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Nutritional status and accumulation of micronutrients in elephant grass cv. Roxo under rainfed conditions

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ADDITIONAL KEYWORDS

Maintenance fertilization.
Nutrient extraction run.
Mineral nutrition.
Pennisetum purpureum.
Leaf nutrient content.

SUMMARY

The objective of this study was to evaluate the nutritional status and micronutrient accumulation run in the shoot of elephant grass cv. Roxo at different seasons under rainfed conditions. Seven growth ages (9, 18, 27, 36, 45, 54 and 63 days) and three growth seasons (rainy, transition and dry) were evaluated in a completely randomized design with split plots arrangement, where the ages were allocated in the plots and the seasons in the subplots, with three replications. It was observed interaction between growth ages x seasons for the contents and accumulations of iron (Fe), zinc (Zn), copper (Cu) and manganese (Mn). In the leaf, Fe (rainy and transition seasons), Zn, Cu and Mn (rainy season) reduced in response to the advancement in the growth age. In the dry season, the Fe content was linearly increased, while the Cu and Mn contents presented quadratic responses with increasing growth ages. The accumulations of Fe, Zn, Cu and Mn showed an increasing linear response with advancement in ages at all cultivation seasons. At 63 days of growth, Fe accumulations of 915.51, 463.93 and 360.00 g ha 1; Zn of 439.19, 111.48 and 86.37 g ha 1; Cu ratio of 56.07, 31.43 and 35.30 g ha 1 and Mn of 333.16, 155.78 and 225.40 g ha 1 (rainy, transition and dry seasons, respectively) were estimated. The accumulation of micronutrients in elephant grass cv. Roxo under rainfed presents the following order: Fe > Zn > Mn > Cu for the rainy and transition seasons, and Fe > Mn > Zn > Cu for the dry season.

Estado nutricional y acúmulo de micronutrientes en capim-elefante cv. Morado en secano

PALABRAS CLAVE ADICIONALES

Abastecimiento de mantenimiento.
Marcha de extracción de nutrientes.
Nutrición mineral.
Pennisetum purpureum.
Contenido de nutriente foliar.

RESUMEN

Se objetivó evaluar el estado nutricional y la dinamica de acumulación de micronutrientes en la parte aérea del pasto elefante cv. Morado en diferentes épocas bajo secano. Se analizarón siete edades de crecimiento (9, 18, 27, 36, 45, 54 y 63 días) y tres épocas de cultivo (lluviosa, transición y sequía), en un delineamiento completamente casualizado en el arreglo de parcelas subdivididas en el tiempo, las edades fueron asignadas en las parcelas y las épocas de cultivo en las subparcelas, con tres repeticiones. Se constató la interacción entre las edades de crecimiento y la época de cultivo para los contenidos y las acumulaciones de hierro (Fe), zinc (Zn), cobre (Cu) y manganeso (Mn). En la hoja, los niveles de Fe (épocas lluviosa y transición), Zn, Cu y Mn (época lluviosa) redujeron en respuesta al avance en la edad de crecimiento. En la época de sequía, el contenido de Fe fue incrementado linealmente, mientras que los niveles de Cu y Mn presentarón respuestas cuadráticas con el aumento de las edades de crecimiento. Los acúmulos de Fe, Zn, Cu y Mn presentarón una respuesta lineal creciente con el avance en las edades en todas las épocas de cultivo. A los 63 días de crecimiento, se estimaron acúmulos de Fe de 915.51, 463.93 y 360.00 g ha 1, Zn de 439.19, 111.48 y 86.37 g ha 1, Cu de 56.07, 31.43 y 35.30 g ha 1 y Mn de 333.16, 155.78 y 225.40 g ha 1 (épocas lluviosas, transición y sequía, respectivamente). La acumulación de micronutrientes en el pasto elefante cv. Morado manejado sobre secano presenta el siguiente orden Fe > Mn > Zn > Cu para las épocas lluviosas y de transición, y Fe > Mn > Zn > Cu para época de sequía.

INFORMATION

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INTRODUCTION

Although expressive, livestock activity in tropical regions still presents modest indexes in relation to its potential. Among the responsible factors, the reduction in the productivity of the forage plant, due to the absence or inefficiency of the fertilization, stands out.

It is possible to increase fertilization efficiency from the nutrient accumulation gait, which allows the understanding of nutrient absorption/extraction dynamics, according to the growth stage of the fodder plant, making possible adjustments and the balancing of the nutrient supply according to the demand (Pegoraro et al., 2014, p.898).

The accumulation and exportation of nutrients by the forage plant may vary according to the age, plant organ, type of nutrient, species, cultivar, management and edaphoclimatic conditions in which the canopy develops (Backes et al., 2018, p. 247; Lopes et al., 2018, p. 4).

Elephant grass (*Pennisetum purpureum*) is widely cultivated because it has high productivity, versatility, and can be managed under cutting or grazing, besides having bromatological characteristics relevant to ruminant production. However, it has high demands on soil fertility to maintain its productive potential, this in turn varies according to soil and climatic conditions.

There are few studies on the progression of micronutrient accumulation for forage plants, mainly in rainfed crops. It is noteworthy that micronutrient fertilization recommendations for fodder plants generally only consider the soil fertility level, disregarding the nutritional demand at the species or cultivar level. Thus, the demand for studies on micronutrient accumulation in tropical regions is explicit, considering the variation of rainfall, mainly in relation to micronutrient requirements by elephant grass cv. Roxo. In view of this context, the objective was to analyze the nutritional status and to establish the micronutrient accumulation curves for elephant grass cv. Roxo handled in three growth seasons.

MATERIAL AND METHODS

The study was performed at the Federal University of Ceará, in the Animal Science Department - NEEF/DZ/CCA/UFC, in Fortaleza - CE (03° 44′ 32″ south latitude and 38° 34′ 40″ longitude west). The climatic classification is Aw′ type tropical rainy, according to Köppen (1936). It was used an elephant grass (*Pennisetum purpureum*) cv. Roxo area established about five years before, cultivated in soil classified as yellow Argisol, with sandy texture. The evaluations were carried out during three successive growth cycles at different seasons (rainy, transition and dry), which were characterized according to the rainfall during the experimental period (**Figure 1**).

Cumulative rainfall of 373.30, 17.30 and 9.60 mm were recorded in the rainy season, transition and dry, respectively, and the potential evapotranspiration of the crop presented daily averages of 39.43; 46.11 and 52.58 mm day[1] for rainy, transition and dry seasons, respectively. The climatological variables were provided by the Agroclimatological Station of the Federal University of Ceará, Pici Campus (**Figure 1**).

The treatments consisted of seven growth ages (9, 18, 27, 36, 45, 54 and 63 days after cutting, which was performed at the soil surface level). The design was completely randomized with

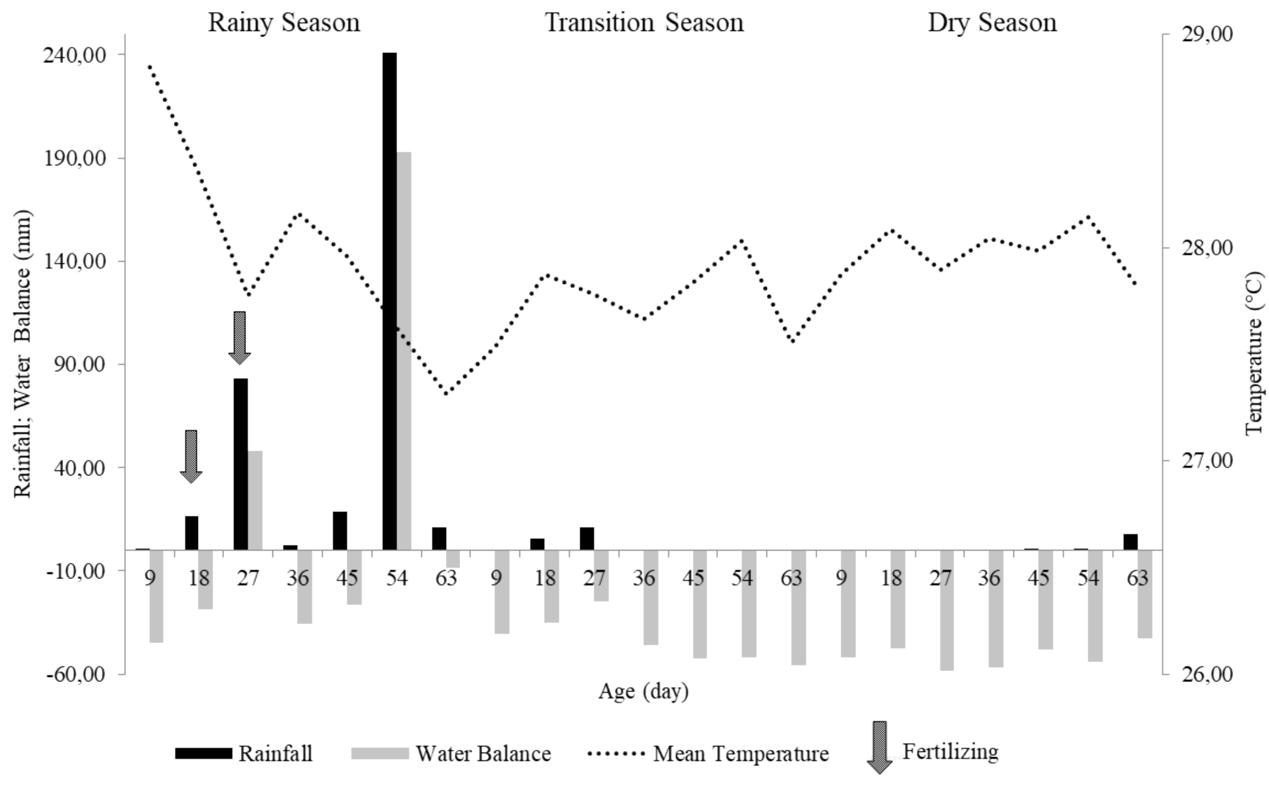

Figure 1. Climatic data of the experimental period (Datos climáticos del período experimental).

split-plot arrangement in time, so that the ages were allocated in the plots and the growth seasons (rainy, transition and dry) in the subplots, with three replications. Each experimental unit measured 3.0 x 3.5m (10.5 m^2).

Prior to the experiment, the chemical analysis of the soil was carried out in the 0 - 0.20 m layer, which presented: pH in water 6.0; 20.89 g kg^1 of O.M.; 397 and 3.91 mg dm^3 of P and K, respectively; 2.8, 1.5, 0.15 and 0.04 cmolc dm^3 of Ca^{2+}, Mg^{2+}, Al^{3+} and Na^+, respectively. Based on these values, maintenance fertilization was carried out at the beginning of the rainy season (CFSEMG, 1999, p.332).

In order to characterize soil fertility, a soil sample was collected at the end of the respective growth season (rainy, transition and dry) in the 0-20 cm deep layer, after which the soil chemical analysis was carried out (**Table I**).

Doses equivalent to 600 kg ha^1 $year^1$ of nitrogen (urea), 200 kg ha^1 of potassium chloride and 50 kg ha^1 of Fritted Trace Elements (FTE BR-12: 0.42 kg ha^1 of copper, 1.0 kg ha^1 of manganese, 4.5 kg ha^1 of zinc, 1.95 kg ha^1 of sulfur and 0.90 kg ha^{-1} of boron) were adopted. Fertilization was carried out in the rainy season, aiming to minimize losses and better efficiencies in the use of fertilizers as a function of water availability, and

Table I. Iron, zinc, copper and manganese contents in leaves and stem fractions of elephant grass cv. Roxo for seven growth ages, at three growth seasons (Contenido de hierro, zinc, cobre y manganeso en hojas y fracciones de tallo de hierba de elefante cv. Roxo para siete edades de crecimiento, en tres temporadas de crecimiento).

Season	Growth Ages (days)							Equation	R^2
	9	18	27	36	45	54	63		
	mg kg^{-1}								
Rainy	155.89A	145.22A	113.60B	86.59C	157.82A	66.58C	103.04B	LFe = 153.94 - 1.017**Age	0.32
Transition	168.37A	146.26A	156.64A	142.02A	142.59B	106.98A	99.97C	LFe = 180.09 - 1.182**Age	0.84
Dry	86.64B	109.09B	113.72B	129.66B	126.02C	89.40B	194.02A	LFe = 79.066 + 1.171**Age	0.40
Rainy	145.22B	166.16A	83.13C	60.13C	62.34C	47.48C	118.50A	SFe = 237.56 - 8.132***Age + 0.094***Age^2	0.70
Transition	175.75A	149.01B	140.11A	86.02A	99.14B	119.86A	44.47C	SFe = 186.78 - 1.957***Age	0.75
Dry	83.66C	61.00C	113.97B	73.48B	106.77A	104.02B	92.06B	SFe = 90,71 ± 19,18	-
Rainy	37.93A	85.04A	57.15A	39.95A	32.83A	30.23A	29.32B	LZn = 67.464 - 0.634***Age	0.37
Transition	39.90A	36.50C	52.17B	29.41C	24.34C	21.26C	5.84C	LZn = 35.921 + 0.617▲Age - 0.017**Age^2	0.82
Dry	33.16A	44.09B	18.77C	37.49B	28.99B	25.16B	31.70A	LZn = 31.340 ± 8.220	-
Rainy	42.41B	190.88A	132.11A	70.93A	58.56A	49.51A	54.68A	SZn = 131.22 - 1.268**Age	0.21
Transition	73.52A	89.14B	113.11B	49.79B	39.70C	28.89C	52.44B	SZn = 100.53 - 1.020***Age	0.44
Dry	41.54B	33.51C	65.75C	31.96C	43.03B	38.34B	44.99C	SZn = 42.730 ± 11.230	-
Rainy	9.10A	13.46A	8.55B	7.90B	6.08B	5.06B	5.16A	LCu = 12.346 - 0.123***Age	0.69
Transition	7.10A	14.36A	11.03A	13.38A	9.20A	9.11A	3.60C	LCu = 4.277 + 0.552*Age - 0.009*Age^2	0.77
Dry	9.50A	5.29B	7.00B	4.15C	4.33C	4.22C	4.12B	LCu = 14.217 - 0.575***Age + 0.008***Age^2	0.70
Rainy	7.60A	27.86A	11.68A	6.62B	5.19B	3.36C	6.68B	SCu = 18.178 - 0.231**Age	0.29
Transition	12.86A	8.61B	10.86A	12.85A	15.99A	5.29B	4.93C	SCu = 7.669 + 0.355***Age - 0.006***Age^2	0.44
Dry	9.57A	6.70B	4.67B	4.59C	4.52B	15.94A	11.24A	SCu = 13.136 - 0.522**Age + 0.008***Age^2	0.53
Rainy	51.36A	36.63B	55.43B	41.23C	36.56B	36.93B	28.68B	LMn = 53.307 - 0.342**Age	0.51
Transition	29.61B	36.10B	59.60B	51.08B	28.41C	30.67C	14.76C	LMn = 12.904 + 2.265***Age - 0.036***Age^2	0.72
Dry	57.82A	93.95A	95.12A	106.67A	97.97A	38.18A	57.09A	LMn = 32.323 + 4.125***Age - 0.063***Age^2	0.63
Rainy	38.05B	66.10A	33.72C	47.25C	36.15C	24.78C	15.58C	SMn = 58.459 - 0.586**Age	0.50
Transition	36.07B	40.10B	49.57B	63.01B	61.06B	46.74B	36.53B	SMn = 12.278 + 2.442***Age - 0.032***Age^2	0.82
Dry	61.37A	74.45A	113.45A	160.09A	149.88A	111.13A	109.02A	SMn = 7.392 + 7.124***Age - 0.085***Age^2	0.81

Leaf Iron content (LFe), Stem Iron content (SFe); Leaf Zinc content (LZn), Stem Zinc content (SZn); Leaf Copper content (LCu), Stem Cooper content (SCu); Leaf Manganese content (LMn), Stem Manganese content (SMn); Means followed by similar uppercase letters in the column did not differ (p>0.05) by the Scott Knott test. Significant at the level of 0.1% (***), 1% (**), 5% (*) and 10% (▲), R^2: coefficient of determination.

Table II. Accumulations of iron, zinc, copper and manganese in elephant grass cv. Roxo for seven growth ages, at three growth seasons (Acumulaciones de hierro, zinc, cobre y manganeso en hierba de elefante cv. Roxo para siete edades de crecimiento, en tres temporadas de crecimiento).

Season	Growth Ages (days)							Equation	R^2
	9	18	27	36	45	54	63		
	--g ha^{-1}--								
Rainy	13.36A	131.56A	219.48A	527.85A	628.80A	635.59A	991.40A	SHFe = - 170.480 + 17.238***Age	0.95
Transition	25.58A	75.13A	124.99B	130.57B	391.25B	426.43B	432.18C	SHFe = - 83.216 + 8.685***Age	0.89
Dry	14.04A	40.10A	129.62B	141.44B	204.49C	168.57C	493.80B	SHFe = - 82.723 + 7.028***Age	0.75
Rainy	3.49A	99.98A	127.36A	336.22A	271.13A	385.75A	406.86A	SHZn = - 41.997 + 7.638***Age	0.89
Transition	7.75A	28.53B	64.02B	43.53B	90.27B	87.18B	113.58B	SHZn = - 3.740 + 1.829***Age	0.89
Dry	6.16A	19.71B	37.35C	45.05B	65.98C	52.90C	98.48C	SHZn = - 6.617 + 1.476***Age	0.89
Rainy	0.77A	15.25A	16.14A	45.39A	35.34A	40.74A	57.97A	SHCu = - 4.276 + 0.958***Age	0.86
Transition	1.32A	13.40A	9.82A	14.82B	32.25B	33.97B	21.46C	SHCu = 0.435 + 0.492***Age	0.65
Dry	1.54A	2.51A	5.49A	5.40C	7.61C	14.22C	31.23B	SHCu = - 6,6544 + 0,455***Age	0.73
Rainy	4.25A	38.99A	93.40A	265.29A	225.73A	280.03A	299.24A	SHMn = - 42.134 + 5.957***Age	0.88
Transition	4.75A	19.10A	50.50B	66.29C	120.76C	157.91B	129.54C	SHMn = - 24.774 + 2.866***Age	0.90
Dry	9.70A	38.76A	82.92A	125.08B	163.67B	114.34C	274.95B	SHMn = - 31.175 + 4.078***Age	0.82

Shoot Iron accumulation (SHFe); Shoot Zinc accumulation (SHZn); Shoot Copper accumulation (SHCu); Shoot Manganese accumulation (SHMn); Means followed by similar letters in the column did not differ (p>0.05) by the Scott Knott test. Significant at 0.1% (***) of probability level; R^2: coefficient of determination.

it was divided in two applications, the first containing 100% of FTE BR-12, 50% of nitrogen and 50% of potassium, performed at the age 18 and the second containing 50% of nitrogen and 50% of potassium performed at the age 27.

At each growth age of the three growth seasons, a sample was taken, using a frame of known area (1.0 x 1.0 m), to estimate the total forage biomass production, with cut at the soil surface level. The harvested biomass was weighed, separated into the fractions leaf, stem and dead material, then packed in paper bags and placed in a forced ventilation oven at 55 ºC until reaching constant biomass. The pre-dried biomass of the three fractions was added to obtain the total forage biomass. The pre-dried leaf and stem biomass were ground and submitted to nitroperchloric digestion to determine iron (Fe), zinc (Zn), copper (Cu) and manganese (Mn), according to the methodology described in Silva (2009).

The nutrient accumulation in the shoot of elephant grass cv. Roxo was obtained from the sum of nutrient accumulation in leaf and stem fractions. These were obtained by the dry matter biomass of the respective fraction (kg ha^{-1}) by the content of the respective nutrients (mg kg^{-1}) at each age of elephant grass cv. Roxo.

The data were submitted to analysis of variance, mean comparison test and regression analysis. The age x season interaction was deployed when significant ($p<0.05$) by the F test. The seasons were compared by the Scott Knott test ($p<0.05$). The ages were evaluated by regression analysis ("T" test, $p<0.05$). The models were selected from the significance of the linear and quadratic coefficients and the coefficient of determination. The data were analyzed using the software SAEG 9.1(UFV, 2007).

RESULTS AND DISCUSSION

The total forage biomass (TFB) of elephant grass cv. Roxo increased along the growth ages in the three studied seasons, having its magnitude affected by them (**Figure 2**). Forage production rates of 237.92, 115.51 and 48.36 kg ha^{-1} day^1 were estimated for rainy, transition and dry seasons, respectively.

At 63 days of age, productivities of 11,653.00; 6305.40 and 2907.40 kg DM ha^1 were observed for rainy, transition and dry seasons, respectively. It is emphasized that elephant grass cv. Roxo was handled in a cycle of up to 63 days of growth, aiming to reconcile agronomic and zootechnical aspects, because although the harvesting of this forage at more advanced ages allows higher productivity, there is a qualitative reduction of biomass with the increase of canopy age (Bhering et al., 2008, p.393, Maranhão et al., 2018, p.15).

The factors and growth ages and seasons were presented significant difference ($p<0.001$) for iron (Fe), zinc (Zn), copper (Cu) and manganese (Mn) contents in elephant grass cv. Roxo (**Table II** and **III**), as well as, there was interaction ($p<0.05$) between them for all variables, which reinforces the need for studies on mineral nutrition of forage plants managed under rainfed conditions.

A linear reduction in LFe levels of 1.02 and 1.18 mg kg^1 was observed for each growth day of elephant grass cv. Roxo in the transition and rainy season, respectively, reaching at age 63 days after cutting (DAC) levels of 89.87 and 105.62 mg kg^1

for rainy and transition seasons, respectively (**Table II**). Probably, this fact occurred due to rainfall availability in the rainy season and residual moisture in the soil in the transition season, which allowed increases in leaf biomass, superior to the accumulation of Fe in the biomass (Ribeiro & Pereira, 2011, p. 814), leading to the effect of dilution and resulting in lower concentrations of Fe in the leaf biomass at the end of the growth cycle, for rainy and transition seasons. This hypothesis is corroborated by the negative correlation between leaf biomass and LFe content for rainy (r = 0.59, p<0.002) and transition (r = 0.62, p<0.001) seasons.

For the dry season, a linear increase in LFe content estimated at 1.17 mg kg^{1} was observed for each day of elephant grass cv. Roxo, resulting in the content of 152.84 mg kg^{1} at 63 days. The environmental conditions restricting the increase in biomass (48.36 kg ha^{1} day^{1}) at that season (**Figure 2**), resulted in the effect of Fe concentration on the leaf fraction, ratified by the high positive correlation between leaf biomass and the LFe content (r = 0.70, p<0.0002).

Iron content in leaf (LFe) of elephant grass cv. Roxo recorded in all ages and growth seasons are comprised in the sufficiency range from 50 to 200 mg kg^{1} (Werner, 1997, p. 266), which shows that Fe was not a limiting factor for the development of forage plant.

Considering the growth seasons, the significance for LFe and iron content in the stem (SFe) varied according to the growth age (**Table II**). In the rainy season, the iron content in the stem (SFe) was adjusted to the quadratic model, with an estimated minimum value of 99.46 mg kg^{1} at 43.12 DAC. This result is probably due to the stretching of the stems observed at this age, as a consequence of the mutual self-shading between canopy leaves and tillers (Silva et al., 2015, p.1196), resulting in the dilution effect of SFe by a marked increase in fraction.

For the transition season, there was a linear decreasing effect on SFe content, with a reduction of 1.96 mg kg^{1} for each growth day, with a content of 63.49 mg kg^{1} at age 63 DAC. This response is probably due to the imbalance between Fe accumulation and the increment of carbon in the stem, mainly because Fe is allocated in greater quantity in the leaves, located in the chloroplasts, being fundamental in the chlorophyll biosynthesis (Prado, 2008, 262). For the dry season, the SFe content did not present a significant adjustment for the tested models, with a mean of 90.71 ± 19.18, probably due to oscillation of the contents during the growth cycle of the forage plant.

The zinc content in the leaf (LZn) was linearly reduced (0.63 mg kg^{1} day^{1}) as a function of the growth age for the rainy season, with a content of 27.51 mg kg^{1} at 63 DAC (**Table II**) due to the probable imbalance between leaf carbon allocation and Zn uptake. It is worth noting that Zn has low translocation in the phloem, so the higher foliar senescence rate observed in the period may also have contributed to the response under study (Marcante et al., 2011, p. 199).

In the transition season, the LZn content was maximized at 18.14 DAC, resulting in 41.51 mg kg^{1}, and subsequently reduced. Probably the residual moisture in the soil and the occurrence of rainfall between 9 and 27 DAC in the transition season (**Figure 1**) potentiated the absorption of Zn, which, accompanied by a smaller biomass increase (**Figure 2**), resulted in

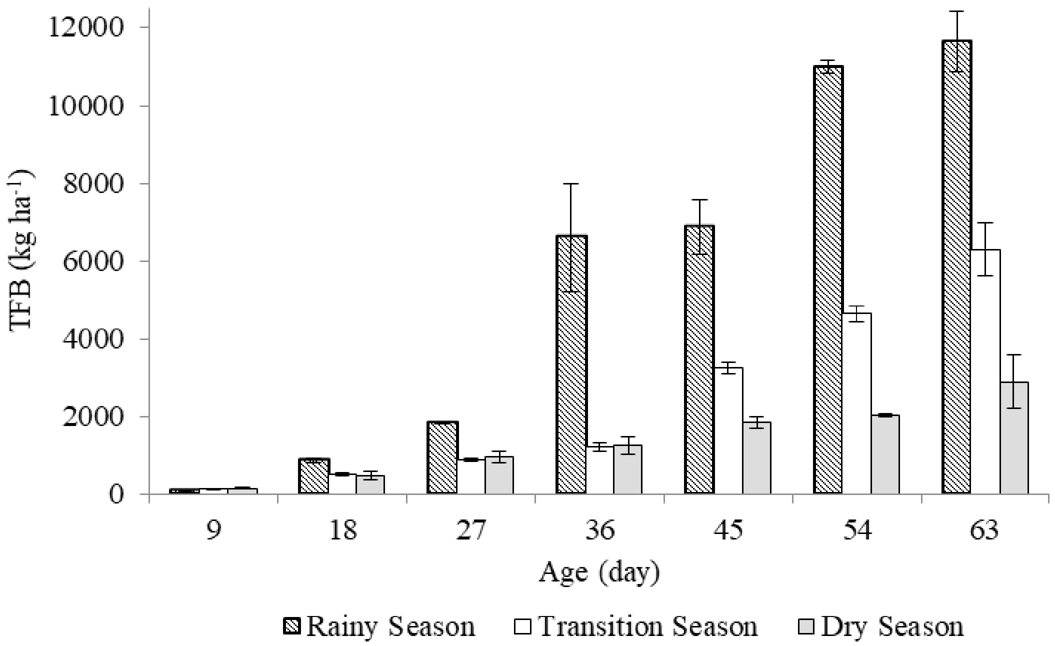

Figure 2. Total forage biomass (TFB) of elephant grass cv. Roxo at seven growth ages in three growth seasons (Biomasa forrajera total (TFB) de hierba de elefante cv. Roxo a las siete edades de crecimiento en tres temporadas de crecimiento).

the observed maximization. For the dry season, the LZn content showed no significance for the tested models, presenting an average value of 31.34 ± 8.22 mg kg^{1}. Possibly these values are related to Zn mobilization of the rhizomes and root system, and it should be noted that no significant correlation was found between LZn content and leaf biomass.

The LZn content of elephant grass cv. Roxo presented values below the sufficiency range (20 and 50 mg kg^{1}; Werner, 1997, p.266), only at age 63 DAC at the transition season and at 27 DAC in the dry season (**Table II**). Analyzing growth seasons, the highest levels of LZn were observed in the rainy season between 18 and 54 DAC and higher levels of zinc in the stem (SZn) in the ages 18 to 63 DAC (**Table II**). The low LZn and SZn contents for the transition and dry seasons are possibly due to the decrease in Zn absorption because of the reduction in soil water potential which was due to the low rainfall (**Figure 1**), since Zn has low soil mobility (Engler et al., 2006, p 131).

SZn content decreased linearly as a function of the growth age for rainy (1.26 mg kg^{1} day^{1}) and transition (1.02 mg kg^{-1} day^{1}) seasons (**Table II**). It is noticed that in the rainy season there was a more pronounced reduction in the SZn content as a function of the growth age, probably due to the pronounced stem elongation, as a morphophysiological mechanism of the forage plant to improve the passage and distribution of the photosynthetically active radiation inside the canopy (Costa et al., 2013, page 231). This hypothesis can be confirmed by the negative correlation between the SZn content and the stem biomass (r = 0.54, p<0.005). Similar to the LZn content for the dry season, the SZn content at that season did not show any adjustment to the models tested in response to the growth rates, with an average value of 42.73 ± 11.23.

It was estimated a linear reduction of 0.12 mg kg^{1} day^{1} of Cu content in the leaf (LCu) for the rainy season, totaling 4.57 mg kg^{1} at 63 DAC. The largest increases in biomass at this season (**Figure 2**) occurred due to higher rainfall (**Figure 1**), allowing higher leaf growth rates in relation to the Cu absorption rate, causing a reduction in LCu content. This response can be confirmed by the high negative correlation (r = 0.71, p<0.0001) observed between LCu content and leaf biomass.

In the transition season, LCu content was maximized at 30.66 DAC, with a content of 12.74 mg kg^{1}. This fact can be explained by the reduction in Cu uptake by the forage, due to the decrease of soil water potential (Silva et al., 2011, p.44), since the contact with the root system occurs predominantly by mass flow (Prado, 2008, p.272).

In the dry season, the LCu content was minimized at 35.52 DAC, to 3.99 mg kg^{1}. The subsequent increase was due to the increase of leaf area index from 1.80 to 2.10, observed between the ages 36 and 45 DAC due to rainfall occurring at the end of the dry season (**Figure 1**). This fact stimulated forage growth, demanding more Cu, since it has a fundamental role in the process of photosynthesis (TAIZ et al., 2017, p.192).

The LCu content of elephant grass cv. Roxo remained inside the sufficiency range (4 to 14 mg kg^{1}, according to WERNER, 1997, p. 266) during the whole experimental period, except at age 63 DAC of the transition season (**Table II**). The contents of LCu and SCu were not influenced by the growth seasons at age 9 DAC. At this age, Cu content was the result of the mobilization of organic reserves of the rhizomes (Davidson & Milthorpe, 1966, p. 190), not being influenced by extrinsic conditions (**Figure 1**).

Considering the growth season factor, it was observed that in the transition, rainy and dry seasons, LCu levels were higher, intermediate and lower, respectively, from 27 to 54 DAC. The copper content in the stem (SCu) differed between growth seasons from age 18 DAC, an effect that was maintained until the end of the forage growth cycle (**Table II**).

In the rainy season, the SCu content of elephant grass cv. Roxo reduced linearly (0.23 mg kg^{1} day^{1}), totaling 3.62 mg kg^{1} at age 63 DAC, probably due to the higher carbon allocation in the stem in relation to the accumulation of SCu, verified by the negative correlation between the stem biomass and the SCu content (r = -0.57, p<0.003). In the transition season, the SCu content of elephant grass cv. Roxo was maximized at 28.14 DAC, with a content of 12.65 mg kg^{1}, values similar to those estimated for the LCu content.

For the dry season, the SCu content was minimized at 30.70 DAC, with a value of 5.12 mg kg^{1}, increasing later due to the occurrence of rainfall at the end of the growth cycle, which although lower than evapotranspiration of the crop (**Figure 1**), may have been sufficient to stimulate the plant growth and also to allow the extraction of nutrients from the soil by the increase of the soil water potential.

The manganese content in the leaf (LMn) decreased linearly (0.34 mg kg^{1} day^{1}) for the rainy season, with a value of 31.76 mg kg^{1} at 63 DAC, due to the imbalance between the increment of leaf biomass and the accumulation of Mn in this fraction. The hypothesis presented can be confirmed by the negative correlation observed between leaf biomass and LMn content (r = -0.55; p<0.005). For the transition and dry seasons, the LMn contents were maximized at 31.28 and 32.53 DAC, with estimated values of 11.91 and 40.56 mg kg^{1}, respectively. Although maximized at close ages, LMn content presented higher values in the dry season, indicating a concentration effect on leaves biomass due to the lower participation of this component in the time of water limitation in the soil.

The LMn content revealed levels below to the recommendation (40 to 200 mg kg^{1}) by Werner (1997, p. 266) at age 9 DAC in the transition season and at ages 18, 45, 54 and 63 DAC in rainy and transition seasons. In the dry season, it was below the recommendation only at age 54 DAC (**Table II**). Considering the season, in general, the LMn content and the manganese content in the stem (SMn) were higher in the dry season than the others (**Table III**). The lower biomass increments (Figure 2) resulted in increase in Mn content in leaf and stem biomass. At the same time, Mn mobilization of the root and rhizome cells may have occurred (Malavolta, 2006, p 367; Freire et al., 2012, page 22).

In the rainy season, the SMn content of elephant grass cv. Roxo was linearly reduced at a rate of 0.58 mg kg^{1} day^{1}. For the transition and dry seasons it was maximized at 37.57 and 41.90 DAC, with levels of 58.15 and 156.64 mg kg^{1}, respectively. In the transition season, the canopy maximized the SMn content earlier, probably due to the greater daily increase of stem biomass. In the dry season, the canopy had its biomass increase more severely (**Figure 2**), which delayed the reduction of the SMn content.

It is worth pointing out the scarcity of micronutrient sufficiency values for elephant grass cultivars, since the sufficiency ranges in the literature (Werner, 1997, p. 266) were determined for elephant grass cv. Napier. Thus, the micronutrient contents presented here can serve as a basis for monitoring the nutritional status of elephant grass cv. Roxo considering the yields and environmental conditions reported in the present study.

The accumulations of Fe, Zn, Cu and Mn in elephant grass cv. Roxo presented positive linear response ($p<0.05$) as a function of growth ages for all growth seasons (rainy, transition and dry), varying the magnitude of the response (**Table III**), justified by the response pattern of forage biomass (**Figure 2**) and the dynamics of the micronutrients contents during the forage growth cycle for the three growth seasons (**Table II**).

Accumulations of SHFe of 915.51; 463.93 and 360.00 g ha^{1}, at 63 DAC, for rainy, transition and dry seasons, respectively (**Table III**). Although LFe and SFe levels may have decreased as a function of the growth age, SHFe accumulation of elephant grass cv. Roxo remained linearly increasing at all growth seasons due to the linear positive increase of TFB as a function of growth ages (**Figure 2**). Fe was the most accumulated nutrient in the shoot of elephant grass cv. Roxo in the three growth seasons. Analyzing the growth season factor, it was verified that the accumulation of Fe in the shoot (SHFe) of the elephant grass cv. Roxo varied according to the growth age, following the response of LFe contents.

Accumulations of SHZn of 439.19, 111.48 and 86.37 g ha^{1}, at 63 DAC, for rainy, transition and dry seasons, respectively (**Table III**). It should be noted that Zn is a precursor of the growth hormone, so its demand for the crop is intrinsic to the biomass increase and the environmental conditions, which will be modulating the production of forage plants managed under rainfed conditions (Prado et al., 2012, p. 87; Taiz et al., 2017, p. 128). Despite the linear reduction in the LZn and SZn contents (**Table II**) for the rainy and transition seasons, SHZn accumulation remained linearly positive at all seasons due to the linear increase of TFB (**Figure 2**).

Zn was the second most accumulated nutrient in the shoot of elephant grass cv. Roxo for rainy and transition seasons and the third most accumulated for the dry season. Analyzing the effect of the growth season on the accumulation of Zn in the shoot (SHZn) of elephant grass cv. Roxo, it was verified, from age 45 DAC, higher values of SHZn for the rainy season, intermediate values for the transition season and lower values for the dry season (**Table III**).

Cu accumulations in the shoot (SHCu) of elephant grass cv. Roxo of 56.07, 31.43 and 35.30 g ha^{1} for rainy, transition and dry seasons, respectively, at age 63 DAC (**Table III**). The highest accumulation of SHCu for the rainy season was due to the higher TFB increase (237.92 kg ha^{1} day^{1}), despite the negative linear behavior of the LCu and SCu content (**Table II**). Cu was the least accumulated nutrient in the biomass of the shoot of elephant grass cv. Roxo in all growth seasons.

From the linear coefficient of the equations estimated for SHCu accumulation in transition and dry seasons, similar daily accumulation of SHCu was observed, indicating that SHCu accumulation and export in elephant grass cv. Roxo was not as severely affected by water restriction as the increase in TFB (**Figure 2**).

Mn accumulations in the shoot (SHMn) of elephant grass cv. Roxo of 333.16, 155.78 and 225.40 g ha^{1}, were estimated at 63 DAC, for rainy, transition and dry seasons, respectively (**Table III**). Mn was the third most accumulated nutrient in the aerial biomass of elephant grass cv. Roxo in rainy and transition seasons, and the second nutrient in the dry season. The SHMn accumulation of elephant grass cv. Roxo in the rainy season was due to the greater productive potential of the forage in the mentioned season (237.92 kg ha^{1} day^{1} of TFB) (**Figure 2**). Despite the lower TFB production of elephant grass cv. Roxo in the dry season (48.37 kg ha^{1}) (**Figure 1**), the accumulation of Mn by the canopy was higher than in the transition season, justifying the higher levels of LMn and SMn (Sylvestre et al., 2012, p. 688), observed in the dry season in relation to the transition season, it is soon noticed the greatest export of Mn by biomass in the dry season.

Substantial accumulations of Fe, Zn, Cu and Mn in the biomass of the shoot of elephant grass cv. Roxo, were observed from age 18 DAC in all growth seasons, probably due to the management of cutting of the forage plant, carried out at ground level, which resulted in slow replacement of leaf area in the initial phase of growth, which contributed to the low accumulation of nutrients in the aerial biomass up to age 18 DAC, since the transport of these nutrients to the shoot occurs, predominantly, through water flow generated by the transpiration foliar. Therefore, the supply of these nutrients in greater proportions to meet the nutritional demand of maintenance should be performed from 18 DAC.

It should be noted that the application of micronutrients, based on Fritted Trace Elements-FTE, exclusively during the rainy season, allowed the forage plant to maintain adequate Fe, Zn, Cu and Mn foliar contents in the three growth seasons, for yields of 11,653.00 kg ha^1 in the rainy season (373.30 mm accumulated); 6,305.40 kg ha^1 in the transition season (17.30 mm accumulated) and 2,907.40 kg ha^1 in the dry season (9.60 mm accumulated), for a growth cycle of 63 days.

CONCLUSIONS

The nutritional status and the micronutrient accumulation run in elephant grass cv. Roxo are modified throughout the growth cycle and according to the growth season under rainfed conditions. Thus, to improve the nutritional efficiency of micronutrients in maintenance fertilization of elephant grass cv. Roxo under rainfed, it is recommended to adopt doses of nutrients that meet the nutritional requirement of the forage in each phase of the cycle, as demonstrated in the present study from the march of accumulation of micronutrients for different growth seasons.

The accumulation of micronutrients in elephant grass cv. Roxo under rainfed presents the following order: Fe > Zn > Mn > Cu (rainy and transition seasons) and Fe > Mn > Zn > Cu (dry season).

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