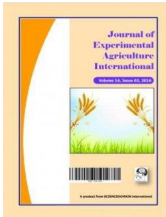

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Agronomic and Energetic Potential of Sorghum Evaluated in Two Consecultive Crops

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Authors' contributions

This work was carried out in collaboration between all authors. Author VAPB designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors VZPB, TSM and AFB managed the analyses of the study. Author LDP managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Aims: Was to evaluate the productive potential of three sorghum agronomic groups (biomass sorghum, saccharine sorghum and forage sorghum) in two cutting seasons (crop and regrowth) and to perform the energy (GJ/ha/cycle) characterization of biomass. Sample: Six sorghum cultivars in three agronomic groups: biomass sorghum (hybrids BD 7607 and BRS 716), saccharine sorghum (hybrids BD 5404 and BRS 511) and forage sorghum (hybrids BD1615 and BRS 655).
Study Design: This cultivars were evaluated in the block design at random, with six replicates and analyzed in time subdivided plots. Place and Duration of the Study: The experiment was conducted in the field being evaluated in two consecutive harvests, during the months of December/2014 to September/2015 and at the end of the cycle of each cultivar the plant evaluations were carried out.

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Methodology: Samples composed of ten plants randomly selected from the useful area of each plot were used: Harvest cycle, regrowth cycle, plant height, total fresh mass production, total dry mass production, percentage participation of the physical components in the total dry mass and total biomass production of the two cutting seasons. The upper calorific power of the physical components of the plants and the potential energy produced were determined.
Results: It was verified that the production of total fresh mass was higher in the crop with respect to the regrowth for all the crops and that the cultivars of sorghum biomass BD 7607 and BRS 716 obtained the highest results with total biomass production of 115 and 119 t/ha, respectively. The yield of the cultivars in regrowth was insignificant. The biomass sorghum cultivars BD 7607 and BRS 716 presented the highest yields of energy / ha with 815 and 654 GJ, respectively.
Conclusion: The amount of energy produced by each type of sorghum is influenced mainly by its agronomic performance.

Keywords: Sorghum bicolor L. Moench; biomass; heat value; bioenergy.

1. INTRODUCTION

Brazil stands out as one of the largest producers of bioenergy in the world [1], being the second largest producer of ethanol from sugarcane (*Saccharum* spp.) And in this production chain, there is the generation of bioelectricity from the generated biomass, guaranteeing the energy self-sufficiency of the industrial units and the sale of surplus electric energy to the electricity distributors [2].

However, the Brazilian bioenergy sector has suffered serious crises due to seasonality in production, climatic variations and the sugarcane off-season that results in high idleness of the industrial units, and consequently, low competitiveness [3]. The promising strategy to leverage bioenergy production would be to include other sources of raw material in the sugarcane harvesting process in order to keep this agroindustrial complex active throughout the year [4].

In this context, sorghum [*Sorghum bicolor* (L.) Moench] has been tested as a promising alternative to increase bioenergy production due to its short cycle, high rusticity and water use efficiency, and can be grown in regions and/or times limiting other plant species of high productive potential, such as sugarcane and corn [5,6].

In addition, the sorghum has the ability to regrow, that is, after harvesting the original crop, the plant conserves its root system alive, which makes it possible to regrow when there are ideal conditions for its development. Thus, regrowth can also be used to produce biomass, which may reduce planting costs and, consequently, the final cost per unit of biomass produced, as well as environmental gain [7].

Among sorghum types with energetic characteristics, saccharine sorghum, used for the production of first generation ethanol due to the high sucrose concentration in the stem; the biomass sorghum, used for direct burning and bioelectricity generation due to the high lignin content and the good performance in the combustion processes; forage sorghum, material used for silage production, which although not used for energy purposes and to increase biomass production in the mills [8].

However, when considering the Brazilian edaphoclimatic conditions, we do not have comparative data of the different agronomic types of sorghum in order to better direct them to the productive sector to choose the most promising material, considering the biomass production per unit area over two harvests consecutive.

The objective of this work was to evaluate the productive potential of three sorghum agronomic groups (biomass, saccharin and forage) in two cutting seasons (crop and regrowth) and to perform the energy characterization (GJ / ha / cycle) of biomass of these materials in order to better target them for bioenergy production.

2. MATERIALS AND METHODS

The experiment was carried out with two subsequent crops, during the months of December 2014 to September 2015, at the Experimental field at the Universidade Federal de Viçosa, in Coimbra, Minas Gerais state, Brazil (20º51'S, 42º46'W and 720 m of altitude). The environmental conditions recorded during the conduction of the experiment are described in Fig. 1.

The sorghum hybrids used are commercial, those with the prefix BRS were purchased from the company Embrapa Milho and Sorgo and the hybrids denominated with prefix BD were acquired from the company Ceres. The six cultivars were divided in three agronomic groups: biomass sorghum (hybrids BD 7607 and BRS 716), saccharine sorghum (hybrids BD 5404 and BRS 511) and forage sorghum (hybrids BD1615 and BRS 655). They were evaluated in the block design at random, with six replicates and analyzed in time subdivided plots. The sowing was performed on December 4, 2014, adopting the manual system. The experimental plots consisted of four lines of 6 linear m each, spaced 0.70 m apart, being considered as useful area for the evaluations the two central lines of the plot, eliminating 1.0 m from each end. Seed density was 9 plants / linear meter.

2.1 Agronomic Characteristics Evaluated

Samples composed of ten plants randomly collected from the useful area of each plot were used, which were collected during the physiological maturity of the grains of each cultivar. Being evaluated: 1) Harvest cycle: counting the number of days from sowing to planting; 2) Regrowth cycle: counting the number of days from the cutting of the first crop to the harvest of the plants; 3) Height of plants (HP); 4) Production of total fresh mass (PMF): determined in kg / plot by weighing the ten complete plants; 5) Total dry mass production (PMS): determined by the difference in weight between samples of freshly harvested material and after being submitted to drying in an oven; 6) Percentage participation of the physical components in the total dry mass: determined by weighing each part (stem, leaf and panicle) of the same; 7) Total biomass production (PBT): determined by the sum of the biomass production in the two cutting seasons.

2.2 Energy Characteristics Evaluated

The upper calorific value of the physical components of the plants sampled only in the harvest was determined. The determination of the Upper Caloric Power (PCS) of each sample was given by the combustion of 1 g of the material in a calorimetric pump and the PCS was quantified in Kcal kg^{-1}.

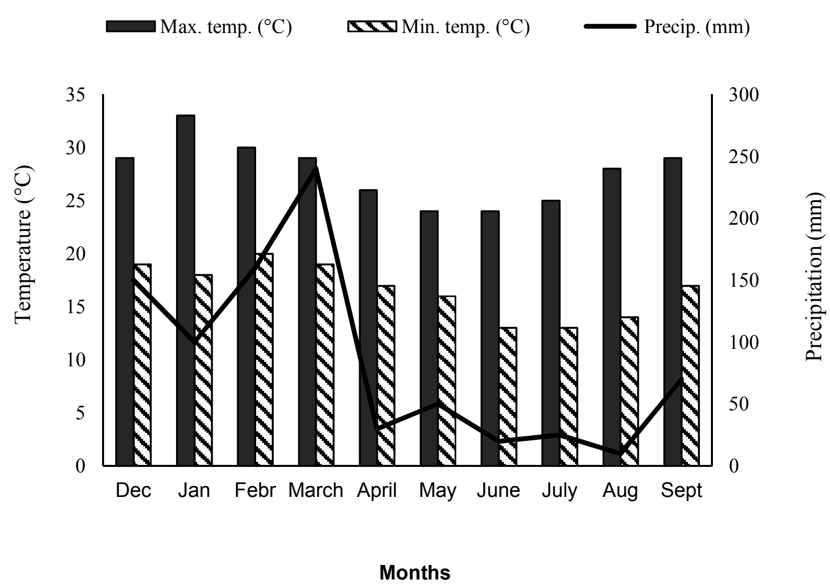

Fig. 1. Cumulative precipitation (mm) and monthly mean temperatures (ºC) during the period of conduction of the experiment. The data were obtained from the meteorological station of the Department of Agricultural Engineering of the Universidade Federal de Viçosa, in Coimbra, Minas Gerais state, Brazil

The potential energy produced was estimated through the dry biomass and the higher calorific value. Estimated potential energy per ton, this was extrapolated to an area of 1 hectare and expressed in Giga joules (GJ), using the following formula (I):

I) EP = PCS x MST, where EP is the potential energy, PCS is the upper calorific value and MST is the total dry mass.

Data were submitted to analysis of variance by the F-test, at 1% and 5%. The Tukey test was applied to compare the cultivars at 5%, a mean comparison test imply a $p < 0.05$.

3. RESULTS AND DISCUSSION

3.1 Agronomic Characterization

It was verified that the cycle length of the cultivars varied according to the sorghum agronomic group. The forage and saccharine cultivars (BRS 655 and BRS 511, respectively) obtained the earliest cycles, both in the harvest and in the regrowth, with 114 and 110 days respectively. The forage and saccharine cultivars (BD 1615 and BD 5405, respectively) presented an intermediate cycle, with 133 days in the harvest and 105 days in the regrowth. The cultivars of biomass sorghum, BD 7607 and BRS 716, were the later cultivars, reaching physiological maturity at 146 and 139 days in the harvest and regrowth, respectively (Fig. 2).

There was a significant effect of cultivars and cut-off time on the following variables: plant height (HP), total fresh mass production (PMF), total dry mass production percentage of the physical components of the plant (PCF). However, the total biomass production (PBT) was influenced only by the cultivars. Several researches enforced known facts about the availability of these types of biomass, together with a brief explanation of possible biomass conversion routes, sustainability measures, and current research and development activities in various region of Nigeria [16]. There was also a highly significant interaction between the cultivar factors and cut seasons, for all variables (Table 1).

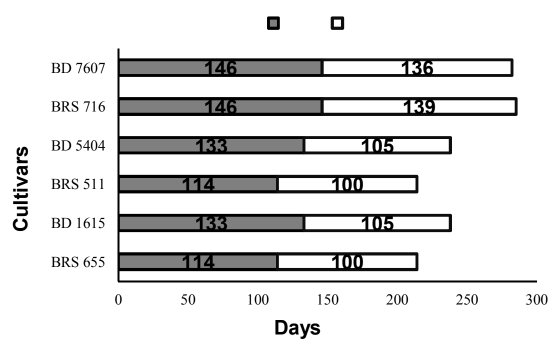

Fig. 2. Duration of the first crop and regrowth cycle of six sorghum genotypes, resulting in the total duration of the two cycles in days

Table 1. Summary of the analysis of variance of the data evaluated in two cutting times

FV	GL	Middle square		
		HP	MFP	MDP
Block	5	3,62 *	1,50 ns	2,23 ns
Cultivars	5	126,35 **	71,09 **	47,30 **
Residue a	25	16,25	435,93	134,21
Cuts	1	2103,33 **	4334,68 **	2287,56 **
Cultivars x Cuts	5	48,61 **	87,22 **	69,86 **
Residue b	30	1,48	662,48	156,39
CV a (%)		5,42	8,85	13,65
CV b (%)		7,77	9,96	13,45

*** - Highly significant effect by the F test at the 1% probability level; * - Significant effect by the F test at the 5% probability level; ns - Not significant. Data: HP: plant height; MFP: total fresh mass production; MDP: total dry mass production*

Analyzing the isolated effect of the cutting season, it was verified that the yields of the variables HP, PMF and PMS in the harvest were significantly higher than the yields found in regrowth (Fig. 3A). Regarding the height of plants, in the crop, it can be observed that the cultivars BD 7607 and BRS 711 (biomass sorghum) presented larger size, with averages of 5.15 and 4.97 m respectively, differing significantly from the others. The cultivar BRS 655 (forage sorghum) had the lowest height, with 2.62m (Fig. 3A). This characteristic is highly influenced by the genetic constitution, being controlled by genes that act independently without affecting the number of leaves and the duration of the growth period, which provided the great variation observed [9].

It was observed that in the first harvest, the cultivars BD 7607 and BRS 716 (biomass sorghum) presented higher total fresh mass (PMF) production, being significantly superior to the others, with an average yield of 110 and 108 t ha^{-1}, respectively. The BRS 655 (forage sorghum) cultivar, with the earliest cycle, presented the lowest total fresh mass yield, with a mean productivity of 52 t ha^{-1} (Fig. 3B).

It was observed a 94 % matter biomass reduction of crop yield for regrowth in biomass sorghum, 87 % reduction of crop for forage sorghum regrowth (BD 5404 and BD 1615, respectively) and reduction of 75% for the regrowth of forage sorghum fo (BRS 511 and BRS 655). In general, these results may be related to the growing season, since regrowth development was carried out during the fall / winter period when climatic conditions were limiting (low temperature and precipitation) at the site (Fig. 1).

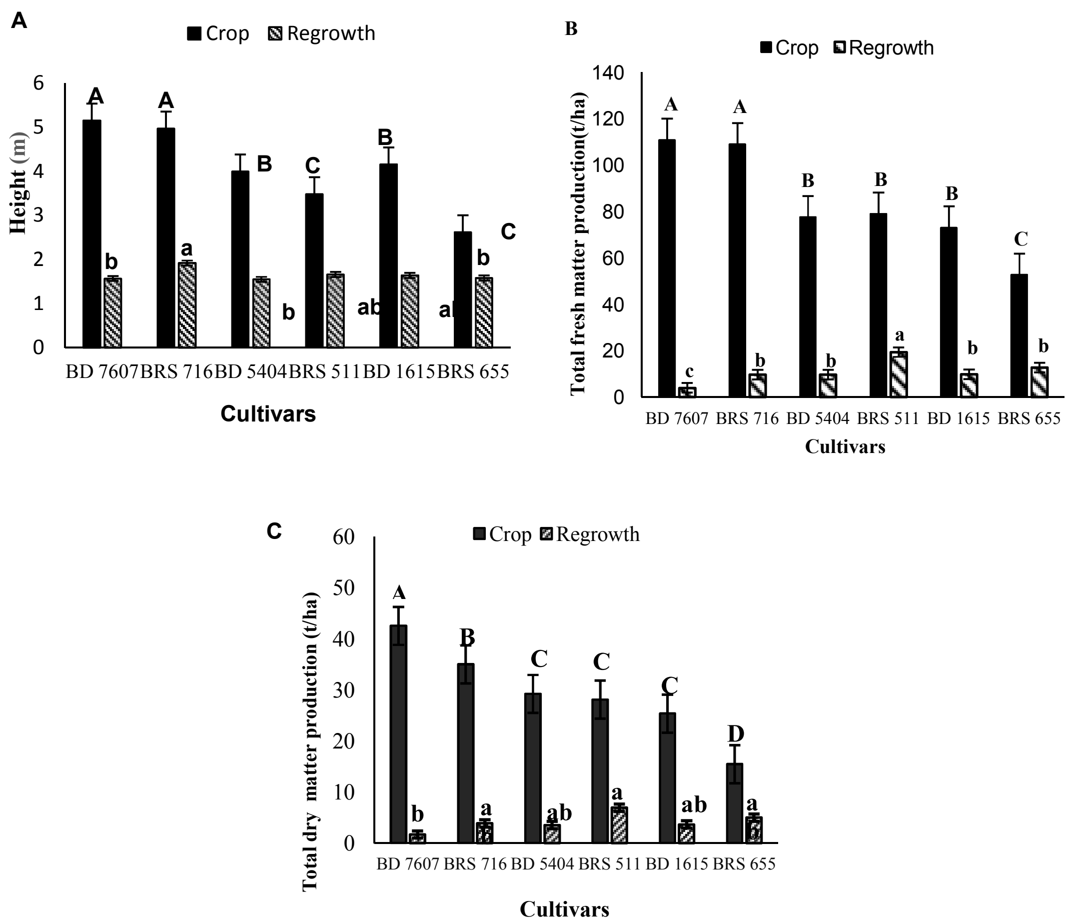

Fig. 3. Effect of cutting season on cultivars: A) plant height; B) production of fresh matter; C) production of dry mass. Followed by the same capital letter in the crop and the same lowercase letter in the regrowth, do not differ by the test of F at the levels of 1 and 5%. Coimbra-MG, Brazil, 2015

In addition, sorghum is a short-day plant and has the induction of flowering for long nights; when it is cultivated in autumn, early flowering occurs due to the inductive photoperiod effect, resulting in lower biomass productivity [10].

In relation to the effect of the interaction between the cultivars and the cutting season, it can be observed that in the first harvest the cultivars belonging to the biomass sorghum group (BD 7607 and BRS 716) were the later ones and presented the highest rates in the HP, PMF and PMS differed significantly from the others (Fig. 3). These variables are desirable for a biofuel crop, as well as: low grain yield, resistance to housing, low water content, biomass quality and others.

When analyzing the cultivars in the regrowth, it was observed that there was little difference for the AP variable, on the other hand the cultivar BRS 511 (sorghum saccharine) presented the highest values of PMF and SMP differing significantly from the others, with 19 t ha^{-1} and 7 t ha^{-1}, respectively (Fig. 3). These results suggest that the use of regrowth is not representative for bioenergy in these climatic conditions, since the highest productivity found in regrowth was only 25 % of the total found in the main crop (Fig. 3).

The cultivars of biomass sorghum (BD 7607 and BRS 716) had better development in the crop because they are photoperiod sensitive cultivars, in this way flowering only occurs after the inductive photoperiod, which is 12 hours and 20 minutes [11]. Under the conditions of this work (southern hemisphere), the floral induction of these materials occurred from March 21, so the vegetative period extended for 4 months, resulting in high biomass productivity.

The cultivar BRS 511 (sorghum saccharine) presented the smallest cycle of development during the harvest, because it is a cultivar insensitive to the photoperiod that blooms at any time of the year [11]. Development of more favorable climatic conditions (higher temperatures and precipitation), optimizing the development of plants. These results indicate that cycle duration significantly interferes with plant growth and development.

The biomass sorghum (BD 7607 and BRS 716) showed the highest yields of both PMF (115 and 119 t ha^{-1} respectively) and PMS (44 and 39 t ha^{-1} respectively), this is mainly due to the development of these cultivars in the first crop (Fig. 4).

However, it should be noted that these materials took approximately 10 months to reach this productivity, with an average of 0.14 t/ha/day of dry matter produced. On the other hand, BRS 655 (forage sorghum) presented the lowest yields of both PMF and PMS (65 and 20 t ha^{-1}, respectively), being significantly lower than the others (Fig. 4.), producing an average of 0.09 t/ha/day of dry matter in approximately 7 months of duration of the two cycles (harvest and regrowth). In this way, the use of regrowth is not particularly advantageous for long cycle materials (biomass sorghum), since the total productive potential of these cultivars is defined by the cultivation of the main crop.

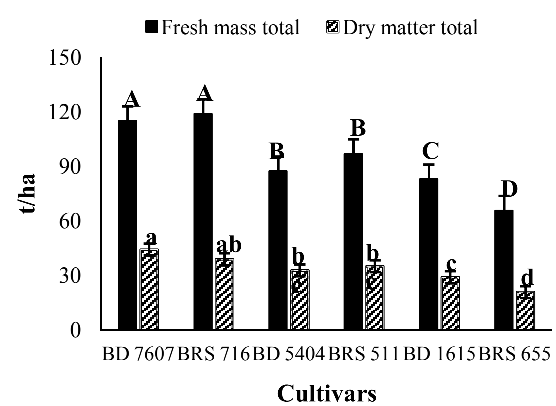

Fig. 4. Production of total fresh mass and total dry matter production, evaluating the sum of the crop with regrowth, of six sorghum cultivars. Followed by the same capital letter in the crop and the same lowercase letter in the regrowth, do not differ by the test of F at the levels of 1 and 5%. Coimbra – MG, Brazil, 2015

It was observed in the percentage participation of the physical components (panicle, leaf and stem) of the plants, that when comparing the two cutting times the panicle participation in the crop was inferior to the other components of the plant for the cultivars: BRS 716, BD 5404, BRS 511 and BD 1615 (Table 2).

Means followed by the same letter, lowercase in the row and upper case in the column, do not differ statistically from each other at 5% probability, by the F test for the cut time and by the Tukey test for the physical components of the plant.

For the cultivars BD 7607 and BRS 655, the panicle participation did not differ statistically from the leaf (Table 2). For cultivars that have a succulent stem (BD 5404, BRS 511 and BD 1615) the lower participation of this component is advantageous for a good yield of the broth in order to produce ethanol, because at the end of the vegetative cycle of the sorghum occurs the translocation of the photoassimilates stored in the (sucrose) to fill the grains present in the panicle [12]. For the other cultivars the yield of the panicle is considered irrelevant, since it does not participate in the production of fiber.

It was also observed that the participation of stems in the harvest was statistically superior to that found in regrowth (Table 2). This result can be explained by the increase of the stand in regrowth due to tillering, which may have caused an increase in the competition for photoassimilates, reducing the development of stalks and decreasing their proportion in the plants. When comparing the cultivars, it was observed that the stem was the physical component of the plant with the highest percentage participation, both in the crop and in the regrowth, with averages of 73.18% and 55.93%, respectively, being statistically superior to the other components. (Table 2).

These results demonstrate that the stem is the portion of the sorghum plant that most influences the productive yield of the cultivars, besides being the physical component of the plant that will contribute in greater quantity in the bioenergy cogeneration.

3.2 Energy Characterization

It was observed that the upper calorific value (PCS) of the parts of the cultivars varied from 4220 to 4590 kcal kg-1 (Fig. 5). These results demonstrate that there are intrinsic factors in the composition of the parts of the plants that influence the upper calorific value. When comparing the values obtained in the analyzes of calorific value of the evaluated cultivars with other energy crops with the same purpose, as analyzed by Paula et al., (2011) [13], sugarcane bagasse (4274,48 Kcal kg^{-1}), corn stalk (4211.88 Kcal kg^{-1}) and eucalyptus (4774 to 8248 Kcal kg^{-1}), it can be inferred that sorghum has a high calorific value and can be used as a raw material source in bioenergy as a source of sustainable energy. It is important to observe the water content at harvest, so that the material can be used without any drying treatment, because the humidity decreases the combustion temperature, making the burning process difficult [14].

Table 2. Percentage participation of the physical components (panicle, leaves and stem) in the dry matter of the plant of six sorghum cultivars, evaluated in two experimental conditions (crop and regrowth)

		Componentes			
		Panicle (%)	**Leaves (%)**	**Stem (%)**	**Dry mass (t/ha)**
BD 7607	Crop	15,80 bB	13,09 bB	72,94 aA	43,63
	Regrowth	25,24 bA	18,82 cA	55,94 aB	1,68
BRS 716	Crop	5,22 cB	18,27 bA	77,10 aA	41,04
	Regrowth	26,70 bA	16,33 cA	56,97 aB	3,87
BD 5404	Crop	6,14 cB	19,79 bA	74,38 aA	24,36
	Regrowth	22,20 bA	17,73 cB	60,08 aB	3,55
BRS 511	Crop	0,99 cB	17,78 bB	81,23 aA	26,23
	Regrowth	12,87 cA	21,87 bA	64,26 aB	6,93
BD 1615	Crop	5,92 cB	14,15 bA	79,94 aA	22,95
	Regrowth	29,56 bA	18,10 cA	54,01 aB	3,66
BRS 655	Crop	18,87 bB	25,55 bA	53,58 aA	19,8
	Regrowth	42,24 aA	13,64 bB	44,31 aB	5,29

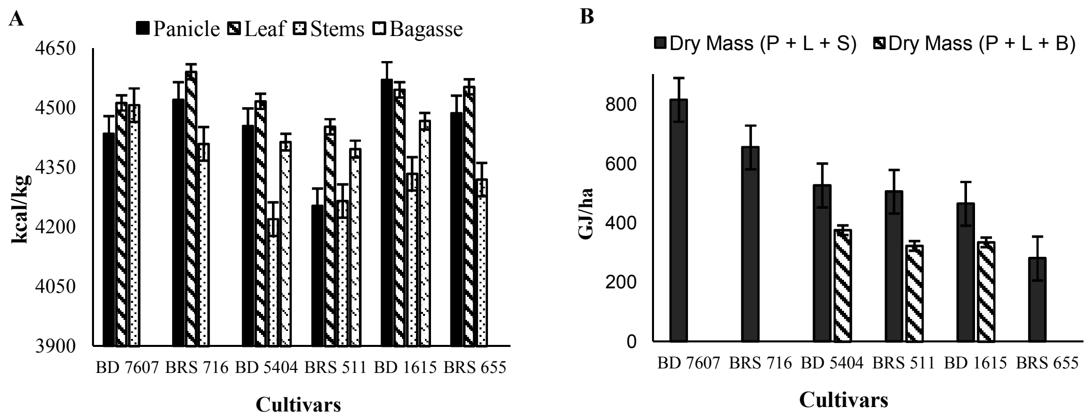

Fig. 5. Energy characterization: A) Upper calorific power (PCS) of the plant parts of six sorghum cultivars; B). Total energy yield / ha / cycle (GJ) of the total dry matter (P = panicle, l = leaf, S = stem and B = bagasse) of six sorghum cultivars. Coimbra- MG, 2015

Therefore, it is necessary to evaluate the condition of the plant at the time of harvest so that the collected material can be readily used in order to obtain high caloric yields.

For the cultivars that presented the succulent stem (BD 5404, BRS 511 and BD 1615), it was possible to verify a higher value of PCS in the bagasse in relation to the stem of the same (Fig. 5). Thus, it can be affirmed that the broth present in the stalks decreases the PCS of the same, when the direct burning is considered without the extraction of the broth. It was observed that there is a direct relation between the total dry matter production and the potential energy production / ha of the cultivars, since the cultivars of biomass sorghum (BD 7607 and BRS 716), which presented the highest PMS values, higher energy values per hectare with 815 and 654 GJ, respectively. The BRS 655 forage sorghum cultivar, which presented the lowest PMS, had the lowest energy yield per hectare with 280 GJ (Fig. 5). However, on marginally productive cropland, perennial grasses provide a feedstock supply while that enrich our environment in a positive manner. Where as several years of researches demonstrated that perennial grasses like switchgrass (*Panicum virgatum* L.) are profitable and environmentally sustainable on marginally productive cropland in the western Corn Belt and Southeastern USA [18].

The sorghum cultivars under study presented, on average, 18 GJ of energy per ton of dry matter (GJ/ t) from the total dry biomass. These results are close to those found for sugarcane bagasse, which present values of 17.89 GJ / t and 17.40 GJ/t [15]. From the study of PIMENTEL, Leonardo Duarte et al, it can be said that; sorghum presents different use potentials that may be exploited by the bioenergy sector according to the agronomic group and plant physical part.[17] Compared to sugarcane bagasse, a residue widely used for the generation of bioelectricity in industrial parks in Brazil, it can be stated that sorghum presents bioenergetic potential characteristic to be widely used in the energy sector.

4. CONCLUSION

It is concluded that the cycle duration of the cultivars is correlated with the accumulation of green mass and consequently the accumulation of dry mass. Therefore, the cultivars of sorghum biomass (BD 7607 and BRS 716) presented higher potential production and potential characteristics to be used in direct combustion and energy cogeneration. In the regrowth there was a significant reduction in the total biomass produced by the cultivars, mainly for the long cycle materials. In this way, the use of regrowth is not particularly advantageous for long cycle materials.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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