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Energy balance of elephant grass biomass for power generation by direct biomass combustion

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In Brazil, elephant grass has been used for thermal energy production, due to the high productivity, energy efficiency, biological nitrogen fixation (BNF) and biomass quality for energy generation by direct burning. The use of biomass depends mainly on the energy balance and biomass characteristics for energy production. The aim of this study was to evaluate the biomass of dry matter yield, qualitative biomass variables and energy balance of two elephant grass genotypes. The experimental design was completely randomized blocks with two elephant grass cultivars (Gramafante and Roxo) and four replications per treatment. Five cultivation cycles were studied. Biomass yield and the contents of acid detergent fiber, lignin, cellulose, ash and calorific value were evaluated. The biomass yields of elephant grass cultivars varied between 12 and 24 Mg ha^{-1}, where the lowest yields were presented by the cultivar Roxo, and the higher yields by Gramafante. The contents of fiber, lignin, cellulose and calorific value did not vary among the genotypes studied. An energy balance was calculated for the complete biomass production lifecycle of elephant grass and the overall energy output/input ratio was 15.1:1. The results show that the elephant grass has highly suitable materials for the production of energy by direct burning.

Key words: *Pennisetum purpureum,* agroenergy, dry matter.

INTRODUCTION

In recent decades, the search for alternative sources of energy in lieu of the use of fossil fuels has been growing globally. Renewable energy sources such as biofuels and biomass are an important strategy to reduce fossil fuel use, especially for countries with large areas available for agriculture and satisfactory rainfall distribution, such as Brazil (Morais et al., 2013). Apart from the success in mitigating greenhouse gases (GHGs) by the Brazilian ethanol program (Boddey et al., 2008; Macedo et al., 2008), there is a growing interest for plant biomass to supply the sectors of the economy in rural areas depending on heat generation for drying processes and

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for electricity generation (Morais et al., 2013).

In the world, the biomass of Poaceaes family of C4metabolism with high productive potential such as *Miscanthus* spp., *Panicum* spp. and *Saccharum* spp.have been highlighted in this scenario (O'Loughlin et al., 2017; Fei et al., 2017). C4 photosynthesis of plants boosts productivity in some of the planet's most ecologically and agronomically important species (Huang et al., 2017). In Brazil, some studies have been carried out with elephant grass (*Pennisetum purpureum*) (Basso et al., 2014; Morais et al., 2013; Quesada, 2005; Samson et al., 2005). Morais et al. (2009) found some ascending genotypes for biomass production for bioenergy generation purposes and observed lignin, cellulose and ash contents suitable for use in direct burning. Morais et al. (2013) quantified greenhouse gas emissions in the elephant grass biomass production system derived from soil preparation and nitrogen fertilization and took an important step to characterize the elephant grass inclusion scenario in the energy scenario.

The main ways in which energetic use of elephant grass biomass has been studied, are the use in thermoelectric plants and for direct combustion in ceramic industries to replace wood and coal. Elephant grass biomass is cut in the field, dried in an appropriate place, and then transported for direct burning. Apart from high dry matter production, the plant material should suit quality parameters for reaching the optimal energetic efficiency, which means high levels of fiber and lignin and low levels of water, N and ash (Lemus et al., 2002; McKendry, 2002). Quesada (2005) and Morais et al. (2013) quantified dry matter production of 30 Mg ha^{-1} year^{-1} with fiber and lignin contents above 60 and 10% respectively, as well as low protein and ash content, using only P and K fertilization, and two cuts per year.

For elephant grass growing in poor N soils, the average dry matter production after two cuts per year was about 30 Mg ha^{-1}, and fiber and lignin contents matched the desirable parameters for energy production from direct burning (Quesada, 2005). Protein content was remarkably reduced in comparison with common levels observed in elephant grass genotypes, destined for forage production. Biomass yield levels were not drastically reduced, in comparison with the ones in fertilized systems (Quesada, 2005). The suitability of the biomass for energy production, together with the possibility of two cuts per year, increase the potential of use of this crop for energy production purposes (Samson et al., 2005).

Another factor that influences the sustainability of the use of biomass is its energy balance. Samson et al. (2005) found that for the agricultural stage of elephant grass production, a value of 21:1 was obtained, showing that for each unit of fossil energy used in the elephant grass production process, 21 units of renewable energy were obtained. This condition is valid when the material is used directly for combustion. For any procedure that promotes changes in the state of biomass, for example, transforming the biomass into coal, there will be changes in the energy balance. Considering a yield of 30 Mg ha^{-1} of dry matter (DM), the crude energy produced is 493 GJ ha^{-1} year $^{-1}$ (Samson et al., 2005).

As input quantities and biomass yields vary according to cropping site and investments made during the process, it is of utmost importance that the necessary measurements are made in each region of the country for a more real characterization. Therefore, the objective in this study was to quantify the biomass yield, qualitative characteristics of the biomass and the energy balance of two elephant grass genotypes, in five cycles, aiming to contribute to optimizing their use for energy generation by direct burning.

MATERIALS AND METHODS

Location and experimental description

This study was performed at the experimental area of the Federal Institute of Roraima- Campus Amajari, located in the town Amajari of Roraima. The study period was between March 2014 and September 2016. The precipitation and minimum, medium and maximum temperatures corresponding to the studied cycles period are shown in Figure 1. The experimental design was completely randomized blocks with four treatments and four replications. The soil of the region was classified as Yellow Argisol (Ultisol), presenting the 0.62 mg dm^3 of phosphorus and 0.03 cmolc dm^3 of potassium availability, besides the 0.14 and 0.06 comlc dm^3 of calcium and magnesium respectively, observed in the soil analysis. The plots consisted of 5 lines with 5 m length and space of 1 m, totalizing an area of 25 m^2 per plot.

Climate variables

The results of precipitation and minimum, medium and maximum temperature are shown in Figure 1. In the three years of study, the highest precipitations were observed between April and August. In this interval, precipitations observed surpassed 300 mm per month. In the remaining months, the rains rarely exceeded 40 mm. As for temperatures, on average, they were close to 30°C in the five cycles studied and did not influence the development of elephant grass genotypes.

Soil preparation and fertilizer application

The area of the experiment remained fallow during the previous 5 years, being only managed to control the spontaneous vegetation by weed wrecking. The stages of soil preparation consisted of a plowing followed by two harrowings performed after fifteen days. After the harrowing, furrows were made to plant elephant grass. In these furrows, single superphosphate fertilizers, potassium chloride and a set of micronutrients in the commercial form of FTE BR12 were applied. The recommendation was based on the soil analysis and corresponded to 80 kg ha^{-1} of P_2O_5, 60 kg ha^{-1} of K_2O and 50 kg ha^{-1} of FTE BR12. After each cut, the nutrients extracted by the crop were replaced.

The doses of P, K and micronutrients were applied based on the mean accumulation of these nutrients in elephant grass plants (Andrade et al., 2005; Moreira et al., 2006).

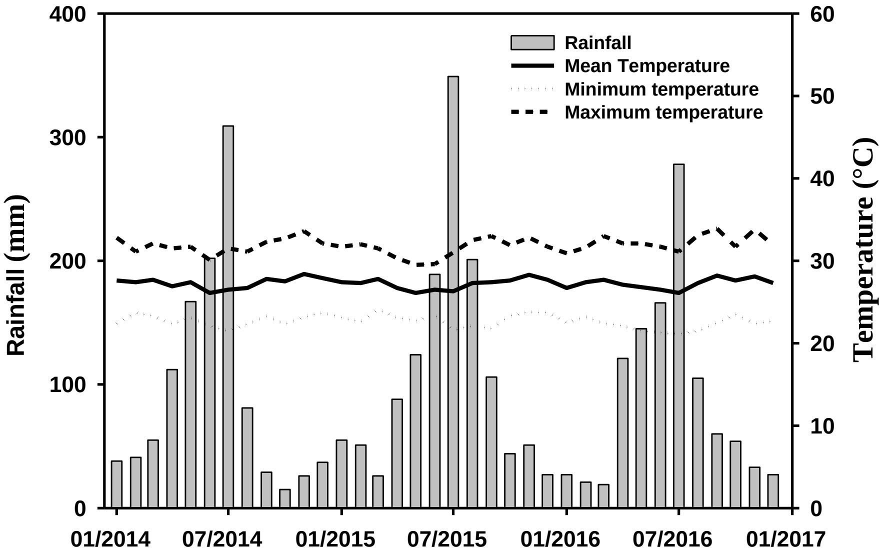

Figure 1. Rainfall precipitation and minimum, medium and maximum temperatures during the experimental period between December 2014 and January 2017, in Boa Vista-RR. Source: Data from INMET (2014 to 2016).

Biomass yield

The treatments were evaluated by harvesting elephant grass biomass after six months of planting. The biomass of the plots was weighed fresh, without separating stem and leaves, and after that, sub-samples were taken, then put in a drying oven at 65°C until weight stabilization and the dry matter fraction of plants was determined. The plant samples were pre-ground in a Wiley type mill (2-mm-sieves) for the chemical analysis performed.

Chemical analysis

The analysis related to neutral detergent fiber (NDF) and its components and ashes were carried out according to the methodology described by Van Soest and Wine (1968). The upper calorific value (UCV) was determined by the calorimeter pump method with the digital calorimeter (model C-200, IKA). The tests were performed according to the ABNT NBR 8633/84 standard and the instrument manual. Those determinations were carried out in partnership with the forage crops department of the Animal Science Institute of the Federal Rural University of Rio de Janeiro.

Energy balance

Each agricultural production activity (tillage, planting, fertilization, irrigation, harvesting, transport and storage) was included in the energy balance. Each input and values used for energy balance were derived by the authors from the field study of Macedo (1997, 1998).

For the energy balance calculations, the average yield of the two elephant grass genotypes in the five crop cycles was considered. The average calorific value data were used to estimate the total energy obtained from elephant grass biomass in an area of 1 hectare. On average, a calorific value of 3822 kcal per kg of elephant grass was observed; it can be considered that it corresponds to 16 GJ/ha of gross energy. The diesel conversion factor of 0.0478 GJ/l and the values for harvesting and maintenance of agricultural machines obtained under laboratory conditions for sugarcane were used. For the transportation of biomass after harvesting and drying, an average distance of 8 km (Round Trip) and 15 min for each stretch were considered.

Statistical analysis

The statistical procedures were those of the SAEG 9.1 (Universidade Federal de Viçosa, 2007). Normality and homogeneity of variance of errors were analyzed using the Lilliefors and Cochran and Bartley tests, respectively. The required conditions were met in all cases. The analysis of variance was performed with the application of the F test. Differences between means were separated by the use of Tukey's test at 5% probability. The climate data were collected on the National Institute of Meteorology of INMET website - Boa Vista Station.

RESULTS AND DISCUSSION

Biomass yield

In the first and fourth cycles, there was statistical difference between genotypes, and dry matter accumulation was always higher for Gramafante cultivar as compared to Roxo, with values of 22.7 and 15.8 of Mg ha^{-1} for Gramafante and 18.5 and 12.3 of Mg ha^{-1} for Roxo.

In the comparison between cycles, for the Gramafante genotype, there was statistical difference between the second and fourth cycles when compared with the other cycles. For the Roxo genotype, the first and the third cycles presented statistical differences when compared with the others cycles (Table 1). The precipitation differences between the first and third cycles as

Table 1. Dry biomass yield of two elephant grass genotypes in a Yellow Latosol in Amajari-RR.

Genotypes	**Dry matter yield (Mg per ha^{-1})**				
	1° Cycle	**2° Cycle**	**3° Cycle**	**4° Cycle**	**5° Cycle**
Elephant grass cv. Roxo	18.5^{Ba}	15.3^{Ab}	21.2^{Aa}	12.3^{Bb}	16.6^{Ab}
Elephantgrass cv. Gramafante	22.7^{Aa}	17.7^{Ab}	23.1^{Aa}	15.8^{Ab}	19.2^{Aa}
Mean	20.6	16.5	22.15	14.05	17.9
Accumulated rainfall (mm) *	955	210	1057	189	875

Means followed by the same capital letter in the columns and small letter in the rows do not differ from each other by the Tukey's test at 5%* and 1%** of probability.

Table 2. Acid detergent fiber (ADF), lignin, cellulose (expressed in %) and calorific value (expressed in Kcal/kg) of the Poaceaes studied (3rd cycle).

Treatments	**^{a}ADF**	**^{a}Lignin**	**^{a}Cellulose**	**^{b}Calorific value**
Elephant grass Cultivar Roxo	39.5	7.3	29	3876^{A}
Elephant grass Culivar Gramafante	39.4	6.9	31	3769^{A}
Mean	36.0^{ns}	6.0^{ns}	28.7^{ns}	3664^{ns}
CV (%)	11.3	12.2	16.7	12.9

Means followed by the same letter in the column do not differ by the Tukey's test at 5%* and 1%** of probability. ns, Not significant.

compared to the second and fourth was greater than 700 mm precipitation.

Considering the average yield of biomass production in the five cycles for each genotype, it was observed that the genotype Gramafante presented productivity that is 15% higher than the Roxo genotype. In the period of 1 year or 2 harvests, the biomass production of the genotypes studied exceeded 30 Mg ha^{-1}. The high productive potential for biomass production observed in elephant grass in the present study is consistent with those already reported in literature.

Morais et al. (2013) observed dry biomass yield of elephant grass above 30 Mg ha^{-1} in six months of cultivation. Andrade et al. (2005) and Queiroz Filho et al. (2000) observed biomass production of more than 40 Mg ha^{-} year^{-1} of dry matter produced annually. These data corroborate those obtained by Quesada (2005), who found an average yield of 35 Mg ha^{-1} of DM in 15 months of cultivation with the application of 80 kg of N fertilizer, working on a Planosol and with all the genotypes of this study. Queiroz Filho et al. (1998) found productivities of 19 Mg ha^{-1} year^{-1} of MS even with fertilization of 100 kg of N ha^{-1}, in the form of ammonium sulphate, values far below those found in this study, in which, if the time of two yields is summed up (15 months), a yield of up to 45 Mg ha^{-1} of DM is observed.

The obtained data surpass productivities of other species used as source of energy. Schemer et al. (2008) in studies with *Panicum virgatum* obtained ethanol from cellulose in the biomass, based on an average productivity of 8.15 Mg. ha^{-1}. This yield is about 75% lower than that obtained by Quesada (2005), which showed an average of 35 Mg. ha^{-1} of MS in studies with elephant grass. It is also worth noting that in the elephant grass culture, it is possible to achieve an energy balance of up to 21.3 (Samson et al., 2005) and in studies carried out by Schemer et al. (2008) balance reached 5.4.

Lemus et al. (2002) in studies with 20 cultivars of *P. virgatum*, obtained an average of 9 Mg. ha^{-1} of biomass with application of 100 kg of N ha^{-1}, yield that can also be considered far below those obtained with elephant grass by Quesada (2001) and Quesada (2005). Botrel et al. (2000), studying new elephantgrass clones, among them, Cameroon, CNPGL 91 F27-01 and CNPGL 91 F06-03, found annual average productivity of 31, 43 and 37 Mg. ha^{-1} year^{-1} of DM respectively. Danalatos et al. (2007) working with *Miscanthus sinensis* under two doses of N fertilizer (50 and 100 kg of N ha^{-1}), observed that there was no significant response to these treatments, obtaining an average yield of 27 Mg. ha^{-1} of DM in 270 days of cultivation. Quesada (2005) found values of up to 30 Mg. ha^{-1} of DM in eight months of cultivation in Cameroon and Gramafante genotypes in the application of N-fertilizer.

Qualitative parameters of biomass

There was no significant difference between the studied genotypes or the cultivation cycles for the fiber, cellulose, lignin and calorific values (Table 2). The levels of acid detergent fiber were close to 40% in the two genotypes studied. The lignin contents were 6.9 for the genotype Roxo and 7.3 for the Gramafante. Regarding the contents

Table 3. Energy balance of elephant grass biomass production.

Field activities	Equipments and vehicles used	Total consumed energy (GJ/ha/year)
Lime application	Tractor Massey Fergusson 290 consuming 20 L/diesel/ha every 3 years	0.31
Heavy plough	Tractor Agrale Deutz BX 4150 consuming 15 L/diesel/ha every 3 years	0.239
Leveling harrow	Tractor Agrale Deutz BX 4150 consuming 8 L/diesel/ha every 3 years	0.127
Furrowing and fertilizer application	Tractor Agrale Deutz BX 4150 consuming 11.6 L/diesel/ha every 3 years	0.185
Distribution of setts	Tractor Massey Fergusson 290 consuming 4.8 L/diesel/ha every 3 years	0.076
Closing of furrows	Tractor Massey Fergusson 290 consuming 2.5 L/diesel/ha every 3 years	0.039
Harvest	Tractor Agrale Deutz BX 4150 consuming 240 L/diesel/ha for six cycles	11.472
Transport for processing*	Tractor Agrale Deutz BX 4150 coupled with wagon and consumption of 12.8 L of diesel for 8 h per day	0.612
Fertilization application		
N	Applied in a rate of 60 kg/ha/year	3.69
P_2O_5	Applied in a rate of 70 kg/ha/year	0.675
K_2O	Applied in a rate of 70 /ha/year	0.47
Fabrication and maintenance of farm machinery 3		2.27
Total fossil energy input for field operations:		20.21
Energy in production of napier grass (18 tons of biomass per hectare) and the arithmetic mean of five cycles x 16 GJ per ton of biomass		288
Energy balance (energy gained/energy invested)		14.6

of cellulose, it was observed in the two studied genotypes values very close to 30%. The calorific value of the biomass of the studied genotypes also did not vary significantly. A calorific value of 3,876 kcal per kg of biomass was associated with the genotype Roxo and 3,796 kcal per kg was associated with the genotype Gramafante.

In studies on elephant grass grown for forage purpose, the fiber content of the whole plant increased and protein content decreased, the longer the plant remains in the field (Andrade et al., 2005). The levels of fiber in the present study were similar to those reported by Savioli et al. (2000) and Campos et al. (2002), which observed values close to 40%, and by Queiroz Filho et al. (2000), who reported values up to 43%, for plants grown for 100 days in the field. According to McKendry et al. (2002), the levels of lignin and fiber observed in the genotypes used in the present study are considered satisfactory for energy production by direct combustion. There was no statistical difference for cellulose contents in genotypes with values ranging from 29 (genotype Roxo) to 31% (genotype Gramafante). The results obtained so far, together with the work of Quesada (2005) and Morais et al (2009, 2013), indicate that this species has good adaptability to soils with low fertility and shows that the N accumulated is partially sustained by the significant contribution of biological nitrogen fixation (BNF) in elephant grass.

Energy balance

The energy efficiency calculations resulted in an energy balance of 15:1. This means that for each unit of energy used in the process of biomass production, 15 units of energy are produced (Table 3). These results corroborate with Samson et al. (2005), who found an energy balance of 21:1 in the production system. These results show the high potential of elephant grass use for bioenergy. Studies on other species have also been performed; these include work of Schemer et al. (2008). The authors' studies on *Panicum virgatum* were based on an average yield of 8.15 Mg. ha^{-1} and obtained an energy balance of 5.4:1. This yield is about 60% lower than that obtained in the present study in which average dry matter yield in three years was 18 Mg. ha^{-1}. The energy balance obtained in the present study was 14.6 and in studies carried out by Schemer et al (2008), it reached 5.4. Danalatos et al. (2007) working with *Miscanthus Sinensis* under two doses of N fertilizer (50 and 100 kg of N ha^{-1}), observed that there was no significant response to these treatments, obtaining an average yield of 27 Mg. ha^{-1} of DM in 270 days of cultivation. Quesada (2005) found values of up to 30 Mg ha^{-1} of DM in eight months of cultivation with genotypes Cameroon and Gramafante without the application of N-fertilizer.

Conclusions

Gramafante cultivar is the most promising for energy production purposes. The energy balance of elephant grass biomass production under the experimental conditions was approximately 15:1, showing its high potential for use in bioenergy through direct burning.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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