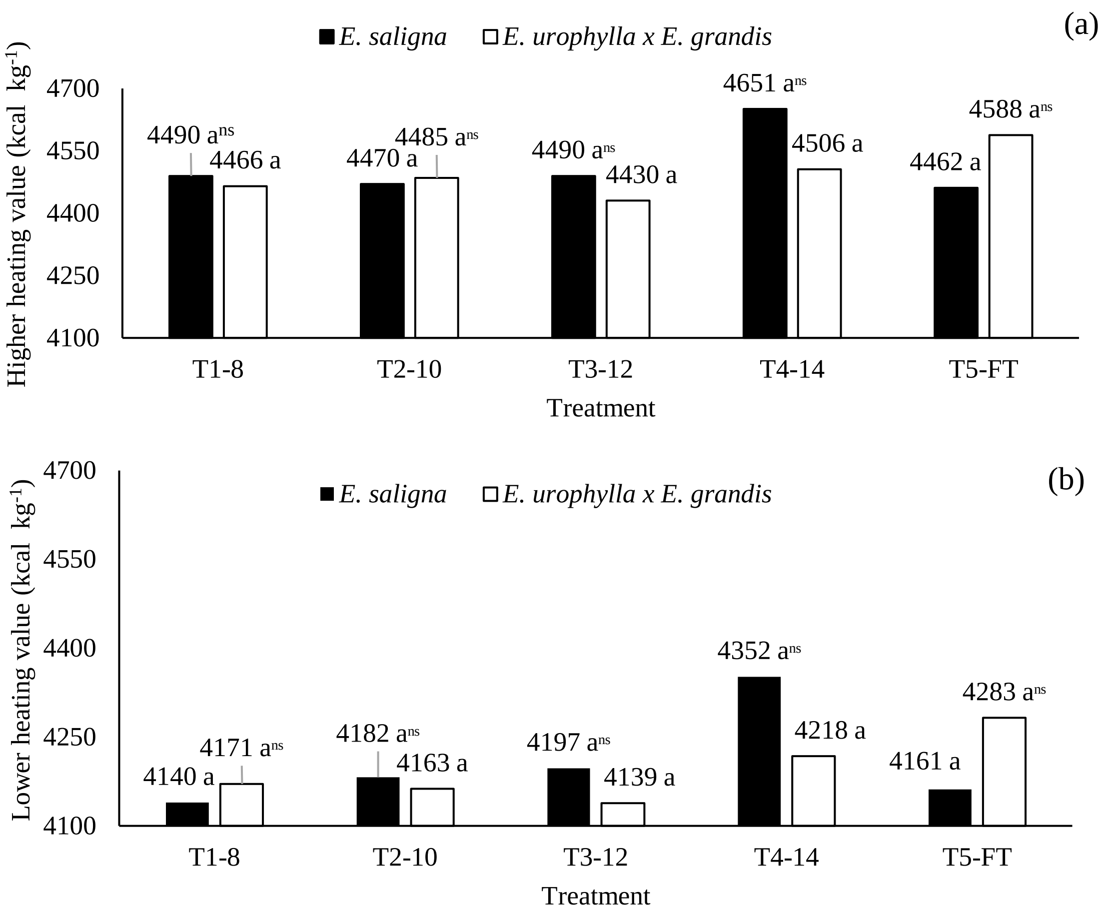

Figure 4. Higher (a) and lower (b) heating values of recovered forest residues. Average values followed by the same letters do not differ between treatments in the same Eucalyptus stand by the Tukey's test ($\alpha = 0.05$). Average values followed by ^{ns} do not differ between Eucalyptus stands in the same treatment, and * differ between Eucalyptus stands in the same treatment by the t-test ($\alpha = 0.05$).

Figura 4 Valores de poder calorífico superior (a) e inferior (b) dos resíduos florestais recuperados. Os valores médios seguidos pelas mesmas letras não diferem entre os tratamentos em um mesmo povoamento de eucalipto por meio do teste de Tukey ($\alpha = 0{,}05$). Os valores médios seguidos por ^{ns} não diferem entre povoamentos de eucalipto em um mesmo tratamento, e * diferem entre povoamentos de eucalipto em um mesmo tratamento pelo teste t ($\alpha = 0{,}05$).

DISCUSSION

In this study, forest residue recovered from wood harvesting in *Eucalyptus* clone stands were characterized considering different minimum tree stem diameters for pulpwood and the use of full trees for energy. Thus, residues recovered from 8 cm minimum stem diameter (T1-8) showed lower dry biomass (Table 3), in which a large forest grinder may be underutilized, since dry biomass production is below the economic threshold of 35 t ha^{-1} established to reduce the grinder's movement. On the other hand, residues recovered from 10 cm minimum stem diameter for pulpwood (T2-10) are close to this value (Table 4), reaching 210.0 and 249.5 t ha^{-1} in the full trees for energy treatment (T5-FT) for *E. saligna* and *E. urophylla* × *E. grandis* stands, respectively.

The use of recovered forest residues or full trees for energy implies in different grinder performance. According to Assirelli *et al.* (2013), full trees required more engine power when comparing the chipping of full trees and final stem sections, but resulted in double productivity and lower fuel consumption. Therefore, similar to studies by Röser *et al.* (2012), Spinelli *et al.* (2018), and Choi *et al.* (2019) regarding the grinder's mechanical performance, wear of parts, screen size, and torque programming are recommended, because this variation in grinder performance may influence the amount of fine dust present in the chips produced, so complementary studies are necessary regarding the different grinder operational factors which may affect chip quality.

Considering the moisture results (Figure 1), it is important to change the drying program for recovered forest residues with larger minimum stem diameters and for full trees, since a longer storage time in the field is required (MANZONE, 2015). However, increased storage time can lead to operational problems in forestry due to loss of planting area, which consequently leads to having to readjust the forestry operations scheduling. Furthermore, wood can reach a point of moisture loss in the field, in which the moisture reduction should be carried out in industry.

Volatile matter contents can be useful to estimate the degree of chip combustion. Lower volatile matter values with higher fixed carbon content results in slower burning and longer time required for complete chip burning. This knowledge enables sizing furnaces and estimating flame formation in biomass oxidation or reduction.

Ash contents for *E. saligna* were affected by the minimum stem diameters, with a reduction from 0.94% to 0.38%, and more similar between the treatments for *E. grandis* × *E. urophylla* (Figure 2c), whose results are consistent with other *Eucalyptus* studies (COATES *et al.*, 2017; SIMETTI *et al.*, 2018). Although the ash content is lower than other components (Figure 3a and 3b), it can be considered an indicator for choosing *Eucalyptus* clones for energy purposes, as *E. urophylla* × *E. grandis* showed a non-statistical difference between residues with a minimum diameter of 10 cm and full trees, and *E. saligna* was more susceptible to the evaluated treatments.

The reduction of branch and leaf proportions in the forest residues by the T4-14 and T5-FT treatments provided a decrease in ash content (Figure 3a and 3b). The leaf/ash relationship showed a similar pattern to that verified by Baker *et al.* (2012). In addition, these results corroborate with Simetti *et al.* (2018), in which the ash content was higher in bark, followed by branches, leaves, and wood in *Eucalyptus* stands. These values can also be related to the amount of nutrients in each tree compartment (GUIMARÃES *et al.*, 2019; HABITZREITER *et al.*, 2019).

Higher heating values (*HHV*) were 4,462 to 4,651 kcal kg^{-1} for *E. saligna* and 4,430 to 4,588 kcal kg^{-1} for *E. urophylla* × *E. grandis* (Figure 4a) and can be related to the proportion of tree compartments in the residue chips. For Simetti *et al.* (2018), *HHV* is higher in wood and branches, while bark had the lowest *HHV*. Therefore, increasing the wood proportion in recovered forest residues improves its fuel properties. The same behaviour was observed for the lower heating value (*LHV*), which showed the relationship between heating values and chemical elements in the chips, since the higher amount of carbon and hydrogen in biomass resulted in higher heating values.

Finally, regarding the interlocking problems in the boiler feed system that motivated this study, there is a need for complementary studies related to fine dust and moisture content, as suggested by Dai *et al.* (2012) and Rackl and Günthner (2016). It is suggested that future studies may evaluate the influence of the drying time in the field of recovered forest residues, since this study showed the need to reprogram the period usually used (60 days), mainly for the T4-14 and T5-FT treatments, which presented higher moisture content. In addition, studies on the performance of the power boiler with the referred treatments are necessary.

CONCLUSIONS

- Residues with minimum stem diameters for pulpwood above 10 cm make it possible to reach the dry biomass concentration required at the economic threshold for the use of recovered forest chip residues. The minimum stem diameter for pulpwood also influenced the chip moisture content, since it showed an increase of 68 and 88% in moisture between 8 cm diameter and full trees for *E. saligna* and *E. urophylla* × *E. grandis*, respectively, which can be a variable to be considered to define field storage scheduling;
- Volatile matter, fixed carbon, and ash content results showed that the recovered residues of *E. urophylla* × *E. grandis* were less susceptible to variations in minimum stem diameters than *E. saligna*. The ash content was the most varied, with a reduction of 43% and 53% between 8 cm diameter and full trees for *E. saligna* and *E. urophylla* × *E. grandis*, respectively.
- Higher and lower heating values showed non-statistical differences between the minimum stem diameters in *Eucalyptus* stands. Therefore, all fuel properties, such as moisture, volatile matter, fixed carbon and ash content need to be jointly evaluated to define the minimum diameter for pulpwood in chip production. Thus, minimum diameters from 10 cm were most feasible for *E. urophylla* × *E. grandis* and *E. saligna* for these conditions, considering moisture and ash content aspects.

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