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The effects of sewage sludge, mineral and organic fertilizers on initial growth of *Urochloa brizantha* cv Marandu (Hochst. ex A. Rich.) R.D Webster

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The application of biosolids on agricultural soils is a procedure used by municipalities and private companies to dispose, purposefully or inadvertently, of residue. This study evaluated the effects of limed sewage sludge and inorganic or organomineral fertilizers on the chemical properties of red latosol and the contents of chlorophyll A and B in the fresh and dry matter of *Urochloa brizantha* cv Marandu. The experimental design was composed of randomized blocks due to a lighting gradient in the greenhouse, with 10 treatments and four replications. Treatments included: mineral fertilizer 3-30-10 (120 kg ha^{-1} P_2O_5); limed sludge (60 kg ha^{-1} N); limed sludge (48 kg ha^{-1} N) + mineral fertilizer 3-30-10 (120 kg ha^{-1} P_2O_5); limed sludge (60 kg ha^{-1} N) + agricultural gypsum (40 kg ha^{-1} S); limed sludge (60 kg ha^{-1} N) + magnesite (30 kg ha^{-1} Mg); limed sludge (60 kg ha^{-1} N) + single superphosphate (120 kg ha^{-1} P_2O_5); limed sludge (60 kg ha^{-1} N) + verdete (60 kg ha^{-1} K_2O); limed sludge (60 kg ha^{-1} N) + agricultural gypsum (40 kg ha^{-1} S) + magnesite (30 kg ha^{-1} Mg) + single superphosphate (120 kg ha^{-1} P_2O_5) + verdete (60 kg ha^{-1} K_2O); organomineral fertilizer 05-24-08 (120 kg ha^{-1} P_2O_5) and control with no addition of nutrient sources. Soil properties, pH, V (base saturation), m (aluminum saturation), OM (Organic Matter), P (Phosphorus), K (Potassium), S (Sulfur), Ca (Calcium), Mg (Magnesium), B (Boron), Cu (Copper), Fe (Iron), Mn (Manganese) and Zn (Zinc), as well as the chlorophyll A and B of fresh and dry matter of *U. brizantha* cv. Marandu were evaluated 30 days after germination. Limed sludge combined, or not, with mineral fertilizers, behaved as a soil corrective, increased the Ca and Mg content of the soil and reduced the Fe and Mn content. The fertilizer sources evaluated did not affect the contents of OM, organic carbon, Cu or B. Single superphosphate mixed with limed sludge and the mixture of gypsum, magnesite, single superphosphate or verdete with limed sludge resulted in greater P and S. content in the soil. Verdete mixed with limed sludge did not increase soil K or chlorophyll B contents. However, Zn contents were increased with the Verdete mixture. The highest level of fresh matter production was obtained with mineral fertilizer, organomineral fertilizer and sludge plus mineral fertilizer. Dry matter production, on the other hand, was increased only by the application of mineral fertilizer.

Key words: Biosolid, forage, mineral nutrition, organic fertilizers.

INTRODUCTION

The disposal of sewage sludge in sanitary landfills, presently accepted by environmental agencies of the Sistema Nacional de Meio Ambiente (SISNAMA) in Brazil, does not cause it to dissipate or eliminate its potential to produce pathologies and environment contamination. It simply delays the problem, to be dealt with in the near future.

According to Smith et al. (2015) the term biosolid describes sewage sludge that has been treated to reduce the level of pathogenic agents. Andrade et al. (2006) and Ceolato et al. (2011) believed that the agricultural use of biosolids is an alternative for the ultimate disposal of this residue as well as to prevent possible adverse effects on the environment and conserve natural resources while simultaneously obtaining agricultural benefits.

Ceolato et al. (2011) used liquid sewage sludge sanitized with hydrated lime for the production of *Urochloa decumbens*. They observed that the sludge functioned as a soil corrective, increasing macro and micro nutrient levels. Backes et al. (2009) evaluated the use of sewage sludge on forage grass formation and determined that the sludge presented similar results to mineral fertilizer. Araujo et al. (2009) used sewage sludge in Ultisol for the development of *U. decumbens* and observed increased dry biomass production and leaf nitrogen content. Chueiri et al. (2007) combined doses of sewage sludge with mineral fertilizer for application on wheat and found higher levels of K, N, Mg, Cu and Zn in the leaves.

From an agriculture perspective, sewage sludge could be used as a biosolid for the recuperation of degraded pasture land and to provide adequate disposal of the residue. *Urochloa Brizantha* cv Marandu is the most planted forage grass in Brazil (Gaspar-Oliveira et al., 2008). According to Mtshali et al. (2014) and Tontti et al. (2016), however, sewage sludge may not contain all of the essential nutrients in adequate quantities for plant development. If this is the case, the sewage sludge would require the supplementation of inorganic fertilizers. Berton and Nogueira (2010) reported that the benefits of sludge are disproportionate to crop needs, especially in relation to potassium and boron, thus requiring adjustments according to the crop.

Silva et al. (2010) stated that alkaline sewage sludge could be used with single superphosphate as a source of mineral nutrients when a level of 0.436% P is taken into account. Specific low cost and easily accessible mineral nutrient sources such as verdete, agricultural gypsum, magnesite, formulated fertilizers and single super-phosphate can be used for balancing nutrients according to forage demands.

Verdete is a green colored rock, composed of 13% quartz, 29% potassium feldspar, 57% mica and less than 1% of other minerals (Kahn et al., 2011). According to Piza et al. (2009) the concentration of K_2O in verdete varies from 7 to 14%. Single superphosphate supplies three macronutrients (phosphorus, calcium and sulfur), the first two of which come from the mineral apatite, while sulfur in the form of sulfuric acid, is used for dissolving the rock, making it the most common source of phosphorus for forage plants (Monteiro, 2008).

Magnesite is the main source of natural magnesium and can be enriched by calcination. It is used as a source of magnesium for agricultural crops (Correia, 2001). Bernardi et al. (2009) have stated that supplying calcinated magnesite is an effective way to provide magnesium for *Panicum maximum* cv. Tanzânia. Agricultural gypsum is a residue of the production of phosphoric acid and despite not changing soil pH, it acts in the subsurface reducing the toxicity of exchangeable Al in plants. It also reduces the toxicity of Al in soil solutions and supplies Ca and S in the 0 to 20 cm layer of latosol (oxisol) (Kaneko et al., 2015).

U. Brizantha cv. Marandu has good adaptation in medium to high levels of soil fertility. However, in order to reach production potential, fertilization is one of the most important factors since it supplies nutrients for metabolic needs and more adequate development (Costa et al., 2009). Brazilian pasture lands, in general, present low animal support capacity, especially due to the sparse use of fertilizers. This reflects directly on meat and milk production.

This study evaluated the chemical properties and chlorophyll A and B contents of Brazilian red latosol, as well as the fresh and dry matter weights of *U. brizantha* cv Marandu fertilized with limed sewage sludge and organic and inorganic fertilizers.

MATERIALS AND METHODS

The experiment was conducted in a greenhouse at the Instituto de Ciências Agrárias of the Universidade Federal de Uberlândia UFU), in Uberlândia, State of Minas Gerais, Brazil, located at 18° 53' 05" S and 48° 15' 37" W, from March to May, 2014. The soil used in the experiment was classified as red latosol (oxisol) of medium texture, collected from the 0 to 20 cm depth layer, in an area of degraded pasture at the experimental farm (UFU). According to the classification of Köppen (1918), the climate of the region has dry winters and rainy summers. The average rainfall in the driest month is approximately 60 mm compared to 250 mm in the wettest month of the summer. The total average rainfall is between 1,500 and 1,600 mm (Mendes, 2001). Rainfall distribution and maximum and minimum temperatures during the time of the experiment are shown in Table 1.

The soil was air dried and passed through a sieve. A sample taken to determine chemical characterization produced the following results: pH_{H2O}= 4.9, P meh^{-1}= .3 mg dm^{-3}, K^+ =21 mg dm^{-3}, S-SO_4^{2-}= 3 mg dm^{-3}, Ca^{2+}=0.2 cmol$_c$ dm^{-3}, Mg^{2+}=0.1 cmol$_c$ dm^{-3}, Al^{3+}=0.4 cmol$_c$ dm^{-3}, organic matter (OM)=2.7 dag kg^{-1}, organic carbon (OC)=1.6 dag kg^{-1}, SB = 0.35 cmol$_c$ dm^{-3}, t=0.75 cmol$_c$ dm^{-3}, T=4.15 cmol$_c$ dm^{-3}, V=8 dag kg^{-1}, m=53 dag kg^{-1}, B= 0.04 mg dm^{-3}, Cu=0.7 mg dm^{-3}, Fe= 41 mg dm^{-3}, Mn=1.2 mg dm^{-3}, and Zn=0.4 mg dm-3.

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Table 1. Rainfall and temperature data of the area of the experiment, Uberlândia, Minas Gerais, Brazil, 2014.

Months	Precipitation (mm)	Maximum temperature (°C)	Minimum temperature (°C)
March	149.10	30.58	19.45
April	61.80	30.28	18.31

Source: INMET (2014).

Table 2. Chemical attributes of limed sewage sludge, Uberlândia, Minas Gerais, Brazil, 2014.

Attribute	Unit	Value	Methodology
pH in $CaCl_2$	-	12.65	Embrapa (2009)[1]
Organic Matter – OM	g kg^{-1}	368.60	Embrapa (2009)
Carbon – C	g kg^{-1}	213.80	Embrapa (2009)
Nitrogen – N	g kg^{-1}	20.88	Embrapa (2009)
Sodium – Na	g kg^{-1}	0.61	Embrapa (2009)
Aluminum – Al	g kg^{-1}	20.10	Embrapa (2009)
Calcium – Ca	g kg^{-1}	302.0	Embrapa (2009)
Magnesium – Mg	g kg^{-1}	4.2	Embrapa (2009)
Phosphorus – P	g kg^{-1}	1.6	Embrapa (2009)
Potassium – K	g kg^{-1}	0.6	Embrapa (2009)
Sulfur – S	g kg^{-1}	12.4	Embrapa (2009)
Iron – Fe	mg kg	12,753.25	Embrapa (2009)
Zinc – Zn	mg kg^{-1}	1180.00	Embrapa (2009)
Cooper – Cu	mg kg^{-1}	157.91	Embrapa (2009)
Cadmium – Cd	mg kg^{-1}	0.45	Embrapa (2009)
Chromium – Cr	mg kg^{-1}	85.34	Embrapa (2009)
Nickel – Ni	mg kg^{-1}	19.86	Embrapa (2009)
Lead – Pb	mg kg^{-1}	ND[2]	Embrapa (2009)

[1/]Embrapa (Brazilian Agricultural Research Corporation). [2/]ND: Not detected.

The sewage sludge used in the experiment was obtained by anaerobic process. After a dewatering step obtained by the addition of iron chlorite and centrifugation at the sewage treatment unit in Uberlândia, MG, the sludge was sanitized with hydrated lime in the proportion of 30% of the sludge dry matter. The sludge originated from households. Its chemical properties are shown in Table 2. This material was dried, crushed and subjected to sulfuric digestion for the determination of N. Nitric-perchloric digestion was used for identification of P, K, Ca, Mg, S, Cu, Fe, Mn, Zn, Na, Ni, Cd, Pb, Al, Mg and Fe levels and calcination in a muffle kiln determined organic matter contents. The pH was determined in $CaCl_2$ solution at .010 ml L^{-1}, according to the methodology proposed by EMBRAPA (2009).

The experimental design was composed of randomized blocks due to a lighting gradient in the greenhouse, with 10 treatments and four replications.

Treatments included: mineral fertilizer 3-30-10 (120 kg ha^{-1} P_2O_5), limed sludge (60 kg ha^{-1} N), limed sludge (48 kg ha^{-1} N) + mineral fertilizer 3-30-10 (120 kg ha^{-1} P_2O_5), limed sludge (60 kg ha^{-1} N) + agricultural gypsum (40 kg ha^{-1} S), limed sludge (60 kg ha^{-1} N) + magnesite (30 kg ha^{-1} Mg), limed sludge (60 kg ha^{-1} N) + single superphosphate (120 kg ha^{-1} P_2O_5), limed sludge (60 kg ha^{-1} N) + verdete (60 kg ha^{-1} K_2O), limed sludge (60 kg ha^{-1} N) + agricultural gypsum (40 kg ha^{-1} S) + magnesite (30 kg ha^{-1} Mg) + single superphosphate (120 kg ha^{-1} P_2O_5) + verdete (60 kg ha^{-1} K_2O), organomineral fertilizer 05-24-08 (120 kg ha^{-1} P_2O_5), and a control (no nutrient sources), as reported in Table 3.

Nutrient application doses were based on the recommendations of Cantarutti et al. (1999) for the establishment of forage grasses. Primary and secondary macronutrient contents of the mineral fertilizers used in the experiment are presented in Table 4.

Each experimental unit consisted of two 5-dm^3 pots. Fifteen seeds of *U. brizantha* cv Marandu were sown in each pot and, 25 days later, thinned to four seedlings per pot (Figure 1).

Watering was provided as needed to maintain soil moisture at 60% of field capacity. Chlorophyll A and B were evaluated 30 days after sowing using a chlorophyll log. Plants were harvested, weighed, dried in an oven until constant weight, and weighed again. Soil samples were air dried, sieved through a 2 mm mesh sieve, and taken to the laboratory for the analysis of pH, V (base saturation), m (aluminum saturation), OM, OC and P, K, S, Ca, Mg, B, Cu, Fe, Mn and Zn contents according to the methodology of EMBRAPA (2009).

Data were submitted to tests of homogeneity of variance, normality of residues and block non additivity using SPSS Statistical Package 17.0. An analysis of variance was conducted with SISVAR (FERREIRA, 2008) and the averages compared by the Scott-Knott test at 0.05 significance. Also, the averages were compared with the control treatment by the Dunnet test at 0.05 significance.

Table 3. Fertilizer sources and application doses of the experiment, Uberlândia, Minas Gerais, Brazil, 2014.

Fertilizer source	Application dose
Mineral fertilizer (MF)	400 kg ha^{-1}
Limed sludge (L)	2.608.70 kg ha^{-1}
Limed sludge (L)+ Mineral fertilizer (MF)	2,608.70 kg ha^{-1}(L) + 400 kg ha^{-1} (MF)
Limed sludge (L) + Gypsum (G)	2.608.70 kg ha^{-1}(L) + 312 kg ha^{-1} (G)
Limed sludge (L) + Magnesite (M)	2.608.70 kg ha^{-1}(L) + 52 kg ha^{-1}
Limed sludge (L) + Single superphosphate (SS)	2.608.70 kg ha^{-1}(L) + 668 k ha^{-1}
Limed sludge (L) + Verdete (V)	2.608.70 kg ha^{-1}(L) + 560 kg ha^{-1}
Limed sludge (L) + G + M + SS + V	2.608.70 kg ha^{-1}(L), 312 kg ha^{-1} (G), 52 kg ha^{-1} (M), 668 kg ha^{-1} (SS), 560 kg ha^{-1} (V)
Organomineral (O)	500 kg ha^{-1}

Table 4. Nutrient contents of each source used in the experiment, Uberlândia, Minas Gerais, Brazil, 2014.

Fertilizer source	N	P_2O_5	K_2O	S	CaO	MgO
	dag kg^{-1}					
Mineral fertilizer	3	30	10	-	-	-
Agricultural gypsum	-	-	-	15	20.3	-
Magnesite	-	-	-	-	-	56
Single superphosphate	-	18	-	12	20	-
Verdete	-	-	11	-	-	-
Organomineral	5	24	8	-	-	-

Figure 1. The experimental site with the pots of *Urocholoa brizantha* cv Marandu.

Table 5. Properties of the soil cultivated with *Urochloa brizantha* cv Marandu, following the application of limed sludge, organomineral fertilizer and mineral fertilizers.

Fertilizer source	pH H_2O	V	m	O.M	O.C
		dag kg^{-1}	dag kg^{-1}	g kg^{-1}	g kg^{-1}
Mineral fertilizer	4.75^{b}	20^{b}	44^{b}	1.90^{ns}	1.10^{ns}
Limed sludge	6.18^{*a}	53^{*a}	0^{*a}	1.75^{ns}	1.02^{ns}
Limed sludge + Mineral fertilizer	6.00^{*a}	47^{*a}	0^{*a}	1.93^{ns}	1.12^{ns}
Limed sludge + Gypsum (G)	6.30^{*a}	56^{*a}	0^{*a}	2.00^{ns}	1.16^{ns}
Limed sludge + Magnesite (M)	6.35^{*a}	53^{*a}	0^{*a}	1.90^{ns}	1.10^{ns}
Limed sludge + Single superphosphate (SS)	6.35^{*a}	56^{*a}	0^{*a}	1.98^{ns}	1.15^{ns}
Limed sludge + Verdete (V)	6.63^{*a}	60^{*a}	0^{*a}	1.98^{ns}	1.15^{ns}
Limed sludge + G+ M+SS+V	6.33^{*a}	57^{*a}	0^{*a}	1.78^{ns}	1.03^{ns}
Organomineral	5.00^{b}	20^{b}	39^{*b}	1.90^{ns}	1.10^{ns}
Control	4.50^{b}	17^{b}	50^{c}	1.83^{ns}	1.06^{ns}
Coefficients of Variation (CV)	5.38%	14.30%	31.51%	11.46	11.53%

ns: Non significant by F test. Averages followed by the same letter in the column do not differ by the Scott-Knott test at 0.05 probability. *Significantly different in relation to the control, by the Dunnet test at 0.05 significance. V: Base saturation; m: aluminum saturation; OM: organic matter; OC: organic carbon (EMBRAPA, 2009).

RESULTS AND DISCUSSION

The values of soil pH, base saturation (V) and aluminum saturation (m) were affected by the treatments evaluated (P<0.05); however, no differences were observed for OM and OC, P>0.05 (Table 5).

The values of soil pH (4.50) and base saturation (17 dag kg^{-1}) (Table 4), determined before addition of the treatments, were classified as low and very low, respectively (Alvarez et al., 1999). The use of limed sludge alone, limed sludge plus mineral fertilizer, limed sludge plus gypsum, limed sludge plus magnesite, limed sludge plus single superphosphate, limed sludge plus verdete, limed sludge plus gypsum, magnesite, single superphosphate and verdete all increased soil pH (6.0 to 6.35) and base saturation (47 to 60%), bringing it to average and high values (Alvarez et al., 1999). As expected, increased pH was due to the alkalinity of the sludge used (pH 12.65) since hydrate lime (Ca $(OH)_2$) was used to eliminate pathogens and to stabilize the residue. Similar results have been reported by Nascimento et al. (2014), who stated that limed sludge increased soil pH from 5.85 to 7.85 in the 0 to 20 cm layer at a dosage of 50.42 t ha^{-1}. Also, Berton and Nogueira (2010) mentioned that fertilization with sludge stabilized with hydrated lime tended to increase soil pH and to reduce potential acidity, mostly by precipitating aluminum. Mineral fertilizer with NPK and the organo-mineral fertilizer did not increase values (pH and base saturation – V) in relation to the control 30 days after sowing *U. brizantha* cv. Marandu.

No significant differences were observed between limed sludge alone and limed sludge supplemented with various fertilizers (mineral fertilizer, gypsum (G), magnesite (M), single superphosphate (SS), verdete (V) or the mixture of gypsum, magnesite, single super-phosphate and verdete) in relation to pH, base saturation (V) and aluminum saturation (m) (Table 5). A maximum value of Al^{+3} saturation tolerated by *U. brizantha* cv. Marandu was found to be 25 dag kg^{-1} and the target base saturation with liming was 45 dag kg^{-1} (Alvarez et al., 1999).

The use of limed sewage sludge alone or combined with some source of mineral fertilizer presented lower values of aluminum saturation (m) than was found with organomineral fertilizer, mineral NPK fertilizer or the control treatment. According to Kiehl (2008) organo-mineral fertilizers vary according to the constitution of the organic and mineral sources that are used; however, it is expected that such fertilizer will correct soil acidity with lower reactive chemical potential. Carvalho et al. (2015) observed improvement in base sum and in effective and total CEC in soil cultivated with olive trees (*Olea europaea*) eight months after application of the organomineral fertilizer, in comparison with the use of mineral fertilizer. Aluminum saturation (m) in soil fertilized organomineral fertilizer and mineral fertilizer presented values of 39 and 44 dag kg^{-1}, respectively, which were lower than the control (50 dag kg^{-1}); however, far too high for the establishment and production of *U. brizantha* cv Marandu. According to Vitorello et al. (2005), the excess of aluminum in tropical soils promotes toxicity to plants and is the main limiting factor for food and biomass production in the world.

Consequences of increased soil pH after the addition of hydrated lime in the sludge liming process include aluminum precipitation and neutralization of H+, resulting in greater amounts of negative electric charges in the soil. Increased soil base saturation was observed in treatments receiving limed sludge, and aluminum

Table 6. Primary (P and K) and secondary (S, Ca, Mg) macronutrients in soil cultivated with *Urochloa brizantha* cv. Marandu after application of limed sludge, organomineral fertilizer and mineral fertilizers.

Fertilizer source	P	K	S	Ca	Mg
	mg dm^{-3}			Cmol$_c$ dm^{-3}	
Mineral fertilizer	7.25^{c}	16.00^{*b}	7.00^{b}	0.50^{b}	0.10^{b}
Limed sludge	1.40^{c}	17.50 ^{a}	19.25^{b}	1.43^{*a}	0.20^{*a}
Limed sludge + Mineral fertilizer	11.85^{*b}	19.00 ^{a}	14.75^{b}	1.30^{*a}	0.14^{a}
Limed sludge + Gypsum (G)	3.53^{c}	15.00^{*b}	28.00^{*b}	1.58^{*a}	0.15^{*a}
Limed sludge + Magnesite (M)	9.08^{b}	16.00^{*b}	16.25^{b}	1.38^{*a}	0.20^{*a}
Limed sludge + Single superphosphate (SS)	18.75^{*a}	15.00^{*b}	51.50^{*a}	1.68^{*a}	0.18^{*a}
Limed sludge + Verdete (V)	3.85^{c}	18.25 ^{a}	16.75^{b}	1.68^{*a}	0.18^{*a}
Limed sludge + G + M+ SS+V	16.05^{*a}	14.00^{*b}	45.00^{*a}	1.58^{*a}	0.20^{*a}
Organomineral (5-24-08)	10.45^{b}	16.75^{*b}	3.00^{b}	0.48^{b}	0.10^{b}
Control	1.28^{c}	21.50 ^{a}	6.00^{b}	0.40^{b}	0.08^{b}
Coefficient of variation (CV)	57.79%	13.30%	50.54%	17.25%	25.01%

Averages followed by the same letter in the column do not differ by the Scott-Knott test at 0.05 probability. *Significantly different in relation to the control, by the Dunnet test at 0.05 significance.

saturation was reduced to zero, indicating that limed sludge, by itself or combined with different mineral fertilizer sources, acts as a soil corrective under the conditions evaluated. Exchangeable aluminum was thus reduced, while increasing soil pH and base saturation (Table 1). Fia et al. (2005) have stated, however, that the doses of limed sludge were considered adequate for plant mineral nutrition result in undesirable increases in soil pH. They recommend its use only as a soil acidity corrective, not as organic fertilizer. According to Ceolato et al. (2011), sewage sludge sanitized with hydrated lime acts as a soil corrective due to its high pH. They report that sludge also supplies calcium and magnesium to forage plants. Under these conditions, the application of sludge residue on agricultural crops has productive as well as social advantages, with less impact on public health and the environment.

Although sewage sludge is rich in organic matter, its application alone or with mineral sources (mineral fertilizer, gypsum (G), magnesite (M), single superphosphate (SS), verdete (V) and its mixture with gypsum, magnesite, single superphosphate and verdete) all did not affect soil carbon or organic matter contents (Table 1). Similarly, Nascimento et al. (2014) did not find increased organic matter content after a single application of limed sludge at 50.42 t ha^{-1} in safflower production. Bueno et al. (2011) reported increases in soil organic matter after several applications of sewage sludge.

Available soil phosphorus (P) levels in the control treatment were below the agricultural acceptable threshold of 1.28 mg dm^{-3} (Table 6). According to Alvarez et al. (1999), adequate soil phosphorus content for the establishment and growth of *U. brizantha* cv Marandu is above 20.1 mg dm^{-3}. Ourives et al. (2010) reported that physical-chemical characteristics of latosols, such as low phosphorus availability, restrict high yield in forage grasses, including Marandu grass. Phosphorus plays important roles in *U. brizantha* cv. Marandu during the establishment stage, improving tillering, root system development and also within the cell energy transfer metabolism, respiration and photosynthesis. All of this is in addition to the structural role of phosphorus in genes and chromosomes, as well as coenzymes, phosphoproteins and phospholipids (Rezende et al., 2011).

The highest phosphorus (P) averages in soil solution were obtained with limed sludge plus single superphosphate (18.75 mg dm^{-3}) and limed sludge mixed with gypsum, magnesite, single superphosphate and verdete (16.05 mg dm^{-3}). These averages were different from the control (1.28 mg dm^{-3}) and from all other treatments evaluated. Higher soil phosphorus contents were due to the mineral fertilizer: single superphosphate. Soil pH conditions following treatments with limed sludge plus single superphosphate, and limed sludge plus gypsum plus magnesite plus single superphosphate plus verdete resulted in greater availability of P in the single superphosphate. According to Silva et al. (2010) limed sewage sludge supplemented with single superphosphate at 0.436 dag kg^{-1} P increases soil extractable P and the accumulation of P in plants.

Phosphorus (P) contents in limed sludge, in mineral fertilizer with NPK, in limed sludge plus agricultural gypsum, in limed sludge plus verdete and in the treatment with no fertilization were not different from each other by the Scott-Knott test. They each presented values lower than the treatments with limed sludge plus magnesite, organomineral fertilizer and limed sludge plus mineral fertilizer with NPK.

Potassium (K) levels in the treatment with limed sludge, limed sludge plus mineral fertilizer, and limed sludge plus verdete, were not statistically different from the control treatment, indicating that their use did not change exchangeable soil K contents. However, a decrease in exchangeable soil K contents was observed in treatments with limed sludge plus gypsum, mineral fertilizer with NPK, limed sludge plus magnesite, limed sludge plus single superphosphate, and limed sludge plus gypsum plus magnesite plus single superphosphate plus verdete, all of which were lower than the control and the other treatments. This finding could be explained by the low dosage of limed sludge (2.6 t ha^{-1}) used in the experiment and low K content of sewage sludge. Bremm et al. (2012) used limed sludge at 15 t ha^{-1} in a clay latosol for maize production and observed that potassium content was not affected by the addition of limed material to the soil; presenting values lower than the non modified soil. Potassium is a macronutrient present in low concentrations in sewage sludge. Usually, complementation is required for agricultural use (Garcia et al., 2009). Although verdete contains 11 dag kg^{-1} K_2O, its use with hydrated lime was not sufficient to increase soil exchangeable K^+ contents in comparison with the control treatment.

Soil sulfur (S) content in the control treatment was 6.0 mg dm^{-3}. According to Fancelli et al. (2007), soils with S contents below 10 to 12 mg dm^{-3} are considered lacking in this element and limiting for plant growth. Fertilization with NPK, limed sludge, limed sludge plus fertilization with NPK, limed sludge plus magnesite, limed sludge plus verdete and fertilization with organomineral fertilizer did not differ among themselves or with the control treatment. Treatment with limed sludge plus agricultural gypsum presented S contents of 28.0 mg dm^{-3}, which was greater than observed in the control (6.0 mg dm^{-3}) but less than the treatment with limed sludge plus single superphosphate (51.5 mg dm^{-3}) and limed sludge mixed with agricultural gypsum, magnesite, single superphosphate or verdete (45.0 mg dm^{-3}). Single superphosphate was the mineral fertilizer source that contributed most to soil S contents, followed by calcium sulfate (agricultural gypsum). Limed sludge did not increase soil S content, thus requiring supplementation with a mineral source.

Exchangeable Ca and Mg contents in the control treatment were 0.40 and 0.08 $Cmol_c$ dm^{-3}, respectively, considered very low for plant establishment and production (Table 2) (Alvarez et al., 1999). The Ca and Mg contents of the soil after addition of NPK fertilizer or organomineral were similar to the control treatment. The fact that Ca and Mg contents did not increase after the addition of mineral or organomineral fertilizers was understood to be because these elements were not present in the formulation of either one. Treatments receiving limed sludge presented higher averages of Ca and Mg than the control, NPK and organomineral fertilizers. Increased Ca and Mg contents in treatments with limed sludge were due to the presence of Ca and Mg in the hydrated lime used for the sanitation of the sludge. Initially, limed sludge presented Ca contents of 302 g kg^{-1} and Mg of 42 g kg^{-1}, respectively. Similar results were reported by Ceolato et al. (2011), who stated that soil Ca and Mg contents increased following the addition of limed sludge for the cultivation of *U. decumbens*. Also, Fia et al. (2005) observed increased Ca and Mg contents in substrates treated with limed sewage sludge.

Soil contents of B and Cu were not affected by the fertilizer sources evaluated (P>0.05) (Table 7). Similar results were reported for Cu in studies by Nascimento et al. (2014), who observed that limed sludge did not affect soil Cu contents at the depth of 0 to 20 cm cultivated with safflower. Boron contents in the treatments evaluated varied from .09 mg dm^{-3} in the control to 0.17 mg dm^{-3} in the organomineral treatment (Table 3). According to Galrão (2004), such levels are considered low (<0.2 mg dm^{-3}) and the use of boron at 2.0 kg ha^{-1} is recommended for the establishment of *Urochloa brizantha* cv Marandu in savannah soil for intensive management systems. Copper contents varied from 0.83 to 0.95 mg dm^{-3} in the treatments, which was considered high (> 0.8 mg dm^{-3}), according to Galrão (2004), for the establishment of *U. brizantha* cv Marandu.

The application of limed sewage sludge alone, or in mixture with inorganic fertilizers, affected soil contents of Zn, Mn and Fe, in soils with higher levels of Zn and lower levels of Mn and Fe in relation to those observed in the control, with organomineral and mineral fertilizer or with NPK (Table 6). Contrasting results were found by Pigozzo et al. (2008), who found higher levels of available Fe and Mn, in soils treated with sewage sludge and cultivated with maize. According to Dechen and Nachtigall (2006), Mn has great affinity with soil organic matter, becoming unavailable to plants. In the present study, limed sewage sludge had a high organic matter content, which may have contributed to complexing the Mn with soil particles. Initially, limed sludge presented high pH (12.65), which could have precipitated the Mn and Fe in the residue, decreasing their availability to plants following soil treatment. Usman et al. (2012) reported that sewage sludge, under alkaline conditions, precipitates heavy metals present in lower availability, when applied to the soil. Lana et al. (2014) stated that there are complex inter-relations affecting Fe availability in residues applied to the soil. The observed Fe content found in the control was 43.25 mg kg^{-1}, which was considered good (> 31 mg dm^{-3}) by Alvarez et al. (1999).

Manganese contents in the control, mineral fertilizer with NPK, and in organomineral treatments were 2.18, 2.08 and 1.95 mg dm^{-3}, respectively. According to Galdrão (2004), the observed values were considered average for savannah soils. Treatments receiving limed sludge alone or in mixture with inorganic fertilizers presented soil Mn contents varying from 1.28 mg dm^{-3}, in limed sludge plus gypsum, magnesite, single superphosphate and verdete, to 1.63 mg dm^{-3}, in limed sludge plus single superphosphate, considered low for the establishment of *U. brizantha* cv Marandu under intensive management in

Table 7. Micronutrients in soil cultivated with *Urochloa brizantha* cv. Marandu, following the application of limed sludge, organomineral fertilizer and mineral fertilizers.

Fertilizer source	B	Cu	Fe	Mn	Zn
			-mg dm^{-3}		
Mineral fertilizer	0.10^{ns}	0.95^{ns}	37.50^{a}	2.08^{a}	0.43^{c}
Limed sludge	0.12^{ns}	0.95^{ns}	27.50^{*b}	1.32^{*b}	1.10^{*b}
Limed sludge + Mineral fertilizer	0.10^{ns}	0.85^{ns}	26.75^{*b}	1.43^{*b}	1.15^{*b}
Limed sludge + Gypsum (G)	0.12^{ns}	0.95^{ns}	24.50^{*b}	1.35^{*b}	1.15^{*b}
Limed sludge + Magnesite (M)	0.10^{ns}	0.90^{ns}	24.25^{*b}	1.38^{*b}	1.28^{*b}
Limed sludge + Single superphosphate (SS)	0.12^{ns}	0.88^{ns}	28.50^{*b}	1.63^{b}	1.28^{*b}
Limed sludge + Verdete (V)	0.10^{ns}	0.95^{ns}	22.75^{*b}	1.33^{*b}	1.73^{*a}
Limed sludge + G + M+ SS+V	0.14^{ns}	0.83^{ns}	21.75^{*b}	1.28^{*b}	1.23^{*b}
Organomineral	0.17^{ns}	0.95^{ns}	37.00^{a}	1.95^{a}	0.40^{c}
Control	0.09^{ns}	0.93^{ns}	43.25^{a}	2.18^{a}	0.23^{c}
Coefficient of variation (CV)	45.79%	35.14%	14.79%	17.63%	20.53%

Averages followed by the same letter in the column do not differ by the Scott-Knott test at 0.05 probability. *Significantly different in relation to the control, by the Dunnet test at 0.05 significance. ns: Not significant by the F test.

savannah soils (Galdrão, 2004). Soils presenting low Mn contents should receive a dose 6.0 kg ha^{-1}, which can be splitted into three applications (Galdrão, 2004).

The highest Zn soil content was observed with limed sludge plus verdete, an average value of 1.73 mg dm^{-3}. Nascimento et al. (2014) observed higher soil Zn content in the 0 to 20 cm layer after treatment with sewage sludge in contrast with the chemical fertilization recommended for safflower. Increased Zn content after fertilization with sewage sludge was also observed in studies by Zuba Júnior et al. (2011), Nogueira et al. (2013) and Cavalcanti et al. (2015). According to Haynes et al. (2009), domestic sewage sludge is usually rich in Zn because this element is present in various healthcare products, such as hand lotion, skin cream, makeup, deodorant, and shampoo, among others. Similarly, Ferraz et al. (2014) stated that increased Zn following fertilization with sludge can be attributed to the disposal of residues rich in trace elements in the sewage system.

Soil Zn content in treatments receiving limed sludge alone (1.10 mg dm^{-3}), limed sludge plus mineral fertilizer (1.15 mg dm^{-3}), limed sludge plus agricultural gypsum (1.15 mg dm^{-3}), limed sludge plus magnesite (1.28 mg dm^{-3}), limed sludge plus single superphosphate (1.28 mg dm^{-3}) and the mixture of limed sludge with gypsum, magnesite, single superphosphate and verdete (1.23 mg dm^{-3}) are all classified, according to Galdrão (2004), with averages in the range of 1.1 to 1.6 mg dm^{-3} (Table 3). The zinc content observed in limed sludge plus verdete (1.73 mg dm^{-3}) is considered high, according to Galdrão (2004). The control treatment, mineral fertilizer with NPK and the organomineral fertilizer presented low Zn contents (0.23, 0.43 and 0.40 mg dm^{-3}, respectively). Savannah soils with low Zn availability should be treated with this fertilizer at a dose of 2.0 kg ha^{-1} for the establishment of *U. brizantha* cv Marandu for intensive management foraging (Galdrão, 2004).

Copper and zinc are considered trace elements and should be monitored in agricultural soils receiving sewage sludge or other by-products, as required by the CONAMA Resolution 375/2006 (Brasil, 2006). In terms of results, adding Cu and Zn to soils with the application of limed sludge, limed sludge plus mineral fertilizer, limed sludge plus agricultural gypsum, limed sludge plus magnesite, limed sludge plus single superphosphate, limed sludge plus verdete, limed sludge plus gypsum, magnesite, single superphosphate and verdete, resulted in Zn contents of 1.9, 1.7, 1.9, 1.8, 1.76 1.9 and 1.66 kg ha^{-1}, respectively. The Cu contents of the same treatments were: 2.06, 2.30, 2.30, 2.56, 2.56, 3.56 and 2.46 kg ha^{-1}, respectively. It is important to note that such values are well below the theoretically accumulated loads for Zn (445 kg ha^{-1}) and for Cu (137 kg ha^{-1}) permitted for inorganic substances by the application of sewage sludge or by-products in agricultural soils, as determined by the CONAMA Resolution 375/2006 (Brasil, 2006).

The fertilizer sources did not affect chlorophyll A contents of *U. brizantha* cv Marandu (P>0.05) (Table 8). This lack of variation in chlorophyll A was also observed by Fassio et al. (2008) for *U. brizantha* cv Marandu, with mineral and organic fertilizers containing 320 kg ha^{-1} N, 90 kg ha^{-1} P_2O_5 and 120 kg ha^{-1} K_2O, associated with arbuscular mycorrhizal fungi. According to Abreu and Monteiro (1999), chlorophyll contents in recently expanded leaf blades of Marandu grass at 14, 28 and 42 days of plant growth were 31, 18 and 14 units, respectively, when nitrogen fertilization was inadequate. In the present study, chlorophyll A content in the control treatment was 24.45 units 30 days after sowing. Chlorophyll A content corresponds, approximately, to three or four times the chlorophyll B content (Table 8). Monteith (1978) states that this is a characteristic of

Table 8. Chlorophyll A and B contents of fresh and dry matter of *Urochloa brizantha* cv Marandu fertilized with limed sewage sludge, and inorganic and organic fertilizers.

Fertilizer source	Chlorophyll A	Chlorophyll B	Fresh matter (g)	Dry matter (g)
Mineral fertilizer	33.95^{ns}	10.05*^{a}	35.66*^{a}	7.09*^{a}
Limed sludge	32.10^{ns}	5.90^{b}	11.45*^{c}	2.47^{d}
Limed sludge + mineral fertilizer	32.48^{ns}	8.58*^{a}	32.79*^{a}	5.82*^{b}
Limed sludge + Gypsum (G)	33.38^{ns}	7.63*^{a}	13.37*^{c}	2.79^{d}
Limed sludge + Magnesite (M)	29.40^{ns}	7.50*^{a}	13.23*^{c}	2.55^{d}
Limed sludge + Single superphosphate (SS)	33.75^{ns}	9.80*^{a}	21.93*^{b}	4.79*^{c}
Limed sludge + Verdete (V)	30.55^{ns}	6.10^{b}	9.43^{c}	1.79^{d}
Limed sludge + G+M+SS+V	34.35^{ns}	9.18*^{a}	24.82*^{b}	4.69*^{c}
Organomineral	31.13^{ns}	7.95*^{a}	32.01*^{a}	5.98*^{b}
Control	24.45^{ns}	4.15^{b}	2.678^{d}	0.63^{e}

Averages followed by the same letter in the column do not differ by the Scott-Knott test at 0.05 probability. *Significantly different in relation to the control, by the Dunnet test at 0.05 significance. ns: Not significant by the F test.

photosynthesis in C4 plants such as *U. brizantha* cv Marandu.

Chlorophyll B contents in the fresh and dry matter of *U. brizantha* cv Marandu were affected by the fertilizer sources evaluated (P<0.05) (Table 8). Mineral fertilizer with NPK, limed sludge plus mineral fertilizer, limed sludge plus gypsum, limed sludge plus magnesite, limed sludge plus single superphosphate, the mixture of limed sludge with gypsum, magnesite, single superphosphate and verdete and the organomineral fertilizer all improved the nutritional state of the plants by supplying mineral nutrients. This resulted in plants with higher chlorophyll B contents than the control. Chlorophyll B contents in limed sludge and in limed sludge plus verdete were not different from the control. According to Martins and Pitelli (2000) liming soil reduces acidity and favors mineral nutrient absorption, increasing chlorophyll A and B contents in *Urocholoa plantaginea*. Costa et al. (2008) reported that there is a direct relation between chlorophyll contents and leaf N concentration in recently expanded leaves of Marandu grass. Increased chlorophyll B content in the present study was a result of the nutrient sources evaluated (mineral fertilizer, agricultural gypsum, magnesite, single superphosphate, organomineral, and the mixture of gypsum, magnesite, single superphosphate and verdete). Limed sludge by itself did not increase chlorophyll B contents at the dosage evaluated (2.6 t ha^{-1}) since it does not supply the mineral nutrients in adequate amounts for forage plants.

Mineral fertilizer with NPK, limed sludge plus mineral fertilizer and organomineral fertilization resulted in increased fresh matter production (Table 4). Dry matter increased only in the treatment with mineral fertilizer plus NPK. However, all treatments evaluated presented fresh and dry matter weights greater than the control. Several studies have demonstrated increased fresh and dry matter of *U. brizantha* cv Marandu following the use of mineral or organic fertilizers (Costa et al., 2008; Lara et al., 2015; Dias et al., 2015).

Conclusions

Limed sludge, applied at 2.6 t ha^{-1}, combined or not with mineral fertilizers increased soil, V (base saturation), pH, reduced aluminum saturations to adequate levels for *U. brizantha* cv. Marandu development, and increased soil Ca and Mg contents, together with lower Fe and Mn soil contents.

Soil organic matter, organic carbon, Cu and B contents were not affected by limed sludge and the fertilizer sources evaluated.

Higher levels of P and S were observed after fertilization with limed sludge combined with single superphosphate and the mixture with gypsum, magnesite, single superphosphate and verdete. Neither verdete nor any of the other fertilizer sources evaluated increased K content. Limed sludge plus verdete resulted in the higher Zn content.

Limed sludge and limed sludge plus verdete did not increase chlorophyll B content of *U. brizantha* cv. Marandu. Limed sludge plus mineral fertilizer and limed sludge plus organomineral fertilizer increased fresh matter of the forage grass evaluated. However, only the mineral fertilizer increased dry matter.

It was concluded that the limed sewage sludge provides agronomic benefits. Additionally, its application on agricultural land, as required by environmental regulations, can produce social and environmental benefits with less impact on public health and the environment.

Conflict of interests

The authors have not declared any conflict of interests.

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