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Elephant grass (*Pennisetum purpureum* Schum.) biomass production as promising alternative source of energy in Brazil's semiarid area using gypsum

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Abstract

As alternative to supply the energy demand in semiarid Brazil, the biomass production of elephant grass (*Pennisetum purpureum* Schum) is a promising alternative. However, the cultivation of grass depends on several factors, including the chemical conditions of some soils which may limit productivity. Thus, the proper use of mineral gypsum as soil corrector can increase the production of biomass. Furthermore, the genetic characteristics of the varieties of elephant grass may influence their ability to produce energy, due to their different levels of fiber and lignin. This study aimed at assessing the energy performance of three varieties of elephant grass grown in the absence and presence of mineral gypsum. Three elephant grass varieties Cameroon, Gramafante and Roxo were cultivated in the field condition in the presence and absence of mineral gypsum in a factorial arrangement (3 × 2), with treatments randomly assigned to four blocks. The research was conducted at the Experimental Station of the Agronomic Institute of Pernambuco in Araripina Pernambuco State, Brazil. The biomass above the elephant grass was cut from the soil surface, 213 days after planting. The evaluations were carried out on traits such as levels of fiber in neutral detergent, acid detergent fiber, lignin, moisture, dry matter content and higher heating value. The elephant grass varieties Cameroon and Gramafante presented higher heating value and high dry matter production reinforced by application of mineral gypsum. The variety Cameroon showed the highest energy production per unit area. Thus, the use of elephant grass mainly of Cameroon and Gramafante varieties has great potential to solve or minimize the energy deficit of Gypsum Pole of Araripe in Pernambuco.

Keywords: elephant grass; energy of plant biomass; gypsum; Gypsum Pole of Araripe; higher heating value.
Abbreviations: ADF_Acid detergent fiber; Al_Aluminum; Ca_Calcium; HHV_Higher heating value; Mg_Magnesium; NDF_Neutral detergent fiber; P_Phosphorus.

Introduction

The rapid growth of world economy in the last century was associated with increased consumption of energy from various sources, especially oil and its derivatives, which can be considered the foundation of modern economics. However, from the point of view of planet sustainability, the use of oil and its derivatives is heavily criticized for being a non-renewable energy source and due to its combustion releases CO_2 to the atmosphere, compromising the ozone layer integrity. Thus, the global scientific community has been researching new sources of energy, called renewable energy in order to reduce the consumption of more polluting and non-renewable energy sources.

One of the alternative sources of renewable energy being widely studied is the plant biomass. However, their use should be done with proper planning, since the demand for energy is creating a serious problem such as deforestation of native forests, in the Caatinga, natural semi-arid biome of Brazil. Tavares and Santos (2013) showed a biome biodiversity risk at Caatinga, in which the survival of the population depended on the potential of its natural resources to survive. The operation of fast-growing species such as elephant grass is a viable alternative to minimize the damage to forest vegetation of the Caatinga. There are few works related to energy biomass production in elephant grass. It has several characteristics that favor its use for purposes such as high productivity and low cycles (Paterlini et al., 2013).

The use of a given material for energy purposes should be mainly based on the knowledge of its calorific value and its ability to produce biomass (Liu et al., 2009). However, the biomass production of elephant grass depends on several factors, among which the soil type and characteristics are important (Morais et al., 2009). For example, when acid and high exchangeable Al is high and there is low availability in exchangeable Ca and Mg and P deficient. The gypsum is a main input that has been shown effective in reducing Al saturation and its toxic effects as well as the elevation of levels of exchangeable Ca on the subsurface. The gypsum can increase the yield of many crops even under water stress conditions, as the main or supporting role. Soratto and Crusciol, (2008) observed that the surface liming increased grain yield of oats under water stress, with more pronounced effects in the presence of gypsum.

In the semi-arid region of Brazil there are most important deposits of gypsum, which are inserted in the gypsum pole of Araripe. Thus, the mineral gypsum produced in this region can increase dry matter production of elephant grass with their role in exchangeable acidity correction on the subsurface, providing greater amount of biomass that can be used as alternative energy source to power the kilns for the production of mineral gypsum widely used in the construction industry.

Thus, this study aimed to evaluate the energy performance of three elephant grass varieties grown in the absence and presence of mineral gypsum in the semiarid Brazil, the region of Gypsum Pole of Araripe.

Results and Discussion

Content of NDF, ADF and lignin

At 213 days after planting, the application of mineral gypsum did not affect the NDF, ADF and lignin in the different varieties of elephant grass (Table 2), showing the vegetable fibers little change by the mineral gypsum addition in the soil, even if this input is a Ca source, which is an important component of the cell wall.

In varieties of elephant grass no differences were observed in the content of NDF, ADF and lignin. This shows that the vegetable fibers, such as cellulose, hemicellulose, lignin and damaged protein, are quantitatively altered depending on the variety. This means that, they are probably stable in different strains of the same plant species, according to Santos et al. (2003) that evaluated the chemical composition of *Pennisetum purpureum* Schum cultivars Pioneiro and Mott. Mistura et al. (2006) evaluated the availability and quality of elephant grass with and without irrigation, fertilized with N and K in the dry season and reported NDF in the dry matter of elephant grass, ranging from 72.45 to 73.93% for non-irrigated area and irrigated area, respectively values next to those found for the varieties of elephant grass that showed NDF levels ranging from 75.14% and 77.57% (Table 2).

The ADF content is a most important feature that the NDF for energy generation, because it consists of less digestible components, essentially lignin, cellulose and carbohydrate richer in C. materials that have ADF levels over 52% of dry matter with ideal quality for burning. Morais et al. (2009) found ADF average content of 43.7% in acrisol and 42.4% in planosol in elephant grass genotypes, near the levels we found for varieties of Cameroon, Gramafante and Roxo. These are higher than those observed by Santos et al. (2003), reporting ADF content of 38.32% and 36.92% in cultivars of tropical grasses Pioneer and Mott, respectively.

The lignin contents are below the reference for an energetic plant material (Table 2). The lignin values above 10% of dry matter imply the quality of material for energy production. Rengsirikul et al. (2011) found 12.5% of the aboveground dry at 6-month-old elephant grass. However, these authors developed their experiment on Bana, Common and Muaklek, varieties, which are different from those used in this work. The contents of ADF and lignin were low (Table 2), but it should be taken into account that these levels were determined in the whole plant, and once leaves have lower content of fibers and lignin, it probably caused dilution of the ADF and lignin content of the aboveground biomass.

Production of dry matter and moisture content

The moisture is an important factor both for the determination of the calorific value (Bech et al., 2009), regarding the energy release of the material and for performance in kilns. The moisture of the grass varieties was not altered by the application of mineral gypsum (Table 3). It is common to credit the gain for crop production when applying mineral gypsum to the greater water use efficiency, but little is known about the physiological changes promoted by the input. Cascardo et al. (1993) evaluated the availability of water and the gypsum doses in water relations of rubber tree, but observed no significant input effect on the variables analyzed such as transpiration, stomatal conductance, leaf temperature, leaf water relative content, leaf total water potential and vapor pressure deficit.

When the moisture data were analyzed in the grass varieties, it was observed that the moisture biomass was different depending on the variety of elephant grass (Table 3), possibly being the result of intrinsic physiological factors of each cultivar. The highest moisture content was found in the Roxo grass (67.98%), compared to Gramafante (61.34%) and Cameroon (61.68%) grasses, which had similar moisture contents. Since the goal of grass biomass production of this work was for energy purposes, the lower levels of moisture implies in more efficient combustion.

The use of materials with high water content results in loss of efficiency once part of the energy that would be used in the gypsum calcinations, for example, will be used to vaporize water from the plant tissue (Bech et al., 2009). By this criterion, the Roxo grass features the less potential for use in gypsum calciner kilns in the Gypsum Pole of Araripe, once the time necessary for reduction of water content from the biomass possibly will be higher than those of other varieties.

The ideal plant for energy purposes must possess other features such as high biomass production, so the product of this material is of good quality for use in ovens (Santos et al., 2014). When analyzing the data of dry matter production, there was variation with the use of mineral gypsum and this variation was dependent on the variety of cultivated elephant grass and vice versa (Table 3). When the mineral gypsum was applied, dry matter production varied significantly in Cameroon grass and remained unchanged in Gramafante and Roxo grasses. With the application of mineral gypsum in the soil plots of Cameroon variety, the dry matter production was higher (8.65 Mg ha^{-1}), compared to control. Probably, the answer to the Ca addition, conveyed by the application of mineral gypsum, was more effective for the Cameroon grass, being able to ameliorate the root environment, promoting greater access to reserves of subsurface water and nutrients, causing Cameroon responded with increased biomass production. Caires et al. (2004) reported that application of lime in combination with gypsum, increased the maize

Table 1. Chemical and physical characterization of soil at depths from 0.0 to 0.2 m and 0.2 to 0.4 m in the area of field trial.

Attribute	Depth (m)	
	0.0 – 0.2	0.2 – 0.4
pH $_{water}$ (1:2,5)	4.85	4.54
pH $CaCl_2$ (1:2,5)	3.30	3.40
Ca^{2+} ($cmol_c$ dm^{-3})	0.95	0.30
Mg^{2+} ($cmol_c$ dm^{-3})	0.68	0.38
K^+ ($cmol_c$ dm^{-3})	0.14	0.09
Na^+ ($cmol_c$ dm^{-3})	0.23	0.24
P (mg dm^{-3})	4.00	1.00
P-rem (mg L^{-1}) [1]	62.95	58.28
Al^{3+} ($cmol_c$ dm^{-3})	0.37	0.70
(H + Al) ($cmol_c$ dm^{-3})	3.74	3.27
CEC $_{effective}$ ($cmol_c$ dm^{-3}) [2]	2.37	1.71
m (%) [3]	15.49	40.90
ESP (%) [4]	3.95	5.49
TOC (g kg^{-1}) [5]	8.1	5.2
$S\text{-}SO_4^{-2}$ (mg dm^{-3})	1.83	0.69
MACS (mg g^{-1}) [6]	0.012	0.018
Total Sand (g kg^{-1})	729.75	722.28
Coarse sand (g kg^{-1})	569.81	551.49
Fine Sand (g kg^{-1})	159.94	170.79
Silt (g kg^{-1})	133.88	143.75
Clay (g kg^{-1})	136.38	133.97
Texture class	Sandy loam	Sandy loam
PD (kg dm^{-3}) [7]	2.99	2.98
SD (kg dm^{-3}) [8]	1.43	1.41
TP (%) [9]	52.26	52.64
K_0 (mm h^{-1}) [10]	65.24	92.83

[1] Phosphorus remaining, [2] Cation exchange capacity; [3] Aluminum saturation; [4] Exchangeable sodium percentage, [5] Total organic carbon, [6] Maximum adsorption capacity of sulfate, [7] Particle density, [8] Soil density, [9] Total porosity, [10] Saturated hydraulic conductivity.

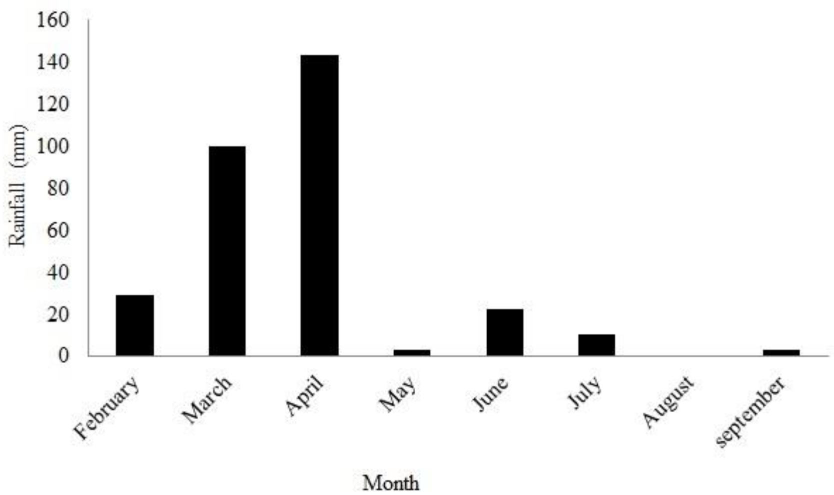

Fig 1. Rainfall during the experimental test at the Experimental Station of the Agronomic Institute of Pernambuco in Araripina/PE.

production by 17%, depends on the increased Ca saturation in the topsoil.

The production of dry matter in different varieties of elephant grass was influenced by the presence or absence of mineral gypsum (Table 3). We found that the presence of mineral plaster in grass cultivation Cameroon and Gramafante provided higher dry matter production in relation to the Roxo grass. In the absence of mineral gypsum, there is a reduction in dry matter production of Cameroon grass, resembling the Gramafante production, but still keeping both higher yields to the Roxo grass. The data suggest that in the absence of gypsum in the Araripe region, it is advisable to cultivate the Cameroon and Gramafante varieties as alternative biomass for energy production, because both have similar lignin content (Table 2).

Moreover, the response to the mineral gypsum for the Cameroon variety is very significant and around 30% more than Gramafante in the absence of feedstock. The application of gypsum also increased the dry matter yield of sorghum variety saccharine IPA 467-4-2 (Rocha et al., 2014). In the regions with abundant mineral gypsum production, the use and application of this input is economically viable, encouraging the indication of the Cameroon variety as very promising for the climatic conditions of Araripe region.

Table 2. Content of neutral detergent fiber (NDF), acid detergent fiber (ADF) and lignin in dry matter of three varieties of elephant grass in the presence and absence of mineral gypsum at 213 days after planting, mean, analysis of variance and coefficient of variation of the variables

ns not significant. Equal uppercase in the row and lowercase letters in column do not differ (F test, $p \leq 0.05$).

Factors	NDF		Mean	ADF		Mean	Lignin		Mean
	Mineral Gypsum			Mineral Gypsum			Mineral Gypsum		
	With	Without		With	Without		With	Without	
	%								
Grass									
Cameroon	73.72	76.56	75.14 a	40.34	41.69	41.01 a	5.25	5.07	5.16 a
Gramafante	76.71	78.42	77.57 a	44.75	45.88	45.32 a	6.74	6.41	6.58 a
Roxo	77.26	77.88	77.57 a	45.59	42.97	44.28 a	6.23	5.63	5.93 a
Mean	75.90 A	77.62 A		43.56A	43.51A		6.07 A	5.70 A	
	F			F			F		
Grass	0.71^{ns}			2.26^{ns}			3.27^{ns}		
Mineral Gypsum	0.80^{ns}			0.00^{ns}			0.66^{ns}		
Grass*Mineral Gypsum	0.11^{ns}			0.56^{ns}			0.08^{ns}		
C.V. (%) Plot	2.21			5.21			8.82		
C.V. (%) Subplot	6.14			9.71			18.84		

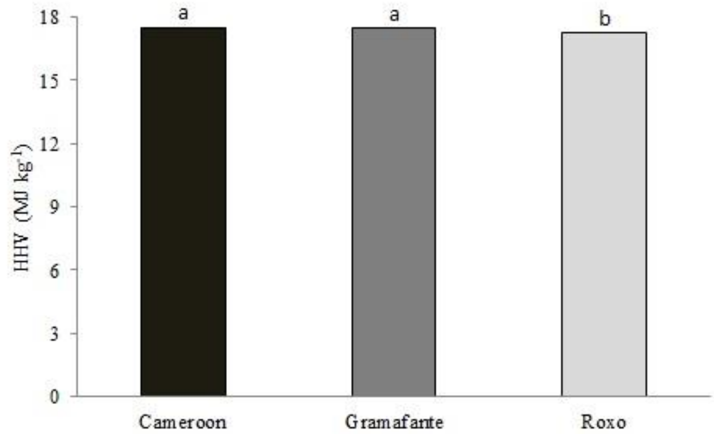

Fig 2. Higher heating value (HHV) of the biomass for three varieties of elephant grass at 213 days after planting. Equal lowercase letters are not different (Tukey test, $p \leq 0.05$).

This increased dry matter production by adding mineral gypsum has also been observed by Guedes et al. (2000) in *Brachiaria decumbens* Stapf, when 0.5 Mg ha^{-1} gypsum applied, similar to the amount used in this work. At this dose, they observed about 29% increase in dry matter production, and at the highest dose (1.5 Mg ha^{-1}), such increase was 46%. Morais et al. (2009) studied the biomass production for energy use of different genotypes of elephant grass and found the same values of dry matter production like those observed in our study. The varieties Cameroon and Gramafante produced 29.5 and 23.6 Mg ha^{-1}, respectively, in the first harvest at 7 months.

Higher heating value (HHV)

The HHV values did not vary by the mineral gypsum application (Fig. 2). This fact is in agreement with Bech et al. (2009), who stated that the HHV of a material is primarily affected by moisture and lignin content, and both variables were not influenced by the application of the product, confirming the results of this work (Table 2 and 3). The HHV data showed significant difference in function of the different varieties of elephant grass (Fig. 2). According to Telmo and Lousada (2011), the material with higher lignin content is also responsible for the largest HHV. According to Tavares and Santos (2013) lignin is rich in carbon and hydrogen, where these components produce heat. Thus, the higher value of HHV was observed in Cameroon and Gramafante varieties, while the Roxo grass had the smallest HHV. However, there was no significant difference in the lignin content of these varieties (Table 2). The Roxo grass presented less HHV, possibly due to moisture differences between the materials (Bech et al., 2009). The HHV measured in this work was conducted with samples dried at 65°C. At this temperature, the humidity may interfere substantially with the HHV of the sample, such as, for Roxo grass presenting high humidity in the field (Table 3) and possibly when dry 65°C, kept higher humidity than other varieties. This causes a considerable energy release from combustion of lignin content of material, which is mainly used to evaporate the largest water content of the sample.

The HHV values produced by the biomass of elephant grass varieties were close to that generated by the wood sample collected in the calciner industry (17.55 MJ kg^{-1}). Some woody species is currently to generate energy for calcination of gypsum, in which the elephant grass biomass can be produced without energy loss, being an alternative to decrease the anthropogenicaction suffered by lumber forest species. The HHV of some tree species also were similar to the value found in the varieties of elephant grass of the

Table 3. Production of dry matter and moisture content of three varieties of elephant grass in the presence and absence of mineral gypsum at 213 days after planting, mean, variance analysis and coefficient of variation of the variables

Factor		Moisture – Mineral Gypsum		Mean	Dry matter – Mineral Gypsum		Mean
		With	Without		With	Without	
		%			Mg ha^{-1}		
Grass							
Cameroon		61.78	61.58	61.68 b	33.29 Aa	24.64 Ba	28.97
Gramafante		62.04	60.64	61.34 b	25.86 Aa	24.45 Aa	25.15
Roxo		69.32	66.64	67.98 a	13.65 Ab	14.69 Ab	14.17
Mean		64.38 A	62.95 A		24.27	21.26	
		F			F		
Grass		18.72**			46.72***		
Mineral Gypsum		2.05 ^{ns}			5.38*		
Grass*Mineral Gypsum		0.52 ^{ns}			5.03*		
C.V. (%)	Plot	3.40			11.71		
	Subplot	3.84			13.96		

^{ns} not significant; *, **, *** significant respectively, the levels of 5%, 1% and 0.1% probability. Equal uppercase letters in the row and lowercase letters in column do not differ (Tukey test, $p \leq 0.05$).

present work. The biomass value observed in this study was also close to vegetable of sawdust Eucalyptus spp. (18.49 MJ kg^{-1}) (Protásio et al., 2011). Telmo and Lousada (2011), studying the calorific value of wood from 17 tree species, found HHV values ranging from 17.63 to 20.81 MJ kg^{-1}. The age of plant affected the higher heating value of wood *Schizolobium amazonicum* Huber ex Ducke (parica), in which the largest value was reported at 5-year-old plant (19.49 MJ kg^{-1}) (Vidaurre et al., 2012). Santos et al. (2003) reported the biomass values in Mott variety of elephant grass (16.94 MJ kg^{-1}), when evaluated the chemical composition of tropical grasses in the forest zone of Pernambuco. Liu et al. (2009), evaluated three grass species subjected to copper stress and observed HHV values close to this work, ranging from 14.65 to 16.74 MJ kg^{-1}, with elephant grass presenting the lowest value.

The Cameroon and Gramafante would be the varieties of choice, if the criterion for the energy purposes is the HHV. However, greater amount of energy was produced per unit of area by the Cameroon variety, when comparing the HHV and considering the dry matter production (Table 3). It produced 580.990 MJ ha^{-1}, while the Gramafante grass presented 451.454 MJ ha^{-1}. Thus, for similar soil conditions, it is recommended the cultivation of the elephant grass Cameroon variety, combined with the application of mineral gypsum, which enhances its production of dry matter. The Cameroon variety can be used as an alternative energy in the Pernambuco semiarid, particularly in calcination furnaces for gypsum in the Gypsum Pole of Araripe that has high demand of plant biomass.

Materials and Methods

Characteristics of the experimental area

To evaluate the effect of the mineral gypsum in soil cultivated with different elephant grass varieties, a field experiment was conducted at the Experimental Station of the Agronomic Institute of Pernambuco (IPA), in Araripina/PE, in the period from January to September 2010. It is located 694 km from Recife, under the geographical coordinates 07 ° 27' S and 40 ° 24' W and 831 m altitude in a soil classified as Ferralsol (Cavalcanti and Lopes, 1994). The vegetation is basically composed of Hyperxerophyla Caatinga with patches of Deciduous Forest. The climate is Bshw', semiarid, hot, rainy summer-autumn under the Koppen's classification, with the rainy season beginning in November and ending in April with 431.8 mm mean annual rainfall (CPRM, 2005). During the experimental trial, the rainfall was 350.2 mm (Fig. 1). The chemical and physical soil characterization (Table 1) was performed at two depths (0.0 to 0.2 and 0.2 to 0.4 m). The other soil characteristics were determined such as: pH (H_2O), pH (0.01 mol L^{-1} $CaCl_2$), Ca^{2+}, Mg^{2+}, K^+, Na^+, Al^{3+}, (H + Al), P and TOC (total organic carbon), according to EMBRAPA (2009); S-SO_4^{2-}, maximum adsorption capacity of sulfate (MACS) and P-remaining (P-rem), as described by Alvarez et al. (2001). Physically, the soil was characterized regarding its granulometry to define the textural class (Ruiz, 2005); bulk density, density of particles, hydraulic conductivity, moisture in the permanent wilting and point field capacity, and indirectly, the total porosity, as describe by EMBRAPA (1997).

Experimental design and treatments

Three varieties of elephant grass were used (Roxo, Cameroon and Gramafante) under two levels of mineral gypsum 0 and 100%, which corresponded to doses of 0 and 0.494 Mg ha^{-1}, calculated according to Alvarez et al. (1999) and applied to the bottom of the crop furrow, forming a factorial (3 × 2). The trial was arranged in four randomized blocks, in a split plot, totaling 24 experimental units. The subplot consisted of seven furrows 6 m long and spaced 1 m, giving a total area of 42 m^2. The floor area was formed by the three central lines discarding 1 m from the ends to avoid boundary effects, totaling 12 m^2.

Conducting of the experiment

The experiment was installed at the beginning of the rainy season (Fig. 1), preceded by the lime application in total area, calculated for the layer correction from 0.0 to 0.2 m depth (Table 1), whose need for liming was estimated by the method of exchangeable Al neutralization or increased levels of exchangeable Ca and Mg (Cavalcanti, 2008). Thus, it was calculated a lime dose corresponding to 0.550 Mg ha^{-1}, which was incorporated with disc grids in all experimental plots eight days before planting. All plots received NPK fertilization, according to the Fertilizer Recommendations for the State of Pernambuco (Cavalcanti, 2008) based on the results of soil chemical analysis (Table 1). Thus, 0.300 Mg ha^{-1} of ammonium sulfate, 0.286 Mg ha^{-1} of triple superphosphate and 0.150 Mg ha^{-1} potassium chloride were applied. All the triple superphosphate was applied in foundation, and the remaining 1/3 in foundation and 2/3 in coverage, 70 days after planting.

Eight days after the application of mineral gypsum the planting of elephant grass varieties was carried out. Planting was done, where 4 Mg ha^{-1} of stem aged 3 months were used and arranged in two rows. So, the basal half of a stem coincided with the upper half of the other. After planting, the stems were cut in cuttings with 4-5 buds, and then the spraying of furrow and seeds were carried with termiticide and subsequent closing the furrow.

Experimental evaluation

Cutting and evaluation of varieties of elephant grass were performed 213 days after planting, when 10 plants were collected randomly in the useful plot, and subsequently weighted and crushed in forage. Subsequently, subsamples were taken, their weight recorded, then dried by forced air circulation oven at 65 °C until constant weight to obtain the dry matter and moisture. Based on the number of tillers per linear meter it was possible to estimate the production of useful plot, correcting the flaws of the shooting of the material used in planting.

After drying, the sample to measure biomass was ground using knife mill with a sieve mesh of 1 mm in diameter, in order to make the determination of neutral detergent fiber (NDF), acid detergent fiber (ADF) and lignin according to Van Soest and Wine (1968), and the higher heating value (HHV) using calorimeter (ABNT, 1984). Subsequently, in order to observe the differences in moisture content among the varieties of elephant grass, samples of biomass dried at 65 °C then were weighted and placed in oven at 105 °C, trying to remove residues of moisture in the plant tissue at 65 °C, obtaining the percentage of water in the material used to determine the HHV.

Statistical analysis

All plants characteristics data related to the energy and biomass were subjected to analysis of variance using the F-test ($p \leq 0.05$). In the variables whose main effects and/or interaction were significant, the Tukey's test was applied ($p \leq 0.05$). The statistical package used was SAS Learning Edition 2.0 (SAS, 2002).

Conclusions

The elephant grass varieties Cameroon and Gramafante presented higher heating value and dry matter production. The Cameroon variety showed the highest energy production per unit area when supplemented with application of mineral gypsum. Thus, the use of elephant grass mainly of Cameroon and Gramafante varieties has great potential to solve or minimize the energy deficit of Gypsum Pole of Araripe in Pernambuco.

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