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Structural characteristics of elephant grass fertilized with organic composted waste from production and slaughter of small ruminants

Características estruturais do capim-elefante adubado com composto orgânico proveniente da produção e do abate de pequenos ruminantes

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Abstract

This study aimed to evaluate the morphophysiological characteristics of irrigated *Pennisetum purpureum* cv. Cameroon subjected to doses of an organic compost from waste generated by production and slaughter of small ruminants. The experiment was carried out in a grassland, during four growth cycles of 60 days. The area is located in the *Embrapa Caprinos e Ovinos* unit, in Sobral – CE, Brazil. Treatments consisted of organic compost doses (0, 13.3, 26.6, 39.9, 53.2 and 79.8 Mg ha^{-1}) plus a mineral fertilization (nitrogen and potassium) at doses equivalent to 720 and 900 kg ha^{-1} year^{-1}, respectively. The experimental design was arranged in completely randomized blocks, totaling four blocks with seven treatments each, in a split plot scheme with repeated readings over time. The plots corresponded to seven doses of an organic compost and an additional treatment (mineral fertilizer), and subplots to four growth cycles. The variables analyzed were total herbage biomass (THB), canopy height (CH), tiller population density (TPD) and water use efficiency for green leaf biomass production (WUE_{GLB}) and green stem biomass (WUE_{GSB}). In the first cycle, TPD decreased linearly with increasing doses of the compost, with 47 tillers m^2 at the dose of 79.8 Mg ha^{-1}, while THB and WUE_{GLB} variables behaved quadratically, with a maximum point of 23.53 Mg DM ha^{-1} cycle^{-1}, and 16.33 kg DM mm^{-1} for the doses of 66.52 and 62.94 Mg ha^{-1} of the organic compost. We concluded plant structural characteristics and water use efficiency were responsive to applications of the organic compost, and we recommend the dose of 67.7 Mg ha^{-1}.

Key words: Composting. Fodder biomass. *Pennisetum purpureum*. Water use efficiency.

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Resumo

Objetivou-se avaliar as características estruturais do *Pennisetum purpureum* cv. Cameroon, irrigado e submetido a doses de composto orgânico proveniente de resíduos da produção e do abate da ovinocaprinocultura. O experimento foi realizado em capineira de capim-elefante, durante quatro ciclos de 60 dias cada, em Sobral, Estado do Ceará. Os tratamentos foram as doses do composto orgânico (0; 13,3; 26,6; 39,9; 53,2; 79,8 Mg ha^{-1}) e um tratamento mineral (nitrogênio e potássio), equivalente a 720 e 900 kg ha^{-1} ano^{-1}. Utilizou-se o delineamento em blocos completos casualizados em esquema de parcelas subdivididas, com leituras repetidas no tempo, onde as parcelas constituíram as doses do composto e os ciclos de crescimento da gramínea, as subparcelas. As variáveis analisadas foram: biomassa total de forragem total (BTF), altura do dossel (ALT), densidade populacional de perfilhos (DPP) e eficiência de uso da água para produção de lâmina (EUA_{LV}) e de colmo (EUA_{CV}). No primeiro ciclo, a DPP apresentou resposta linear decrescente com o incremento das doses do composto ministrado, com valor de DPP estimada em 47 perfilhos m^2 na dose de 79,8 Mg ha^{-1}. As variáveis BFT e EUA_{LV} comportaram-se de maneira quadrática, com ponto de máximo de 23,53 Mg de MS ha^{-1} ciclo^1 e 16,33 kg de MS mm^{-1} nas doses de 66,52 e 62,94 Mg ha^{-1} do composto orgânico, respectivamente. Conclui-se que as características estruturais e a eficiência de uso da água do capim-elefante foram responsivas ao uso do composto orgânico, sendo recomendado a aplicação de 67,7 Mg ha^{-1}.

Palavras-chave: Biomassa de forragem. Compostagem. Eficiência de uso da água. *Pennisetum purpureum*.

Introduction

Goat and sheep farming play a significant socio-economic role with significant contributions on income generation and supply of high quality food. Brazil currently holds the eighteenth heading, rearing around 25.4 million animals (ANUALPEC, 2014). As any other farming activity, sheep and goat raising often generate environmentally harmful wastes. Among the impacts are contamination of soil and water, mainly through leaching of N (NO_3^-) and phosphorus, proliferation of insects and other animals, generation of unpleasant odors, as well as emergence of infectious agents compromising public health (EARHART et al., 1995; DELAUNE et al., 2006; PARDI et al., 2006; PACHECO; YAMANAKA, 2008;).

Composting is a controlled process of organic matter biochemical decomposition, transforming it into a more stable product with fertilizing properties and different from its source material. It is known that this process reduces negative effects of waste and, consequently, further environmental impacts by the activity along a production chain. Still, the technique enables the use of different substrates, identifying values of its physical and chemical composition colluding with the Normative Instruction No. 23 from Brazil (BRASIL, 2005). Moreover, it helps to reduce pathogenic bacteria and unwanted seeds (CURCI et al., 2007; BELLAVER; KONZEN, 2010; CESTONARO et al., 2010).

The Northeastern Brazil holds the largest share of the national flock of small ruminants, with nearly 90.0% goats (9.0 million) and 56.7% sheep (17.6 million) (IBGE, 2014). Based on the above data together with the respective production indexes such as prolificacy rate (1.5 births yr^{-1}), mortality rate (10%) and average carcass weight at one year of age (20 kg animal^{-1}) (EMBRAPA, 2005), a production of 22 tons of carcass can be estimated and plus 1.5 or 2.0 Mg bulking agents (manure and crop residues), used in composting, are able to generate up to 60.5 thousand Mg compost annually. Because the composting process is easy to perform and to use material from the proper farm, this technique requires low investment in infrastructure; being, therefore, economically feasible and can even be adopted in family farming units.

Organic composts are interesting alternatives as a source of nutrients for plants, and depending upon the composition – C/ N ratio and degree of humification, the composted material may exhibit characteristics similar to mineral fertilizers, with the ready release of nutrients. However, unlike traditional organic manures of high C/ N ratios, this compost can be used as source of nitrogen, phosphorus, potassium and other elements (CAMARGO; BERTON, 2006; MALAVOLTA et al., 2006; POHLMANN et al., 2009), in addition to have a positive effect on fodder production (ARAÚJO et al., 2009; RODRIGUES et al., 2011; FREITAS et al., 2012; ORRICO JUNIOR et al., 2013).

Given this context, the present study aimed to evaluate the structural responses of *Pennisetum purpureum* cv. Cameroon under irrigation and subjected to increasing doses of an organic compost from waste generated by production and slaughter of small ruminants for four crop growth cycles.

Material and Methods

The experiment was carried out in Sobral, Ceará State – Brazil (34 º2› South latitude, 40º 21’ West longitude and altitude of 83m) from December 2013 to August 2014. The local climate is a BShw type, according to Köppen’s classification, which stands for hot semi-arid, characterized by one dry period (July-December) and one rainy season (January-June), with average yearly rainfall of 759.2 mm, of which 95.1% occurs during the rainy season. The annual average temperature is 28 ºC, with an average maximum of 35 °C and minimum of 22 °C. The average relative humidity during the year is 69%. Table 1 presents the weather average data of temperature, relative humidity, rainfall and solar radiation, recorded during the experiment in a weather station of the National Institute of Meteorology (INMET, 2014).

Table 1. Means of temperature, relative humidity, radiation and rainfall during the experimental period.

Cycles	Mean temperature (º C)	Mean humidity (%)	Mean radiation (k j m^{-2})	Mean rainfall (mm)
1	28.5	89.0	1416.7	77.0
2	27.7	92.0	1441.4	279.0
3	27.0	97.0	1327.6	374.0
4	27.9	88.0	1420.1	10.0

Note: Means of temperature; humidity; radiation and rainfall of growth cycles (1, 2, 3 and 4), respectively.

Previously, deformed composite samples of soil were collected within the layers of 0.0-0.2 and 0.0-0.4 m depth, using a Dutch auger, for subsequent chemical and grain size analyses. Table 2 shows the results of these analyses for each variable, which were: pH in water; organic matter (by Walkley-Black method); phosphorus, potassium and sodium (by Mehlich-1); calcium, magnesium and aluminum (by 1M KCl); potential acidity (by Ca acetate); base sum, cation exchange capacity, base saturation and exchangeable sodium rate (calculations); sulfur – sulfate (by barium chloride); boron (by hot water); copper, iron, manganese and zinc (by Mehlich^{-1}); clay, silt and sand fractions (by the pipette method) and performed as Donagema et al. (2011).

Table 2. Chemical and grain size analyses of soil samples collected within the experimental area.

Layer	pH	OM	P	K	Ca	Mg	H+Al			Al	BS	CEC
(m)		g dm^{-3}	mg dm^{-3}		------------ $mmol_c$ dm^{-3} ------------							
0.0 – 0.2	7.0	16	36	31	50	19	13			0	74.2	87.2
0.2 – 0.4	7.2	7	36	31	54	17	12			0	76.1	88.1
	V	ESR	S	Na	Cu			Fe	Zn		Mn	B
	----- % -----		mg dm^{-3}		------------- mg dm^{-3} ------------							
0.0 – 0.2	85	5.08	11	102	0.5			54	1.5		38	0.38
0.2 – 0.4	86	4.84	8	98	0.5			32	1.0		20	0.23
	Clay		Silt		Total Sand				Coarse Sand			Fine Sand
		-------------------- g kg^{-1} --------------------										
0.0 – 0.2	254		216		530				60			470
0.2 – 0.4	239		251		510				70			440

Note: pH – Hydrogenionic potential; OM – Organic matter; P – Phosphorus; K – Potassium; Ca – Calcium; Mg Magnesium; H+Al – Potential acidity; Al – Aluminum; S – Sulphur; Na – Sodium; Cu – Copper; Fe – Iron; Zn – Zinc; Mn – Manganese; B – Boron; CEC – Cation exchange capacity; ESR – Exchangeable sodium rate; V – Base saturation.

Composting of solid residues from production and slaughter of goats and sheep was made in a masonry shed with colonial tiles and concrete flooring, with an area of 128 m^2. Composting cells were of 3.5 x 2.0 x 1.6 m (width, depth and height, respectively), in a plug-in assembling of wood boards in grooves, anchored in concrete columns.

Composting piles were continuously loaded with passive aeration, i.e. windrows were not turned because of the carcasses and aeration occurred by convection. Water was solely sprinkled at the time of stacking; the first layer of 0.4 m was made of structuring materials (50% goat and/ or sheep manure plus 50% minced elephant grass leftovers from animal feeders and tree pruning wastes). The structuring materials corresponded to 1.5 to 2.0 times the weight of solid residues used in the process.

The second layer comprised solid remains from small ruminants, being positioned in rows 0.2 m away from side walls and from each other. An amount of water was added to the solid remains, corresponding to 40% of its total weight. Yet the third layer was formed by the same structuring material and other layers were formed successively until it attained the maximum cell height. The last layer was singly formed by goat and/ or sheep manure. The composting period lasted nearly 120 days.

Table 3 displays the chemical characteristics of the compost, conducted according to methods described in Abreu et al. (2006). After 120 days, organic compost moisture was about 10%. Moreover, an absence of thermotolerant coliforms, total bacteria and *E. coli* was noteworthy until the end of the composting process. This outcome is in accordance with Resolution number 375/ 2006 of the (CONAMA, 2006), which sets “criteria and procedures for agricultural use of sewage sludge from sewage treatment plants and derivatives, besides other measures”; this regulation was used as a benchmark because there is no specific legislation for composts from animal production and slaughter.

Table 3. Average values of the compost chemical properties.

N_{in}	$N\text{-}NO_3^-$	$N\text{-}NH_4^+$	Nt	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
---------------------- mg kg^{-1} ----------------------					
20	30	2.051	175	138	6.7

Note: N_{in} – Inorganic nitrogen; $N\text{-}NO_3^-$ – Nitrate; NH_4^+ – Ammonium; Nt – Total nitrogen; C – Carbon; P – Phosphorus; K – Potassium; Ca – Calcium; Mg – Magnesium; S – Sulphur; Na – Sodium; pH – Hydrogenionic potential ($CaCl_2$); B – Boron; Cu – Copper; Fe – Iron; Mn – Manganese; Zn – Zinc.

This study was performed in a grassland, which has been grown with elephant grass (*Pennisetum purpureum* cv. Cameroon) for five years, on a Fluvic Neosol of flat topography. The area was irrigated by low-pressure fixed sprinkling (pressures < 2.0 kgf cm), which was daily performed at nighttime, aiming to reduce water losses, mainly by wind effect, as well as potential losses of nutrients, particularly nitrogen through volatilization given the elevated temperatures during the daytime. The water depth applied corresponded to a crop evapotranspiration (ETc) of 7.5 mm day^{-1}, at an efficiency rate of 73%, based on a water depth used for relative water use efficiency (WUE) of 10.3 mm day^{-1}. At the beginning of each cycle, the system was checked by means of rain gauges, which were set 50 cm above the ground throughout the entire experimental area and spaced by 3.0 m, to determine water distribution uniformity.

Treatments consisted of organic compost doses (0, 13.3, 26.6, 39.9, 53.2, and 79.8 t ha^{-1}), besides a treatment with nitrogen and potassium applications equivalent to 720 and 900 kg ha^{-1} yr^{-1}, respectively. The experimental design was arranged in completely randomized blocks, totaling four blocks with seven treatments each, in a split plot scheme with repeated readings over time. The plots corresponded to the six doses of the compost from production and slaughter wastes of small ruminants, plus an additional treatment (mineral fertilizer); the subplots comprised four grass growth cycles (60 days), totaling 28 plots, each of 25 m².

The amount of compost used on the grassland was determined to provide a nitrogen dose of 120 kg ha^{-1} cycle^{-1}, being based on the compost nitrogen content and moisture level, as well as meeting crop demands for intensive production (FONSECA et al., 2010), with cuttings made each 60 days (SANTOS et al., 2010). This is because of an optimization of the quality and quantity relationship promoted by this cutting interval under favoring climate and soil conditions since, from this period onwards, there is a sharp decline in fodder nutritional value. Compost applications were carried out once after standardization cut (prior to the beginning of the first cycle); and fertilizers were applied after each cut in the additional treatment (totaling four applications). The used doses were zero – half standard dose (13.3 Mg ha^{-1}); standard dose (26.6 Mg ha^{-1}); one-and-a-half times the standard dose (39.9 Mg ha^{-1}); two-and-a-half times the standard dose (53.2 Mg ha^{-1}) and three-and-a-half times the standard dose (79.8 Mg ha^{-1}). In the additional treatment, 120 kg N ha^{-1} (urea) and 150 kg K_2O ha^{-1} (potassium chloride) were applied per cycle (FONSECA et al., 2010). Mineral fertilization was divided into two fractions, the first at the beginning of each cycle (five days after the cut) and the second at half cycle (thirty days after the cut). Both organic and mineral fertilizers were spread over the entire area of each plot.

At the end of each growing cycle, plant structural characteristics were ascertained for each plot: a) canopy height (CH), sampling eight points per plot using graduated ruler; b) the number of live leaves per tiller (NGL), counting the number of fully expanded leaves with exposed ligules, considering as 0.5 if ligule was unexposed, and sampling eight tillers randomly per plot; c) total herbage biomass (THB), death herbage biomass (DHB), green fodder (GLB), green leaf blade (GLB) and green stem (GSB), as well as relationships between live/ death material (LM/DM) and leaf/ stem (L/S). Plants were cut at ground level and the measurements were estimated from the total biomass taken within two 1.0-m² sampling frames. Then, samples were taken to the laboratory for separation of living from dead material, and leaf blades from stems. Fractions were packed in hollow paper bags, weighed, labeled and dried in an air-forced oven at 55°C, until constant weight and, later, weighed again; d) leaf and stem water use efficiency (WUE_{GLB} and WUE_{GSB}) were estimated by the ratio between GLB and/ or GSB with daily water depth; e) tiller population density (TPD) was estimated by the average tiller counting in two samplings performed per plot using 0.5-m² frames. Leaf area index (LAI) was calculated with the aid of a grid board (4.0 cm²), where leaves were spread for counting of the number of vertices of overlapping leaf blades per square, using the following equation:

$$LAI = \frac{(Aframe \times Msample)}{Mframe};$$

In which: LAI = leaf area index (non-dimensional); A_{frame}= area of the leaves under the frame (cm²); M_{sample}= biomass of the leaf blade sample (g); M_{frame}= biomass of leaves under the frame (g).

First, data were analyzed for normality and homoscedasticity. Then, they underwent analysis of variance by F-test, mean comparison test and regression analysis. Based on these, interactions between fertilizer doses and growth cycle was breakdown only if significant at 5% probability. The effect of the cycles was assessed by the Tukey's test at 5% error probability. T model choice in regression analysis was made based on linear and quadratic coefficient significances, using t-test of Student, also at 5% error probability.

Later, a contrast analysis proceeded between the additional treatment (mineral fertilizer) and treatments with organic fertilizer. As an aid tool for statistical analysis, we used the statistical software SISVAR (FERREIRA, 2011).

Results and Discussion

Tables 4 and 5 show a summary of the variance analysis for structural characteristics and biomass components for plants subjected to increasing compost doses. Analyzing doses singly, we observed an increasing linear effect for most variables, except for NGL, TPD, and the ratios LM/DM and L/S.

Regarding the effect of growth cycles, we noted differences for all variables ($p<0.01$), being higher in the first cycle and decreasing in the following cycles. This outcome might be related to release and availability of nutrients from the organic compost and its influence on plant growth and development. It is noteworthy that the compost has a low C/N ratio (Table 3), which promotes a prompt release of nutrients. This fact combined with its unique application (after standardization cut), and associated with a medium soil texture (Table 2) under irrigation contributed to the decreasing of potential residual effects of the compost.

Table 4. Analysis of variance and of dose and cycle isolated effects, and interaction doses x cycle on structural characteristics of elephant grass cv. Cameroon under different levels of organic compost from wastes of small ruminant production and slaughter.

DOSES	CH	NGL	TPD	ALL	LAI	Internodes
(Mg ha^{-1})	(cm)	(leaf tiller^{-1})	(tiller m^{-2})	(cm)		Nº
0	88.31	8.15	38.04	60.90	2.09	3.19
13.3	106.91	7.80	39.97	74.59	2.96	4.28
26.6	125.67	8.54	36.68	79.75	3.70	4.79
39.9	139.80	8.23	39.91	81.93	4.14	5.22
53.2	146.09	8.69	37.94	95.75	4.61	6.23
79.8	160.96	8.45	39.37	98.81	5.17	6.84
F-significance	**	ns	ns	**	**	**
CV_1 (%)	10.69	9.83	21.28	14.42	37.92	29.63
Cycles						
1	159.28^a	8.18^a	56.58^a	103.81^a	5.08^a	5.82^a
2	124.38^b	8.14^b	37.68 ^{b}	79.06^b	3.91^b	4.70^b
3	121.07^b	8.09^b	27.39^c	77.50^b	3.52^b	5.71^a
4	108.12^c	7.90^b	32.91 ^{b}	67.45^c	2.66^c	4.20^c
F-significance	**	**	**	**	**	**
CV_2 (%)	7.40	8.90	9.83	9.62	20.15	11.26
MSD	7.25	0.56	5.11	6.03	0.58	0.44
D x C	**	ns	**	**	ns	*

Note: CH – Canopy height; NGL- Number of live leaves; TPD- Tiller population density; ALL- Average leaf of length; LAI- Leaf area index; AIN- Average of tiller internodes; MSD – Minimum Significant Difference; (D X C) – Doses x Cycles, Means followed by the same letter do not differ from each other ($p<0.05$) by the Tukey's test; ns (non-significant) and significant at 1% (**) and 5% (*).

Table 5. Analysis of variance and of dose and cycle isolated effects, and interaction doses x cycle on biomass components of elephant grass cv. Cameroon under different levels of organic compost from wastes of small ruminant production and slaughter.

DOSES	THB	DHB	GLB	GSB	LM/DM	L/S	WUE_{GLB}	WUE_{GSB}
(Mg ha^{-1})	------------Mg DM ha^{-1}------------				------------kg DM ha^{-1}------------			
0	4.45	0.37	2.09	1.96	14.95	1.32	4.83	4.48
13.3	7.10	0.48	3.04	3.58	15.99	0.96	6.97	8.06
26.6	9.89	0.66	3.94	5.28	16.78	0.84	9.06	11.95
39.9	11.33	0.74	4.24	6.35	16.44	0.79	10.14	14.88
53.2	12.53	0.84	4.69	6.99	20.27	0.91	11.29	16.47
79.8	14.03	0.96	5.22	7.85	17.65	0.87	12.03	18.46
F-significance	**	**	*	*	ns	ns	**	*
CV_1 (%)	36.39	36.54	26.74	47.93	48.38	62.5	24.42	45.72
Cycles								
1	17.17^a	1.32^a	5.77^a	10.08^a	13.72^b	0.63^b	12.43a	21.83a
2	8.32^b	0.44^b	3.65^b	4.22^b	21.65^a	1.16^a	7.13b	8.28c
3	7.87^{bc}	0.49^b	3.401^b	3.98^b	17.55^{ab}	0.97^{ab}	11.97a	14.05b
4	6.398^c	0.46^b	2.75^c	3.18^b	15.74^{ab}	1.04^a	4.86c	5.62c
F-significance	**	**	**	**	*	**	**	**
CV_2 (%)	23.29	36.06	20.44	29.63	53.18	50.66	22.08	30.83
MSD	1.77	0.19	0.61	1.22	6.98	0.36	1.53	2.93
D x C	**	**	ns	**	ns	ns	*	**

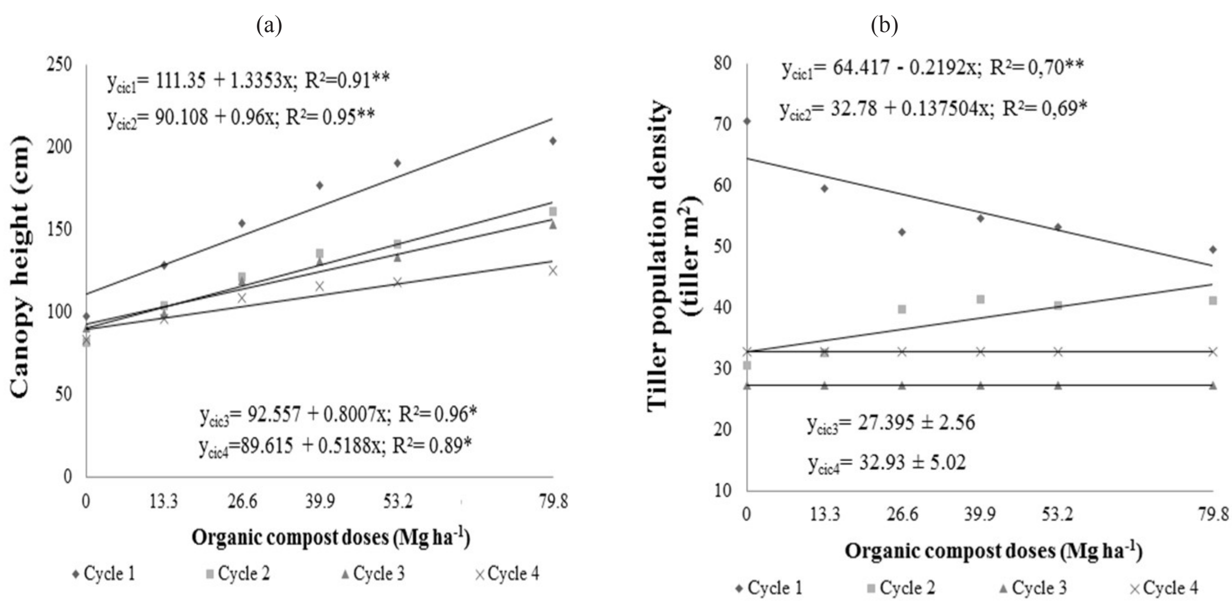
Note: THB- Total herbage biomass; DHB – Death herbage biomass; GLB- Green leaf biomass; GSB – Green stem biomass; LM/DM – Live and death ratio; L/S- Leaf and stem ratio; WUE_{GLB}- Water use efficiency for green leaf biomass production and WUE_{GSB} – Water use efficiency for green stem biomass production, $Y_{PH}= 95.906 + 0.9037^{**}$; $R^2 = 0.94$; $X_{NGL} = 8.31 \pm 0.31$; $X_{TPD}= 38.65 \pm 1.31$; $Y_{ALL}= 65.4884 + 0.4654x$; $R^2 = 0.91^{**}$; $Y_{LAI}= 2.4306 + 0.038x$; $R^2 = 0.94^{**}$; $Y_{internode}:= 3.19 + 0.0451x$; $R^2 = 0.96^{**}$; $Y_{THB} = 4457.13 + 227.70x – 1.35x^2$; $R^2 = 0.99^{*}$;$Y_{DHB}= 406.11 + 7.5711x$; $R^2 = 0.95^{**}$; $Y_{GLB} = 2161.26 + 230.82x – 0.41x^2$; $R^2 = 0.99$; $Y_{GSB}= 1939.04 + 144.56x – 33.56x^2$; $R^2 = 0.99$; $Y_{LM/DM}= 17.01 \pm 1.82$; $Y_{L/S}= 0.94 \pm 0.19$; $Y_{WUEGLB}= 5.85 + 0.090x$: R^2: 90.29^{**} $Y_{WUEGSB} = 6.22 + 0.1754x$; $R^2 = 0.92^{**}$; CV% – Coefficient of variation, MSD – Minimum Significant Difference; (D X C) – Doses x Cycles, Means followed by the same letter do not differ from each other ($p<0.05$) by the Tukey's test; ns (non-significant) and significant at 1% (**) and 5% (*).

Furthermore, there was no interaction between doses and cycles for variables as CH, TPD, ALL, and the number of internodes, THB, DHB, GSB, WUE_{GLB} and WUE_{GSB} (kg DM mm^{-1}).

Also, an increasing linear behavior was observed for canopy height in all evaluated cycles (Figure 1a). In cycle 1, the dose 79.8 Mg ha^{-1} raised plant heights 96% taller than those in control. In turn, in cycle 4, control and the dose of 79.8 t ha^{-1} promoted heights of 89.6 cm and 131, respectively, i.e. reductions of 24 and 66% compared to the first cycle. The canopy height is affected by nutrient availability, in particular nitrogen, which promotes an increase in biomass, and a great number of stems and leaves for plant support, what causes severe shadowing, and hence morphological changes in plants. According to Taiz and Zeiger (2013), plant shading causes a reduction in red and extreme red ratios (R: ER) underneath the canopy, detected by phytochrome system, contributing to stem elongation and consequently, higher plants.

Conversely, TPD had a decreasing linear effect in cycle 1 as compost doses increased (Figure 1b). Again, this effect may be due to the single dose application at the beginning of the experiment, increasing material accumulation in the soil, which worked as a physical barrier to basal bud sprouting. These basal buds are affected by reducing levels of red: far red ratios, detected by phytochrome system, inhibiting, therefore, tillering, especially in the highest doses. Over the cycles, this effect was reduced, given the fitting of the material subjected to periodic irrigations. Importantly, quantity and quality of light are stimulating factors for tillering; once the light shines directly on the buds, the same sprout (SANTOS et al., 2009; VITOR et al., 2009).

Figure 1. Effects of interactions between doses of the organic compost from wastes of small ruminant production and slaughter and plant growth cycles on CH- Canopy height (a) and TPD – Tiller population density (b), wherein y= estimated values from regression equation analyzed for each variable; significant at 1% (**) and 5% (*) of error probability.

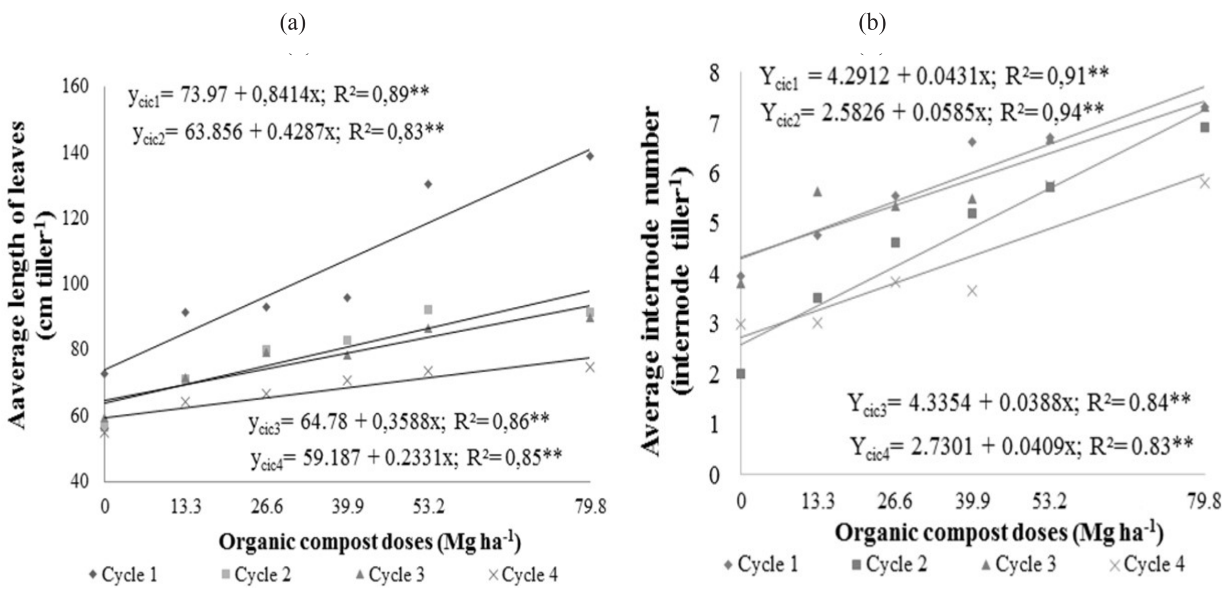


In the second cycle, TPD had around 44 tillers m^{-2}, which is less than in cycle 1 (47 tillers m^2), when the highest dose of the compost was used. This confirms the hypothesis that the organic compost acted as a physical barrier, limiting tillering. The reduction of this variable in cycle 2, and the absence of further significant responses in cycles 3 and 4 (27.39 and 32.93 tillers m^2) may have been derived from a lower availability of nutrients in the soil, in particular N, as it acts on meristematic tissue activation (axillary buds), so its deficit increases the number of dormant buds, limiting tillering (NABINGER, 1996; MOTA et al., 2010).

On the other side, ALL had linear positive responses to the increasing doses in all cycles (Figure 2a). In cycle 1, the values reached 73.97 and 141.1 cm for the doses 0 and 79.8 Mg ha^{-1}, being the highest dose 90% higher than control was. However, decreases in this variable were observed in the other cycles. In the fourth cycle, the values dropped to 77.78 cm at the dose of 79.8 t ha^{-1}, i.e. a reduction of 55% over the first cycle. This result proves the discussion previously held on the declining release of nutrients by a low C/N ratio of the tested material, plant nutrient exports, irrigation and medium textured soil, resulting in less available residual nutrients.

The number of internodes was increased linearly with compost doses every cycle (Figure 2b). This variable monitors CH growth as it takes part directly in division and elongation of meristematic cells (TAIZ; ZEIGER, 2013). Possibly, the number of internodes formed in subsequent cycles was influenced by lower nutrient supply promoted by the unique dose of compost applied, reducing the crop growth rate cycle after cycle.

Figure 2. Effects of interactions between doses of the organic compost from wastes of small ruminant production and slaughter and plant growth cycles on ALL – Average length of leaf, AIN – Average internodes number tillers^{-1} (a), wherein y= estimated values from regression equation analyzed for each variable; significant at 1% (**) and 5% (*) of error probability.



When we analyze the interaction (dose x cycle) for the total herbage biomass (THB), there is a quadratic response in cycle 1 with maximum point estimated at 23.5 Mg DM ha^{-1} cycle^{-1} in a dose of 66.52 Mg ha^{-1} of the organic compost. Such a response is justified by GLB and GCB variables, which follow the same pattern of response. Moreover, such a response can be attributed to the Maximum Law, which claims that the excess of nutrient in the soil reduces the efficacy of others; and the Law of diminishing returns, i.e., adding the increased dose of a nutrient soil, the increments in production are becoming smaller. Corroborates this response, the low C/N ratio of the organic compost, the trial has been carried out in irrigated conditions, the successive extraction of nutrients by cut grass and the higher ALL observed in cycle 1, which possibly stimulated the shading and therefore reduced THB after the maximum point (Figure 3a).

When analyzing interactions between dose and cycles for THB, we noted a quadratic response in cycle 1 with a maximum point estimated at 23.5 Mg DM ha^{-1} cycle^{-1}, using a dose of 66.52 Mg ha^{-1}. This is mainly justified by the responses of GLB and GSB, which follow the same pattern. A possible explanation is linked to the law of maximum, in which the excess of a nutrient in soil might reduce the efficiency of others. Besides of that, there is the effect of the law of decreasing increments, which states that increasing doses of a nutrient added to the soil may decrease yield raises. Also, there are other factors acting on that as the lower C/N ratio of the compost, irrigation conditions and subsequent extraction of nutrients by grass cut. Furthermore, increasing ALL values in cycle 1 have possibly stimulated shadowing, and hence THB decrease after the maximum point (Figure 3a).

In further cycles, THB showed a linear positive response to the increasing doses (Figure 3a). In the fourth cycle, values were estimated in 4.03 and 9.2 Mg DM ha^{-1} cycle^{-1} for 0 and 79.8 Mg ha^{-1}. Using 79.8 Mg ha^{-1} of compost promoted an increase in THB of 128% compared to control. Notwithstanding, in this cycle, the highest dose provided a fall of 60% in THB if compared to the first cycle. Such reduction is related to decreasing values of GLB and GSB (Figure 4), supported by nutrient exports and total exhaustion of the compost applied in a single dose in cycle 1. In percentage, GSB represented 58 and 51% THB in cycles 1 and 4 respectively, referring to the highest dose (79.8 Mg ha^{-1}), being a variable of utmost importance.

With regard to DHB, in cycles 1 and 3, a linear growth was verified for the increasing doses of the compost, while in 2 and 4 there were no significant differences, with averages of 449.82 and 452.3 kg DM ha^{-1}, (Figure 3b). In cycle 1, DHB in doses 0 and 79.8 Mg ha^{-1} were estimated in 529.29 and 2289.5 Kg DM ha^{-1} cycle^{-1}, which are related to higher leaf senescence rates. Senescence is associated with nutrient supply, especially nitrogen, which speeds up plant physiological processes, intensifying mutual shading and reducing leaf photosynthetic ability underneath canopies and leaf life as well (SILVA et al., 2009). Throughout the cycles, the reduction of GLB and GSB minimized the effects on senescence physiological processes, with further DHB reductions.

Both GLB and GSB showed a quadratic behavior in cycle 1, while in the remaining cycles, the response was linear and positive (Figure 4). These results can be supported by the law of maximum, as discussed above. The values of GSB and GLB were estimated in 7.5 and 1.4 mg DM ha^{-1} cycle^{-1}, with a maximum point for the doses of 67.73 and 63.05 Mg ha^{-1}, respectively. This reaching of a critical LAI (95% photosynthetically active radiation interception) in 60 days of growth was responsible for that found. In cycle 4, the estimated values for GLB and GSB were 1.7 and 1.9 Mg DM ha^{-1} cycle^{-1} related to the dose of 0 t ha^{-1}. By applying 79.8 t ha^{-1} of the compost, these values were estimated in 4.0 and 4.7 Mg DM ha^{-1} cycle^{-1}, respectively. GLB reduction in the fourth cycle is explained partly by the behavior of ALL, which responded similarly, since its reduction directly corroborated GLB reduction.

Figure 3. Effects of interactions between doses of the organic compost from wastes of small ruminant production and slaughter and plant growth cycles on total herbage biomass (THB) (a) and death herbage biomass (DHB) (b) of elephant grass, wherein: y= estimated values from regression equation analyzed for each variable; significant at 1% (**) and 5% (*) of error probability.

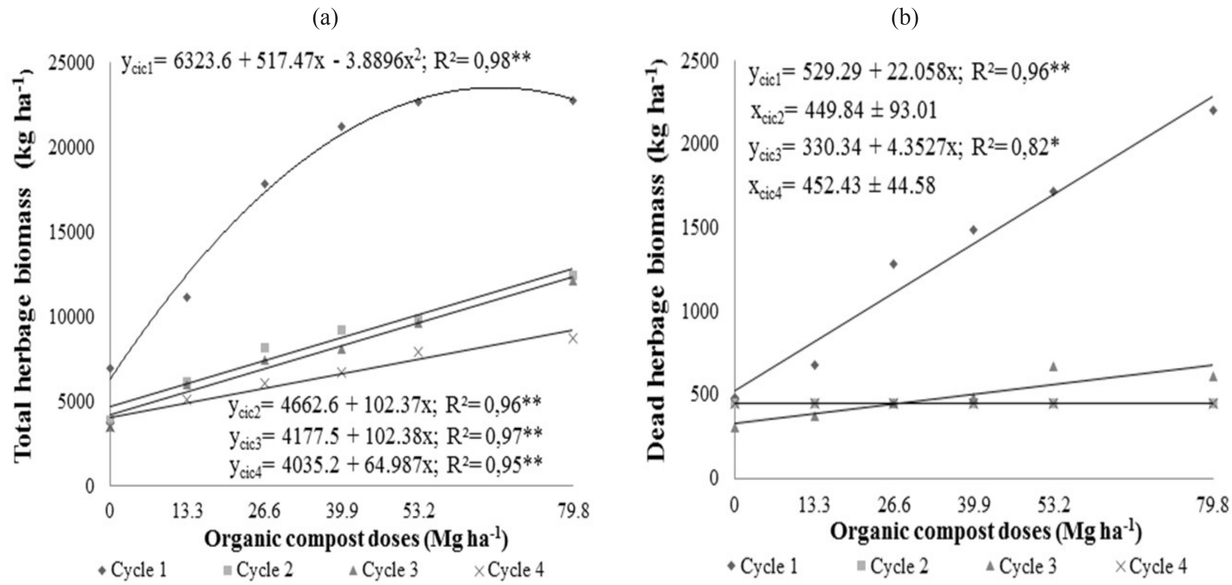
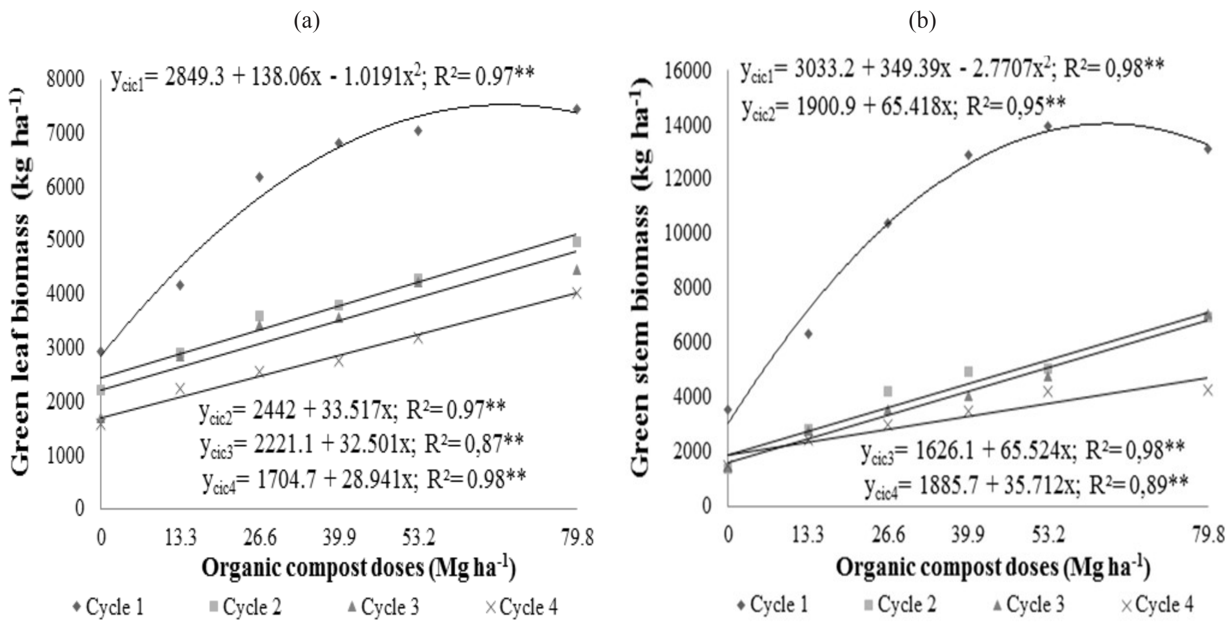


Figure 4. Effects of interactions between doses of the organic compost from wastes of small ruminant production and slaughter and plant growth cycles on green leaf biomass (GLB) (a) and green stem biomass (GSB) (b) of elephant grass, wherein: y= estimated values from regression equation analyzed for each variable; significant at 1% (**) and 5% (*) of error probability.



WUE_{GLB} and WUE_{GCB} revealed a significant interaction between doses and cycles (Figure 5). In both variables, we identified a quadratic effect during the first cycle, with a maximum of 16.33 and 30.83 kg DM mm^{-1} water in the doses of 62.94 and 60.28 t ha^{-1}, respectively, following the same behavior of GLB and GSB. For the other cycles, we noted an increasing linear effect with increasing doses, however, with decreases in WUE due to biomass reduction (GLB) for both variables. In this study, water levels were properly maintained to ensure grass productivity, which confirms the hypothesis that nutrient availability is a limiting factor from cycle 2 onwards. It can be explained by the compost's low C: N ratio (9: 1) and a high.

As for the contrast analysis between doses and mineral fertilization (Tables 6 and 7) in cycle 1, there was no effect for most of the variables except NGL, LAI and L/S ratio. The responses of the other variables corroborate the assumption of rapid availability of nutrients from the compost due to its low C: N ratio. However, for the remaining growth cycles, we observed superior results ($p < 0.05$) by the structural characteristics of elephant grass subjected to mineral fertilization. It might have occurred due to its installment over cycles, optimizing the balance between nutrient supply and demand by plants in a timescale.

Figure 5. Effects of interactions between doses of the organic compost from wastes of small ruminant production and slaughter and plant growth cycles on water use efficiency for green leaf biomass production (WUE_{GLB}, kg DM mm^{-1}) and for green stem biomass production (WUE_{GSB}, kg DM mm^{-1}) of elephant grass, wherein: y= estimated values from regression equation analyzed for each variable; significant at 1% (**) and 5% (*) of error probability.

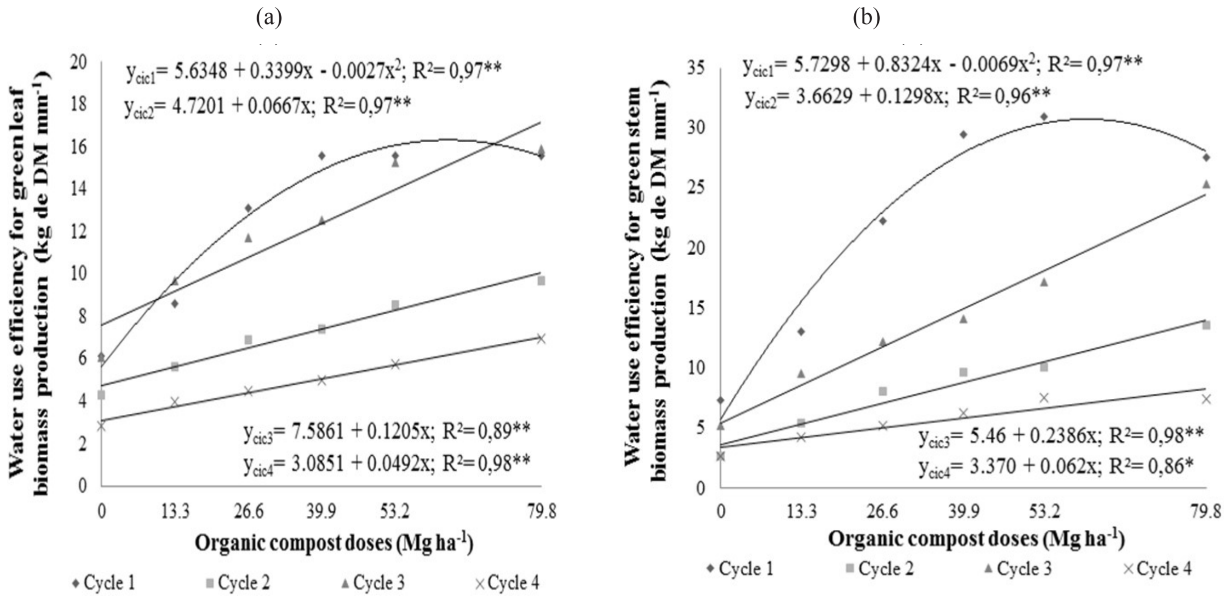


Table 6. Contrast analysis between doses of organic compost and mineral fertilization.

Treatments	CH	NGL	TPD	ALL	LAI	Nº of Internodes	THB	DHB
							--Mg DM ha^{-1}--	
Cycle 1								
Organic compost	159.29	8.20	56.6	104.13	5.85	5.81	8.612	0.660
Mineral fertilization	161.33	7.39	60.5	108.80	6.86	5.62	8.753	0.524
F-significance	0.08^{ns}	5.05*	1.32^{ns}	0.55^{ns}	11.09**	0.26^{ns}	0.02^{ns}	2.74^{ns}
Cycle 2								
Organic compost	124.38	8.08	37.6	81.90	3.90	5.00	4.230	0.237
Mineral fertilization	153.54	8.18	40.8	97.97	6.40	5.30	6.594	0.372
F-significance	33.65**	0.001^{ns}	1.59^{ns}	28.17**	20.64**	12.75**	11.35**	3.77^{ns}
Cycle 3								
Organic compost	121.07	8.94	27.4	77.50	3.51	5.71	3.440	0.253
Mineral fertilization	165.65	9.35	35.5	96.82	7.64	7.83	7.346	0.556
F-significance	15.27**	0.98^{ns}	10.54**	20.70*	9.52*	75.71**	0.83**	7.71*
Cycle 4								
Organic compost	108.12	7.91	32.9	67.45	2.66	4.20	3.236	0.253
Mineral fertilization	158.9	8.52	26.0	93.59	6.94	5.80	7.829	0.353
F-significance	82.41**	3.56^{ns}	1.43^{ns}	51.43**	178.93**	34.33**	104.03**	2.51^{ns}

Note: CH- Canopy height; NGL- Number of live leaves; TPD- Tiller population density; ALL- Average leaf length; LAI- Leaf area index; Number of internodes; Leaf/stem ratio; THB- Total herbage biomass; DHB- Death Herbage biomass. Means followed by the same letter do not differ from each other (p<0.05) by the Tukey's test; ^{ns} (non-significant) and significant at 1% (**) and 5% (*).

Table 7. Contrast analysis between doses of organic compost and mineral fertilization.

Treatments	GLB	GSB	LM/DM	Ratio	WUE_{GLB}	WUE_{GSB}
	--Mg DM ha^{-1}--			(L/S)	---(kg DM mm^{-1})---	
			Cycle 1			
Organic compost	3.182	4.769	13.81	0.62	6.85	10.33
Mineral fertilizer	3.760	4.469	21.42	0.84	7.36	8.71
F-significance	0.51^{ns}	0.35^{ns}	7.17*	32.19**	0.09^{ns}	1.50^{ns}
			Cycle 2			
Organic compost	1.811	2.062	18.81	1.35	4.37	5.28
Mineral fertilizer	2.782	3.439	30.27	0.87	5.22	6.45
F-significance	10.76**	7.83**	5.45*	0.53^{ns}	8.07**	6.02*
			Cycle 3			
Organic compost	1.722	1.987	16.12	0.96	6.05	7.0
Mineral fertilizer	3.368	4.584	15.38	0.82	6.71	8.37
F-significance	5.51**	9.71**	0.33^{ns}	0.46^{ns}	5.95^{ns}	7.49*
			Cycle 4			
Organic compost	1.470	1.589	15.40	1.21	2.59	2.81
Mineral fertilizer	3.107	4.356	22.40	0.73	5.30	7.46
F-significance	38.01**	90.17**	3.95^{ns}	0.99^{ns}	35.79**	85.80**

Note: GLB- Green leaf biomass; GSB- Green stem biomass; LM/DM – Live and death mass ratio; L/S – Leaf and stem ratio; WUE_{GLB}- Water use efficiency for green leaf biomass production and WUE_{GCB} – Water use efficiency for green stem biomass production. Means followed by the same letter do not differ from each other (p<0.05) by the Tukey's test; ^{ns} (non-significant) and significant at 1% (**) and 5% (*).

Conclusions

Plant structural characteristics and water use efficiency by elephant grass cv. Cameroon proved to be responsive to the use of the organic compost. The highest values were obtained in the first cycle, recommending applications of 67.7 Mg ha^{-1}. Initially, the compost showed high nutrient-release rates, giving rise to a demand for supplementation with chemical or organic fertilizations from the second cycle onwards, to ensure the same yield.

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