Water Air Soil Pollut (2018) 229: 132
https://doi.org/10.1007/s11270-018-3786-1

Production and Bromatological Characteristics of Elephant Grass—*Cenchrus purpureus* (Schumach.) Morrone—Planted Under Application of Industrial Biosolid and Chemical Fertilization

Talles Iwasawa Neves · Claudio Augusto Uyeda · Cleiton de Souza Silva · Raphael Abrahão

Received: 28 November 2017 / Accepted: 21 March 2018 / Published online: 29 March 2018

Abstract Biosolid, i.e., dehydrated sludge from effluent treatment stations, has been progressively used as an agricultural fertilizer due to its high organic matter and nutrient contents. Elephant grass (*Cenchrus purpureus* (Schumach.) Morrone) presents easy adaptation and high yields, being used for animal feeding and for energy purposes. The objective of this work was to analyze the production and bromatological parameters of elephant grass with four different doses of biosolid, one of chemical fertilizer and a control plot, with two replicates each. A field experiment was carried out using a randomized block design with three blocks, totaling 18 plots, which received biosolid fertilization at 1×, 2×, 4×, and 8× the levels recommended by the Brazilian National Environment Council, along with conventional chemical fertilization and no fertilization, all under similar drip irrigation. Tukey's test indicated a significant difference at $p < 0.01$ for total production in the first cut and acid detergent fiber in the second cut. At $p < 0.05$, significant differences were detected for total nitrogen and total protein in the first cut. The elephant grass yield under "1× biosolid" was similar to that reached with chemical fertilization. Physical and bromatological characteristics indicated potential use as animal feed and energy source. For doses higher than specified by Brazilian standards (2×, 4×, and 8×), further studies are required to verify possible contamination from heavy metals, pathogenic microorganisms, and n.

Keywords Treated sludge · Chemical fertilizers · Forage plant · Production · Animal feed · Energy

1 Introduction

An inherent characteristic of effluent treatment stations (ETSs), especially biological stations, is the production of sludge, the final disposal of which poses a major challenge, especially since the creation of Law 12305/10 (Brazil 2010), which banned its disposal in landfills. Due to significant contents of nitrogen and phosphorus, this residue can be used in agricultural areas as a soil conditioner or fertilizer, after receiving appropriate processing (Melo et al. 2001). The use of biosolids in agriculture can be an economic alternative to farmers,

---

T. I. Neves · C. de Souza Silva
Graduate Program in Renewable Energies, Federal University of Paraíba (Universidade Federal da Paraíba – UFPB), João Pessoa, Brazil

T. I. Neves
e-mail: talles.neves@cear.ufpb.br

C. de Souza Silva
e-mail: cleiton.souza@cear.ufpb.br

C. A. Uyeda
Federal Institute of Pernambuco (Instituto Federal de Pernambuco – IFPE), Vitória de Santo Antão Campus, Recife, Brazil
e-mail: claudio.uyeda@vitoria.ifpe.edu.br

R. Abrahão (✉)
Department of Renewable Energy Engineering, Federal University of Paraíba (Universidade Federal da Paraíba – UFPB), UFPB, João Pessoa, Brazil
e-mail: raphael@cear.ufpb.br

since it can totally or partially replace the use of inorganic fertilizers, besides being a more sustainable alternative for final disposal (Behling 2009).

Owing to its high levels of nitrogen, biosolid is a good alternative fertilizer for agricultural crops, including forage crops. The use of nitrogen fertilizers has been one of the limiting factors in producing and improving the economic performance of forage crops (Vitor 2006). The use of nitrogen fertilizers has positive effects in terms of both forage production and nutritional value (Andrade et al. 2003). Nabinger and Medeiros (1995) report that the nitrogen available determines the growth and development of a plant, with higher nitrogen availability corresponding to faster formation of axillary buds and, consequently, tillering of the respective buds, until the leaf area reaches a certain critical value, thereby changing the amount of light that reaches the late buds.

Among the several forages planted in Brazil, elephant grass—*Cenchrus purpureus* (Schumach.) Morrone—stands out because it is a tropical species that has been widely used in animal feed for meat and milk production, is present in all regions of Brazil, and exhibits easy adaptation, good production levels, and easy establishment (Vitor 2006; Magalhães et al. 2009). This forage originated from Subtropical Africa, and arrived in Brazil in the mid-1920s, being cultivated in all regions of the country (Oliveira et al. 2017; Quéno et al. 2011).

In addition to its use in animal feeding, elephant grass has been widely used as biomass for energy purposes. The biomass of elephant grass has potential for the production of biofuel, alcohol, and charcoal and can be burnt directly for methane production (Anderson et al. 2008; Jakob et al. 2009; Lee et al. 2010; Lima et al. 2011; Morais et al. 2012; Samson et al. 2005; Smeets et al. 2009; Strezov et al. 2008). This forage is a promising alternative for energy production because of its great potential for biomass production (Derezs et al. 2006). According to Samson et al. (2005) and Morais et al. (2011), elephant grass is one of the main forage species used for this purpose, as a result of its high production capacity, low input requirements in its production process, and good biomass quality.

Thus, the objective of this work was to analyze and compare the production parameters and bromatological parameters of elephant grass under increasing doses of biosolid and chemical fertilizers, thereby evaluating the possibility of using elephant grass as biomass, both as an energy source and as an animal feed.

2 Materials and Methods

The experiment was performed in an experimental farm in the city of Pedras de Fogo (Paraíba state, Northeast Brazil) in an area where biosolid was never used and that had not been cultivated for more than 6 years. The municipality is located in the microregion of the Southern Coast of Paraíba, which is classified as As—tropical climate (winter rains)—according to the Köppen-Geiger climate classification.

Five fertilization treatments (four with biosolid and one with chemical fertilization) were used in addition to the control plot, with two replicates for each treatment, totaling 18 plots of 2 m × 2 m each, chosen at random, as shown in Fig. 1.

The soil was prepared before the experiment started. The area for forage planting and development was harrowed and plowed to facilitate the growth and development of the plant and its management (Italiano 2004). Manual cleaning was performed, and the soil was plowed using a tractor (Lopes 2004).

The biosolid used in the experiment was produced by a textile industry ETS of the industrial district of João Pessoa/PB, whose treatment is based on an extended-aeration, activated-sludge biological system. Its application was determined according to the Brazilian National Environment Council (better known by its acronym in Portuguese, Conama) (Brazil 2006), which defines criteria and procedures for the agricultural use of sewage sludge generated in sewage treatment plants and its byproducts and contains other provisions. For the calculation of the application rate, a physicochemical analysis of the biosolid was performed according to the same resolution.

The application rate according to Conama Resolution 375/06 (Brazil 2006) was calculated based on the available amount of nitrogen in the biosolid and the requirements of this element for the full development of the crop to be established. The application rate was calculated using Eq. 1.

$$\text{Application rate (t/ha)} = \text{N recommended (kg/ha)/N available (kg/t)} \quad (1)$$

where

N recommended	Quantity of nitrogen recommended for the crop, according to the State's official recommendation;

N available	Quantity of nitrogen calculated according to annex 3 of Conama Resolution 375/06 (Brazil 2006)

The dose of nitrogen fertilizer recommended for the elephant grass crop was determined using information collected from the literature, as fertilization data from the state of Paraíba were scarce. Saraiva and Carvalho (1991) did not observe significant effects on the production of elephant grass (dry matter) when a dose of 120 kg of N/ha combined with phosphate fertilization was applied, whereas Monteiro (1994) recommended doses ranging from 30 to 300 kg of N/ha. In the present experiment, a dose of 200 kg of N/ha was used.

The calculation of the nitrogen available in the biosolid was performed according to annex 3 of Conama Resolution 375/06 (Brazil 2006) using Eq. 2.

$$N_{avail}\ (mg/kg) = (MF/100) \times (N_{Kj} - N_{NH4}) + 0.5\ x\ (N_{NH4}) + (N_{NO3} + N_{NO2}) \qquad (2)$$

where

MF	Nitrogen mineralization fraction (%);
N_{Kj}	Kjeldahl nitrogen (Kjeldahl nitrogen = total organic nitrogen + ammonia nitrogen (mg/kg);
N_{NH4}	Ammonia nitrogen (mg/kg);
N_{NO3} + N_{NO2}	Nitrate and nitrite nitrogen (mg/kg).

With the data collected in the physicochemical analysis of the biosolid, the following application rates were determined (Table 1) using the above equations, on a dry basis, for the four treatments that used the biosolid.

The 1× biosolid dose was calculated according to the guidelines of Conama Resolution 375/06 (Brazil 2006). In the other treatments, namely, 2×, 4×, and 8× biosolid, the doses applied were 2×, 4×, and 8× the dose calculated according to the said Resolution, respectively.

The doses of biosolid were fractionated as follows: 15% of the total dose 1 day before elephant grass planting, 30% after 11 days, 30% after 18 days, and 25% after 34 days of planting. Before being applied, the biosolid underwent a stabilization process using hydrated lime. According to Conama Resolution 375/06 (Brazil 2006), it is mandatory to use a stabilization method to inactivate pathogens and reduce vector attraction. Laboratory tests were performed with crude biosolid mixed with lime in the proportions of 10, 20, 30, 40, and 50% of the dry weight of the biosolid, reaching a ratio of 30% lime to dry weight of the biosolid to reach pH 12 after 48 h and pH above 11.5 after 24 h to achieve alkaline stabilization of the biosolid. The lime was mixed with the biosolid on the day of application to the soil.

Chemical fertilization at elephant grass establishment, in addition to supplying nitrogen deficiencies, should provide sufficient phosphorus and potassium to meet the crop's annual requirements; for this crop, 50 to 100 kg of P_2O_5/ha/year and 80 to 100 kg of KCl/ha/year are suggested, as many soils are potassium deficient (Werner 1986; Evangelista and Lima 2002). In the experiment, 100 kg/ha/year of both single superphosphate and potassium chloride was used. Thus, the fertilizer mix used had the following ratio: 200:100:100 (N:P:K). The fertilizer mix was applied only once, 1 day before planting the seedlings. The nitrogen source used was urea, which was also applied in a single application, 1 day before planting.

Planting was performed 1 day after application of chemical fertilizers and biosolid. In the soil preparation, approximately 15-cm-deep furrows were opened, which were spaced 1 m apart. The elephant grass seedlings were placed in the furrows, in pieces with three buds each, and spaced 1 m apart, according to the experience of the local farmers and based on the information in the scientific literature regarding elephant grass planting (Alcântara and Bufarah 1986; Gomide 1997; Martins and Fonseca 1998; Evangelista and Lima 2002).

The irrigation was performed using drippers, with a flow rate of 1.5 L/h, a spacing of 0.50 m between drippers, and one line of drippers per planting row.

The daily irrigation water depth was calculated using the methodology of Hargreaves and Samani (1982). For this purpose, a digital thermometer was installed in the experimental area to calculate the daily reference evapotranspiration from the maximum, minimum, and mean temperatures and the radiation using Eq. 3.

$$ET_0 = 0.0023 \times (Tmean + 17.78) \times (Tmax - Tmin)0.5 \times (RA \times 0.408) \qquad (3)$$

where

ET_0	Reference evapotranspiration (mm/h);
Tmean	Mean temperature;
Tmax	Maximum temperature;
Tmin	Minimum temperature;
RA	Extraterrestrial radiation (MJ/m^2).

The extraterrestrial radiation was tabulated according to the latitude of the site and the month of the year. After the calculation of the reference evapotranspiration, the evapotranspiration of the crop was calculated using Eq. 4.

$$ET_C = ET_0 \times Kc \qquad (4)$$

where

ET_C	Crop evapotranspiration (mm/h);
Kc	Crop coefficient.

The crop coefficient was tabulated. The values recommended by Alencar et al. (2009) for elephant grass were used.

Once the ET_C was calculated, the daily irrigation depth was determined using Eq. 5.

$$IW = (ET_C/Ei) \times 100 \qquad (5)$$

where.

IW	Irrigation depth (mm/day);
Ei	Irrigation water application efficiency (%).

The elephant grass was cut manually and the green matter was weighted per plot after 4 months of planting in the first cut and after 8 months of planting in the second cut. To estimate the plant height, three plants of the middle row of each plot were randomly selected, and the simple average of the three heights was calculated. The stem/leaf ratio was calculated using Eq. 6.

$$\text{Stem/leaf ratio} = Ws/(Wgm{-}Ws) \qquad (6)$$

where

Wgm	Green matter weight of the middle row of each plot;
Ws	Weight of stems without leaves;
Wgm − Ws	Leaf weight.

Twenty random plants were collected from the middle row of each plot for the purpose of obtaining a composite sample to use in the bromatological analyses. Sixteen elephant grass plants were sufficient to perform the micronutrient analysis with a 10% error in the experiment of Primo et al. (2013) in Sobral (Ceará - Brazil). Once collected, the samples were sent directly to the laboratory responsible for the analyses, which used the methodology described by Bezerra Neto and Bareto (2004).

Using a randomized block design with six treatments (control plot, chemical fertilization, and 1, 2, 4, and 8× biosolid), with two replicates each, and totaling 18 experimental plots, statistical analysis of the data was performed using analysis of variance (ANOVA) through the *F* test and using the Tukey test to compare the means at the 1 and 5% levels of significance.

3 Results and Discussion

There was a significant effect ($p < 0.01$) for the treatments only for the total production variable in the first cut (TP1) (Table 2). The control and chemical fertilization treatments were statistically similar but different ($p < 0.01$) from the treatments 1× and 2× biosolid, which were also statistically similar. The treatments 4× and 8× biosolid differed from each other ($p < 0.01$) and from all other treatments in terms of the TP1 parameter. Evaluating the means using the Tukey test, there was a trend of increasing mean production in the first cut with the addition of biosolid in the soil for the control and chemical fertilization treatments. In the 1× biosolid treatment, as determined according to Conama Resolution 375 (Brazil 2006), the mean productions were greater than those obtained in the chemical fertilization and control treatments. Some authors, such as Pereira Jr et al. (1997), have found similar results for other crops; the aforementioned studies found that in a 3-year experiment, maize production was higher in treatments in which biosolids were used compared with chemical fertilization and the control lot.

Although it was not significant, a difference was observed in the mean production between the two cuts of elephant grass. A similar trend was expected with the first cut, which did not occur. It was observed that during the post-first cut period, in mid-April 2016, there was high rainfall in the experimental area, reaching cumulative volumes of 280.7 mm for that month alone (Aesa Executive Agency for Water Management of the State of Paraíba 2017). Thus, preferred paths of rainwater runoff among the experimental plots were observed, which may have caused leaching of materials from one plot to another. Thus, nutrients carried by this runoff may have caused the aforementioned difference in mean production between treatments in the two cuts. Na et al. (2016) found growth differences for three different grass types in different growth seasons.

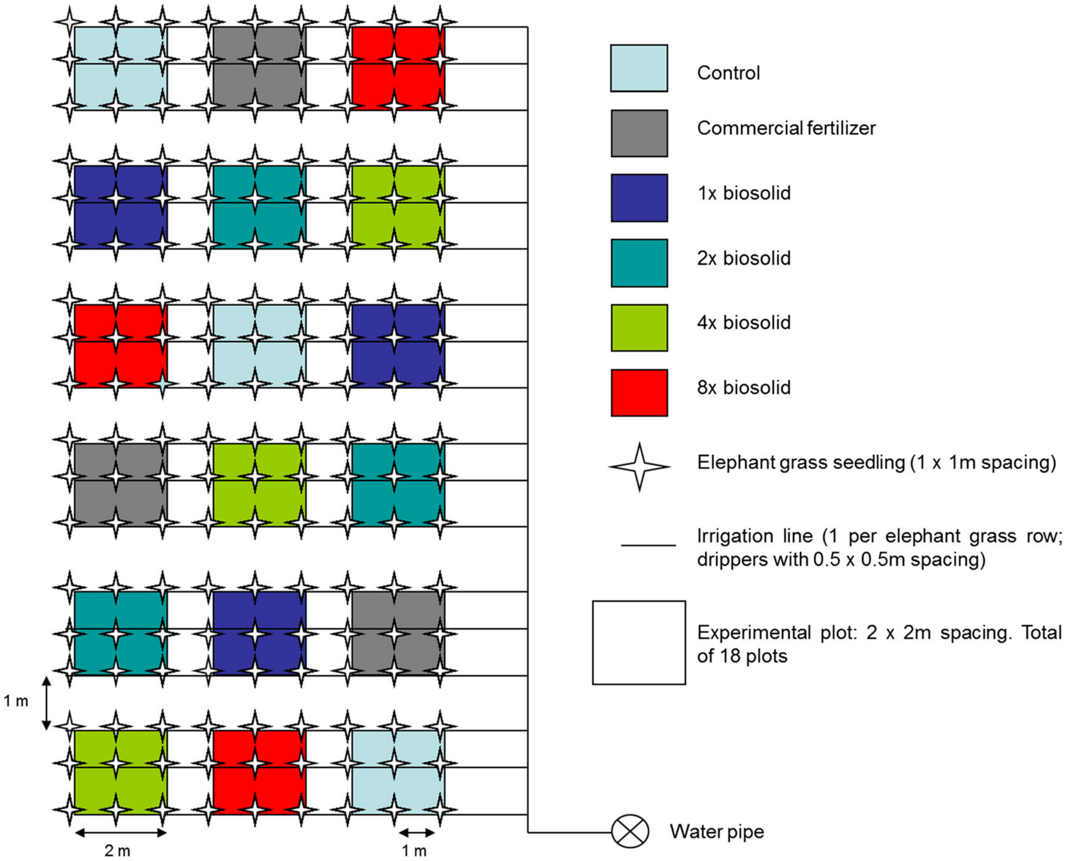

Fig. 1 Schematic representation of the experimental design applied. Source: Neves (2017)

Regarding the stem/leaf ratio, a parameter that is often evaluated for assessing the use of biomass as an energy source, there was a tendency of growth in the biosolid treatments compared with the others. All the mean values found in all treatments were greater than those found by Morais (2008) in an experiment in which they evaluated five different genotypes of elephant grass. Flores et al. (2012) did not find significant differences for the stem/leaf relationship between the treatments of their experiment for two species of elephant grass (fertilized and not fertilized).

Regarding the plant height parameter, the values found in both cuts were similar to those found by Deschamps (1999) in his experiment, which employed the same cutting period. Santos et al. (2001) for a cutting period of 3 months, using standardization cuts, found a mean plant height value of 1.63 m for an elephant grass cultivar.

Tables 3 and 4 present the results obtained for the bromatological parameters of elephant grass in the first and second cuts. It was observed that there were significant differences between treatments in terms of the following variables: total nitrogen (TN1) and total protein (p1) in the first cut and dry matter (DM2) in the second cut, all at $p < 0.05$, and acid detergent fiber (ADF1) in the first cut ($p < 0.01$).

There was a trend of increased mean values for the parameters total nitrogen and total protein with increased biosolid dose in both cuts compared with the chemical fertilization and control treatments. Some authors report for experiments with elephant grass that the highest levels of proteins in the plant are directly related to the nitrogen fertilizer doses (Ribeiro 1995; Andrade

Table 1 Amount of biosolid applied

Biosolid	Amount
1× biosolid	10.14 ton/ha year
2× biosolid	20.28 ton/ha year
4× biosolid	40.56 ton/ha year
8× biosolid	81.12 ton/ha year

Table 2 Summary of the ANOVA of the following variables: plant height in the first (PH1) and second (PH2) cut, stem/leaf ratio in the first (S/L_1) and second (S/L_2) cut, and total production in the first (TP1) and second (TP2) cut of the elephant grass

Source of variation	DF	PH1 Mean squares	S/L_1	TP1	PH2	S/L_2	TP2
Block	2	0.495^{ns}	1.03*	46.78^{ns}	0.04^{ns}	1.38**	100.73^{ns}
Treatments	5	0.531^{ns}	0.27^{ns}	463.41**	0.06^{ns}	0.28^{ns}	102.42^{ns}
Residual	10	0.299	0.23	38.88	0.06	0.17	84.77
Total	17						
CV (%)		21.31	24.47	19.61	12.94	21.46	30.60
Treatment		Mean					
		PH1 (m)	S/L_1	TP1 (kg/plot)	PH2 (m)	S/L_2	TP2 (kg/plot)
Control		2.03a	1.63a	23.08a	1.89a	1.73a	36.63a
Chemical fertilization		2.51a	1.99a	17.86a	2.02a	1.67a	31.37a
1× biosolid		3.07	1.59a	25.99ab	1.84a	1.66a	19.92a
2× biosolid		2.14a	2.07	30.23ab	222a	2.06a	33.40a
4× biosolid		2.93a	2.32a	42.95bc	1.86a	2.39a	32.00a
8× biosolid		2.73a	2.19a	50.72c	1.94a	2.15a	27.23a

Means with equal letters do not differ from each other

ns not significant

**Significant at the 1% level; *significant at the 5% level

et al. 2003; Costa et al. 2004; Mistura et al. 2004). The results are similar to those found by Magalhães et al. (2009) who found that for three different cultivars of elephant grass, higher levels of protein were obtained in the treatments in which greater doses of nitrogen fertilizer were used.

Although some ADF values were less in the biosolid treatments than those in the chemical fertilization

Table 3 Summary of the ANOVA of the following variables: dry matter (DM1), mineral matter (MM1), total nitrogen (TN1), total protein (p1), acid detergent fiber (ADF1), and neutral detergent fiber (NDF1) in the first cut of the elephant grass

Source of variation	DF	DM1 Mean squares	MM1	TN1	p1	ADF1	NDF1
Block	2	0.53^{ns}	0.40^{ns}	0.03^{ns}	0.99^{ns}	9.28*	14.92^{ns}
Treatments	5	0.13^{ns}	2.04^{ns}	0.27*	10.56*	20.02**	18.57^{ns}
Residual	10	0.87	1.25	0.05	2.05	1.69	4.53
Total	17						
CV (%)		0.98	10.56	16.04	16.17	3.46	3.03
Treatment		Mean					
		DM1 (%)	MM1 (%)	TN1 (%)	p1 (%)	ADF1 (%)	NDF1 (%)
Control		94.98a	11.51a	1.14	7.15a	36.25a	68.73a
Chemical fertilization		95.41a	11.47a	1.17a	7.31a	38.30ab	70.55a
1× biosolid		95.43a	1087a	1.55ab	9.69ab	34.98a	68.04a
2× biosolid		95.01a	9.97a	1.22a	7.64a	40.95b	72.60a
4× biosolid		95.42a	9.91a	1.49ab	9.29ab	40.19b	73.45a
8× biosolid		95.24a	9.67a	1.92b	12.01b	35.10a	67.44a

Means with equal letters do not differ from each other

ns not significant

**Significant at the 1% level; *significant at the 5% level

Table 4 Summary of the ANOVA of the following variables: dry matter (DM2), mineral matter (MM2), total nitrogen (TN2), total protein (p2), acid detergent fiber (ADF2), and neutral detergent fiber (NDF2) in the second cut of the elephant grass

Source of variation	DF	DM2 Mean squares	MM2	TN2	p2	ADF2	NDF2
Block	2	1.84*	3.45^{ns}	0.05^{ns}	2.13^{ns}	2.22^{ns}	5.34^{ns}
Treatments	5	0.22^{ns}	3.97^{ns}	0.04^{ns}	1.64^{ns}	2.93^{ns}	12.13^{ns}
Residual	10	0.43	2.30	0.04	1.49	4.97	14.19
Total	17						
CV (%)		0.69	13.62	18.13	17.94	5.38	5.02
Treatment		Mean					
		DM2 (%)	MM2 (%)	TN2 (%)	p2 (%)	ADF2 (%)	NDF2 (%)
Control		95.47a	8.83a	0.99a	6.22a	41.06a	74.20a
Chemical fertilization		95.22a	11.51a	0.99a	6.19a	43.00a	71.75a
1× biosolid		94.88a	11.89a	1.05a	6.54a	41.75a	75.22a
2× biosolid		95.19a	11.25a	1.14	7.12	40.06a	76.91a
4× biosolid		95.56a	11.67a	1.30	8.14a	41.89a	75.12a
8× biosolid		95.56a	11.70a	1.05a	6.57a	41.07a	77.31a

Means with equal letters do not differ from each other

ns not significant

*Significant at the 5% level

treatment and even in the control plot, all the mean values were greater than those reported by Nussio et al. (1998) and Kauter et al. (2006) for use of elephant grass as an energy source, for which fiber values must be greater than 30%. For neutral detergent fiber (NDF), all mean values were greater than those found by Andrade et al. (2003), which were 58.9 and 65.3% in the dry and rainy seasons, respectively, in the first and second cut.

The means found for the parameter mineral matter (MM) were satisfactory, although Vale et al. (2011) state that values greater than 7%, which occurred in all treatments in the two cuts, can compromise combustion when elephant grass is used for energy purposes. High ash content can cause energy losses, affect heat transfer, and decrease the calorific value of the biomass (Klautau 2008). Nevertheless, the mean values found in the experiment were very close to those found by Demirbas (2004) for rice husk, 11.3%, and greater than those found by the same author for sugarcane bagasse 22.3%, two biomasses used for burning and energy production.

The mean values for dry matter (DM) were greater than 94% in all treatments in both the first and second cuts. Rueda et al. (2016) did not find difference in the first 185 days of establishment of several species of elephant grass in relation to dry matter, with increase in this parameter only in the second and third years of the experiment. Some authors mention that DM production can be increased by combining biosolid with chemical fertilizers, depending on the biosolid or even the soil deficiencies, since both can have different characteristics. Anjos and Matiazzo (2000) added nitrogen and phosphorus fertilizers to the biosolid in their experiment, and Rangel et al. (2002) added potassium chloride to the biosolid.

As can be observed from Tables 3 and 4, there was a tendency of decreasing values of nitrogen and total protein and an increase in both NDF and ADF from one cut to the other. There was a tendency for fiber content to increase as the plant aged, whereas digestible components, such as protein and nitrogen, tended to decrease. Cabral et al. (2006) evaluated the NDF and crude protein levels in different cuts for an elephant grass genotype in the dry season and in the rainy season, finding higher NDF values and lower crude protein levels as the cutting interval increased; Martins-Costa et al. (2008) obtained similar results.

In all treatments evaluated in the present study, elephant grass suitable for energy use and animal supplementation was produced. The mean production in the treatment with the biosolid dose determined according to the Conama Resolution 375/06 (Brazil 2006) exhibited a trend that was very similar to that found for chemical fertilization. Regarding the treatments in which doses greater than the recommended level were used, new studies should be performed to better evaluate possible soil and plant contamination.

4 Conclusion

The results obtained in this study suggest that biosolid is able to supplement the soil with the nutrients necessary to produce high-quality elephant grass for both animal feed and energy use. The dose determined according to Conama Resolution 375/06 (Brazil 2006) enabled similar production to chemical fertilization when adding the two cuts, in addition to satisfactory bromatological characteristics for energy use and animal supplementation.

For doses greater than the level recommended by Conama Resolution 375/06 (Brazil 2006), in spite of the excellent results achieved, new studies should focus on possible soil and ground water contamination, mainly by heavy metals, pathogenic microorganisms, and even excess nitrogen, regardless of the levels being within the required limits determined according to the physicochemical and microbiological characterization of the biosolid.

Funding Information This work was supported by PB Ambiental Gestão de Resíduos and by the National Council for Scientific and Technological Development (CNPq), under projects 305419/2015-3 and 401687/2016-3.

References

Aesa Executive Agency for Water Management of the State of Paraíba [in Portuguese]. (2017) http://site2.aesa.pb.gov.br/aesa/medicaoPluviometrica.do?metodo=chuvasDiariasMapa. Accessed 10 January 2017.

Alcântara, P.B., Bufarah, G. (1986). Forage plants: grasses and legumes [in Portuguese]. São Paulo: Editora Nobel.

Alencar, C. A. B., Cunha, F. F., Martins, C. E., Cóser, A. C., Rocha, W. S. D., Araújo, R. A. S., et al. (2009). Pasture irrigation: Actuality and recommendations for use and management [in Portuguese]. *Revista Brasileira de Zootecnia, 38*, 98–108.

Anderson, W. F., Dien, B. S., Brandon, S. K., & Peterson, J. D. (2008). Assessment of bermudagrass and bunch grasses as feedstock for conversion to ethanol. *Applied Biochemistry and Biotechnology, 145*(1–3), 13–21.

Andrade, A. C., Fonseca, D. D., Queiroz, D. S., Salgado, L. T., Cecon, P. R., et al. (2003). Nitrogen and potassium fertilization in elephant grass (Pennisetum purpureum Schum, cv. Napier) [in Portuguese]. *Ciência e Agrotecnologia, 27*, 1643–1651.

Anjos, A. R. M., & Matiazzo, M. E. (2000). Heavy metals in maize plants grown on latosoils repeatedly treated with biosolids [in Portuguese]. *Science in Agriculture, 57*, 769–776.

Behling, M. (2009). Nodulation, accumulation of nitrogen in soil and plant, and soybean productivity in soil treated with industrial sludge from treatment plant [in Portuguese]. *Bragantia, Campinas, 68*(2), 453–462.

Bezerra Neto, E., Bareto, L.P. (2004). Chemical and biochemical analyzes in plants [in Portuguese]. Imprensa Universitária – UFRPE, Recife.

Brazil, Resolution no. 375, of August 29, 2006. (2006). Defines criteria and procedures for the agricultural use of sewage sludge generated in sanitary sewage treatment plants and their by-products, and provides other measures [in Portuguese]. Http://www.mma.gov.br/port/conama/res/res06/res37506.pdf (2016). Accessed 02 January 2016.

Brazil. Law no 12305, of August 2, 2010. (2010). Institutes the National Solid Waste Policy; amends law n. 9605, of February 12, 1998; and makes other measures [in Portuguese]. Available in: Http://www.mma.gov.br/port/conama/legiabre.cfm?codlegi=636 (2016). Accessed 12 January 2016.

Cabral, L.D., Bherinhg, M., Abreu, J.G., Reverdito, R., Pereira, G.A.C., Kaiser, J., Miranda, L., Zervoudakis, T., Souza, A.L., et al. (2006). Crude protein and NDF contents of the purple elephant grass obtained at different cutting ages in the *Cuiabana* lowland [in Portuguese]. ZOOTEC – Centro de Convenções de Pernambuco.

Costa, N.L., Townsend, C.R., Magalhães, J.A., Paulino, V.T., Pereira, R.G.A., et al. (2004). Nitrogen fertilization for elephant grass (Pennisetum purpureum cv. Cameroon), pure or intercropped with tropical forage legumes [in Portuguese]. In: Annual Meeting of the Brazilian Zootechny Society, Campo Grande.

Demirbas, A. (2004). Combustion characteristics of different biomass fuel. *Progress in Energy and Combustion Science Turquia, Elsevier, 30*, 219–230.

Deresz, F., Paim-Costa, M. L., Cóser, A. C., Martins, C. E., Abreu, J. B. R., et al. (2006). Chemical composition, digestibility and availability of elephant grass cv. napier managed under rotational grazing [in Portuguese]. *Revista Brasileira de Zootecnia, 35*, 863–869.

Deschamps, F. C. (1999). Implications of the growth period on the chemical composition of elephant grass cultivars (Pennisetum purpureum Schumach.) [in Portuguese]. *Revista Brasileira de Zootecnia, 28*(6), 1358–1369.

Evangelista, A.R., Lima, J.A. (2002). Silages: from cultivation to silo [in Portuguese]. Lavras.

Flores, R. A., Urquiaga, S., Alves, B. J., Collier, L. S., & Boddey, R. M. (2012). Yield and quality of elephant grass biomass produced in the cerrados region for bioenergy. *Engenharia Agrícola, 32*(5), 831–839.

Gomide, J.A. (1997). Formation and use of elephant grass pasture [in Portuguese]. In: Carvalho, M.M., Alvin, M.J., Xavier, D.F., Carvalho L.A.: Elephant grass: production and use, 81–115. Coronel Pacheco: Embrapa-Cattle of Milk.

Hargreaves, G. H., & Samani, Z. A. (1982). Estimation of potential evapotranspiration. *Journal of Irrigation and Drainage Division, ASCE, 108*(3), 225–230.

Italiano, E.C. (2004). Recommendations for the cultivation and use of elephant grass [in Portuguese]. Embrapa Mid-North. Documents.

Jakob, K., Zhou, F., & Paterson, A. H. (2009). Genetic improvement of C4 grasses as cellulosic biofuel feedstocks. *Vitro Cellular e Developmental Biology*, Gaithersburg*, 45*(3), 291–305.

Kauter, D., Lewandovski, I., & Claupeina, W. (2006). Quantity and quality of harvestable biomass from Populus short rotation coppice for solid fuel use. A review of the physiological basis and management influences. *Biomass and Bioenergy, 24*, 411–427.

Klautau, J.V.P. (2008). Experimental analysis of a concurrent flow firewood furnace for grain drying. Dissertation (MSc. in Water and Environmental Engineering) [in Portuguese], Federal University of Paraná, Curitiba.

Lee, M. K., Tsai, W. T., Tsai, Y. L., & Lin, S. H. (2010). Pyrolysis of napier grass in na induction-heating reactor. *Journal of Analytical and Aplied Pyrolysis*, Amsterdam*, 28*(2), 110–116.

Lima, R. S. N., Daher, R. F., Gonçalves, L. S. A., Rossi, D. A., Amaral Júnior, A. T., Pereira, M. G., & Ledo, F. J. S. (2011). RAPD and ISSR markes in the evaluation of genetic divergence among accessions of elephant grass. *Genetics and Molecular Research, 10*(3), 1304–1313.

Lopes, B.A.O. (2004). Elephant grass. Nutritional methods and feeding of ruminants [Portuguese]. Viçosa.

Magalhães, J. A., Rodrigues, B. H. N., Carneiro, M. S. S., Andrade, A. C., Costa, N. L., Pinto, M. S. C., Filho, W. J. E. M., et al. (2009). Influence of nitrogen fertilization and cutting age on the crude protein and neutral detergent fiber contents of three elephant grass cultivars [in Portuguese]. *Redvet, 10*(4), 13.

Martins, C. E., & Fonseca, D. M. (1998). Soil management and fertility in elephant grass pastures [in Portuguese]. *Informe Agropecuário, Belo Horizonte, 19*(192), 44–54.

Martins-Costa, R. H. A., Cabral, L. S., Bhering, M., Abreu, J. G., Zervoudakis, J. T., Rodrigues, R. C., Oliveira, I. S., et al. (2008). Nutrient value of elephant grass obtained at different cutting ages [in Portuguese]. *Revista Brasileira de Saúde e Produção Animal, 9*(3), 397–406.

Melo, W.J., Marques M.O., Melo, V.P. (2001). Agricultural use of biosolids and soil properties [in Portuguese]. *Biossólidos na Agricultura*, São Paulo, 1, 289–363.

Mistura, C., Fonseca, D.M., Fagundes, J.L., Moreira, L. de M., Morais, R.V., Nascimento Junior, D., Vitor, C.M.T., Ribeiro Junior, J. I., et al. (2004). Evaluation of the chemical composition of elephant grass fertilized with nitrogen [in Portuguese]. In: Annual Meeting of the Brazilian Zootechny Society, Campo Grande.

Monteiro, F.A. (1994). Fertilization for the establishment and maintenance of elephant grass [in Portuguese]. In. Carvalho, L.A., Carvalho, M.M., Martins, C.E., Vilela, D. (eds). Elephant grass: production and use, pp. 49–79, Coronel Pacheco: Embrapa-Cattle of Milk.

Morais, R.F. (2008). Potential productivity and biological nitrogen fixation efficiency of five elephant grass genotypes (*Pennisetum purpureum* Schum.), for use as an alternative energy source [in Portuguese]. Thesis, Rural University of Rio de Janeiro, Seropédica.

Morais, R. F., Quesada, D. M., & Reis, V. M. (2011). Contribution of biological nitrogen fixation to elephant grass (*Penniseteum purpureum* schum.) *Plant and Soil, 349*, 1–12.

Morais, R. F., Quesada, D. M., Reis, V. M., Urquiaga, S., Alves, B. J. R., & Boddey, R. M. (2012). Contribution of biological nitrogen fixation to elephant grass (*Pennisetum purpureum Schum.*) *Plant and Soil, 356*, 23–34.

Na, C. I., Sollenberger, L. E., Fedenko, J. R., Erickson, J. E., & Woodard, K. R. (2016). Seasonal changes in chemical composition and leaf proportion of elephant grass and energycane biomass. *Industrial Crops and Products, 94*, 107–116.

Nabinger, C., Medeiros, R.B. (1995). Production of seeds of *Panicum maximum* Jacq [in Portuguese]. Symposium on Pasture Management, Piracicaba, 59–128.

Neves, T.I. (2017). Energetic use of biosolids generated by the textile industry as fertilizer for the production of elephant grass—*Cenchrus purpureus* (Schumach.) Morrone [in Portuguese]. Dissertation of Master's Degree, Federal University of Paraíba, João Pessoa.

Nussio, L. G.; Manzano, R. P.; Pedreira, C. G. S. (1998). Food value in plants of the genus Cynodon. In: Symposium on pasture management [in Portuguese]. Piracicaba: Foundation for Agrarian Studies Luiz de Queiroz.

Oliveira, M. L., Daher, R. F., Menezes, B. R., Vivas, M., Rocha, A. D. S., Ponciano, N. J., & Silva, V. B. (2017). Genetic diversity of elephant grass (Cenchrus purpureus [Schumach.] Morrone) for energetic production based on quantitative and multi-category traits. *Chilean Journal of Agricultural Research, 77*(1), 48–57.

Pereira Jr, A.B., Valim, M.C.A., Souza, J.L., Gonçalves, R.F., et al. (1997). Use of sludge generated in anaerobic tank type Imhoff as an agricultural input for maize (*Zea mays* L.) [in Portuguese] in: Brazilian Congress of Sanitary and Environmental Engineering, 398p., Foz do Iguaçu.

Primo, A.C.A., Melo, M.D., Modesto, V.C., Pompeu, R.C.F.F., Natale, W., Souza, H.A., et al. (2013). Foliar sample size for nutritional status evaluation of macronutrients and SPAD index of irrigated elephant grass [in Portuguese]. In: Northeastern Congress of Animal Production, 3 p., Fortaleza.

Quéno, L. M. R., Souza, A. N., Angelo, H., Vale, A. T., & Martins, I. S. (2011). Production cost of eucalyptus and elephant grass biomass for energy. *Cerne, 17*, 417–426.

Rangel, O.J.P., Silva, C.A., Bettiol, W., Manzatto, C. W., et al. (2002). Accumulation of Mn, Zn, Cu, Ni and Pb in latosoil cultivated with corn under the effect of sources and doses of sewage sludge [in Portuguese]. In: FERTBIO 3, Rio de Janeiro.

Ribeiro, K. G. (1995). Fodder yield and nutritive value of "dwarf" elephant grass under five nitrogen doses reaching 80 and 120 cm in height [in Portuguese]. 60p. Dissertation (MSc. in Animal Science), Federal University of Viçosa, Viçosa.

Rueda, J. A., Ortega-Jiménez, E., Hernández-Garay, A., Enríquez-Quiroz, J. F., Guerrero-Rodríguez, J. D., & Quero-Carrillo, A. R. (2016). Growth, yield, fiber content and lodging resistance in eight varieties of *Cenchrus purpureus* (Schumach.) Morrone intended as energy crop. *Biomass and Bioenergy, 88*, 59–65.

Samson, R., Mani, S., Boddey, R., Sokhansanj, S., Quesada, S., et al. (2005). The potential of C4 perennial grasses for developing a global. *Critical Reviews in Plant Sciences, 24*, 1–35.

Santos, E. A., Silva, D. S., & Filho, J. L. Q. (2001). Mapping and some morphological characteristics of elephant grass cv.

purple under four cutting heights in two seasons of the year [in Portuguese]. *Revista Brasileira de Zootecnia, 30*, 24–30.

Saraiva O.F., Carvalho, M.M. (1991). Nitrogen and phosphate fertilization for establishment of elephant grass in red-yellow latosoil, clayey texture [in Portuguese]. *Revista Brasileira Ciência do Solo*. Campinas, 15, 201–205.

Smeets, E. M. W., Lewandovski, I. M., & Faaij, A. P. C. (2009). The economical and environmental performance of Miscanthus and switchgrass production and supply chains in a European setting. *Renewable and Sustainable Energy Reviews*, New York*, 13*, 1230–1245.

Strezov, V., Evans, T.J., Hayman, C. (2008). Thermal conversion of elephant grass (*Pennisetum purpureum* Schum.) to bio-gas, bio-oil and charcoal. Bioresource Technology, Essex, 99 (17), 8394–8399.

Vale, A. T., Mendes, R. M., Amorim, M. R. S., Dantas, V. F. S., et al. (2011). Energetic potential of biomass and charcoal from the epicarp and the peach pine tree (Jatropha curcas) [in Portuguese]. *Cerne, 17*(2), 267–273.

Vitor, C.M.T. (2006). Nitrogen fertilization and water depth on elephant grass growth [in Portuguese]. Thesis (PhD in animal science), Federal University of Viçosa, Viçosa, 90 p.

Werner, J.C. (1986). Pasture fertilization [in Portuguese]. Nova Odessa: Institute of Animal Science.