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Scientific Article

Growth and nutrient accumulation in elephant grass crop

Crescimento e acúmulo de nutrientes na cultura do capim-elefante

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ABSTRACT - Elephant grass fertilization is performed more efficiently by analyzing growth curves and nutrient accumulation. This study evaluated elephant grass's growth, dry matter production, and nutrient accumulation. A sampling design was used, with plant collections over time. Elephant grass was cultivated in four plots of 27 m^2 during two cultivation cycles. Destructive sampling of four plants was carried out per collection to evaluate dry matter production and nutrient accumulations. In the first cycle, plants were collected at 21, 35, 49, 63, 77, 91, 105 and 119 days after planting. After the last collection of the first cycle, a standardization cut was made, eliminating the remaining plants in the experimental plots. The second cycle of collections was carried out at 21, 35, 49, 63, 77, 91, and 105 days after the uniformity cut. In all collections, the number of tillers per linear meter was counted, and the height of the plants was evaluated. The data were subjected to nonlinear regression analysis. The accumulation of nutrients by elephant grass accompanied the production of dry matter. The highest rates of dry matter production occurred around 70 days. The greatest height growth occurred from 18 to 102 days in the 1st cycle and 8 to 61 days in the 2nd cycle. Nutrient accumulation showed the following decreasing order: K>N>Mg>Ca>P>S>Fe>Mn>Zn>Cu (1st cycle); and K>N>Mg>Ca>P>S>Fe>Zn>Mn>Cu (2nd cycle).

Keywords: *Pennisetum purpureum*. Fertilization. Macronutrients. Micronutrients.

RESUMO - A adubação do capim-elefante é realizada de forma mais eficiente ao analisar as curvas de crescimento e acúmulo de nutrientes. Com isso, objetivou-se avaliar o crescimento, a produção de matéria seca e os acúmulos de nutrientes do capim-elefante. Foi utilizado um delineamento de amostragem, com coletas de plantas ao longo do tempo. O capim-elefante foi conduzido em quatro parcelas de 27 m^2, durante dois ciclos de cultivo. Foram realizadas amostragens destrutivas de quatro plantas por coleta, para avaliar a produção de matéria seca e os acúmulos de nutrientes. No primeiro ciclo, as plantas foram coletadas aos 21, 35, 49, 63, 77, 91, 105 e 119 dias após o plantio. Após a última coleta do primeiro ciclo, foi realizado um corte de uniformização, eliminando as plantas restantes nas parcelas experimentais. O segundo ciclo de coletas ocorreu aos 21, 35, 49, 63, 77, 91 e 105 dias após corte de uniformização. Em todas as coletas foi realizada a contagem do número de perfilhos por metro linear e avaliada a altura das plantas. Os dados foram submetidos à análise de regressão não linear. O acúmulo de nutrientes pelo capim-elefante acompanhou a produção de matéria seca. As maiores taxas na produção de matéria seca ocorreram por volta dos 70 dias. O período de maior crescimento em altura ocorreu dos 18 aos 102 dias no 1º ciclo, e dos 8 aos 61 dias no 2º ciclo. O acúmulo de nutrientes apresentou a seguinte ordem decrescente: K>N>Mg>Ca>P>S>Fe>Mn>Zn>Cu (1º ciclo); e, K>N>Mg>Ca>P>S>Fe>Zn>Mn>Cu (2º ciclo).

Palavras-chave: *Pennisetum purpureum*. Adubação. Macronutrientes. Micronutrientes.

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INTRODUCTION

Elephant grass (*Cenchrus purpureus* syn. *Pennisetum purpureum*) is widely cultivated in Brazil, mainly for feeding dairy herds (COSER et al., 2000). Due to its versatility when offered to animals, it can be recommended for both grazing and preserved forage as silage or hay. Historically, elephant grass has been used as an important complement to bulky animal feed on rural properties (OLIVEIRA et al., 2022).

The wide use of this forage plant is attributed to its high production of dry matter, with high nutritional value, in addition to developing well under different edaphoclimatic conditions (HINOJOSA et al., 2014; MARANHÃO et al., 2020a). However, the level of exploitation of this species by Brazilian livestock farming is modest compared to its potential. Among the factors that restrict this activity, the absence or inefficiency of fertilization of native or cultivated pastures stands out (MARANHÃO et al., 2020b), largely caused by the lack of knowledge about the nutritional demands of elephant grass according to the phenological stages of this crop.

Elephant grass fertilization can be performed efficiently by analyzing growth curves and nutrient accumulation. The period of greatest nutrient accumulation by the plant usually coincides with the highest growth rate and the highest dry matter production (TAIZ et al., 2017). By describing the entire growth stage of a crop, it is possible to understand the dynamics of absorption/extraction of nutrients and, thus, offer them according to the plant's demand, especially at times of greater nutritional demand, as well as replacing the minimum amounts extracted from the soil, to maintain its fertility.

Several factors influence the mineral composition of forage, such as the morphological structure of the plant, genetic differences between species, edaphoclimatic conditions, and the interval of cuts. At the time of cutting, elephant grass extracts from the soil 8.11 to 133.17 kg ha^{-1} of N, 8.92 to 30.68 kg ha^{-1} of P, 162.58 to 644.81 kg ha^{-1} of K, 2.66 to 8.05 kg ha^{-1} of Ca, 5.16 to 18.41 kg ha^{-1} of Mg, 0.40 to 6.16 kg ha^{-1} of S, 432.18 to 991.40 g ha^{-1} of Fe, 98.48 to 406.86 g ha^{-1} of Zn, 21.46 to 57.97 g ha^{-1} of Cu, and 129.54 to 299.24 g ha^{-1} of Mn (MARANHÃO et al., 2018; MARANHÃO et al., 2020b; OLIVEIRA et al., 2022).

To produce quality forage, the soil must provide all the nutrients the plant needs for its development. These nutrients must be supplied to plants throughout their production cycle in adequate quantities to avoid production losses due to problems with nutrient deficiency or excess. Thus, it is important to know the nutritional needs of elephant grass and its ability to extract nutrients from the soil throughout its growth and, thus, to develop strategies for fertilization management.

However, when making fertilization recommendations, producers usually consider only the levels of nutrients present in the soil, disregarding the nutritional demand of the forage species in question. Thus, this study aimed to evaluate elephant grass cv. Cameroon growth, dry matter production, and nutrient accumulation.

MATERIAL AND METHODS

The work was carried out from January to July 2017 in the Experimentation Area of the Forage Study Group (GEFOR) (5°53'35.12" South latitude, 35°21'47.03" West longitude, and 11 m altitude), belonging to the Agricultural School of Jundiaí (EAJ), Federal University of Rio Grande do Norte (UFRN), Macaíba Campus, RN, Brazil. According to Köppen's classification, the local climate is As' type, characterized by a dry winter between September and December. Throughout the experiment, air temperature and rainfall values were monitored (Figure 1). Air temperature was measured using a probe, and precipitation was obtained through readings taken from a rain gauge, both installed at the experiment site.

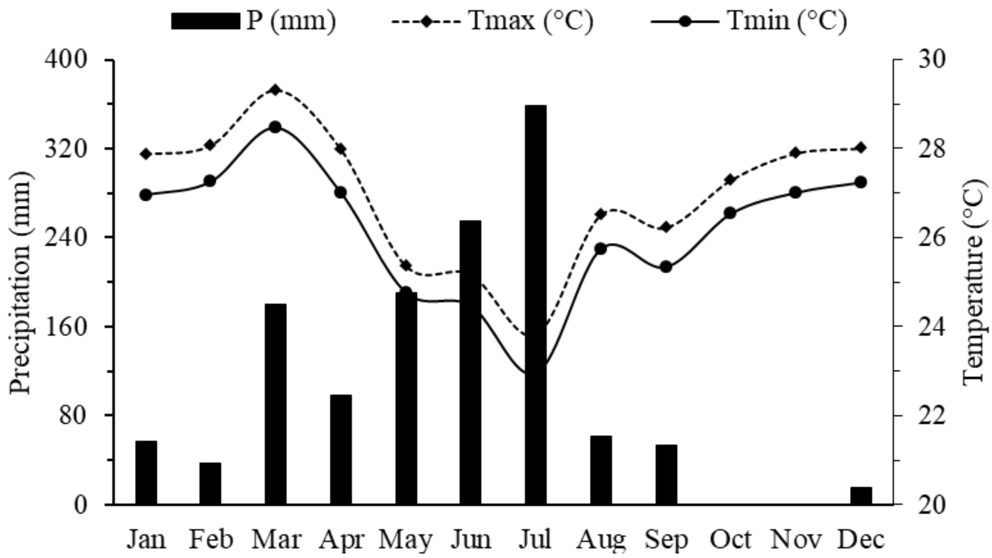

Figure 1. Precipitation (P) and maximum (Tax) and minimum (Tmin) temperatures in the experimental area in 2017 in the municipality of Macaíba, RN, Brazil.

The soil in the experimental area is classified as *Neossolo Quartzarênico* (Quartzipsamment) (SANTOS et al., 2018). Before setting up the experiment, soil sampling was conducted in the experimental area at 0-0.20 m depth for chemical characterization and particle-size analysis. All analyses followed the analytical methods described by Teixeira et al. (2017). The data obtained are described in Table 1.

The experiment used a sampling design, with collections carried out over time, in a population of elephant grass plants (*Cenchrus purpureus* syn. *Pennisetum purpureum*), cultivar Cameroon. The population stand was composed of healthy, normal, and fully competitive plants, grown in an experimental area of 108 m² (3.0 x 36 m), divided into four plots of 27 m^2 (3.0 x 9.0 m), corresponding to the replications. The plots contained four planting rows, 9.0 m long and 0.70 m apart. The two central rows were considered usable for analysis and effective data collection, and the lateral rows were used only to estimate the number of tillers per linear meter.

Table 1. Soil chemical characterization and particle-size analysis (0 to 20 cm) of the experimental area.

pH	P	K	Na	Ca	Mg	Al	H+Al	OM	SB	CEC	V	Sand	Silt	Clay
	mg dm^{-3}			cmol$_c$ dm^{-3}				mg dm^{-3}	cmol$_c$ dm^{-3}		(%)	g kg^{-1}		
5.9	1.0	33.0	5.3	0.4	1.2	0.1	0.8	2.5	2.0	2.5	67	940	40	20

OM = Organic matter; SB = Sum of bases; CEC at pH 7,0 (total) = Cation Exchange capacity; V = Base saturation.

The plant stand was conducted during two cultivation cycles, in which destructive sampling of four plants at different times was carried out to evaluate the dry matter production and nutrient accumulation in the aerial part of elephant grass. In the first cycle, growth and nutrient accumulation analyses were performed at 21, 35, 49, 63, 77, 91, 105 and 119 days after planting. After the last collection of the first cycle, a standardization cut was carried out in all experimental plots to eliminate the remaining plants, thus starting the second growth cycle of elephant grass. Sampling in the second cycle was conducted at 21, 35, 49, 63, 77, 91, and 105 days after the standardization cut.

Planting was carried out by distributing the entire culms in furrows (planting rows), following the end-to-end system. After being placed at the bottom of the furrow, the culms were cut into setts of approximately 70 cm. In response to reference evapotranspiration, irrigation was applied by a conventional sprinkler system composed of fixed lateral lines, with an average flow rate of 3.0 m^3 per hour and an irrigation interval of two days.

Basal fertilization was carried out during planting in furrows 15.0 cm from the planting row, applying 60 kg ha^{-1} of N, 150 kg ha^{-1} of P_2O_5, 75 kg ha^{-1} of K_2O, 30 kg ha^{-1} of S, and 3.0 kg ha^{-1} of Zn. The main sources used were urea (45% N), triple superphosphate (36% P_2O_5 and 10% Ca), potassium chloride (58% K_2O), ammonium sulfate (20% N and 22% S), and FTE BR-12 (source of micronutrients), respectively. The commercial product FTE BR-12 is composed of Mo (0.01%), B (1.8%), Cu (0.8%), Mn (2.0%) and Zn (0.7%).

Topdressing was also carried out in furrows 15.0 cm from the planting row. In the first cultivation cycle, which lasted 119 days, two fertilizations were carried out, one at 30 days after planting (DAP) and the other at 60 DAP. In each of these fertilizations, 270 kg ha^{-1} of N plus 37.5 kg ha^{-1} of K_2O were applied, totaling 600 kg ha^{-1} of N and 150 kg ha^{-1} of K_2O for the first cycle (basal + topdressing).

In the second cultivation cycle, which lasted 105 days, counting from the standardization cut, total doses of 600 kg ha^{-1} of N plus 150 kg ha^{-1} of K_2O were also applied, divided into three applications. The first fertilization was performed two days after the standardization cut, with 60 kg ha^{-1} of N plus 75 kg ha^{-1} of K_2O; the second and third fertilizations were applied at 30 and 60 days after standardization cut, with equal doses of 270 kg ha^{-1} of N plus 37.5 kg ha^{-1} of K_2O. To not limit the extraction of nutrients by elephant grass, the fertilization recommendation was above that recommended in the literature for pastures (HOLANDA et al., 2017).

The plants were cut close to the ground, fractionated, and left to dry in a forced air circulation oven at 65 ºC until they reached constant weight. With elephant grass dry matter values, the average estimate of the number of tillers per linear meter, and the spacing used for elephant grass, it was possible to determine the yield of matter in "t ha^{-1}". The number of tillers per linear meter was evaluated in all collection periods, by counting the tillers along one linear meter of the lateral rows of each plot. At the end of the experiment, the average estimate was 11.7 tillers per linear meter. In each collection, the average height of the plants was also estimated, measuring with a graduated ruler 12 distinct points in the central rows of each replication.

Samples of plant dry matter were ground in a Wiley mill and then subjected to chemical analysis to quantify macro (N, P, K, Ca, Mg, and S) and micronutrient (Fe, Cu, Mn, and Zn) contents, following the methodology proposed by Miyazawa et al. (2009). Nutrient accumulations were calculated by multiplying dry matter production by N, P, K, Ca, Mg, S, Fe, Cu, Mn, and Zn contents.

Data were analyzed using descriptive statistics. The curves were fitted to the sigmoidal function (nonlinear regression analysis), according to the equation ŷ = a/(1+e-(x-xo/b)), where ŷ = dependent variable (plant height, dry matter, and nutrient accumulation); a = maximum point of the curve; e = base of the Napierian logarithm, b = fitting parameter; x = independent variable (collection times); and, xo = inflection point (the point at which the maximum rate of change of the function occurs).

To help discuss the results, the minimum (CPmin) and maximum (CPmax) curvature points were calculated using the parameters of the nonlinear equations, where CPmin = xo - 2b and CPmax = xo + 2b (CAVALCANTE et al., 2018). CPmin indicates the moment in the curve (graphs) when significant gains in plant growth, dry matter production, and nutrient accumulation begin. On the other hand, CPmax indicates the moment when these gains begin to stabilize.

RESULTS AND DISCUSSION

At the beginning of elephant grass growth, dry matter (DM) production was not very significant, with relatively low initial values in both cycles. The relevant gains (CPmin) in DM were observed from 42 (1st cycle) and 32 (2nd cycle) days after planting or cutting, producing 3.90 and 5.25 t ha^{-1}, respectively. On the other hand, the average increments in DM began to stabilize (CPmax) in the 1st and 2nd cycles, at 95 and 105 days after planting or cutting, with a yield of 30.48 and 38.42 t ha^{-1}, respectively. The highest elephant grass dry matter accumulation rates occurred around 70 days (Figure 2A).

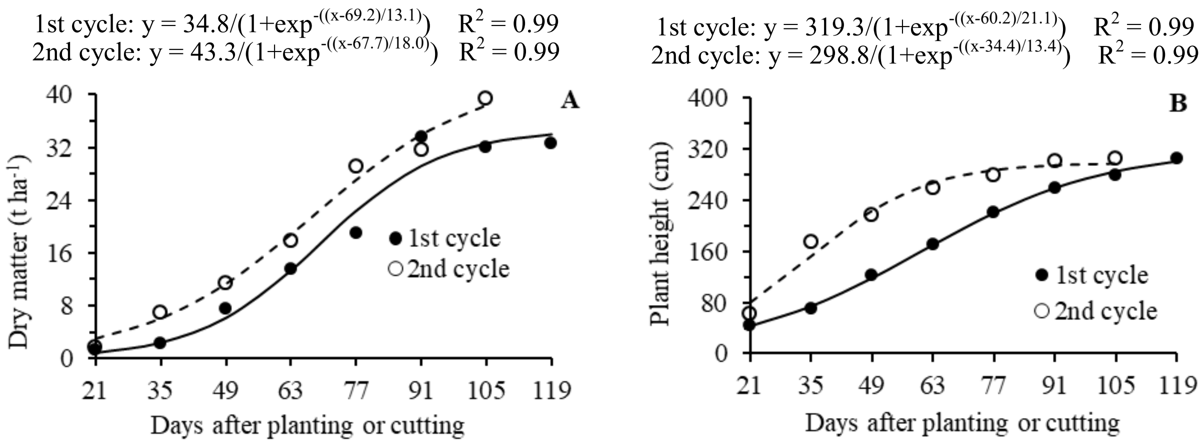

Figure 2. Growth rate evaluated by dry matter yield (A) and plant height (B) of elephant grass in two cultivation cycles.

At the beginning of their development, plants use a large part of the photoassimilates to produce new roots (TAIZ et al., 2017). With the growth of the root system, the plant starts to explore a greater volume of soil and access to water and nutrients increases. Consequently, it develops faster. Thus, the difference in DM production between the minimum (CPmin) and maximum (CPmax) curvature points in the 2nd cycle, ten days earlier, can be attributed to a larger root system already established in this cycle when compared to the 1st cycle, which had a root system still in development.

Elephant grass began to express significant gains in height (CPmin) at 18 and 8 days after planting or cutting, with 38.11 and 36.35 cm, respectively. From this point on, an accelerated growth of elephant grass (CPmax) is evident, stabilizing at 102 days in the 1st cycle, with a height of 280.57 cm, and at 61 days in the 2nd cycle, with 262.79 cm. The daily growth rate of the plants occurred continuously and increased until 60 and 35 days for the 1st and 2nd cycle, respectively (Figure 2B).

Upon reaching the highest growth rate in the first cycle (at 60 days) and in the second cycle (at 35 days), the elephant grass plants reached a height of 1.55 m. According to Maranhão et al. (2018), elephant grass must be managed for 63 days to match the yield and quality of the biomass produced. Harvesting at advanced ages reduces forage quality due to a lower leaf/stalk ratio, which occurs naturally due to the leaf senescence process associated with increased fiber in the stalk.

In both cycles, nitrogen (N) was elephant grass's second most accumulated nutrient. N accumulation was initially slow, similar to the accumulation of DM (Figure 2A). The significant gains (CPmin) occurred from 33 and 10 days, with 40.84 kg ha^{-1} in the 1st cycle and 32.64 kg ha^{-1} in the 2nd cycle. The periods of highest N requirement by elephant grass (CPmax) were observed at 75 and 100 days, with an accumulation of 301.77 and 241.19 kg ha^{-1} in the 1st and 2nd cycles, respectively. The highest rates of N accumulation occurred at 55 days in both cycles (Figure 3A).

With the difference observed between the CPmin values, it is possible to infer that the application of N in the 2nd cycle can be performed earlier compared to the application of the 1st cycle since the applied N will be used more efficiently, synchronizing its availability in the soil with the plant demand. The earlier N accumulation in the 2nd cycle is related to plants' greater root development at this time, promoting greater nutrient absorption.

N is one of the nutrients required in large quantities, performing several essential functions for plant development (TAIZ et al., 2017). Therefore, the scarcity of this nutrient in the soil leads to N deficiency in the plant, inhibiting its growth. In many production systems, nitrogen availability is almost always a limiting factor, influencing plant growth more than any other nutrient, hence the similarity between N accumulation (Figure 3A) and DM production (Figure 2A) in the aerial part of elephant grass.

The management of nitrogen fertilization is very complex since N is a nutrient that has high mobility in the soil, being subject to several losses. Therefore, considering the nitrogen dynamics in the soil and the CPmin of this nutrient, it would be interesting to carry out topdressing nitrogen fertilization around 30 days in the 1st cycle and 10 days in the 2nd cycle. Thus, this nutrient would be offered throughout the critical phase of nitrogen accumulation and dry matter production of elephant grass. There is also the possibility of splitting the fertilization into topdressing since nitrogen has a high probability of leaching losses in *Neossolos Quartzarênicos* (Quartzipsamments).

Among the macronutrients analyzed in this study, phosphorus (P) occupies the fifth place in descending order of nutrient accumulation in the aerial part of elephant grass. The CPmin for phosphorus occurred at 26 and 13 days (1st and 2nd cycle), accumulating 4.53 and 4.95 kg ha^{-1}. In the 1st cycle, around 65 days, P accumulation began to stabilize, with 33.02 kg ha^{-1}, and, in the 2nd cycle, this occurred at 106 days, with an accumulation of 36.76 kg ha^{-1}. The highest P requirement for elephant grass was observed at 45 days in the 1st cycle and 60 days in the 2nd cycle (Figure 3B).

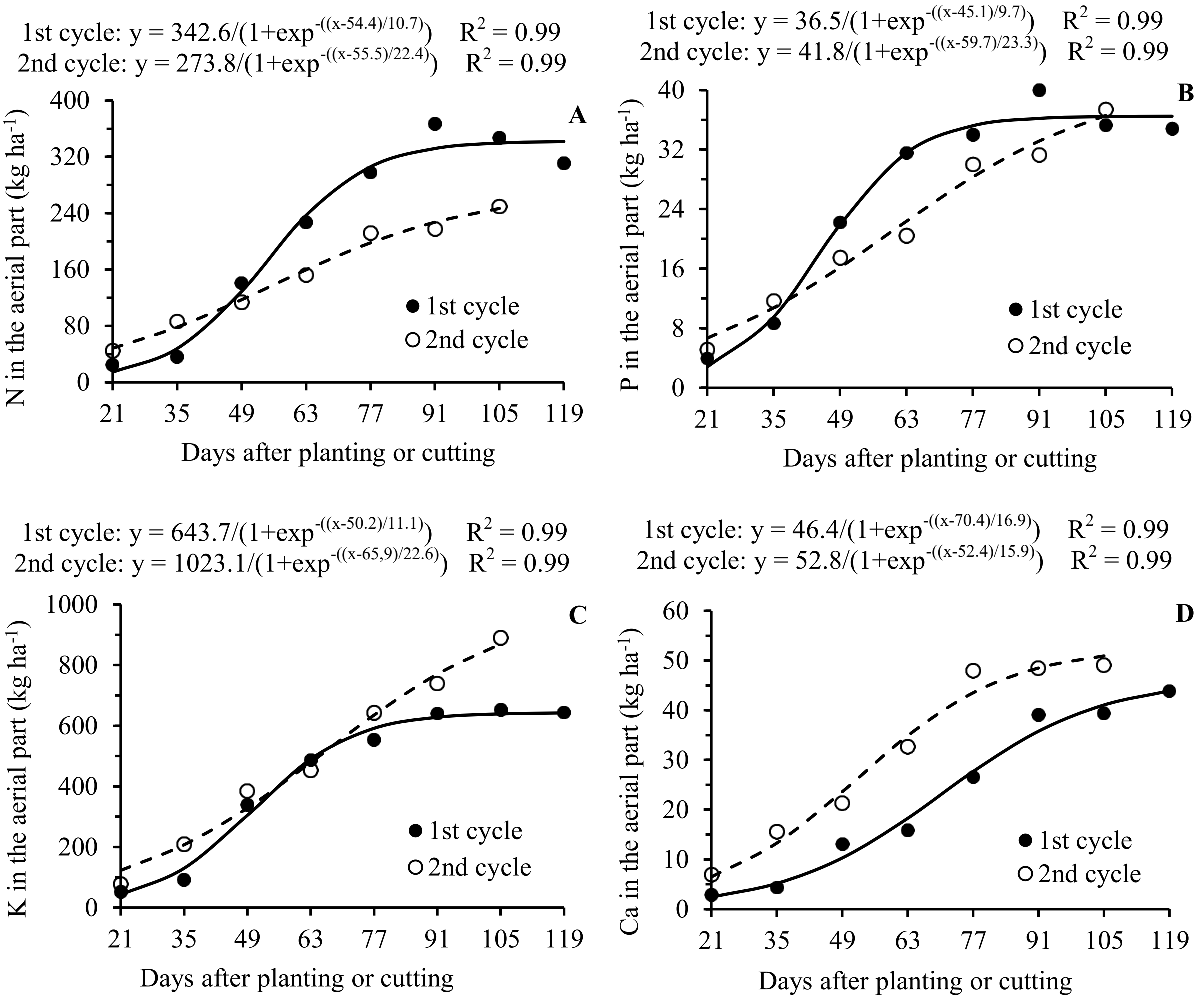

Figure 3. Nitrogen (A), phosphorus (B), potassium (C), and calcium (D) accumulation rates by elephant grass in two crop cycles.

P is crucial in plant metabolism, playing an important role in cell energy transfer, respiration, and photosynthesis (BARRA et al., 2019). Because it is a nutrient that is poorly used by plants (LIMA, 2020) due to its low mobility in the soil, the values of P extracted and accumulated in the aerial part of elephant grass are relatively low, especially when compared to the accumulation of other macronutrients. However, phosphorus is among the most limiting nutrients for plant production in soils of tropical and subtropical climate regions (OLIVEIRA et al., 2021). This occurs because phosphorus has a high affinity for iron and aluminum oxides (SILVA et al., 2018), making the soil a competitor for the plant.

Thus, soils with low clay proportions, such as the *Neossolo Quartzarênico* (Quartzipsamment), have low adsorption capacity for this element. This explains the positive relationship in phosphorus accumulation observed up to 65 days in the first cycle and 106 days in the second cycle (Figure 3B). Therefore, this nutrient must be applied at the planting of elephant grass. This application will be sufficient to meet the plants' initial demand and maintain the elephant grass's yield throughout the following cycle.

In both cycles, potassium (K) was the most exported nutrient to the aerial part of elephant grass. Significant increases in K accumulation began at 28 days in the 1st cycle and 20 days in the 2nd cycle, accumulating 76.73 and 121.96 kg ha^{-1}, respectively (Figure 3C). At 72 and 111 days, K accumulation began to stabilize (CPmax), with estimated values of 121.96 kg ha^{-1} in the 1st cycle and 901.16 kg ha^{-1} in the 2nd cycle. Similar to the pattern of N accumulation (Figure 3A), an earlier K accumulation was also observed in the 2nd cycle (Figure 3C), compared to the 1st cycle.

The maximum rates of K accumulation were observed at 50 and 65 days in the 1st and 2nd cycles, respectively (Figure 3C). K accumulation at 50 days was 319.19 kg ha^{-1} (1st cycle), and at 65 days, 501.55 kg ha^{-1} (2nd cycle), values higher than those observed with the other macronutrients (Figures 3 and 4). Maranhão et al. (2018), evaluating accumulation and partition of macronutrients in elephant grass cv. Roxo, managed at different ages and growing seasons, also found that potassium was the nutrient that accumulated the most in the aerial part of elephant grass, with an accumulation at 63 days of 645, 276, and 163 kg ha^{-1} in the rainy, transition, and dry periods, respectively.

The increase in K accumulation by elephant grass observed in this work can probably be explained by the increase in nitrogen accumulation throughout the development of this forage. According to Galindo et al. (2018), with an increase in nitrogen accumulation, the root system will develop more, favoring plant access to a greater volume of soil and, consequently, water and nutrients, among them potassium. For Dominico et al. (2020), another likely explanation would be luxury consumption, in which the plant accumulates the nutrients in the biomass without a corresponding increase in forage production.

Depending on the amount of rainfall, dose of nutrients applied, and soil texture, potassium is subject to significant losses through leaching (GOMES et al., 2022). Therefore, considering this information and based on the results found in the present study, potassium fertilization in elephant grass topdressing can be carried out 20 days after planting or cutting, making this nutrient available to the plants throughout the critical phase of potassium accumulation, whether in the 1st or 2nd cycle. Potassium dynamics in the soil is very similar to that of nitrogen, with a high probability of losses due to leaching in sandy soils. Therefore, potassium fertilizer can also be divided into more than one application.

At the end of the cycles, calcium (Ca) was the fourth most accumulated macronutrient by elephant grass. In the 1st cycle, the significant increments (CPmin) started at 36 days, with 5.42 kg ha^{-1}, and in the 2nd cycle, at 20 days, with 6.12 kg ha^{-1}. On the other hand, the maximum accumulations were observed at 104 and 84 days in the 1st and 2nd cycle, with estimated values of 40.77 and 46.41 kg ha^{-1}, respectively. The maximum daily accumulation of Ca by elephant grass occurred at 70 days in the 1st cycle and at 52 days in the 2nd cycle (Figure 3D).

When evaluating macronutrient accumulation in elephant grass, Maranhão et al. (2018) observed an estimated calcium accumulation rate of 0.15 kg ha^{-1} day^{-1}, resulting in an accumulation of 5.98 kg ha^{-1} at 63 days in the rainy season. Differently from what was found in the present study, the authors mentioned above reported that in the rainy season, calcium was the fifth most accumulated nutrient in the aerial part of elephant grass. According to Raij (2011), calcium is a nutrient required in very varied amounts by most crops, within ranges of 10 to 200 kg ha^{-1}.

Ca is an element with low mobility in the plant. It performs different functions in plant tissues, such as elongation and cell division, which are drastically reflected in root growth (TAIZ et al. 2017). The value of CPmin at the beginning of each cycle can be observed to indicate its importance for elephant grass cultivation (Figure 3D). Thus, the most appropriate time to add calcium to the soil is around 30 days, in both cycles studied, when this nutrient begins to show more significant accumulations.

The beginning of significant gains (CPmin) in magnesium (Mg) in the aerial part of elephant grass was observed at 36 and 18 days, with an estimated accumulation of 11.79 and 10.47 kg ha^{-1} in the 1st and 2nd cycle, respectively. At 90 days of the 1st cycle, the increments began to stabilize (CPmax), with a production of 87.43 kg ha^{-1} and, in the 2nd cycle, at 86 days, with 78.57 kg ha^{-1}. The highest rates of daily Mg accumulation in elephant grass occurred at 62 and 52 days for the 1st and 2nd cycle, respectively (Figure 4A).

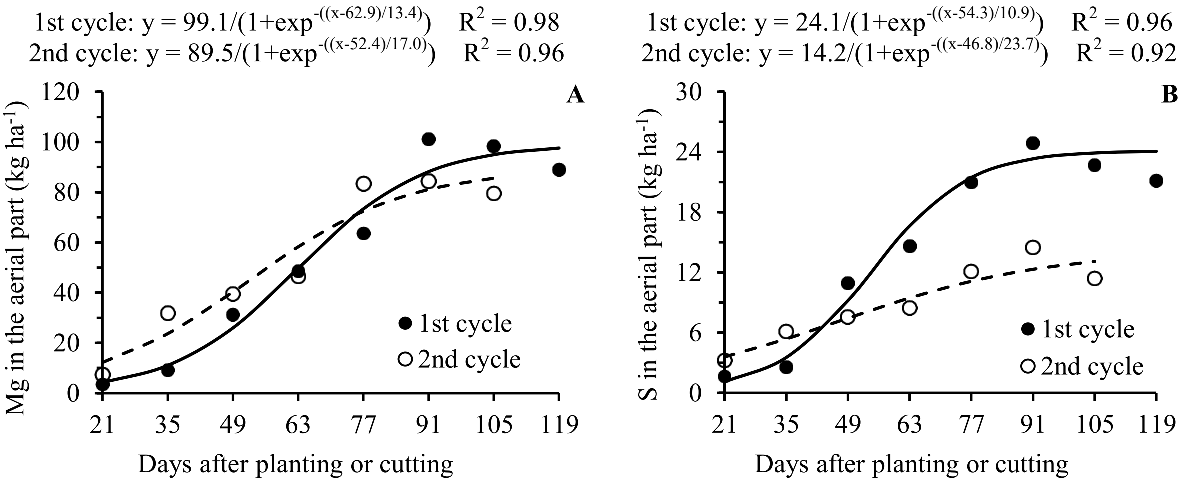

Figure 4. Magnesium (E) and sulfur (F) accumulation rates by elephant grass in two crop cycles.

In the present study, Mg was the third most accumulated macronutrient in the aerial part of elephant grass. A different result was found by Maranhão et al. (2018), who observed that this element was the fourth most accumulated nutrient in the aerial part of elephant grass cv. Roxo in the rainy and transition seasons and fifth in the dry season. This possibly occurred because the plants were subjected to different climatic conditions, possibly altering nutrient accumulation dynamics. According to Lange et al. (2021), Mg has a structural role in the chlorophyll molecule and is also an enzymatic activator in many plant metabolic processes.

At the end of the two cycles, sulfur (S) was the macronutrient least exported by elephant grass. The minimum curvature point was observed at 31 and 14 days with values of 2.69 and 2.61 kg ha^{-1} for the 1st and 2nd cycles, respectively (Figure 4B). The earlier accumulation of S at the beginning of the 2nd cycle is probably due to the mobilization of organic reserves present in elephant grass rhizomes (MARANHÃO et al., 2018), similar to what occurred with N (Figure 3A).

The highest S accumulation rate was obtained at 53 (1st cycle) and 43 days (2nd cycle). Based on the regression equations, it is observed that at these moments (53 and 43 days), the elephant grass aerial part accumulated 11.41 and 6.75 kg ha^{-1} of S, in that order (Figure 4B). With conditions similar to those of the 2nd cycle, that is, in the rainy season, Maranhão et al. (2018), evaluating the accumulation of macronutrients in elephant grass, reported similar results, with S accumulation estimated at 4.82 kg ha^{-1} at 63 days.

The highest accumulation of S by elephant grass was observed at 75 days in the 1st cycle, with 20.27 kg ha^{-1}, and in the 2nd cycle, with 12.09 kg ha^{-1}. According to Raij (2011), sulfur requirements for most crops are 10 to 30 kg ha^{-1} of S and may be higher for more demanding species. Therefore, the accumulations of S obtained in this work are within the range cited by the authors.

S is important in plant growth and development mainly because it participates in protein constitution (FIORINI et al., 2017), which determines significant increases in the yield and quality of the product obtained. Therefore, sulfate fertilization must be carried out when planting to make this nutrient available to elephant grass at critical times (CPmin). If necessary, you can also plan to split the recommended annual dose, avoiding losses due to leaching, especially in sandy soils.

At the end of the 1st and 2nd cycles, iron (Fe) was the most accumulated micronutrient in the aerial part of elephant grass. In the 1st cycle, the significant increments (CPmin) started around 50 days, with 395.79 g ha^{-1}, and in the 2nd cycle, at 30 days, with 313.30 g ha^{-1}. On the other hand, the maximum accumulations were observed around 70 days in both cycles, with estimated values of 2468.13 g ha^{-1} in the 1st cycle and 2430.40 g ha^{-1} in the 2nd cycle. The maximum Fe accumulation by elephant grass occurred at 62 and 50 days in the 1st and 2nd cycle, respectively (Figure 5A).

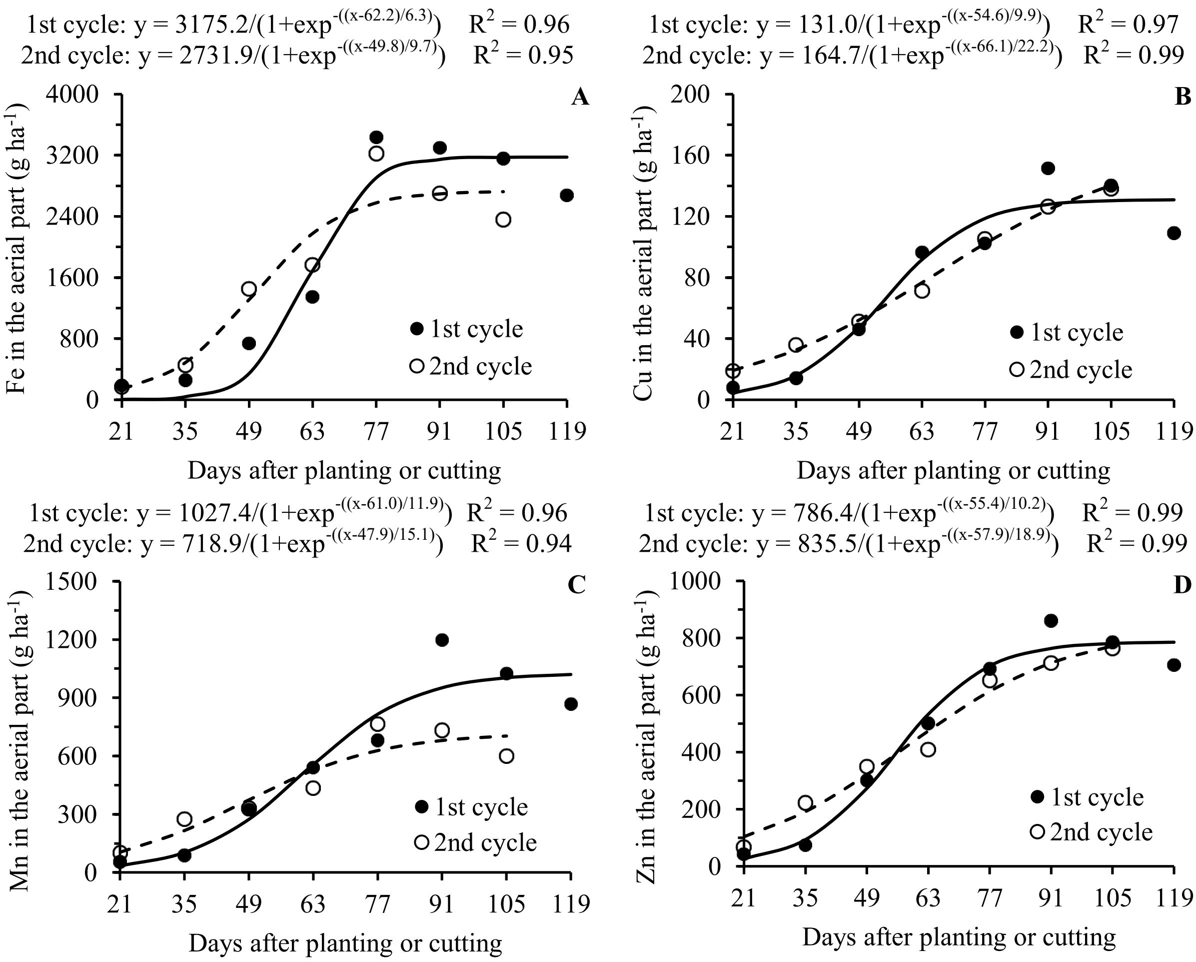

Figure 5. Iron (A), copper (B), manganese (C), and zinc (D) accumulation rates by elephant grass in two crop cycles.

High levels of Fe in the aerial part of elephant grass were also observed by Maranhão et al. (2020b), who found that elephant grass cv. Roxo accumulated 915.5, 463.9, and 360.0 g ha^{-1} at 63 days for the rainy, transition, and dry seasons, respectively, being the micronutrient most accumulated by the crop. One of the main functions of Fe in plants is to facilitate the occurrence of metabolic reactions that activate enzymes participating in the photosynthetic process (RAMOS et al., 2017). In addition, iron is indispensable for proper functioning of the respiratory process, nitrogen fixation, and electron transfer (ALEXANDRE et al., 2012).

Elephant grass showed significant gains (CPmin) in copper (Cu) at 35 and 22 days, accumulating 15.85 and 19.92 g ha^{-1} in the 1st and 2nd cycles, respectively. Cu accumulation began to stabilize at 75 days in the 1st cycle (CPmax), with 87.43 g ha^{-1}, and at 86 days in the 2nd cycle, with 78.57 g ha^{-1}. The highest rates of Cu accumulation occurred at 62 days in the 1st cycle and 52 days in the 2nd cycle (Figure 5B).

The aerial part of elephant grass accumulated relatively low values of Cu in both cycles, so it ranked last among the micronutrients analyzed in the present work. Maranhão et al. (2020b) reported that Cu was also the least accumulated micronutrient by elephant grass. As an essential nutrient, copper is vital in processes such as photosynthesis and respiration (TAIZ et al., 2017), and its deficiency may compromise crop yield.

The beginning of significant gains in manganese (Mn) in the 1st cycle was observed 37 days after planting (CPmin), with an accumulation of 119.97 g ha^{-1} and, in the 2nd cycle, 17 days after cutting, with 83.12 g ha^{-1}. At 85 and 78 days, the increases in Mn accumulation began to stabilize, with 907.09 and 633.02 g ha^{-1} in the 1st and 2nd cycle, respectively. The greatest Mn requirement by elephant grass occurred at 61 days in the 1st cycle and at 48 days in the 2nd cycle (Figure 5C).

Mn was the second most accumulated nutrient in the elephant grass aerial part in the 1st cycle and the third in the 2nd cycle. Maranhão et al. (2020b) also reported different orders of accumulation in the aerial biomass of this forage, with Mn being the third most accumulated nutrient by elephant grass cv. Roxo in the rainy season and the second in the dry season. Manganese is important in several vital plant processes, such as photosynthesis, respiration, elimination of reactive oxygen species (ROS), hormone signaling, and others (ALEJANDRO et al., 2020). Thus, its deficiency compromises plant growth, development, and yield (CREMONESI et al., 2019).

Among the micronutrients analyzed in this work, zinc (Zn) occupies the third (1st cycle) and second (2nd cycle) place in decreasing order of micronutrient accumulation in the elephant grass aerial part (Figure 5D). The CPmin for Zn occurred at 35 and 20 days (1st and 2nd cycle), accumulating 93.27 and 98.95 g ha^{-1}. In the 1st cycle, 75 days after planting, Zn accumulation began to stabilize, with 685.73 g ha^{-1}, and, in the 2nd cycle, this occurred 95 days after cutting, with an accumulation of 732.75 g ha^{-1}. In both cycles, the highest Zn requirement by elephant grass was observed around 56 days.

Zn is an essential micronutrient for plant growth and physiological processes (MUNIRAH et al., 2015), and its deficiency has limited agricultural production in Brazil, resulting in losses in crop quality and yield (PRADO, 2008). In plants, in general, Zn is vital for nutritional regulation, reproductive growth, chlorophyll synthesis, and carbohydrate production, also acting as a regulatory cofactor for a wide range of enzymes and proteins (TRIPATHI et al., 2015).

The interval between the beginning of significant gains (CPmin) and the maximum daily rate of micronutrient accumulation corresponds to the greatest nutritional demand for elephant grass. In the 1st cycle, substantial accumulations of Fe, Cu, Mn, and Zn in the aerial part of elephant grass cv. Cameroon were observed between 35 and 60 days after planting and, in the 2nd cycle, this range occurred earlier, starting at 20 days, and extending until 65 days after cutting. Therefore, the supply of micronutrients to meet the nutritional demand for maintenance of elephant grass cv. Cameroon must be performed after 35 and 20 days, in the 1st and 2nd cycle, respectively.

CONCLUSIONS

The total accumulation of nutrients by elephant grass followed the dry matter production. The greatest growth in height of elephant grass occurred from 18 to 102 days in the 1st cycle and from 8 to 61 days in the 2nd cycle, with higher rates of dry matter accumulation around 70 days. Nutrient accumulation showed the following decreasing order: K>N>Mg>Ca>P>S>Fe>Mn>Zn>Cu (1st cycle); and K>N>Mg>Ca>P>S>Fe>Zn>Mn>Cu (2nd cycle).

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