Renewable Energy 121 (2018) 309–314

Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

Management of *Eucalyptus* short-rotation coppice and its outcome on fuel quality

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ARTICLE INFO

Article history:
Received 10 August 2017
Received in revised form
20 November 2017
Accepted 12 January 2018

Keywords:
Thermochemical properties
Biomass
Energy crops
Short rotation coppice
Bioenergy

ABSTRACT

Earlier experiments with young *Eucalyptus* short-rotation coppice (SRC) in tropical environment have not evaluated the quality of whole-tree biomass fractions, and as such their total energy potential is still unknown. As this system is managed with a higher planting density and fertilization level compared to conventional plantations, the quality of forest biomass needs to be assessed. Hence, the goal of this study was to analyze how the short-rotation coppice affected the quality of stem, branches, and leaves used for power generation. Samples were collected from high-density plantation of *Eucalyptus* at two years old, and the thermochemical properties were evaluated. Carbon and ash content were lower for the stem fraction in higher density of planting, although the higher heating value was not significantly different from each treatment. Overall, the fuel quality of whole-forest biomass was not influenced by management practices. Statistically significant differences were found only between the whole-tree fractions. *Eucalyptus* SRC provided biomass qualitatively close to that from conventional forest systems and has potential to be quickly and feasible energy option.

1. Introduction

Biomass feedstock is a pathway to achieve a low carbon footprint in the future [1,2]. Perennial bioenergy crops appear to be important players for developing sustainable land use [3].

Solid biomass be combusted directly in boilers to produce heat and electricity or used to provide derived fuels from thermochemical processes (viz., pyrolysis, gasification, and liquefaction) [4] or as bio-oil [5]. With respect to biomass use in power generation, knowledge about their composition and properties as well as environmentally safe handling are necessary [6,7].

Considerable variation is seen in the elemental, immediate, structural, and chemical composition of the biomass (agricultural and forest crops) types [8–10]. These variations have notable impact on each step of the whole supply chain, such as handling of raw materials, transportation, drying, storage, and the design of the power conversion systems [11]. Moreover, thermochemical properties are very important in ranking the best resources for power generation [12,13].

High-density energy wood plantation has been regarded as a renewable resource worldwide. Studies have been conducted on *Salix* and *Populus* species managed in SRC in Europe [14,15]. In South America, especially in Brazil, *Eucalyptus* species have been used for SRC management [16], as these plantations provide a high productivity in a small planting area, about 19 t dry matter ha^{-1} $year^{-1}$ with harvesting cycles of two to three years [17]. Whole-tree biomass from SRC is harvested and chipped simultaneously by a modified forager and transported to thermal power plants [18].

Some doubts remain about the effect of this management system on the fuel quality (proximate and elemental chemical composition) of such young material. For *Populus* species, Monedero et al. [13] observed that planting density had a more significant effect on combustion properties than site characteristics (such as soil properties).

Recent experiments with young *Eucalyptus* SRC in a tropical environment [14,15] did not evaluate the quality of whole-tree biomass fractions (stem, branches, and leaves), and very little is known about its energy potential. Hence, the goals of this study were: (1) to determine the thermochemical properties of *Eucalyptus* SRC for bioenergy purposes, and (2) the effect of different

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https://doi.org/10.1016/j.renene.2018.01.033

planting densities and fertilization regimes on whole-tree biomass.

2. Materials and methods

2.1. Sampling and material preparation

This work was carried out at Botucatu (22° 53′ 09″ S and 48° 26′ 42″ W) in São Paulo state of Brazil. The local area has an average altitude of 872 m a.s.l., a mean annual precipitation of about 1428 mm year^{-1}, and an annual average temperature of 20 °C.

Plantations of interspecific hybrid clone, *Eucalyptus urophylla* × *Eucalyptus grandis* were established for two years, each with high, but different, planting densities and fertilization regimes. Plots (450 m^2 each) had two different spacing modules: 2.8 × 0.5 m (7142 trees hectare^{-1}) and 2.8 × 1.5 m (2380 trees hectare^{-1}). Table 1 shows the two different fertilization regimes in which dose 1 corresponds to one-quarter of dose 2 (the conventional dose).

Two years after planting, the diameter at breast height (DBH) and height of all trees on the plots, as well as of randomly selected four mean tree samples per treatment were measured. Each tree was divided into three fractions: stem, branches, and leaves, and a composite sample was used for each biomass fraction. The branches and leaves of the trees were removed. Then, five discs were collected at the following positions along the stem: 0%, 25%, 50%, 75%, and 100% of total stem height according to the method described by Ref. [19].

For the fuel quality analysis, an experimental design of completely randomized blocks with 2 spacing density × 2 fertilization regimes × 3 biomass fractions × 3 repetitions was finalized.

2.2. Laboratory procedures and properties

Forest biomass was sawed in Wiley type mill followed by sifting in 40–60 mesh screens. The thermochemical properties were determined according to standard methods (see Table 2).

Ultimate composition (CHNS) was obtained at elemental analyzer model 2400 Parkin Elmer by modified Pregl-Dumas method. Then, oxygen content was determined as the balance out of 100% [20].

2.3. Statistical analysis

Data normality was assessed by Shapiro-Wilk's test ($p < .05$). The effect of density planting (D), fertilization level (F), and biomass fraction (B) on thermochemical properties of *Eucalyptus* SRC was evaluated by ANOVA complemented by Tukey's test ($p < .05$). Biomass fraction was taken into account as the whole-tree biomass was used for bioenergy purposes [26,27].

Table 1
Description of the fertilization regimes.

Fertilizing levels	Days after planting	Dose 1	Dose 2
Fertilizer		g plant^{-1}	
NPK (6-30-10)	0	35.0	140
NPK (19-00-19) + B (0.7%) e Zn (3%)	180	27.5	110
NPK (19-00-19) + B (0.7%) e Zn (3%)	360	27.5	110

Table 2
Summary of standards and methods used to assess the forest biomass properties.

Properties	Initials	Standards and methods
Carbon, hydrogen, nitrogen, sulfur	CHNS	Pregl-Dumas method
Oxygen	O	[20]
Ash	A	[21]
Fixed carbon	FC	[20]
Volatile matter	VM	[22]
Holocellulose	HC	Delignification using $NaClO_2$
Acid-insoluble lignin	L	[23]
Total extractives	E	[24]
Higher Heating Value	HHV	[25]

3. Results and discussion

3.1. Fuel quality of whole-biomass of Eucalyptus SRC for bioenergy use

All treatments were statistically different among biomass fractions—stem, branches, and leaves (Table 3), and larger differences were observed between woody fractions and leaves.

Leaf biomass had higher hydrogen and carbon content than other fractions, which contributed to more energy released on combustion. Positive correlation has been observed between the amount of these elements and the calorific value of the biomass [28]. However, the leaves have a higher amount of nitrogen and sulfur which can damage the environment due to emissions of their ozone-depleting oxides [29]. Results above the limiting content of 0.6% and 0.2% for N and S, respectively, can induce emission problems [30].

Further, the C/N ratio was higher for woody fractions (104 and 120 for branches and stem, respectively) than leaves (28). Greater C/N ratio implies a lower decomposition rate when the biomass is left on the field after harvesting for reduction of moisture content and, consequently, energy content is slightly affected.

For proximate analysis, the stem fraction showed greater volatile matter, which contributes to the ignition of biomass, and the leaves fraction had a higher fixed carbon content, which increases its burning period in the boiler [12]. High results of ash content for leaves mean the trees could be defoliated before use.

Levels of acid-insoluble lignin and total extractives in the stem are similar to those reported by Ref. [8] and are statistically different for the leaves fraction. Among the biomass fractions, lignin content was similar for the stem and branches.

Energy of combustion varies considerably with the chemical composition. Compounds such as resin, tannins, lignin, terpenes, and waxes have high energy values whereas carbohydrates have

Table 3
Effect of biomass fraction on thermochemical properties of *Eucalyptus grandis* × *E. urophylla* at 2 years old grown on short rotation forest.

Properties	Unit	Stem	Branches	Leaves
Carbon	wt% (d.b.)	44.3 ± 0.5 b	44.7 ± 0.5 b	49.1 ± 0.6 a
Hydrogen	wt% (d.b.)	7.4 ± 0.5 b	7.5 ± 0.3 b	8.2 ± 0.3 a
Oxygen	wt% (d.b.)	46.7 ± 1.0 a	45.8 ± 0.8 b	37.5 ± 0.8 c
Nitrogen	wt% (d.b.)	0.37 ± 0.1 c	0.43 ± 0.1 b	2.0 ± 0.3 a
Sulfur	wt% (d.b.)	0.09 ± 0.0 b	0.10 ± 0.0 b	0.13 ± 0.0 a
Ash	wt% (d.b.)	1.1 ± 0.2 c	1.5 ± 0.3 b	3.1 ± 0.6 a
Fixed carbon	wt% (d.b.)	14.4 ± 1.2 c	17.3 ± 1.0 b	18.4 ± 0.6 a
Volatile matter	wt% (d.b.)	84.5 ± 1.3 a	81.2 ± 1.1 b	78.5 ± 0.7 c
Holocellulose	wt% (d.b.)	81.5 ± 1.5 a	68.4 ± 2.1 b	34.9 ± 1.9 c
Acid-insoluble lignin	wt% (d.b.)	21.6 ± 0.8 a	20.7 ± 0.9 ab	20.2 ± 2.7 b
Total extractives	wt% (d.b.)	2.0 ± 0.8 c	12.4 ± 1.2 b	37.9 ± 1.3 a
Higher Heating Value	MJ kg^{-1}	18.9 ± 0.3 c	19.2 ± 0.3 b	22.0 ± 0.2 a

The means that do not differ from each other at the 0.05 significance level by Tukey's test are marked with the same letters in the same line.