Revista
Brasileira de
Ciência do Solo

Division – Soil Use and Management | Commission – Soil Fertility and Plant Nutrition

Soil fertility and nutritional status of elephant grass fertilized with organic compost from small ruminant production and slaughter systems

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ABSTRACT: The application of organic composts derived from animal husbandry or agro-industry is a promising option to improve nutrient cycling and supply of soils and, consequently, forage production. The objective of this study was to evaluate the soil chemical properties and the nutritional state of elephant grass in response to rates of organic fertilizer composted from the waste of small ruminant production and slaughter systems. The experiment was conducted on a Fluvisol of a forage field with elephant grass var. Cameroon, and was arranged in a randomized block design with split-plots with repeated measures over time. Six rates of organic compost (0, 13.3, 26.6, 39.9, 52.3, and 79.8 t ha^{-1}, in plots) and an additional treatment with mineral fertilizers were evaluated in four growth periods (60, 120, 180, and 240 days, in subplots) with four replications, resulting in a total of 28 plots. Soil fertility was evaluated after the fourth growth period, while leaf analysis was determined in every 60-day period. The increasing rates of organic compost increased the concentrations of OM, NH_4^+, NO_3^-, $NH_4^+ + NO_3^-$, P and base saturation, while the H+Al values decreased and the N and P contents increased in the plants. Compared with mineral fertilization, soil inorganic nitrogen and phosphorus increased by 34 and 97 % in response to the application of organic compost. In response to the application of organic compost, the leaf contents of all studied nutrients remained adequate in all studied periods, except for the macronutrient N and micronutrient Mn.

Keywords: composting, *Pennisetum purpureum*, organic residue.

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Received: February 26, 2020
Approved: July 06, 2020

How to cite: Pereira GAC, Primo AA, Meneses AJG, Araújo MDM, Pompeu RCFF, Guedes FL, Souza HA. Soil fertility and nutritional status of elephant grass fertilized with organic compost from small ruminant production and slaughter systems. Rev Bras Cienc Solo. 2020;44:e0200031.
https://doi.org/10.36783/18069657rbcs20200031

INTRODUCTION

On a global scale, Brazil has herds of around 8.8 and 17.6 million heads of sheep and goats, respectively. A major part of this impressive flock (90 % of the goats and 60 % of the sheepin Brazil) is concentrated in the northeast of the country, for being the two main livestock activities of the predominantly small family farmers of that region (Aquino and Lacerda, 2014). Along with the increase in agricultural and agro-industrial activities of the last decades, a substantial amount of organic waste has been generated. Bans on the use of urban, industrial, and animal solid residues, as well as the lack of knowledge about possible applications in agriculture, have led to the disposal of these materials in landfills, thereby creating another environmental liability (Abdel-Raouf et al., 2012).

Composting has come into use in many regions around the world, for being considered a reasonable option for the destination of dead animals, for contributing to meeting the increasing demand for organic fertilizers, at low production costs and with a high economic return for animal husbandry (Misselbrook et al., 2012). The number of poultry and pig farms using composting in Brazil has increased in the last few years, and researchers have investigated this form of treatment of remains of dead animals from cattle (Otenio et al., 2010), fish (Araújo et al., 2011), and sheep and goat farming (Souza et al., 2016). Most livestock farms have areas destined for forage fields, where elephant grass *(Pennisetum purpureum)* is frequently planted in Brazil because of its high dry matter yield, acceptability, forage quality, photosynthetic efficiency, and good response to nitrogen and phosphate fertilization (Pereira et al., 2010).

Numerous studies have addressed the management of this tropical forage. However, studies evaluating its responses to fertilization with organic compost are scarce. Thus, nutrient sources from waste of livestock production systems are interesting alternatives to intensify nutrient cycling and raise the yield of elephant grass. Thus, the objective of this study was to evaluate soil chemical properties and the nutritional state of elephant grass pasture in response to the application of organic compost rates produced from small ruminant production and slaughter systems.

MATERIALS AND METHODS

The experiment was carried out in an experimental area of Embrapa Sheep and Goats, in Sobral, Ceará, Brazil (34° 20' S latitude, 40° 21' W longitude; 83 m a.s.l.). The regional climate was classified as BSh according to Köppen Classification System, i.e., hot and semi-arid, withan average annual precipitationof 759 mm and mean temperature of 28 °C (Inmet, 2014).

Before the experiment was initiated, soil was collected to assess fertility. The chemical and texture properties of the 0.00-0.20 and 0.20-0.40 m layers are listed in table 1. In the 0.00-0.20 m layer, the pH was high, OM content low, the P content was excellent, K low, Ca excellent, Mg excellent, sum of bases were high, CEC was high, BS excellent, and the contents of B medium, Cu low, Fe high, Mn high, and Zn medium, according to Alvarez V et al. (1999). In the 0.20-0.40 m layer, the contents of chemical properties were close to those of the surface layer, except for OM, with a content of less than 1 %.

Based on the particle size analysis (Table 1), the soil was classified as a Fluvisol (Fluvent/ *Neossolo Flúvico*) with a sandy loam texture, according to Santos et al. (2018). The area was irrigated by a low-pressure fixed sprinkler system (pressure <2.0 kgf cm^{-2}). Irrigation was applied every night to minimize water loss, especially due to wind, and to control potential nutrient losses by volatilization due to the high day temperatures. The evapotranspiration of the applied water volume corresponded to 7.52 mm day^{-1}, with an efficiency of 73 % of the application.

The experimental compost was produced by mixing (solid) waste from goat and sheep slaughterhouses with a blend of 50 % pen manure and 50 % feeder and tree-pruning residues, 1.5 to 2.0 times the amount of slaughterhouse waste. More detailed information about the process of compost production is given in the study of Souza et al. (2019a). The compost decomposition period lasted approximately 120 days. At the end of this period, the material contained 10 % moisture (chemical properties shown in table 2). The contents of N and Ca of the organic compost were close to 2 %, that of K near 1.5 %, and the C/N ratio was 9/1.

A completely randomized block design with split-plots with four replications and repeated measures over time was adopted. Plots corresponded to six rates of organic compost and an additional treatment (mineral fertilization), whereas the sub-plots corresponded to four growth periods (60 days each), resulting in a total of 28 experimental units (5 × 5 m).

Table 1. Soil chemical and particle-size properties in the experimental area

Layer	pH(H_2O)	OM	P	K	Ca^{2+}	Mg^{2+}	H+Al	Al^{3+}	SB	CEC
m		g dm^{-3}	mg dm^{-3}		mmol$_c$ dm^{-3}					
0.00-0.20	7.0	16	36	31	50	19	13	0	74.2	87.2
0.20-0.40	7.2	7	36	31	54	17	12	0	76.1	88.1
	BS	**ESP**	**S-SO$_4^{2-}$**	**Na**	**B**	**Cu**	**Fe**	**Mn**	**Zn**	
	%		mg dm^{-3}							
0.00-0.20	85	5.08	11	102	0.38	0.5	54	38	1.5	
0.20-0.40	86	4.84	8	98	0.23	0.5	32	20	1.0	
	Clay		**Silt**		**Total sand**		**Coarse sand**		**Fine sand**	
	g kg^{-1}									
0.00-0.20	254		216		530		60		470	
0.02-0.40	239		251		510		70		440	

pH: potential of hydrogen; OM: organic matter; P: phosphorus; K: potassium; Ca: calcium; Mg: magnesium; H+Al: potential acidity; Al: aluminum; SB: sum of bases; CEC: cation-exchange capacity; BS: base saturation; ESP: exchangeable sodium percentage; S: sulfur; Na: sodium; Cu: copper; Fe: iron; Zn: zinc; Mn: manganese; B: boron - (Alvarez V et al., 1999). Methods (Silva et al., 2009): pH(H_2O) at a soil:solution ratio of 1:2.5; OM: was determined according to the Walkley-Black method; P, K, Na, Cu, Fe, Mn, and Zn were extracted with Mehlich-1; Ca^{2+}, Mg^{2+}, and Al^{3+} were extracted by KCl 1 mol L^{-1}; B: was extract by hot water; S-SO$_4^{2-}$: based on the reaction with barium chloride. Methods (Donagema et al., 2011): Clay, silt and sand: pipette method.

Table 2. Mean values of the chemical properties of the compost

IN	N-NO$_3^-$	N-NH$_4^+$	TN	C	C/N
mg kg^{-1}			g kg^{-1}		
355	250	105	20.3	175	9
P	**K**	**Ca**	**Mg**	**S**	**Na**
g kg^{-1}					
9	15.7	21.9	5.5	2.8	2.1
B	**Cu**	**Fe**	**Mn**	**Zn**	**pH($CaCl_2$)**
mg kg^{-1}					
20	30	2,051	175	138	6.7

IN: inorganic nitrogen; N-NO$_3^-$: nitrate; NH$_4^+$: ammonium; TN: total nitrogen; C: carbon; P: phosphorus; K: potassium; Ca: calcium; Mg: magnesium; S: sulfur; Na: sodium; pH: potential hydrogen ($CaCl_2$); B: boron; Cu: copper; Fe: iron; Mn: manganese; Zn: zinc. Methods (Bataglia et al., 1983): after nitroperchloric digestion: P was determined by colorimetry; K by flame photometry; S by turbidimetry; Ca, Mg, Cu, Fe, Mn, and Zn by atomic absorption spectrophotometry; total nitrogen by the Kjeldahl method; and boron by calcination. Methods (Abreu et al., 2006): pH($CaCl_2$) at a soil:solution ratio of 1:2.5; N-NO$_3^-$ and NH$_4^+$: Kjeldahl method; C was determined by dry combustion using an elemental analyzer.

The amount of organic compost applied to the forage field was determined to provide a rate of 120 kg ha^{-1} of N in each growth period and was based on the N content and the crop requirements for intensive production, with harvest cuts at intervals of 60 days (Fonseca et al., 2010). Thus, the standard rate of applied compost was determined, based on the N content of the compost and the N crop requirements for the four growth periods.

The experimental treatments consisted of organic compost rates of 0, 13.3, 26.6, 39.9, 53.2, and 79.8 t ha^{-1}, corresponding to zero standard rate (0), half (1/2), full (1.0), one and a half (1.5), twice (2.0), and three times the standard rate (3.0); plus an additional treatment (mineral fertilization) with N (urea) and K_2O (potassium chloride), corresponding to 120 kg of N and 150 kg of K_2O per hectare in each growth period.The organic fertilizer was applied in a single dose, at the beginning of the experiment, after an initial leveling cut of the forage. Mineral fertilization was applied as follows: first fertilization at the beginning of each growth period (five days after initial cut) and the second in the middle of the growth period (30 days after initial cut), as recommended by Fonseca et al. (2010). Organic and mineral fertilizers were distributed by broadcasting, on the entire area of each plot (25 m^2). For both N sources (organic and mineral), a standard rate of 720 kg ha^{-1} yr^{-1} of N was considered.

The soil chemical properties were evaluated for the layers 0.00-0.20 and 0.20-0.40 m. The soil was sampled at the end of the fourth growth periods and chemically analyzed for fertility properties (pH_{H2O}, OM, P, K, Ca, Mg, H+Al, S-SO_4^{2-}, Na, SB, CEC, base saturation, and micronutrients), as proposed by Silva et al. (2009). Additionally, soil samples were collected from the 0.00-0.20 m layer to determine inorganic nitrogen, N-NH_4^+, N-NO_3^-, and NH_4^+ + NO_3^- (Silva et al., 2009). For leaf analysis, composite samples (six single samples per plot) were taken, by collecting the first newly-expanded leaf (Werner et al., 1997) of forage plants on the 60th day after the initial cut, in all four evaluation growth periods. Macro- and micronutrient analyses were performed as described by Bataglia et al. (1983).

The data were analyzed by analysis of variance (F test), a mean comparison test and regression analysis, and the interaction organic fertilizer rates × growth period was unfolded only when significant. The Tukey test (5 % probability) was used to compare the effect of the growth periods. For regression analysis, the choice of the models was based on the significance of the linear and quadratic coefficients, by the Student’s t test. Thus, a contrast analysis of the treatments with mineral and with organic fertilizer rates was performed. Software SISVAR (Ferreira, 2019) was used for the statistical analysis.

RESULTS

The presence of organic compost influenced the properties ammonium, nitrate, sum of nitrogen, and ammonium (inorganic N) fractions, organic matter (OM), phosphorus (P), potential acidity, base saturation (BS), boron (B), iron (Fe), and zinc (Zn) in the 0.00-0.20 m soil layer (Table 3). According to the contrast analysis, fertilization with organic compost raised the contents of ammonium, nitrate and inorganic nitrogen, P, BS, sodium (Na), and exchangeable sodium percentage in the soil more than mineral fertilization (Table 3).

Mineral fertilization induced higher levels of potential acidity and sulfur concentrations in the 0.00-0.20 m layer than organic compost (Table 3). Thus, it can be inferred that mineral fertilization caused higher soil acidification than organic compost, which may be attributed to the nitrification of ammonia N, derived from urea, which was the soluble source of this nutrient. The compost rates of 45.2, 52.4, and 48.3 t ha^{-1}, respectively, increased the concentrations of ammonium, nitrate, and inorganic N (N-NH_4^++ N-NO_3^-), whereas higher application rates reduced these N forms (Figure 1).

The soil OM content increased linearly in response to the application of organic compost (Table 4). The increasing linear effect on the boron content resulting from compost

Table 3. Mean values, F test, and coefficient of variation for the soil chemical properties in the 0.00-0.20 m layer in response to organic compost rates applied to elephant grass

Rate	$N\text{-}NH_4^+$	$N\text{-}NO_3^-$	IN	$pH(H_2O)$	OM	P	K	Ca^{2+}	Mg^{2+}	H+Al	SB	CEC	BS	B	Cu	Fe	Mn	Zn	$S\text{-}SO_4^{2-}$	Na	ESP
$t\ ha^{-1}$		$mg\ kg^{-1}$			$g\ dm^{-3}$	$mg\ dm^{-3}$				$mmol_c\ dm^{-3}$			%				$mg\ dm^{-3}$				%
0	6.9	13.3	20.2	7.2	22	34	35	70	28	15.3	103	118	87	0.28	0.7	29.8	36	2.0	4.0	98	3.6
13.3	20.3	16.2	36.5	7.0	23	37	31	75	30	14.3	109	124	88	0.29	0.7	25.3	33	2.0	5.0	91	3.0
26.6	34.9	22.4	57.3	7.2	24	47	27	61	29	13.8	94	108	87	0.27	0.8	26.0	34	2.0	4.3	80	3.3
39.9	21.1	29.0	50.1	7.2	30	88	25	75	32	12.8	112	125	90	0.38	0.5	22.5	37	3.1	4.3	98	3.4
53.2	20.2	25.7	46.0	7.2	33	91	29	69	30	12.5	103	116	89	0.36	0.8	22.5	36	3.1	6.5	95	3.6
79.8	19.9	22.7	42.6	7.3	39	93	31	71	33	12.3	109	121	90	0.40	0.6	16.0	38	4.8	3.5	104	3.7
F test	**	**	**	ns	*	**	ns	ns	ns	**	ns	ns	**	**	ns	*	ns	**	ns	ns	ns
CV (%)	16.6	23.1	15.6	2.8	24.9	43.0	27.0	13.0	13.0	7.4	12.0	10.7	1.3	18.0	28	21.9	15.0	36.0	43.2	10.0	11.3
Contrast																					
Rates (×)	20.6	21.6	21.0	7.2	34	65	30	70	30	13.5	105	119	89	0.33	0.7	24.1	36	2.8	4.6	94	3.4
Mineral F.	3.8	11.8	15.6	7.1	26	33	27	71	27	15.3	102	117	87	0.26	0.7	24.6	36	1.9	6.8	76	2.8
F test	**	**	**	ns	ns	*	ns	ns	ns	**	ns	ns	*	ns	ns	ns	ns	ns	*	**	**

$N\text{-}NH_4^+$: ammonium; $N\text{-}NO_3^-$: nitrate; IN: inorganic nitrogen; pH: potential hydrogen; OM: organic matter; P: phosphorus; K: potassium; Ca: calcium; Mg: magnesium; H+Al: potential acidity; SB: sum of bases; CEC: cation-exchange capacity; BS: base saturation; B: boron; Cu: copper; Fe: iron; Mn: manganese; Zn: zinc; $S\text{-}SO_4^{2-}$: sulfur; Na: sodium; ESP: exchangeable sodium percentage. Mineral F: mineral fertilization; ns, * and **: not significant, significant at 5 and 1 % probability, respectively. Methods (Silva et al., 2009): $pH(H_2O)$ at a soil:solution ratio of 1:2.5; OM: was determined according to the Walkley-Black method; P, K, Na, Cu, Fe, Mn, and Zn were extracted with Mehlich-1; Ca^{2+}, Mg^{2+}, and Al^{3+} were extracted by KCl 1 mol L^{-1}; B: was extract by hot water; S: based on the reaction with barium chloride.

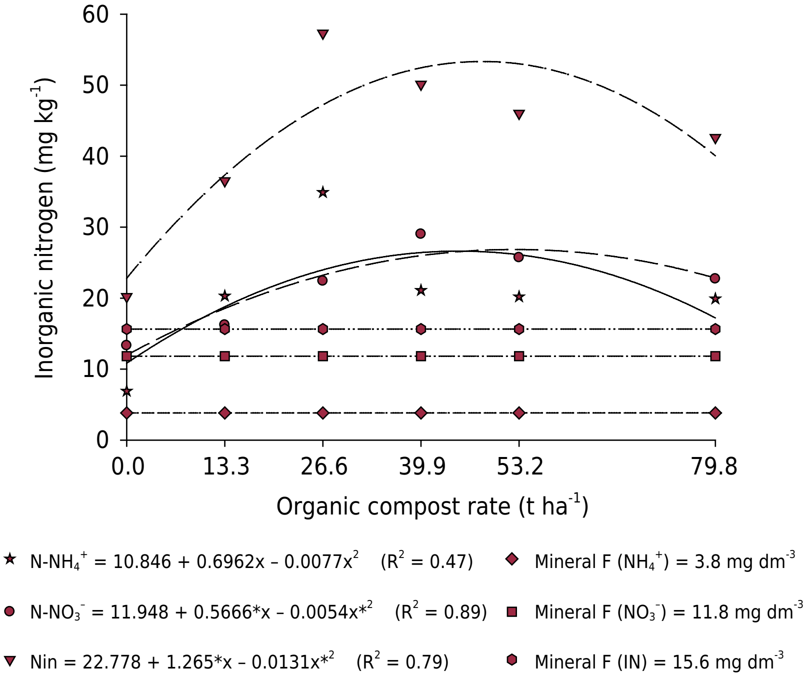

Figure 1. Contents of nitrate, ammonium, and inorganic nitrogen ($N\text{-}NH_4^+ + N\text{-}NO_3^-$) in response to organic compost and mineral fertilization rates applied to elephant grass in the 0.00-0.20 m layer. *: significant at 5 % probability.

applications (Table 4) can be explained by the organic character of the tested nutrient (Table 2), and the release of this micronutrient by OM mineralization. The same effect was observed for the soil Zn contents (Table 4), which increased by 0.0367 mg dm^{-3}, at each ton of applied compost. For the soil Fe content, a decreasing linear effect was observed in response to organic compost rates (Table 4), since Fe^{2+} ions are reduced in soil with a pH of around 7.0 (Table 3). In the 0.20-0.40 m layer, the organic compost influenced the variables pH, potential acidity, BS, and Na (Table 5).

Table 4. Regression equation for the effect of organic compost rates on soil chemical properties in a forage field with elephant grass cv. Cameroon

Variable	Compost rate	R^2
	0.00-0.20 m layer	
OM	y = 20.427 + 0.23x**	0.95
P	y = 32.946 + 0.8972x**	0.81
H+Al	y = 14.811 – 0.0381x**	0.88
V	y = 87.272 + 0.0355x**	0.62
B	y = 0.2679 + 0.0018x**	0.73
Fe	y = 29.143 – 0.1544 x**	0.92
Zn	y = 1.5284 + 0.0367x**	0.88
	0.20-0.40 m layer	
H+Al	y = 13.94 – 0.0265x**	0.77
BS	y = 88.194 + 0.0284x**	0.89
Na	y = 90.02 + 0.2992x**	0.72

**: significant at 1 % probability.

Table 5. Mean values, F test, and coefficient of variation for soil chemical properties in the 0.20-0.40 m layer, in response to organic compost rates applied to elephant grass

Rate	pH	OM	P	K	Ca^{2+}	Mg^{2+}	H+Al	SB	CEC	BS	Cu	Fe	Zn	Mn	B	$S\text{-}SO_4^{2-}$	Na	ESP
t ha^{-1}		g dm^{-3}	— mg dm^{-3} —		——— $mmol_c$ dm^{-3} ———					%	——— mg dm^{-3} ———							%
0	7.1	11	37	23	71	29.5	14.5	105.2	119.7	88	0.7	19.8	1.3	25.4	0.18	5.3	95	3.5
13.3	7.0	14	40	29	73	28.3	13.5	105.8	119.3	89	0.7	22.9	1.2	27.0	0.20	4.5	88	3.3
26.6	7.2	11	30	24	74	29.3	12.8	107.7	120.7	89	0.7	17.5	1.2	23.5	0.20	5.0	93	3.4
39.9	7.0	13	37	25	73	29.5	12.8	106.9	119.7	89	0.7	69.7	1.2	23.3	0.25	4.8	103	3.8
53.2	7.3	10	33	25	73	31.8	12.3	110.2	122.4	90	0.6	18.1	1.2	26.0	0.25	5.5	113	4.0
79.8	7.3	10	35	29	75	32.8	12.3	112.9	125.2	90	0.6	17.4	1.3	27.0	0.27	4.5	111	3.9
F test	ns	ns	ns	ns	ns	ns	**	ns	ns	*	ns	ns	ns	ns	ns	ns	**	ns
CV (%)	1.6	23.2	40.2	18	10	14.7	5.6	10.7	9.8	1.1	19.3	15.8	24.1	26.4	33.0	22.7	9.3	12.3
Contrast																		
Rates (×)	7.1	11	35	26	73	30.2	13.0	108.1	121.1	89	0.7	27.5	1.2	25.4	0.23	4.9	101.0	3.6
Mineral F.	7.0	10	54	24	71	28.5	12.8	102.9	115.6	89	0.6	19.3	1.4	28.5	0.23	5.0	79.5	3.0
F test	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	**	*

pH: potential hydrogen; OM: organic matter; P: phosphorus; K: potassium; Ca: calcium; Mg: magnesium; H+Al: potential acidity; SB: sum of bases; CEC: cation-exchange capacity; BS: base saturation; B: boron; Cu: copper; Fe: iron; Mn: manganese; Zn: zinc; $S\text{-}SO_4^{2}$: sulfur; Na: sodium; ESP: exchangeable sodium percentage. Mineral F: mineral fertilization. ns,*, and **: not significant, significant at 5 and 1 % probability, respectively. Methods (Silva et al., 2009): pH(H_2O) at a soil:solution ratio of 1:2.5; OM was determined according to the Walkley-Black method; P, K, Na, Cu, Fe, Mn and Zn were extracted with Mehlich-1; Ca^{2+}, Mg^{2+}, and Al^{3+} were extracted by KCl 1 mol L^{-1}; B: was extract by hot water; S: based on the reaction with barium chloride.

The contrast analysis of the subsurface layer (Table 5) indicated that only the variables sodium content and exchangeable sodium percentage differed significantly between mineral and organic fertilization. Organic fertilization provided increases in both properties since, by supplying OM and salts (Table 2) to irrigated areas with sandy loam texture, the compost reduced Na retention and increased Na leaching into the subsurface layer. An increasing linear effect was observed for BS and Na in response to organic compost applications (Table 4). The opposite result was found for potential acidity (Table 4), which decreased by 0.0265 $mmol_c$ dm^{-3} at each ton of compost applied. Thus, it can be inferred that compost fertilization tends to increase the soluble base content. In addition, because the area was irrigated, the increase in BS and decrease in H+Al intensified the incorporation of organic material into the soil.

Thus, the concentration of exchangeable sodium in the profile remained at levels considered acceptable in relation to possible soil salinization/sodification problems and consequent potential hazards for the groundwater. Although the percentage of exchangeable sodium (ESP) did not differ between the two layers (0.00-0.20 and 0.20-0.40 m) of soil treated with compost rates, the observed percentages rule out possible problems of salinization/sodification.

Leaf analysis (Table 6) showed an effect of organic compost rates on N and P in the sampled leaf of elephant grass. The data were best fitted to increasing linear and quadratic models, respectively (Figures 2a and 2b).

Table 6. Mean values, F test, and coefficient of variation for nutrient contents in the sampled leaf of elephant grass cv. Cameroon in response to organic compost rates

Rate	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn
t ha^{-1}	g kg^{-1}						mg kg^{-1}				
0	13.7	2.0	15.6	3.1	1.5	1.6	10.5	6.7	98	18	19
13.3	14.0	2.7	16.2	3.1	1.5	1.4	14.4	6.8	116	17	19
26.6	14.3	2.8	14.8	3.3	1.7	1.5	11.2	6.8	136	17	19
39.9	14.8	2.9	14.3	3.2	1.7	1.7	12.8	7.1	116	17	20
53.2	14.3	3.1	15.7	3.3	1.8	1.6	9.4	6.8	129	17	21
79.8	15.5	3.2	16.0	3.2	1.8	1.7	11.6	7.5	124	16	21
F test	**	**	ns	ns	ns	ns	ns	ns	ns	ns	ns
CV$_1$ (%)	8.3	13.1	27	13.5	21.5	27.8	31.3	25.1	46.4	27.1	13
Growth period											
1	15.1a(1)	2.2c	18.4a	0.8c	0.3c	2.3a	9.6b	8.1a	163.5a	18.6a	19.7ab
2	15.3a	2.9b	15.7b	4.1a	1.7b	1.6b	11.8ab	7.1ab	144.3ab	15.3b	19.8a
3	14.4a	3.2a	12.0c	4.4a	2.8a	1.3bc	12.7a	5.9c	96.2bc	16.7ab	21.7a
4	12.9b	2.8b	15.6b	3.6b	1.9b	1.2c	12.5a	6.6bc	75.3c	16.3ab	17.7b
F test	**	**	**	**	**	**	**	**	**	**	**
CV$_2$ (%)	8.6	9.6	11.9	14.7	19.5	30.3	30.5	20	53.6	19.6	14.1
R× P	ns	**	ns	ns	ns	ns	ns	ns	ns	ns	ns

(1) Means followed by the same letter in a column do not differ by Tukey's test (5 % probability).^{ns}, *, and **: not significant and significant at 5 and 1 % probability by the F test, respectively. Methods (Bataglia et al., 1983): after nitroperchloric digestion: P was determined by colorimetry; K by flame photometry; S by turbidimetry; Ca, Mg, Cu, Fe, Mn, and Zn by atomic absorption spectrophotometry; N by the Kjeldahl method; and B by calcination.

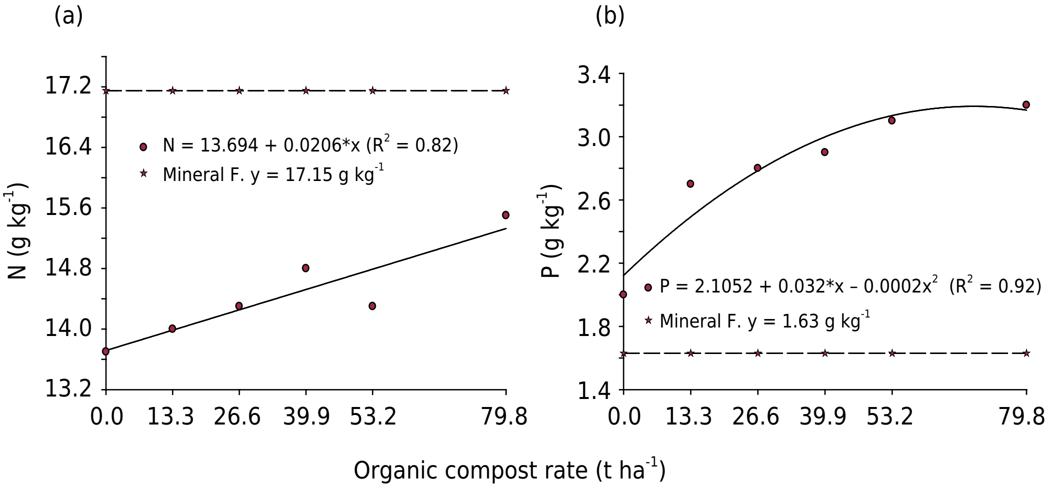

Figure 2. Content of nitrogen (a) and phosphorus (b) in the elephant grass sample leaf in response to organic compost rates and mineral fertilization. **: significant at 1 % probability.

Regarding the partitioning of the interaction organic compost rate × growth period, only leaf P concentration was significantly affected (Table 6). However, a linear response was found for growth period 2 and a quadratic response for growth periods 3 and 4, with maximum values of 3.85 and 3.34 g kg^{-1} at the compost rates of 70 and 59.1 t ha^{-1}, respectively (Figure 3). Although the increasing rates raised the soil P contents and maximum values were observed in the plants in the last growth periods, it can be concluded that lower compost rates would be sufficient for this nutrient. Contrast analysis was performed for the mean nutrient content of the sampled leaf of elephant grass in response to organic compost rates and mineral fertilizer (Table 7). In all growth periods, the results of organic fertilization were better than those of mineral fertilization for P. The magnesium (Mg) content was higher under mineral fertilization only in growth period 1, while in the second, third, and fourth growth period the content was higher under organic fertilization. This effect demonstrates that Mg contained in the organic compost was mineralized and taken up by the plants.

Mineral fertilization raised the N concentration in the first and last growth periods. An analogous result was found for K, with a higher content than that provided by organic fertilization in growth period 3. This fact can be explained by the decrease in mineralization of organic compost and the application of mineral fertilizers, whose source is soluble, in every growth period.

DISCUSSION

For phosphorus, the results are explained by the amount of P in the organic compost and the lack of mineral phosphate fertilization. The increase in available P_2O_5 was due to the release of organic acids during decomposition and later reaction with P in the soil solution, resulting in complex organic phosphorus molecules (Guppy et al., 2005). This reaction prevents soluble P precipitation and blocks the P adsorption sites in the solid phase, reducing the soil adsorption capacity (Bueno et al., 2011).

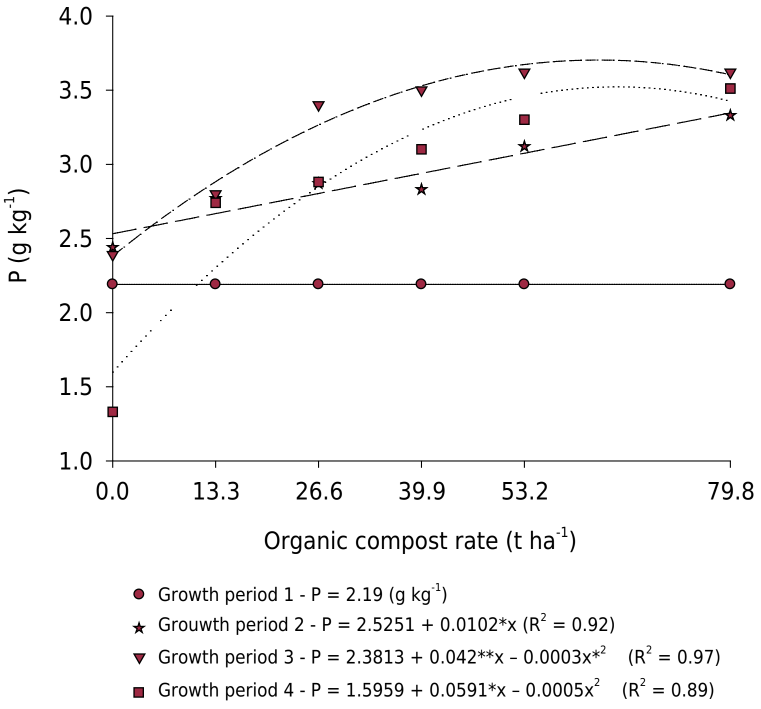

Figure 3. Phosphorus content in the elephant grass sample leaf in response to organic compost rates, in different growth periods. * and **: significant at 5 and 1 % probability, respectively.

Table 7. Mean values and contrast analysis for nutrient contents in the elephant grass sample leaf in response to organic compost rates and mineral fertilization

Contrast	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn
	g kg^{-1}						mg kg^{-1}				
					Growth period 1						
Rate (R; mean)	15.1	2.2	18.4	0.8	0.3	2.3	8.9	8.1	163.5	18.6	19.7
Mineral. F.	17.2	1.6	13.9	0.8	0.4	2.5	10.0	9.0	172.0	20.5	25.8
R vs. Mineral. F.	**	**	**	ns	*	ns	ns	ns	ns	ns	**
					Growth period 2						
Rate (R; mean)	15.5	2.9	15.7	4.1	1.8	1.6	11.8	7.1	144.3	15.6	20.0
Mineral. F.	16.6	1.7	16.0	4.1	1.5	1.8	12.5	7.5	144.0	29.0	23.8
R vs. Mineral. F.	ns	**	ns	ns	**	ns	ns	ns	ns	**	**
					Growth period 3						
Rate (R; mean)	14.5	3.2	12.0	4.4	2.8	1.3	13.5	5.8	96.2	16.7	21.5
Mineral. F.	14.4	2.0	15.9	4.0	1.8	1.4	17.0	6.0	111.0	33.0	22.0
R vs. Mineral. F.	ns	**	*	ns	**	ns	ns	ns	ns	**	ns
					Growth period 4						
Rate (R; mean)	12.2	2.8	15.6	5.8	2.4	1.7	12.3	6.9	75.3	16.3	17.7
Mineral. F.	16.5	1.8	18.5	3.8	1.6	1.2	11.8	8.0	106.0	34.0	25.3
R vs. Mineral. F.	**	**	ns	ns	*	ns	ns	ns	*	**	**

^{ns}, *, and **: not significant and significant at 5 and 1 % probability, respectively.

The increase in base saturation possibly occurred by hydrogen adsorption of the applied organic material (organic acid release), with higher basic cations, as reported elsewhere (Damatto Junior et al., 2006). The increase in sodium concentration in the 0.20-0.40 m layer can be explained by the compost rates applied to the soil. This compost was, among others, formed by the carcass of animals, which had received this element (Na) for being an essential micronutrient in animal husbandry (Pinheiro et al., 2011).

The difference in the rates between the maximum N values in response to the organic compost rates is consistent, since the mineralization process requires the transformation from ammoniacal N into nitrate (Cantarella, 2007). A predominance of nitrate over ammonium contents was also observed (Figure 1), indicating that the nitrification process was not limited (Sahrawat, 2008), mainly at high organic compost rates (from 45.2 t ha^{-1} upwards). A similar result was described by Rogeri et al. (2015), in a study with poultry litter applied to a Cambisol (Inceptisol/*Cambissolo Húmico*), and by Araújo et al. (2020), with the same organic compost as in this study, in a laboratory experiment.

A possible explanation for the results of soil nitrogen may be associated with different factors, e.g., N volatilization losses, since the experiment was carried out at high temperatures (± 28 °C) and a soil pH of around 7.0 (Table 3), which are favorable conditions for volatilization (Sangoi et al., 2003). Also, as the experimental area was irrigated, part of the N may have leached. An increased OM content in the soil is the main benefit of the agricultural use of organic waste, in view of its contribution to the improvement of the soil chemical, physical, and biological properties (Kindler et al., 2009).

In an evaluation of carbon mineralization from the same organic compost as used in this study, but under laboratory conditions, the percentage of mineralization was 98 % at an organic compost rate of 3.75 t ha^{-1} and 72 % at the rate of 30 t ha^{-1} (Pereira et al., 2019). The authors claimed that in relation to the occurrence of the “priming effect”, a hypothesis that cannot be ruled out is that the application of animal production residues can stimulate the decomposition of native organic carbon in the soil, and that the application of organic compost raises the decomposition rate of soil native C by almost 10 % (Pereira et al., 2019). This discussion is important for the application of adequate rates of organic fertilizers. In our study, at each 1 Mg ha^{-1} of applied organic compost, organic matter increased by 0.23 g dm^{-3}, which is important, since this observation occurred at the end of the fourth forage cut and the value was higher than that at the beginning of the experiment (Table 1).

The organic compost rates had an increasing linear effect on P contents (Table 4). The increased availability of this element in response to compost application may be attributed to the increased content of organic material, which is less strongly retained in the soil because of mineralization and organic phosphate formation, resulting in a higher P release (Gatiboni et al., 2008). The compost rates of 0.0 and 79.8 t ha^{-1} induced a linear reduction of potential acidity, with estimated values between 14.81 and 11.77 $mmol_c$ dm^{-3} in the 0.00-0.20 m layer, respectively (Table 4). According to Cassol et al. (2011), this decrease was due to the presence of soluble bases.

In the same layer, Souza et al. (2016) observed increases in phosphorus, potassium, sodium, and zinc contents in soil under corn fertilized with organic compost from animal production waste. In an evaluation of different soluble P sources in sorghum, however, the agronomic efficiency of the same organic compost studied here was not better than that of triple superphosphate or monoammonium phosphate (Souza et al., 2019b). On the other hand, Oliveira et al. (2019) cited that organic compost derived from residues from the production and slaughter of small ruminants is adequate to be used as a source of phosphorus, comparable to other agricultural residues that can potentially be used as fertilizers. In relation to mineral fertilization, inorganic nitrogen and phosphorus increased by 34 and 97 % (medium values), respectively, in response to organic compost compared with mineral fertilization in the 0.00-0.20 m layer, indicating how advantageous organic fertilization is.

The intensified leaching of sodium from the soil surface to the subsurface layers after compost application (Table 4) can be explained by a number of factors, e.g., the low plant uptake, low Na adsorption, high soil mobility, and irrigation of the forage field (Silva et al., 2010). Our results suggest Na leaching since the compost was applied on the surface and the area was irrigated. The ESP values were below the threshold of 15 % that indicates soil sodicity (Richards, 1997); i.e., after the four growth periods studied here, no excessive levels of soil salinization/sodification were detected in any of the experimental plots. Thus, the concentration of exchangeable sodium in the profile remained at levels considered acceptable, preventing salinization/sodification problems and consequently, potential hazards for the groundwater. The soil can be classified as adequate with regard to salinity.

In a comparison of the adequate contents recommended in the literature for forage plants (Werner et al., 1997), we observed that the N contents in growth periods 1 and 2 met the nutritional standards (15-25 g kg^{-1}) (Werner et al., 1997). However, after the 3rd growth period, the leaf nitrogen content sank below the recommended values for the crop, which reinforces the idea of limited forage growth due to a lack of N caused by the application of organic compost. A possible explanation is that organic compost can rapidly release N due to its low C/N ratio, and consequently, there might have been leaching losses, thus reducing N availability. The other nutrients (P, K, Ca, Mg, and S) were within the range considered adequate by Werner et al. (1997) (Table 6).

In general, regardless of the high fluctuations observed over the growth periods, micronutrients such as copper, iron, boron, and zinc were within the range considered adequate (Werner et al., 1997). Manganese responded differently, with levels below the recommended values for the crop (Werner et al., 1997) (Table 6). However, this result was expected, since the formation of stable complexes between organic matter and manganese causes deficiency problems, resulting in reduced plant uptake. Rapid initial mineralization followed by a decline is commonly observed in mineralization studies of residues applied to the soil (Mantovani et al., 2006). The greater amount of N mineralized in the beginning is attributed to the presence of easily mineralized organic fractions, with a subsequent predominance of more recalcitrant structures (Yagi et al., 2009).

Other data that explain the differences between mineral and organic fertilization are the plant N and P contents (Table 7). Under organic fertilization, the only nutrient source consisted of the compost applied at the beginning of the experiment. Increases in the soil contents of inorganic nitrogen and phosphorus were observed, compared to mineral fertilization, although the contents of both nutrients in the diagnosis leaves did not follow the same pattern. The leaf P content was higher in response to organic than to mineral fertilizers (in all cuts), while the opposite result was observed (in the first and fourth cut) for nitrogen. This could be explained by the low C/N ratio of the organic compost, with consequent rapid mineralization, which accelerated plant availability of the nutrients in the first growth periods (Pereira et al., 2019).

Similar results were found in a laboratory study on mineralization, where organic compost from residues of goat and sheep production and slaughter increased the concentrations of inorganic nitrogen and organic carbon, with increments of 70 and 69 % at rates of 7.5 and 30 Mg ha^{-1}, respectively (Araújo et al., 2020). Thus, this organic compostis rapidly mineralized in the soil, with a half-life of 45.8 days for carbon and 44.1 days for nitrogen, due to its low C/N ratio (7.4:1) (Araújo et al., 2020). Given the results of the above mineralization study and our results under field conditions, the application of organic compost is only interesting for one growth period in cut forages but could be an interesting option to improvenutrient cycling in livestock systems. From the economic point of view, on the other hand, each cycle of organic compost application implies higher costs, because the quantity needed is greater than that of soluble fertilizers and requires an uninterrupted compost production, which could be limiting for large-scale applications. In a study that evaluated the economic value of organic compost derived from residues from the production and slaughter of small ruminants as corn fertilizer, the authors estimated the price of the compost at R$ 0.25 kg^{-1}, which is the same value as that of castor bean, an agro-industrial residue (Souza et al., 2015).

Another option for the use of organic compost is the combined use with mineral fertilizers (mixture). The leaf diagnosis showed that our results were better for some nutrients in response to compost application than mineral fertilization, thus the mix of these two sources can be an interesting option. From the environmental point of view, the rapid mineralization of organic compost can promote the same impacts as when soluble fertilizers with N at high rates are applied, resulting in leaching losses and possible contamination. On the other hand, other benefits of the use of organic compost are worth mentioning, aside from the nutrient increase, such as higher soil OM content (Table 4).

CONCLUSIONS

The tested organic compost rates fertilization provided an increase in the contents of soil organic matter, phosphorus and base saturation, and a decrease in potential acidity. In response to the application of organic compost, the leaf contents of all studied nutrients remained adequate in all studied periods, except for the macronutrient N and micronutrient Mn.

ACKNOWLEDGMENTS

The authors wish to thank the Empresa Brasileira de Pesquisa Agropecuária (Embrapa) for supporting this research (Project No. 03.12.01.012.00.00). They are indebted to the Brazilian Council for Scientific and Technological Development (CNPq), for granting scholarships for excellence in research (No. 311039/2017-0).

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REFERENCES

Abdel-Raouf N, Al-Homaidan AA, Ibraheem IBM. Microalgae and wastewater treatment. Saudi J Biol Sci. 2012;19:257-75. https://doi.org/10.1016/j.sjbs.2012.04.005

Abreu MF, Andrade JC, Falcão AA. Protocolos de análises químicas. In: Andrade JC, Abreu MF, editores. Análise química de resíduos sólidos para monitoramento e estudos agroambientais. Campinas: Instituto Agronômico; 2006. p. 121-58.

Alvarez VVH, Novais RF, Barros NF, Cantarutti RB, Lopes AS. Interpretação dos resultados das análises de solos. In: Ribeiro AC, editor. Recomendações de fertilidade do solo do estado de Minas Gerais. Viçosa, MG: Comissão de Fertilidade do Solo do Estado de Minas Gerais; 1999. p. 25-32.

Aquino JR, Lacerda MAD. Magnitude e condições de reprodução econômica dos agricultores familiares pobres no semiárido brasileiro: evidências a partir do Rio Grande do Norte. Rev Econ Sociol Rural. 2014;52:167-88. https://doi.org/10.1590/S0103-20032014000600009

Araújo FB, Sanes FSM, Strassburguer AS, Medeiros CAB. Avaliação de adubos orgânicos elaborados a partir de resíduo de pescado, na cultura do feijão (*Phaseulos vulgaris)*. Cadernos de Agroecologia. 2011;6:1-5.

Araújo MDM, Feitos MM, Primo AA, Taniguchi CAK, Souza HA. Mineralization of nitrogen and carbon from organic compost from animal production waste. Rev Caatinga. 2020;33:310-20. https://doi.org/10.1590/1983-21252020v33204rc

Bataglia OC, Furlani JPF, Teixeira PR, Furlani PR, Galo JR. Métodos de análise química de plantas. Campinas: Instituto Agronômico de Campinas; 1983.

Bueno JRP, Berton RS, Silveira APD, Chiba KM, Andrade CA, Maria IC. Chemical and microbiological properties of on Oxisol treated with successive applications of sewage sludge. Rev Bras Cien Solo. 2011;35:1461-70. https://doi.org/10.1590/S0100-06832011000400040

Cassol PC, Silva DCP, Ernani PR, Filho OK, Lucrécio W. Atributos químicos em Latossolo Vermelho fertilizado com dejeto suíno e adubo solúvel. Rev Cien Agrovet. 2011;10:103-12.

Cantarella H. Nitrogênio. In: Novais RF, Alvarez V VH, Barros NF, Fontes RLF, Cantarutti RB, Neves JCL, editores. Fertilidade do solo. Viçosa: Sociedade Brasileira de Ciência do Solo; 2007. p. 375-470.

Damatto Junior EF, Bôas RLV, Leonel S, Fernandes DM. Alterações em propriedades de solo adubado com rates de composto orgânico sob cultivo de bananeira. Rev Bras Frutic. 2006;28:546-9. https://doi.org/10.1590/S0100-29452006000300048

Donagema GK, Campos DVB, Calderano SB, Teixeira WG, Viana JHM. Manual de métodos de analises de solo. Rio de Janeiro: Embrapa Solos, 2011.

Ferreira DF. Sisvar: a computer analysis system to fixed effects split-plot type designs. Rev Bras Biom. 2019;37:529-35. https://doi.org/10.28951/rbb.v37i4.450

Fonseca DM, Martuscello JA. Adubação e fertilidade do solo em capim elefante. In: Lira MA, editor. Capim elefante: fundamentos e perspectivas. Recife: IPA-UFRPE; 2010. p. 10341.

Gatiboni LC, Kaminski J, Rheinheimer DS, Brunetto G. Fósforo da biomassa microbiana e atividade de fosfatases ácidas durante a diminuição do fósforo disponível no solo. Pesq Agropec Bras. 2008;43:1085-91. https://doi.org/10.1590/S0100-204X2008000800019

Guppy CN, Menzies NW, Moody PW, Blamey FPC. Competitive sorption reactions between phosphorus and organic matter in soil: a review. Soil Res. 2005;43:189-202. https://doi.org/10.1071/SR04049

INMET – Instituto Nacional de Metereologia; 2014. Available at: http://www.inmet.gov.br/portal/index.php?r= estacoes/estacoesautomaticas. Accessed on: Dec 20, 2014.

Kindler R, Miltner A, Thullner M, Richnow HH, Kästner M. Fate of bacterial biomass derived fatty acids in soil and their contribution to soil organic matter. Org Geochem. 2009;40:29-37. https://doi.org/10.1016/j.orggeochem.2008.09.005

Mantovani JR, Ferreira ME, Cruz MCP, Barbosa JC, Freiria AC. Mineralização de carbono e de nitrogênio provenientes de composto de lixo urbano em Argissolo. Rev Bras Cien Solo. 2006;30:677-84. https://doi.org/10.1590/S0100-06832006000400008

Misselbrook TH, Menzi H, Cordovil C. Preface–recycling of organic residues to agriculture: agronomic and environmental impacts. Agr Ecosyst Environ. 2012;160:1-2. https://doi.org/10.1016/j.agee.2012.08.003

Oliveira LS, Costa MC, Souza HA, Blum J, Albuquerque GHS, Abreu MGP, Maia DS. Characterization of organic wastes and effects of their application on the soil. J Agric Sci. 2019;10:291-8. https://doi.org/10.5539/jas.v10n6p291

Otenio MH, Cunha CM, Rocha BB. Compostagem de carcaças de grandes animais. Juiz de Fora: Embrapa CNPGL; 2010.

Pereira AV, Auad AM, Lédo FJS, Barbosa S. *Pennisetum purpureum*. In: Fonseca DM, Martuscello JA, editores. Plantas forrageiras. Viçosa, MG: Universidade Federal de Viçosa; 2010. p. 197-219.

Pereira MS, Blum J, Souza HA, Taniguchi CK. Organic carbon decomposition in soil amended with organic compost from slaughterhouse residues. J Agric Sci. 2019;10:7-14. https://doi.org/10.5539/jas.v10n8p7

Pinheiro RSB, Sobrinho AGS, Andrade ENA, Nery E. Composição mineral da carcaça e dos cortes da carcaça de ovinos jovens e adultos. Arch Vet Sci. 2011;16:31-6. http://hdl.handle.net/11449/73055

Richards LA. Diagnóstico y rehabilitación de suelos salinos e sódico. México: Editorial Limusa; 1997.

Rogeri DA, Ernani PR, *Késia* S, Lourenço KS, Cassol PC, Gatiboni LC. Mineralização e nitrificação do nitrogênio proveniente da cama de aves aplicada ao solo. Rev Bras Eng Agric Amb. 2015;19:534-40. https://doi.org/10.1590/1807-1929/agriambi.v19n6p534-540

Sahrawat KL. Factors affecting nitrification in soils. Commun Soil Sci Plan. 2008;39:1436-46. https://doi.org/10.1080/00103620802004235

Sangoi L, Ernani PR, Lech VA, Rampazzo C. Lixiviação de nitrogênio afetada pela forma de aplicação da uréia e manejo dos restos culturais de aveia em dois solos com texturas contrastantes. Cienc Rural. 2003;33:65-70. https://doi.org/10.1590/S0103-84782003000100010

Santos HG, Jacomine PKT, Anjos LHC, Oliveira VA, Lumbreras JF, Coelho MR, Almeida JA, Araújo Filho JC, Oliveira JB, Cunha TJF. Sistema Brasileiro de Classificação de Solos. Brasília: Embrapa; 2018.

Silva DF, Matos AT, Pereira OG, Cecon PR, Moreira DA. Disponibilidade de sódio em solo com capim tifton e aplicação de percolado de resíduo sólido. Rev Bras Eng Agric Amb. 2010;14:1094-100. https://doi.org/10.1590/S1415-43662010001000011

Silva FC, Abreu MF, Pérez DV, Eira PA, Abreu CA, Raij B Van, Gianello C, Coelho AM, Quaggio JA, Tedesco MJ, Silva CA, Cantarella H, Barreto WO. Métodos de análises químicas para avaliação da fertilidade do solo. In: Silva FC, editor. Manual de análises químicas de solos, plantas e fertilizantes. Brasília, DF: Embrapa Informação Tecnológica; 2009. p. 107-90.

Souza HA, Araújo MDM, Benites VM, Pompeu RCFF, Guedes FL, Natale W, Melo AC, Leite LFC. Agronomic efficiency and productivity of sorghum in response to fertilizers with different phosphorus solubilities in greenhouse conditions. J Agric Sci. 2019b;11:177-86. https://doi.org/10.5539/jas.v11n17p177

Souza HA, Melo MD, Primo AA, Vieira LV, Pompeu RCFF, Guedes FL, Natale W. Use of organiccompost containing waste from small ruminants in corn production. Rev Bras Cienc Solo. 2016;40:e0150385. https://doi.org/10.1590/18069657rbcs20150385

Souza HA, Oliveira EL, Faccioli-Martins PY, Santiago L, Pirmo AA, Melo MD, Pereira GAC. Características físicas e microbiológicas de compostagem de resíduos animais. Arq Bras Med Vet Zootec. 2019a;71:291-302. https://doi.org/10.1590/1678-4162-9735

Souza HA, Vieira LV, Primo AA, Melo MD, Feitosa TS, Souza IM, Pereira GAC, Guedes FL, Pompeu RCFF, Natale W. Dose econômica e eficiência agronômica de composto orgânico proveniente de resíduos da criação e abate de pequenos ruminantes e de adubo nitrogenado na produção de grãos de milho em Luvissolo Háplico, no semiárido cearense. Sobral: Embrapa Caprinos e Ovinos; 2015.

Werner JC, Paulino VT, Cantarella H, Andrade NO, Quaggio JA. Forrageiras. In: van Raij B, editor. Recomendações de adubação e calagem para o Estado de São Paulo. Campinas: Instituto Agronômico; 1997. p. 74-85.

Yagi R, Ferreira ME, Cruz MCP, Barbosa JC. Mineralização potencial e líquida de nitrogênio em solos. Rev Bras Cienc Solo. 2009;33:385-94. https://doi.org/10.1590/S0100-06832009000200016