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The amazonian capim-açú is less nitrogen dependent than antelope grass to produce leaf dry matter[1]

O capim-açú amazônico é menos dependente de nitrogênio que o capim canarana para produzir matéria seca de folhas

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HIGHLIGHTS:
Potential of native species for forage production in Baixada Maranhense.
Comparison between the performance of capim-açú (Paspalum plicatulum) and antelope grass (Echinochloa pyramidalis).
Capim-açú has a high nitrogen use efficiency under lower N doses compared to antelope grass.

ABSTRACT: The Maranhão floodplain is dominated by native grasses like capim-açú (*Paspalum plicatulum*, Mich.). Due to scarce information on nutrient demands of native species, farmers are replacing native pastures by exotic and potentially invasive species such as antelope grass (*Echinochloa pyramidalis*, Lam). The aim of this study was to compare the growth of capim-açú and antelope grass, under varying N and K doses, to better understand the potential of capim-açú to be used as forage. The experiment was carried out in pots, consisting of a 2 × 5 × 2 factorial scheme (2 species × 5 N doses × 2 K doses) with four repetitions, in a completely randomized design. The N doses of 0, 50, 100, 150 and 200 mg dm^{-3} were combined with 10 and 30 mg dm^{-3} K_2O. The capim-açú produces higher leaf to stem ratio aboveground by using lower nitrogen and potassium doses than antelope grass. Leaf, stalk, and total dry matter production of both studied species do not respond to potassium doses.

Key words: *Paspalum plicatulum*, *Echinochloa pyramidalis*, fertilization, plant growth, potassium

RESUMO: Devido à escassez de informações das espécies nativas, as pastagens naturais têm sido substituídas por espécies exóticas e potencialmente invasoras como o capim canarana (*Echinochloa pyramidalis*). Assim, O objetivo deste estudo foi comparar o crescimento do capim-açú e do capim-antílope, em diferentes doses de N e K, para melhor compreender o potencial do capim-açú para ser utilizado como forragem. O experimento foi conduzido em vasos, em um esquema fatorial 2 × 5 × 2 (2 espécies × 5 doses de N × 2 doses de K) com quatro repetições, em delineamento inteiramente casualizado. As doses de N de 0, 50, 100, 150 e 200 mg dm^{-3} foram combinadas com 10 e 30 mg dm^{-3} K_2O. O capim-açú produz mais matéria seca de folhas e menos matéria seca do caule acima do solo, utilizando menor dose de nitrogênio, quando comparado ao exótico capim canarana. A produção de folhas, caules e matéria seca total de ambas as espécies estudadas não responde às doses de potássio.

Palavras-chave: *Paspalum plicatulum*, *Echinochloa pyramidalis*, adubação, crescimento, potássio

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Introduction

In order to withstand growing food demands, food production must be increased in a sustainable way; by increasing productivity or by using marginal lands (Pittelkow et al., 2015; Chaldhary et al., 2018). The Maranhão floodplain ("Baixada Maranhense"), Brazil, is a typical boundary area, located between the Amazonian rain forest and dry savanna, characterized by alternating periods of intense rainfall and flooding with severe dry seasons (Silva et al., 2015; 2019). Capim-açú grass (*Paspalum plicatulum* Mich) naturally occurs in the Maranhão floodplain; however, due to scarce information on nutritional requirements of capim-açú, farmers often replace native pastures with exotic species (Tamele et al., 2017) such as antelope grass (*Echinochloa pyramidalis* Lam). Antelope grass is considered an invasive species (López Rosas et al., 2015), that may lead to future environmental problems. Pasture grasses usually are very responsive to N availability in the soil (Paiva et al., 2012; Costa et al., 2013; Gazola et al., 2019), and this response can be more evident under suitable K supply (Prajapati & Modi, 2012; Sanchês et al., 2013; Morais et al., 2016). In addition, antelope grass plant characteristics (Clayton et al., 2006) are very different from those of capim-açú (Machado et al., 2013), which may lead to differences in plant growth responses to N and K fertilization. Moreover, some studies suggest that native plants have a series of characteristics that provide resilience and fast recovery after the drought period (Maranhão et al., 2019), and may have a higher nitrogen use efficiency compared to exotic species (Reed et al., 2011; Shivega & Aldrich-Wolfe, 2017). Thus, the hypothesis that capim-açú and antelope grass may respond differently to N and K supply was evaluated by comparing the growth of capim-açú to antelope grass, under varying N and/or K doses of fertilization.

Material and Methods

The experiment was carried out under greenhouse conditions at the Universidade Federal do Maranhão, in Chapadinha, MA, Brazil (03° 44' 06" S, 43° 19' 00" W, at 100 m of altitude), Brazil, in 2015. The soil, and plant seedlings used in this assay were all collected at Ingaí Farm, in Vitória do Mearim, MA (03° 27' 51" S, 44° 51' 47" W), located in the legal Amazon area (Figure 1).

The soil was classified as a Plinthosol (Plinthaquox), and it was collected from the layer of 0-0.20 m, during rainy season, where grasses are normally growing. This soil was dried under room conditions, mechanically homogenized, sieved (mesh of 5 mm), and characterized following methods described by Raij et al. (2001). The chemical characteristics of the soil were: pH = 4.6, P = 7 mg dm^{-3}, organic matter = 19 g kg^{-1}, S = 5 mg dm^{-3}, K = 1.1 mmol$_c$ dm^{-3}, Ca = 21 mmol$_c$ dm^{-3}, Mg = 9 mmol$_c$ dm^{-3}, H + Al = 22 mmol$_c$ dm^{-3}, Al = 7 mmol$_c$ dm^{-3}, cation exchange capacity = 53 mmol$_c$ dm^{-3}, and sum of bases = 31 mmol$_c$ dm^{-3}, corresponding to a base saturation (V%) of 58%.

A series of 80 identical plastic pots (0.20 m height, 0.20 m average diameter, 0.031 m^2 of soil surface area) were filled with 6 dm^3 of the mentioned soil (density = 1.4 kg dm^{-3}). According to the soil analysis, and following recommendations of Cantarutti et al. (1999), liming was not needed because the soil V% (58%) was above that indicated for growing grasses (50%), and P fertilization was done by applying 15 mg dm^{-3} P (equivalent to 70 kg ha^{-1} P_2O_5) as simple superphosphate (18% P_2O_5) which was completely incorporated manually, mixing into the soil of each pot separately. Then the soil was moistened and seedlings were planted. Six individual tillers of antelope grass were planted in each pot, while for capim-açú three clumps (containing 10 tillers each) were planted per pot to compensate for morphological differences among species, and to culture equivalent seedlings.

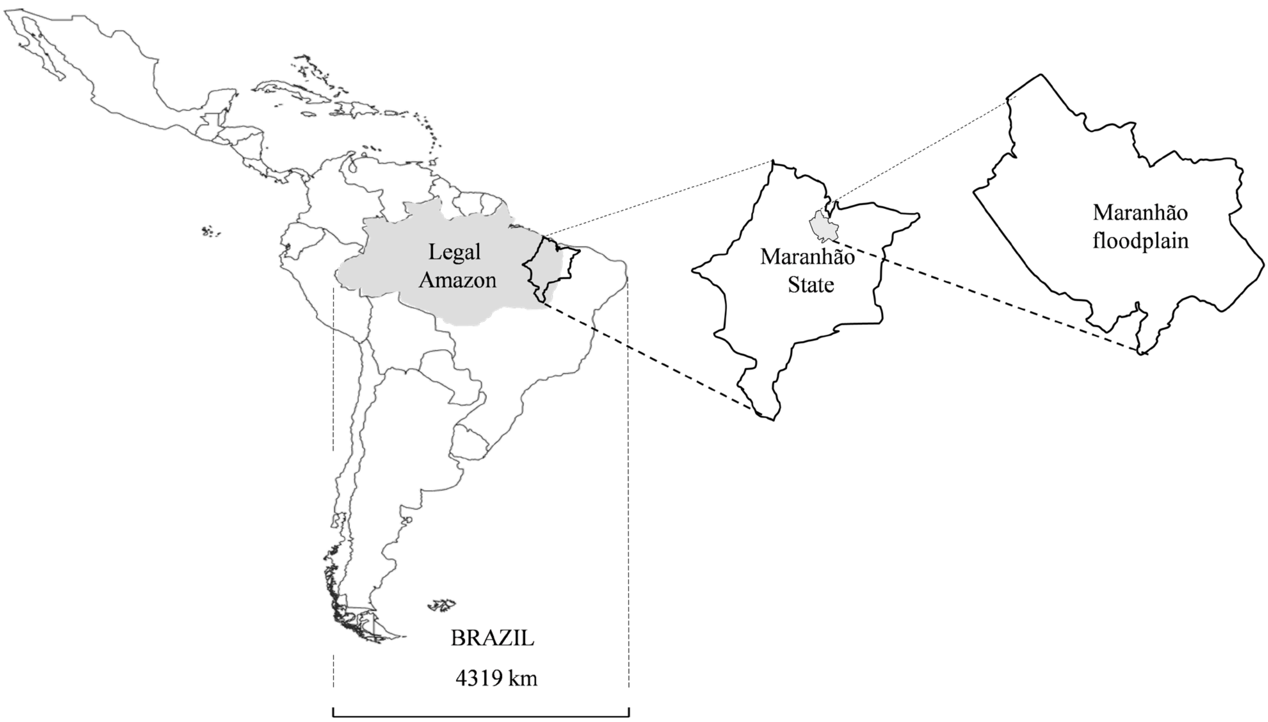


Figure 1. Location of the Maranhão Floodplain ("Baixada Maranhense") in the area of Legal Amazon, and in the Maranhão State, Brazil

Plants of all experimental units were irrigated daily (to maintain approximately 70% of maximum soil capacity) and grown under the same conditions until 30 DAP (days after planting). At this time, all plants were cut at 10 cm above the soil surface to standardize growth and begin treatment applications.

The experiment consisted of a 2 × 5 × 2 factorial scheme (2 species × 5 N doses × 2 K doses, respectively). The native forage species studied was capim-açú (*Paspalum plicatulum* Mich) in comparison to an exotic species: antelope grass (*Echinochloa pyramidalis* Lam). The N doses applied to the soil were: 0, 50, 100, 150 and 200 mg dm^{-3} (respectively equivalent to doses of 0, 100, 200, 300 and 400 kg ha^{-1} N, incorporated in a 0.20 m soil layer) applied in the form of granular urea. The K doses tested were 10 and 30 mg dm^{-3} K_2O (respectively equivalent to 20 and 60 kg ha^{-1} K_2O) as KCl. The 20 treatments were carried out in pots (6 dm^3), with four repetitions.

The total fertilizer amount related to each respective treatment was divided and applied in three equal portions and applied on the soil surface at 30 (after plants standardizing cut), 58 and 86 DAP (just after the first and second plants cut for respectively first and second evaluation, as below described). Irrigation was applied immediately after each fertilizer's application, in order to incorporate the fertilizers into the soil. The experiment was conducted in a completely randomized design, with pot positions changed weekly in order to circumvent possible environmental variations in the greenhouse.

Plants of all experimental units were evaluated in three consecutive sampling dates: at 58, 86 and 114 DAP, corresponding to periods of approximately one month between cuts (Costa et al., 2010). At each sampling date, the number of living and dead tillers were counted and the antelope grass and capim-açú plants were cut at 15 and 10 cm, respectively, above the soil surface to mimic pasture grazing of cattle and to evaluate additional biometric traits. The harvested samples were fractionated into sub-samples of leaf blade, and stalks (stalk+sheath). For dry matter determination all samples were dried at 65 ± 3 °C to a constant weight. Total plant shoot dry matter was estimated by adding leaf and stalk dry matter. Leaf dry matter proportion over total plant shoot dry matter was calculated and expressed as % (grams of leaf dry matter per 100 g of total plant shoot dry matter).

For plants leaf area determination of each experimental unit, in first instance a sub sample of 10 fully expanded leaf blades were separated into sections of 10 cm length with uniform width. Using the measured width and length the area (A) of those leaf sections were calculated, and dry matter (W) determined. Total plant leaf area (LA) of each experimental unit was estimated by using the formula: LA = LDM · (A/W), in which LA = total leaf area (cm^2) of the experimental unit; LDM = total leaf dry matter (g) of the experimental unit; A = area (cm^2) of the leaf sections; W = dry weight (g) of the leaf sections (Sanchês et al., 2013).

Nitrogen utilization efficiency (NUE) was determined by using the formula: NUE = $(DM_N - DM_0)/N$; where: DM_N = Dry matter (g per pot) of treatment with N; DM_0 = Dry matter (g per pot) of treatment without N; N = nitrogen (g per pot) of that treatment (Cabral et al., 2013).

For leaf area (LA), leaf dry matter (LDM), stalk+sheath dry matter (SDM), total plant dry matter (TDM), number of living tillers (NLT), number of dead tillers (NDT), proportion of leaves on shoot (%L) and NUE determination, values obtained at each of the three sampling dates (58, 86 and 114 DAP) were added.

Statistical analyses were performed using AgroEstat software (Barbosa & Maldonado Junior, 2014). Data related to number of living tillers and dead tillers were transformed to √x to reach normal distribution before statistical analysis. Then, data were subjected to analysis of variance. When F test was significant ($p \leq 0.05$), polynomial regression analysis was applied, in order to describe the effect of the five N doses, and Tukey test to compare between species, and to compare means from the two K tested doses, was carried out.

Results and Discussion

All studied variables were influenced by species and N dose, although independent effects of these factors were detected only for number of living tillers and number of dead tillers (Table 1). Potassium dose (K) significantly ($p \leq 0.01$) affected only the number of dead tillers and the % of leaf on the shoot (Table 1).

Antelope grass showed higher leaf area than capim-açú, and values increased in a quadratic model reaching maximum plant leaf area at 145 mg dm^{-3} N. Doses of N above 145 mg dm^{-3} caused leaf area to decrease. Besides leaf area of capim-açú showed smaller values compared to that of antelope grass, it responded linearly to N doses (Figure 2A). Although capim-açú showed lower leaf area compared to that of antelope

Table 1. Summary of analysis of variance for growth variables of capim-açú (*Paspalum plicatulun*) and antelope grass (*Echinochloa pyramidalis*)

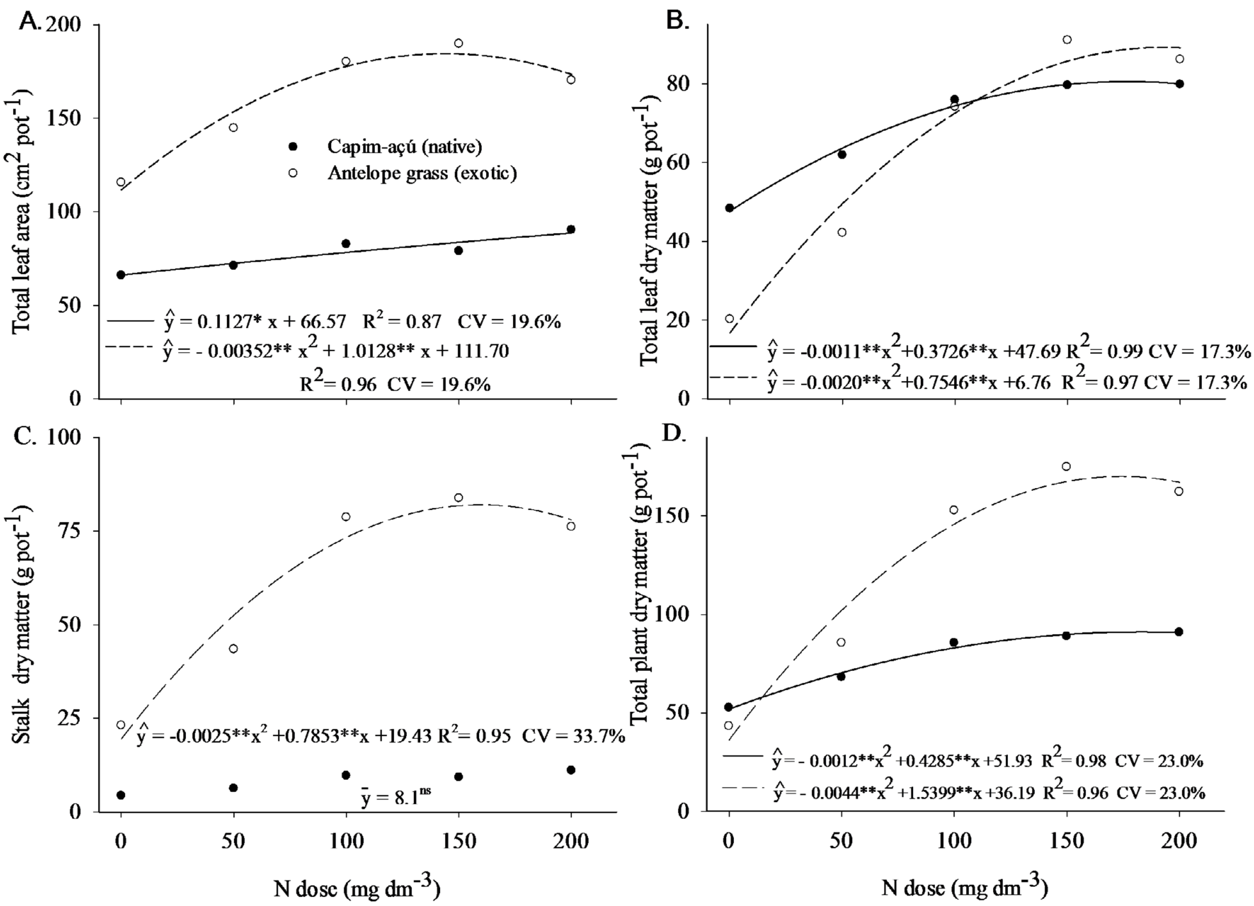
Causes of variation	Variables						
	LA	LDM	SDM	TDM	NLT	NDT	% L
Species (spp)	247.6**	4.6*	372.6**	34.0**	225.4**	65.8**	1004.5**
Potassium (K)	0.8^{ns}	0.4^{ns}	2.3^{ns}	0.5^{ns}	0.6^{ns}	10.2**	10.2**
Nitrogen (N)	10.4**	44.7**	26.4**	32.1**	8.6**	3.4*	0.4^{ns}
spp × K	1.4^{ns}	0.1^{ns}	0.2^{ns}	0.3^{ns}	2.9^{ns}	1.1^{ns}	0.0^{ns}
spp × N	4.0**	6.6**	14.4**	5.1**	2.1^{ns}	0.6^{ns}	1.7^{ns}
K × N	0.6^{ns}	2.3^{ns}	1.3^{ns}	0.6^{ns}	0.1^{ns}	0.9^{ns}	2.6^{ns}
spp × K × N	0.3^{ns}	0.7^{ns}	0.6^{ns}	0.4^{ns}	0.2^{ns}	1.1^{ns}	2.5^{ns}
CV (%)	19.6	17.3	33.7	23.0	26.9	31.2	6.9

LA - Leaf area; LDM - Leaf dry matter; SDM - Stalk + sheath dry matter; TDM - Total plant shoot dry matter; NLT - Number of living tillers; NDT - Number of dead tillers; % L - % of leaf on plant shoot; *, **, ^{ns} - Significant by F test at $p \leq 0,05$, at $p \leq 0,01$ and not significant, respectively grass under the same conditions (Figure 2A), leaf dry matter production was higher for capim-açú at N doses below 100 mg dm^{-3} (Figure 2B).

Under no N fertilization, capim-açú produced approximately 2.4 times more leaf dry matter than antelope grass. Antelope grass needed a dose of approximately 50 mg dm^{-3} N to reach the same leaf dry matter as capim-açú at 0 mg dm^{-3} N. However, at 100 mg dm^{-3} both grasses produced the same values of dry matter (Figure 2B). For doses higher than 100 mg dm^{-3} N capim-açú leaf dry matter was not responsive, while antelope grass continued to increase. Thus, capim-açú leaf production was lower than that of antelope grass at high N doses (Figure 2B). The lower leaf area (Figure 2A) and higher leaf dry matter of capim-açú, at N doses below 100 mg dm^{-3} (Figure 2B), indicates that capim-açú has more dense leaves (more dry matter per unit of leaf area).

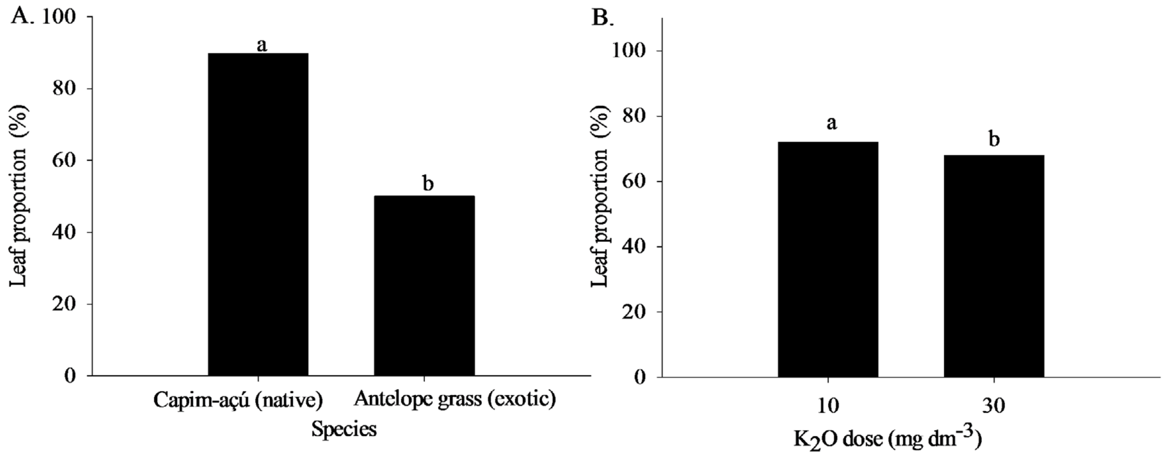
The best results of leaf dry matter production of the native capim-açú are in agreement with those found by Costa et al. (2013), reinforcing the idea that native species have relatively lower N demand (Shivega & Aldrich-Wolfe, 2017) compared to exotic species (Oliveira et al., 2016).

For stalk weight, there was an N fertilization effect ($p \leq 0.05$) for antelope grass, with a quadratic increment reaching the maximum yield at 157 mg dm^{-3} N (Figure 2C). For total plant (stalks + leaves) dry matter, significant ($p \leq 0.01$) effect of the interaction species × N dose was observed (Table 1), and antelope grass plants showed a positive quadratic effect with increasing N doses, reaching the maximum total dry matter production at 175 mg dm^{-3} N. Total plant dry matter of capim-açú was less responsive than antelope grass, although it increased linearly with increases in applied N (Figure 2D). The difference between species observed for stalks and total dry matter (Figures 2C and D) can be justified by the fact that antelope grass is a perennial grass, reaching 1.8-2.4 m height, with upright stems, and with stems continuing to nodes above ground level (Clayton et al., 2006), what leaded to a mean of 50.1% leaf in our research (Figure 3A). By its turn, capim-açú grass has few stems aboveground (average of 89.7% leaf, Figure 3A), which led to a lower total dry matter production than antelope grass (Figure 2D). These results also indicated that increasing K dose leaded to smaller proportion of leaves dry matter, independently of species (Figure 3B). However, this K effect was not observed for mulato grass (Cabral et al., 2017). The Maranhão floodplain area has periods of flooding and intense dry seasons. This leads to the necessity to cultivate grasses that may tolerate those conditions, and produce enough biomass to also be harvested and stored as hay in order to feed animals during periods of less food availability (flooding and/or dry seasons). In this context, the predominance of leaves in capim-açú grass (Figure 3A) also makes this species a good choice to be harvested and conserved as hay. Besides species, K dose also affected ($p \leq 0.01$) leaf proportions (Table 1, Figure 3B). Plants grown under dose of 30 mg dm^{-3} K_2O showed leaf proportions 5.5% lower than those grown under 10 mg dm^{-3} K_2O (Figure 3B).



Pot - Plastic pots with 6 dm^3 and soil surface area of 0,032 m^2; *, **, ns - Significant by F test at $p \leq 0,05$, at $p \leq 0,01$ and not significant, respectively

Figure 2. Leaf area (A), leaf dry matter (B), stalk dry matter (C) and total plant dry matter (D) of capim-açú (*Paspalum plicatulum*) and antelope grass (*Echinochloa pyramidalis*) in function of N dose

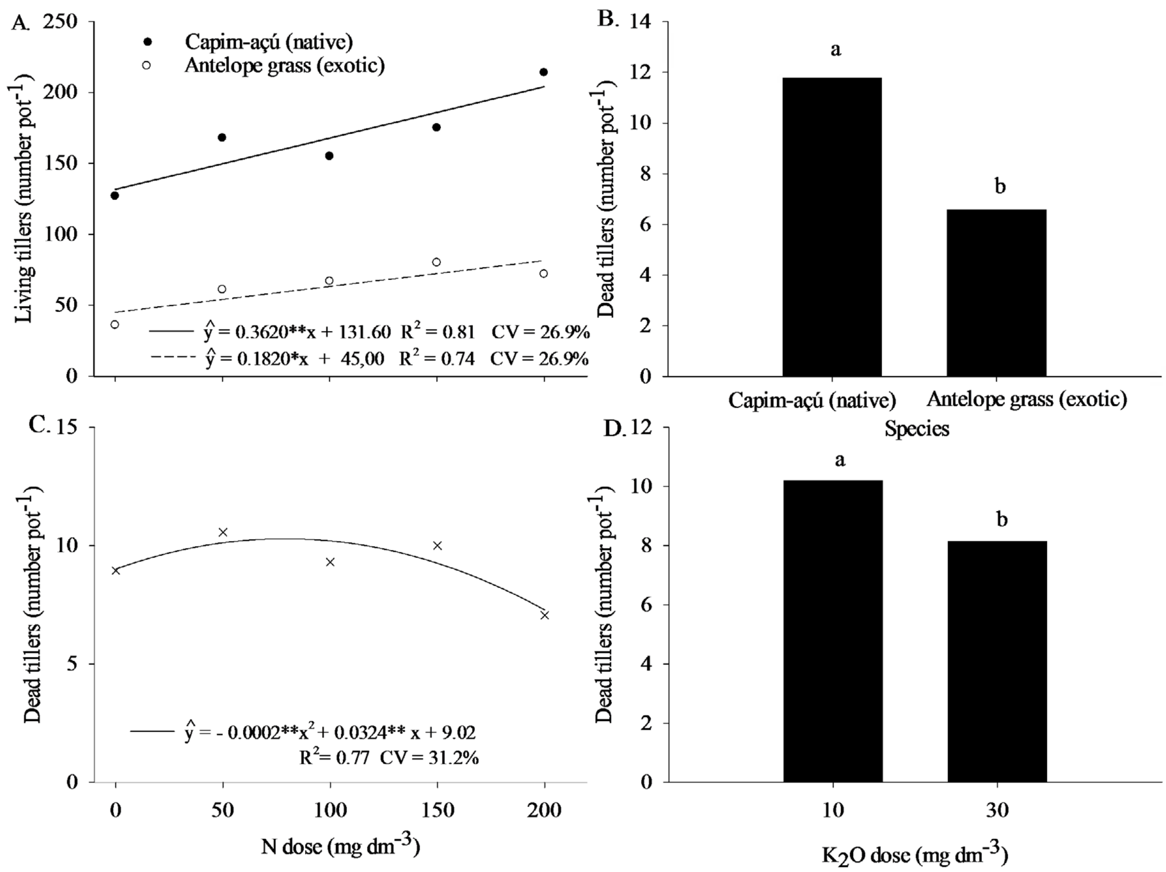


Means (bars) followed by distinct letter differ at p ≤ 0.05 by the Tuckey test

Figure 3. Leaf proportion (dry matter of leaves over total shoot dry mass, expressed as %) in studied species (A), and due to potassium dose (B), of capim-açú (*Paspalum plicatulum*) and antelope grass (*Echinochloa pyramidalis*)

Capim-açú showed significantly ($p \leq 0.01$) more living tillers than antelope grass across N doses (Table 1, Figure 4A). For both species N doses induced significant ($p \leq 0.01$) effect (Table 1) on the number of living tillers, and this variable increased linearly with N dose (Figure 4A). In addition, other researchers determined that capim-açú retains high rates of leaf elongation as well as high values of leaf area for actively growing tillers when fertilized with N (Machado et al., 2013). Also, in the present study living tillers of capim-açú responded to N and K similar to mulato grass (Cabral et al., 2017), and better than palisade grass which is extensively used by farmers due to its high productivity (Sanchês et al., 2013). This supports that capim-açú could be considered as a potential alternative as forage plant to be used in the floodplain Maranhão region, Brazil, Therefore, its replacement by exotic and potentially invasive species like antelope grass (López Rosas et al., 2015) would not seem to be a good alternative.

Number of dead tillers was affected independently by N, K, and spp. (Table 1). Capim-açú showed a greater number of dead tillers compared to antelope grass (Figure 4B). The N dose induced a quadratic effect, increasing the number of dead tillers until the dose of 78 mg dm^{-3} N, but values slightly decreased upon further N doses (Figure 4C). Also, 30 mg dm^{-3} K_2O caused



pot - Plastic pots with 6 dm^3 and soil surface area of 0,032 m^2; *, ** - Significant by F test at $p \leq 0,05$ and $p \leq 0,01$, respectively; Means (bars) followed by distinct letter differ at $p \leq 0.05$ by the Tuckey test

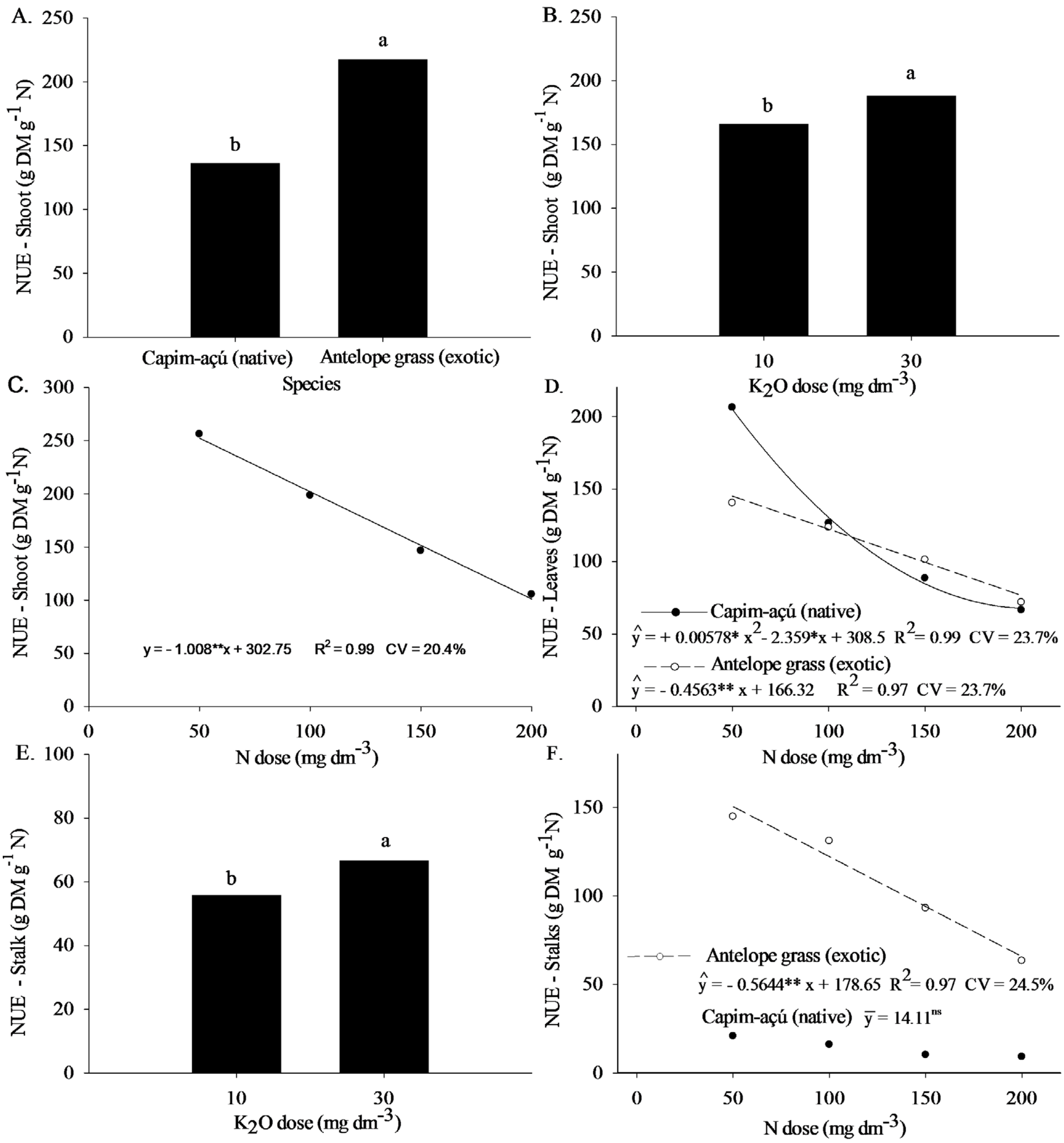
Figure 4. Number of living tillers (A) and number of dead tillers (B) as a function of N dose, also number of dead tillers in each species (C) and in each K dose (D), of capim-açú (*Paspalum plicatulum*) and antelope grass (*Echinochloa pyramidalis*)

a smaller number of dead tillers compared to the dose of 10 mg dm^{-3} K_2O (Figure 4D), probably because K stimulated the maintenance of living tillers as reported by Cabral et al. (2017). Another interesting characteristic of capim-açú is the ability to maintain more living tillers than antelope grass (Figure 4A). This is an indication that in pasture recovery, or new pasture formation, capim-açú would be more efficient than antelope grass. Although capim-açú has more tillers than antelope grass (Figures 4A, B), this species showed a lower proportion of dead to total tillers compared to that of antelope grass. Increasing K dose reduced the number of dead tillers, and this effect of K was independent of the species and N dose, since no significant ($p > 0.05$) interaction effect was detected with N doses or with species, for this variable (Table 1).

In this research, it was observed that the increase of K dose from 10 to 30 mg dm^{-3} K_2O was important to reduce tiller death (Figure 4D), and this was expected because K is important in the activation process of at least sixty enzymes involved in plant growth, photosynthesis reactions and ATP (adenosine triphosphate) production, in stomata activity, in sugar, water and nutrient transport in the plant, as well as protein and starch synthesis (Prajapati & Modi, 2012).

A significant F value ($p \leq 0.05$) was detected for the three-way interaction of N, K, and spp for the dead dry matter production (Table 1). The participation of K dose in the three-way interaction (Table 1) reveals that K should have affected this variable in some way, and that further studies are needed for better understand this effect.

For total plant aerial part (shoot) NUE was influenced by species ($p \leq 0.01$), N ($p \leq 0.01$), and K ($p \leq 0.01$) independently, while NUE for leaves and stalks N effect varied ($p \leq 0.01$) with species (Figure 5, Table 2).



Pot - Plastic pots with 6 dm^3 and soil surface area of 0,032 m^2; * and ** - Significant by F test at $p \leq 0,05$ and $p \leq 0,01$, respectively; Means (bars) followed by distinct letter differ at $p \leq 0.05$ by the Tuckey test

Figure 5. NUE (nitrogen use efficiency), expressed as grams of dry matter (DM) per gram of N, by plants shoot due to species (A), K dose (B), and N dose (C); by leaves due to species and N dose (D), and K dose (E); and by stalks due to species and N dose (F), of capim-açú (*Paspalum plicatulum*) and antelope grass (*Echinochloa pyramidalis*)

Table 2. Summary of analysis of variance for nitrogen use efficiency of plant shoot (NUE - Shoot), leaves (NUE - Leaves), ant stalk+sheath (NUE - Stalks), for capim-açú (*Paspalum plicatulun*) and antelope grass (*Echinochloa pyramidalis*)

Causes of variation	Variables		
	NUE - Shoot	NUE - Leaves	NUE - Stalks
Species (spp)	61.2**	2.6^{ns}	472.3**
Potassium (K)	4.6*	2.1^{ns}	6.4*
Nitrogen (N)	39.4**	31.9**	23.7**
spp × K	0.1^{ns}	0.2^{ns}	0.4^{ns}
spp × N	1.7^{ns}	5.2**	13.6**
K × N	1.5^{ns}	1.6^{ns}	1.4^{ns}
spp × K × N	0.1^{ns}	0.2^{ns}	0.4^{ns}
CV (%)	20.4	23.7	24.5

*, **, ^{ns} - Significant by F test at $p \leq 0{,}05$, at $p \leq 0{,}01$ and not significant, respectively

Capim-açú showed lower NUE for plant shoot as antelope grass (Figure 5A). However, at N doses lower than 100 mg dm^{-3} the NUE of capim-açú leaves was higher than that for leaves of antelope grass (Figure 5D), what is in agreement with data of dry matter production (Figure 2B). Also, NUE of antelope grass stalks was decreased linearly with the increase of N dose, while do not affected the NUE of capim-açú stalks (Figure 5F). The decrease of NUE by increasing N dose found in this research (Figures 5C, D, F) was also reported by other authors (Magalhães et al., 2012; Cabral et al., 2013; Costa et al., 2016).

Data of NUE (Figure 5) associated to that of dry matter production (Figure 2), and proportion of leaves (Figure 3A) suggests that capim-açú has a high NUE under lower N doses (below 100 mg dm^{-3} N) to produce leaf dry matter, while antelope grass under the same low N doses utilizes great part of N to produce stalks. By increasing K dose from 10 to 30 mg dm^{-3} K_2O, NUE was improved by 13 and 20% in plant shoot and stalks (Figures 5B, E), respectively. For leaves, NUE also had a slight increase (10.3%), but this difference was not enough to be detected by Tuckey test at $p \leq 0.05$. The observed tendency of NUE increase with K dose is related to the fact that K is responsible for activation of many enzymes in plant N uptake and photosynthesis, translocation of assimilates and protein synthesis (Prajapati & Modi, 2012; Morais et al., 2016).

Further studies are needed, mainly on the field, in order to know if the found results also occur under real soil and climatic conditions of Maranhão floodplain, and other areas. Also, future studies involving comparison of nutritional quality of the fresh matter and hay of these species should be developed to confirm the expected good quality of capim-açú for animal feed.

Conclusions

1. The Amazonian native grass capim-açú produces greater leaf dry matter and lower aboveground stalk dry matter when using lower N doses than antelope grass.

2. Leaf, stalk and total dry matter production of both species do not respond to K doses from 0 to 30 mg dm^{-3} K_2O applied on a Plinthosol from the Maranhão Floodplains.

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