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***Regional communication***

# Nitrogen and phosphorus fertilizer application to Elephant grass (*Cenchrus purpureus* syn. *Pennisetum purpureum*) cultivar 'Cameroon' in an arenosol in Rio Grande do Norte, Brazil

## *Fertilización con nitrógeno y fósforo en pasto elefante cv. Cameroon en un arenosol en Rio Grande do Norte, Brasil*

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**Abstract**

Elephant grass (*Cenchrus purpureus* syn. *Pennisetum purpureum*) stands out for its high dry matter production per unit area and good nutritional value and is cultivated throughout Brazil. This study aimed to evaluate the performance of Elephant grass cultivar 'Cameroon' fertilized with nitrogen (N) and phosphorus (P) at different rates. The experimental design was in randomized blocks with 10 treatments and 4 replicates. The treatments consisted of 5 doses of N (0, 200, 400, 600 and 800 kg N/ha) all with 66 kg P/ha and 5 doses of P (0, 22, 44, 66 and 88 kg P/ha) all with 600 kg N/ha. The variables evaluated during 3 harvests were: shoot dry matter (DM) yield, N and P concentrations in shoots, and uptakes of N and P in forage. Results showed that, in the arenosol of the experimental area, high doses of N and P could produce high yields of the grass (40–41 t DM/ha) over 260 days. The grass extracted large amounts of N (on average, 800 kg N/ha over 260 days) and P concentrations were significantly affected by P fertilization only in the last harvest, where it increased from 0.27 to 0.78 g P/kg DM. However, application of only 200 kg N/ha will produce more than 60 % of the DM yield response achieved with 800 kg N/ha. Similarly, there seems little merit in applying more than 22 kg P/ha with the N. Longer-term studies are needed to test these hypotheses along with economic assessments to determine the financial soundness of such decisions.

**Keywords:** Export, extraction, nutrient, yield.

**Resumen**

El pasto elefante destaca por su alta producción de materia seca por unidad de área y por su buen valor nutricional, se cultiva en todo Brasil. Este trabajo tuvo como objetivo evaluar la productividad del pasto elefante cultivar 'Cameroon' fertilizado con diferentes dosis de nitrógeno (N) y fósforo (P). El diseño experimental fue en bloques al azar con diez tratamientos y cuatro repeticiones. Los tratamientos consistieron en cinco dosis de nitrógeno (0, 200, 400, 600 y 800 kg/ha de N) todo con 66 kg/ha de P y cinco dosis de fósforo (0, 22, 44, 66 y 88 kg/ha de P) todo con 600 kg/ha de N. Las variables evaluadas fueron: rendimiento de materia seca (MS) de los brotes, concentraciones de N y P en los brotes y absorción de N y P en el forraje. Los resultados mostraron que, en el arenosol del área experimental, se puede producir altos rendimientos de pasto (40–41 t MS/ha) en 260 días, cuando se aplica altas dosis de N y P. El pasto extrajo grandes cantidades de N (en promedio, 800 kg N/ha durante 260 días) y las concentraciones de P se vieron significativamente afectadas por la fertilización con fósforo solo en la última cosecha, donde aumentó de 0.27 a 0.78 g P/kg MS. Sin embargo, la aplicación de solo 200 kg

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N/ha producirá más del 60 % de la respuesta de rendimiento de MS lograda con 800 kg N/ha. De manera similar, no se justifica aplicar más de 22 kg P/ha con el N. Se necesitan estudios a más largo plazo para probar estas hipótesis junto con evaluaciones económicas para determinar la solidez financiera de tales decisiones.

**Palabras clave:** Exportación, extracción, nutrientes, producción.

## Introduction

Elephant grass (*Cenchrus purpureus* Schum.) Morrone (syn. *Pennisetum purpureum* Schum.) stands out for its high dry matter (DM) production per unit area and good nutritional value, being cultivated throughout Brazil and tolerating unfavorable climatic conditions, such as drought and cold temperatures (Queiroz Filho et al. 2000). Historically, this plant has been used as a forage reserve, and is an important complement to bulky feed for animals on rural properties. In addition to this use, in recent years research has shown that Elephant grass has the potential to be used as an alternative biomass for energy production, mainly due to its high dry matter yields (Mello et al. 2002; Quesada et al. 2003).

Elephant grass has high nutritional requirements, due to its high production potential. Thus, any nutritional deficiency during its development will limit production (Avalhaes et al. 2009). Arenosols are sandy soils with low levels of organic matter and low water retention (Costa et al. 2013). In Brazil, arenosols are common in coastal regions and in regions with high precipitation rates, where leaching of basic cations can cause low fertility (Speratti et al. 2018). However, there is little information on the effects of fertilizer application on production of Elephant grass on arenosols.

Nitrogen (N) is directly linked to processes involved in plant growth and development (Porto et al. 2012), being an essential constituent of proteins and important in the photosynthetic process, due to its participation in the chlorophyll molecule (Martuscello et al. 2016). Optimal fertilizer requirements must be carefully defined as cost of N fertilizers is high (Primavesi et al. 2004).

After N, phosphorus (P) is the nutrient that most limits forage production when limited in supply (Oliveira et al. 2007; Foloni et al. 2008). Although the total amount of P in soil is relatively high, it is generally not found in its plant-available form (Santos et al. 2010). P has important functions at the initial stage of development of forage plants, when there is intense meristematic activity due to root system development and tillering. In addition, P is essential for cell division, due to its role in the structure of nucleic acids (Cantarutti et al. 2002). It is also crucial for plant metabolism in energy transfer in cells, respiration and photosynthesis, being a structural component of genes and chromosomes, as well as many coenzymes, phosphoproteins and phospholipids.

Considering the importance of both nutrients in maintaining the productive potential of Elephant grass, as well as the lack of tables of recommendations calibrated for the arenosols in the region, it is important to conduct studies evaluating the responses of agricultural crops as a function of varying doses of essential nutrients. Thus, this study aimed to evaluate the performance of Elephant grass cultivar 'Cameroon' fertilized with N and P at a range of doses in an endeavor to develop an understanding of optimal levels of these nutrients to apply. A serious concern for soil management is the amount of N and P which is taken up by the pasture grass. The amount of N and P that is absorbed by the pasture is crucial for the extrapolation of the fertilizer dose. The correct amount of N and P promotes optimal plant growth and it makes fertilization economically viable. In addition, the correct dose of N can avoid contamination of water courses by leaching of excess of N. We also evaluated N and P concentration and uptake to understand Elephant grass growth in response to N and P doses.

## Materials and Methods

The field experiment was installed in an area of the Agricultural School of Jundiaí, belonging to the Federal University of Rio Grande do Norte, in Macaíba-RN, Brazil (5°53' S, 35°21' W; 15 masl).

The local climate is a transition between the types As and BSw of Köppen's classification system, with high temperatures throughout the year (annual average 27 °C, maximum 32 °C and minimum 21 °C). Average annual rainfall is 1,071 mm, with rainy season from March to July (IDEMA 2013).

The soils of the experimental area are classified as arenosols (quartzipsamments), with sandy texture and gently sloping topography (Beltrão et al. 1975). Before the experiment, 20 individual soil samples were collected from the 0–20 cm horizon of the experimental area and homogenized to obtain a composite sample, which was sent to the laboratory for chemical and physical characterization (Table 1), following the methodology proposed by EMBRAPA (1997).

**Table 1.** Chemical and physical characteristics in the 0–20 cm horizon of the soil of the experimental area before the experiment

| pH[1] | OM | $N_{total}$ | P | $K^+$ | $Na^+$ | $Ca^{2+}$ | $Mg^{2+}$ | $Al^{3+}$ | (H+Al) | Sand | Silt | Clay |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ($H_2O$) | (g/kg) | | (mg/dm³) | | | (cmol$_c$/dm³) | | | | (g/kg) | | |
| 5.9 | 2.64 | 0.70 | 1 | 32.8 | 5.3 | 0.4 | 1.2 | 0.05 | 0.83 | 940 | 40 | 20 |

OM = organic matter.

The experimental design was randomized blocks with 11 treatments and 4 replicates. The treatments consisted of 5 levels of nitrogen (N) (0, 200, 400, 600 and 800 kg N/ha) in the presence of 66 kg P/ha and 5 levels of phosphorus (P) (0, 22, 44, 66 and 88 kg P/ha) in the presence of 600 kg N/ha. All treatments were fertilized with 125 kg K/ha, 30 kg S/ha, 1.0 kg B/ha, 3.0 kg Zn/ha and 0.5 kg Cu/ha (Table 2). The commercial fertilizers used in applying the nutrients were urea, ammonium sulfate, triple superphosphate, potassium chloride and FTE BR-12 as source of the micronutrients.

**Table 2.** Doses (kg/ha) of nutrients applied in the various treatments to evaluate effects on DM yield of Elephant grass and concentrations and uptake of N and P.

| Treatment | N | P | K | S | B | Zn | Cu |
|---|---|---|---|---|---|---|---|
| 1 | 0* | 66 | 125 | 30 | 1 | 3 | 0.5 |
| 2 | 200 | 66 | 125 | 30 | 1 | 3 | 0.5 |
| 3 | 400 | 66 | 125 | 30 | 1 | 3 | 0.5 |
| 4 | 600 | 66 | 125 | 30 | 1 | 3 | 0.5 |
| 5 | 800 | 66 | 125 | 30 | 1 | 3 | 0.5 |
| 6 | 600 | 0* | 125 | 30 | 1 | 3 | 0.5 |
| 7 | 600 | 22 | 125 | 30 | 1 | 3 | 0.5 |
| 8 | 600 | 44 | 125 | 30 | 1 | 3 | 0.5 |
| 9 | 600 | 66 | 125 | 30 | 1 | 3 | 0.5 |
| 10 | 600 | 88 | 125 | 30 | 1 | 3 | 0.5 |

*Control

Each experimental plot was 2.8 m wide by 3.0 m long and contained 4 rows of Elephant grass, with inter-row spacing of 0.7 m. The usable area of the plot measured 4.2 m², consisting of the 2 central rows.

Initially, soil tillage was performed as light harrowing using a tractor, the area was demarcated by delimiting the total space of the experiment, blocks and plots, and then furrows were opened manually with a hoe. All doses of P, S, B, Zn and Cu were applied at the bottom of the furrow before planting, together with 10 % of the N dose and 10 % of the K dose.

The remaining 90 % of N and K fertilizers was split into equal amounts and applied on 6 occasions: 30 and 60 days after planting, 15 and 45 days after the first harvest and 15 and 45 days after the second harvest. Urea, ammonium sulfate and potassium chloride used in these top-dressings were applied in furrows 0.15 m from the grass rows.

The Elephant grass (*Cenchrus purpureus*) cultivar 'Cameroon' was planted by placing whole stems of the grass at the bottom of the furrows according to the end-to-end system, and then cutting them into approximately 70-cm-long pieces. During the study, whenever necessary, the grass was irrigated using a conventional sprinkler.

Following planting, the Elephant grass was studied for 260 days between December 2016 and August 2017. The first harvest was performed at 110 days after planting at an average height of 288 cm, the second harvest at 75 days later at an average height of 245 cm and the third harvest at 75 days later at an average height of 227 cm, i.e. at intervals of 110, 75 and 75 days.

At each harvest, plants from the middle 2 rows (usable area) of each plot were cut at soil level to determine the amount of dry matter produced in each plot. After weighing of the fresh forage, all harvested plants from each plot were chopped with a forage chopper machine (M-600 Chopper with a 3 hp engine) and then homogenized. Samples of this chopped material were then collected and dried in a forced-air circulation oven at 65 ºC. After reaching a constant weight, the samples were weighed and ground in a Wiley-type mill and mineralized by sulfuric acid digestion, following the methodology of Tedesco et al. (1995). N was quantified by the Kjeldahl method and P was quantified by colorimetric method. N and P uptakes were calculated by multiplying DM yield by the N and P concentrations.

After data collection and tabulation, results were subjected to analyses of variance and regression, using the software program SISVAR v. 5.6 (Ferreira 2011). For each characteristic evaluated, the mean square of residuals of the analysis of variance was used as an experimental error to test the significance of the coefficients of the regression models to be fitted. We also compared the means by the LSD test at the 5 % probability level.

## Results

Analyses of variance and regression revealed a significant positive effect of increasing N fertilizer level on forage dry matter (DM) yield at all harvests and, consequently, on the accumulated DM yield over the 3 harvests (Table 3).

**Table 3.** Effects of N fertilizer level on dry matter yield of Elephant grass at 1st, 2nd and 3rd harvests (intervals of 110, 75 and 75 days) and overall, and estimates of the parameters of the fitted regression models (square root, linear and quadratic).

| N dose (kg/ha) | Dry matter yield (t DM/ha) | | | Total |
|---|---|---|---|---|
| | 1st harvest | 2nd harvest | 3rd harvest | |
| 0 (Control) | 11.2 | 7.23 | 6.64 | 25.1 |
| 200 | 16.8 | 8.33 | 9.64 | 34.8 |
| 400 | 18.0 | 8.68 | 9.80 | 36.5 |
| 600 | 19.1 | 10.25 | 12.17 | 39.8 |
| 800 | 18.1 | 12.48 | 10.60 | 41.3 |
| Average | 16.7 | 9.5 | 9.8 | 35.5 |
| LSD | 4.7 | 2.3 | 2.2 | 7.2 |
| ANOVA | ** | ** | ** | ** |
| $b_0$ | 11.18 | 6.91 | 6.68 | 25.18 |
| $b_1$: X | -0.0108 | 0.0062 | -0.0041 | -0.0051 |
| $b_2$: $X^{0.5}$ | 0.5629 | - | 0.2518 | 0.7097 |
| $b_3$: $X^2$ | - | - | - | - |
| $R^2$ | 0.98 | 0.93 | 0.99 | 0.99 |

Application of all fertilizer levels increased DM yield relative to Control at first and third harvests and overall (total production) (Table 3). However, at the second harvest, only N doses higher than 600 kg N/ha produced more DM than the Control (Table 3).

The square root model was the most suitable for representing the effects of N fertilizer level on DM yields at the first and third harvests plus total production of Elephant grass, while the simple linear model was the most suitable for representing DM yield at the second harvest (Table 3). Highest DM yield over the 260 days of occurred at a dose of 800 kg N/ha (41.3 t DM/ha). Mean DM yield at the first harvest exceeded those at the second and third harvests.

DM yield increase with the first 200 kg N/ha was greater than increases with subsequent increments of 200 kg/ha (Table 3).

There was a positive effect of N fertilizer level on N concentration in harvested forage at the first and third harvests ($P<0.01$), but differences failed to reach significance at the second harvest, despite absolute values being similar for all harvests (Table 4). At the first harvest, N applications of 600 and 800 kg N/ha increased N concentration in forage relative to Control, while at the third harvest applications of 400 kg N/ha and above increased N concentration in forage ($P<0.01$).

N uptake by Elephant grass increased significantly ($P<0.01$) with applications of 200 kg N/ha and above at first and third harvests and overall (Table 4). However, at the second harvest, only N doses of 600 and 800 kg N/ha had greater N uptake than Control (Table 4).

N uptake by Elephant grass at the first harvest (208–480 kg N/ha) exceeded those at the second and third harvests (150–260 and 124–290 kg N/ha, respectively) (Table 4).

DM yields of Elephant grass at the first and second harvests were not affected by P application ($P>0.05$; Table 5). However, at the third harvest and overall, application of 44 kg P/ha and above significantly increased DM yields ($P<0.01$; Table 5).

**Table 4.** Effects of N fertilizer level on N concentration in forage and N uptake by Elephant grass at 1st, 2nd and 3rd harvests (intervals of 110, 75 and 75 days, respectively) and overall, and estimates of the parameters of regression models (square root, linear and quadratic).

| N dose (kg/ha) | N concentration (g/kg) | | | N uptake (kg/ha) | | | Total |
|---|---|---|---|---|---|---|---|
| | 1st harvest | 2nd harvest | 3rd harvest | 1st harvest | 2nd harvest | 3rd harvest | |
| 0 (Control) | 18.7 | 20.8 | 18.7 | 208.2 | 149.8 | 123.6 | 482 |
| 200 | 19.3 | 19.3 | 21.6 | 320.6 | 160.7 | 207.9 | 689 |
| 400 | 21.0 | 17.7 | 23.6 | 380.6 | 156.8 | 231.0 | 768 |
| 600 | 26.7 | 24.5 | 26.7 | 509.1 | 251.1 | 277.8 | 1,038 |
| 800 | 25.4 | 21.9 | 25.4 | 451.0 | 268.2 | 301.6 | 1,021 |
| Average | 22.2 | 20.9 | 23.2 | 373.9 | 197.3 | 228.4 | 800 |
| LSD | 4.4 | 5.7 | 3.1 | 89.1 | 69.8 | 52.1 | 141.3 |
| ANOVA | ** | ns | ** | ** | ** | ** | ** |
| $b_0$ | 18.53 | 19.36 | 18.4 | 200.2 | 147.7 | 124.3 | 477.2 |
| $b_1$: X | -0.1244 | - | - | - | - | 4.7208 | - |
| $b_2$: $X^{0.5}$ | 0.0146 | 0.0037 | 0.0199 | 0.7264 | 0.0056 | 0.055 | 1.0838 |
| $b_3$: $X^2$ | - | - | 0.00001 | 0.00049 | 0.0002 | - | 0.00046 |
| $R^2$ | 0.83 | 0.20 | 0.95 | 0.93 | 0.88 | 0.99 | 0.95 |

**Table 5.** Effects of P fertilizer level on dry matter yield of Elephant grass at 1st, 2nd and 3rd harvests (intervals of 110, 75 and 75 days, respectively) and overall, and estimates of the parameters of regression models (square root, linear and quadratic).

| P dose (kg/ha) | Dry matter yield (t DM/ha) | | | Total |
|---|---|---|---|---|
| | 1st harvest | 2nd harvest | 3rd harvest | |
| 0 (Control) | 14.76 | 8.19 | 6.98 | 29.93 |
| 200 | 19.02 | 10.24 | 9.28 | 38.54 |
| 400 | 17.92 | 10.63 | 11.02 | 39.57 |
| 600 | 16.61 | 11.56 | 11.28 | 39.45 |
| 800 | 19.30 | 11.22 | 12.08 | 42.58 |
| Average | 17.79 | 10.37 | 10.13 | 38.29 |
| LSD | 3.49 | 2.52 | 2.45 | 5.97 |
| ANOVA | ns | ns | ** | ** |
| $b_0$ | 14.98 | 8.29 | 7.05 | 30.10 |
| $b_1$: X | -0.0623 | 0.0892 | 0.1144 | -0.0849 |
| $b_2$: $X^{0.5}$ | 0.9173 | - | - | 2.0232 |
| $b_3$: $X^2$ | - | -0.0006 | -0.0007 | - |
| $R^2$ | 0.59 | 0.96 | 0.99 | 0.96 |

P concentrations in Elephant grass forage at the first and second harvests were not significantly affected by P fertilizer level applied (P>0.05; Table 6), while at the third harvest P concentration increased linearly with increasing level of P fertilizer application (P<0.01).

Uptake of P by Elephant grass followed the same trend as data for P concentration in forage, with no significant effect of P fertilizer application (P>0.05) at the first and second harvests and a positive linear effect at both the third harvest and overall (P<0.01) (Table 6).

## Discussion

While this study has shown that Elephant grass cultivar 'Cameroon' showed good growth responses to application of N fertilizer, the greatest response per unit of N applied occurred with the first 200 kg N/ha. Sixty percent of the total N response in DM yield occurred with the application of only 200 kg N/ha. In fact, the increase in DM yield with the first 200 kg N/ha was 50 % greater than the total response to the next 600 kg N/ha, a fine example of the law of diminishing returns. While average DM yield decreased by 42 % from the first to the second harvest and remained at a similar level for the third harvest, the longer growth period prior to the first harvest would have played a major part in the higher yields at that stage, along with the higher application of N to all treatments during that growth period (40 vs. 30 % of total N applied). Release of nutrients in soil following cultivation prior to planting may have also contributed.

Higher DM yields at the first harvest after planting, compared with those at later harvests, have also been reported by other authors (Morais et al. 2009; Santos et al. 2014). In those studies, growth period between planting and the first harvest was longer than growth

**Table 6.** Effects of P fertilizer level on P concentration in forage and P uptake by Elephant grass forage at 1st, 2nd and 3rd harvests (intervals of 110, 75 and 75 days, respectively) and overall, and estimates of the parameters of regression models (square root, linear and quadratic).

| P dose (kg/ha) | P concentration (g/kg) | | | P uptake (kg/ha) | | | Total |
|---|---|---|---|---|---|---|---|
| | 1st harvest | 2nd harvest | 3rd harvest | 1st harvest | 2nd harvest | 3rd harvest | |
| 0 (Control) | 0.83 | 0.20 | 0.27 | 12.35 | 1.67 | 1.33 | 15.35 |
| 200 | 0.83 | 0.51 | 0.34 | 15.96 | 4.88 | 3.23 | 24.07 |
| 400 | 0.89 | 0.49 | 0.44 | 16.12 | 5.19 | 4.86 | 26.17 |
| 600 | 0.82 | 0.56 | 0.55 | 13.04 | 5.54 | 7.36 | 25.94 |
| 800 | 0.88 | 0.54 | 0.78 | 17.09 | 6.92 | 7.77 | 31.78 |
| Average | 0.85 | 0.46 | 0.48 | 14.91 | 4.84 | 4.91 | 24.66 |
| LSD | 0.48 | 0.37 | 0.15 | 9.00 | 3.77 | 1.15 | 8.36 |
| ANOVA | ns | ns | ** | ns | ns | ** | ** |
| $b_0$ | 0.832 | 0.20 | 0.23 | 12.55 | 1.75 | 1.51 | 17.72 |
| $b_1$: X | - | 0.0835 | - | 0.7973 | 0.6523 | - | - |
| $b_2$: $X^{0.5}$ | 0.0004 | -0.0051 | 0.0056 | -0.0507 | -0.0150 | 0.0770 | 0.1589 |
| $b_3$: $X^2$ | - | - | - | - | - | - | - |
| $R^2$ | 0.19 | 0.97 | 0.95 | 0.41 | 0.96 | 0.97 | 0.85 |

periods prior to subsequent harvests. The average accumulated DM yields for the 3 harvests obtained in our study, despite being high, were still lower than the yields of 61.9–85.3 t DM/ha observed in the studies of Santos et al. (2014) and Morais et al. (2009). Those authors cultivated Elephant grass in soils with higher fertility than that of the arenosol used in the present study (Table 1). In addition, total growth periods in those studies (660 days) were much longer than the 260 days in the present study.

Despite limited differences in N concentration in harvested forage with increasing N application rates, N uptake by the forage generally increased with increase in N application. It is worth pointing out that both N concentration and N uptake are highly subject to the effects of dilution and DM yields of forage, because of the increase in DM accumulation in shoots following application of N fertilizer. Thus, the limited variation in N concentration in forage merely masked the increased uptake of N by plants as level of N fertilizer increased. However, N concentration in forage at harvest ranged from 1.87 to 2.67 % for individual treatments at individual harvests. The N content exceed the level the N content normally found in grasses (1.5 to 2.0 %), but the N contents are adequate for Elephant grass (Avalhaes et al. 2009; Morais et al. 2011). Although converting leaf nitrogen content to leaf protein by multiplying by 6.25 may overestimate the true protein content of raw materials, it is widely accepted as an industry standard (Walsh et al. 2018). The higher levels of N, equivalent to 16.7 % protein, are adequate even for high-producing dairy cows (Busanello et al. 2017; Alessio et al. 2020).

A serious concern for soil management is the amount of N which is taken up by the pasture grass. Total uptake of N by the various treatments during the 260 days ranged from 480 to 1,040 kg N/ha. Under a cut-and-carry system of feeding, removal of these amounts of N from the soil-pasture system could lead to a depletion of soil N levels over time unless the manure from animals is returned to the pasture or N fertilizer is applied. Flores et al. (2012), testing the effects of N fertilizer and harvest age on DM production of Elephant grass in the Brazilian Cerrado, observed that applying 150 kg N/ha produced an uptake of 471 kg N/ha at 180 days after planting. Fagundes et al. (2007) evaluated the influence of N fertilizer application on DM production of Elephant grass cultivar 'Guaçu' and observed an increase in N extraction by the grass as level of N applied increased. In the Control treatment in our study, 482 kg N/ha was taken up by Elephant grass, which would have come from the mineralization of soil organic matter and breakdown of plant residues incorporated into the soil before planting plus biological nitrogen fixation. Morais et al. (2011), using $^{15}N$ natural abundance technique, reported contributions of biological N fixation above 50 % of the N requirement in Elephant grass. The association of Elephant grass plants with some $N_2$-fixing bacteria, such as *Gluconacetobacter diazotrophicus*, *Herbaspirillum seropedicae* and *H. frisingense*, has been reported in the literature (Kirchhof et al. 2001; Reis et al. 2001; Camelo et al. 2021; Santos et al. 2021). In another study, Morais et al. (2009) observed N accumulation of 217 kg N/ha in Elephant grass cultivar 'Cameroon', when harvest was delayed until 12 months after planting.

Martuscello et al. (2009), studying critical levels of P in soil and in the shoots of Elephant grass during establishment, obtained lower DM yields than those found in this study. The highest yields were 9.3 and 12.7 t DM/ha, combined yields from first and second harvests at 50 and 110 days after planting, following applications of 52 and 131 kg P/ha, respectively. P concentration in forage at the second and third harvests in our study increased with increase in P doses applied to the soil. Martuscello et al. (2009) also observed an increase in P concentration in Elephant grass as a function of increase in P doses applied. At both first and second harvests, these authors recorded average P concentrations in plant material of 1.0 g/kg DM for the control and 1.4 g/kg DM when 131 kg P/ha was applied, higher than those obtained in the present study for similar conditions of low initial P availability (0.6 $mg/dm^3$). On the other hand, Moreira et al. (2006) found P concentrations in plants at the first harvest of 0.7 g/kg DM for control and 1.7 g/kg DM, when 131 kg P/ha was applied. In general, P concentrations in herbage >0.3 % are adequate for ruminants (Suttle 2010). In Elephant grass, application of 22 kg P/ha fulfilled this objective in our study.

## Conclusions

In the arenosol of the experimental site, while high doses of nitrogen and phosphorus produced the highest yields of elephant grass cultivar 'Cameroon', i.e. 37.4–40.0 t DM/ha over 3 harvests (260 days) with doses of 600 kg N/ha, satisfactory DM yields were obtained at 200 kg N/ha. Further longer-term studies (over at least 2 years) are needed to confirm this finding along with economic assessments to determine the financial soundness of these strategies. It appears that there is little merit in applying more than 22 kg P/ha to the grass pastures, but longer-term studies would determine if this hypothesis is correct.

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*(Note of the editors: All hyperlinks were verified 8 July 2022).*

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