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ORIGINAL ARTICLE

Productivity of Marandu grass as a function of liming and phosphate fertilization in a Typic Hapludult from Amazonia

Produtividade de capim-marandu em função da calagem e da adubação fosfatada em argissolo na Amazônia

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ABSTRACT: Little information is available concerning liming and phosphate fertilization for grassland maintenance in Amazonia. The dry-weight yield of *Brachiaria brizantha* was assessed over three harvest periods as a function of top-dressing with lime and phosphorus. The experimental design consisted of fully randomized blocks with four replicates arranged in subdivided plots according to the sampling season (plots), phosphorus application rate (0, 30 and 60 kg ha^{-1} P_2O_5) (subplots) and presence or absence of liming (sub-subplots). The grass was harvested by cutting 25 cm above the soil level, and the 0- to 5-, 5- to 10-, 10- to 20- and 20- to 40-cm soil layers were sampled 3, 9 and 13 months after liming. Top-dressing with phosphorus and lime had no effect on the dry-weight yield, nutrient uptake or crude-protein percentage of the *Brachiaria brizantha* shoots. However, phosphorus and lime treatment reduced the soil acidity and increased the calcium, magnesium and phosphorus levels in the upper soil layers.

RESUMO: *Na Amazônia, existem poucas informações sobre calagem e adubação fosfatada na manutenção de pastagens. Foram avaliados, neste trabalho: a produção de massa seca, o teor e a extração de nutrientes, e o percentual de proteína bruta de Brachiaria brizantha em três épocas de corte, além das modificações químicas do solo após aplicação de calcário em superfície e doses de fósforo. Utilizou-se o delineamento em blocos casualizados, com quatro repetições, em esquema de parcelas subsubdivididas, composto por épocas de amostragem (parcelas), doses de fósforo (0, 30 e 60 kg* ha^{-1} P_2O_5*) (subsubparcelas) e sem e com aplicação de calcário (subsubparcelas). Os cortes na parte aérea da pastagem (25 cm acima do solo) e a amostragem de solo nas camadas de 0-5, 5-10, 10-20 e 20-40 cm de profundidade foram realizados aos três, nove e treze meses após a calagem. Não houve efeito da aplicação de doses de fósforo e calcário superficialmente sobre a produção de massa seca, a extração de nutrientes e o percentual de proteína bruta na parte aérea da Brachiaria brizantha. No solo, a aplicação de fósforo e calcário promoveu diminuição da acidez e elevação dos teores de cálcio, magnésio e fósforo nas camadas superficiais.*

KEYWORDS
Brachiaria brizantha
Crude protein
Fertility
Nutrient uptake
Tropical soils

PALAVRAS-CHAVE
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Solos tropicais

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1 Introduction

According to the 2006 Agricultural Census, the Amazon region supports a total of 31,936,849 head of cattle, corresponding to 18.61% of the national herd. The state of Pará, Brazil, hosts 13,726,598 head, or 8% of the national herd and 43% of the herd in the northern region (IBGE, 2006). Beef and dairy cattle husbandry are among the primary economic activities in the southeastern region of Pará State, Brazil (MATTOS et al., 2010). Pastures sown with forage grasses are used as the primary food source for cattle in this region. These pastures consist primarily of grasses of the genus *Brachiaria* (Marandu grass) (DIAS-FILHO, 2011).

After pasture establishment, soil management practices that involve correction and fertilization are rarely used; therefore, this system is extractive, contributing to pasture degradation (DIAS-FILHO, 2011). The factors causing this degradation include poor training, severe pest and disease outbreaks, inadequate grazing management (high stocking rates, lack of pasture rotation and/or insufficient rest periods), lack of hygiene and insufficient soil maintenance and corrective fertilization (DIAS-FILHO, 2011).

Maintenance fertilization aims to maintain soil-fertility levels that are satisfactory for plant development, similar to those provided by corrective fertilization (WERNER et al., 1997), and to replace the nutrients extracted by grazing.

In pasture management, liming and phosphorus fertilization are important to maintain forage growth and animal production (TEIXEIRA; OLIVEIRA; VEIGA, 2007). When lime is incorporated into the soil or applied to the surface, its beneficial effects include increased pH, reduced aluminum (Al) concentrations and increased exchangeable-calcium (Ca) and magnesium (Mg) concentrations in the soil (SORATTO; CRUSCIOL, 2008). Phosphate fertilization is essential for greater forage productivity because phosphorus (P) plays an important role in root growth and activity, helping the plants to absorb nitrogen under conditions of low availability of this growth-limiting nutrient (SANTOS et al., 2009). Additionally, P influences grass tillering and the nutritional value of the forage (MACEDO, 2004).

Therefore, liming and phosphate fertilization improve the mineral nutrition of the plant and the nutritional value of the forage and help to maintain the productive capacity of pastures over time (MAGALHÃES et al., 2007). According to the National Research Council (2000), P and Ca are also important animal nutrients, primarily affecting bone development. Therefore, forage plants are likely to supply the nutritional needs of the animals that ingest them.

During pasture maintenance, lime and phosphate fertilizers must be applied to the soil surface, usually after forage cutting, as practiced in the direct-seeding system. In Pará State, Brazil, the phosphorus application rate for the maintenance of Marandu-grass pastures varies from 60 to 80 kg P_2O_5 ha^{-1} in soils with low to moderate phosphorus concentrations (TEIXEIRA; OLIVEIRA; VEIGA, 2007).

In the present study, we evaluated the productivity, nutrient concentrations and uptake and crude-protein percentage of Marandu grass and the chemical attributes of the soil during three sampling periods after limestone and phosphorous application.

2 Materials and Methods

The experiment was conducted at the Xavier Site (6° 00’ 10” S, 49° 57’ 43” W) in southeastern Pará State, Brazil (Figure 1), from November 2007 to February 2009.

The soil at this site is a Dystrophic Yellow Argisol (EMBRAPA, 2006) cultivated with *Brachiaria brizantha* cv. Marandu (Marandu grass) for 15 years after the cutting and burning of the primary forest. The local topography is gently

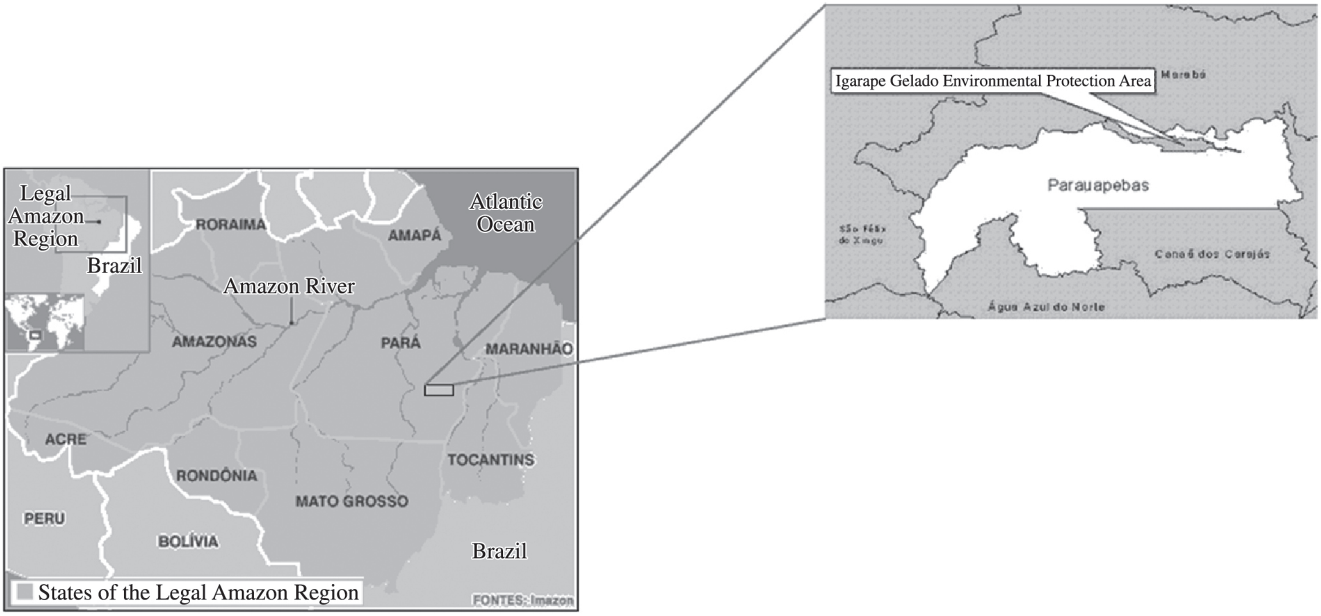

Figure 1. Location of the Igarapé Gelado Environmental Protection Area, Parauapebas, Pará.

rolling, and the substrates are derived from Pre-Cambrian granitic rocks and metasediments (BRASIL, 1974).

According to the Köppen Classification, the regional climate is Awi, with a winter dry period (May to October) and a marked summer wet period with torrential rains (November to April). The average annual temperature is 29 °C, and the relative air humidity can exceed 90% in the rainy months but drops below 50% during the dry season. The annual rainfall can reach 2,800 mm (Figure 2) (PARAUAPEBAS, 2009).

Prior to the establishment of the experiment, one pasture in the experimental area was undergoing agricultural degradation, as evidenced by the numerous termite mounds, high weed infestation and intense froghopper (*Deois* spp.) attacks.

Following mechanical clearing of the area in December 2006, when the woody plants and residues remaining from the primary forest (logs and stumps) were removed, conventional soil preparation was performed to renovate the pasture. The new pasture was established by sowing 5 kg ha^{-1} of pure, viable Marandu grass seeds according to the methodology recommended by Lima et al. (2009).

A chemical analysis of the 0-0.20-m soil layer was performed according to the methodology of Silva (2009) after the pasture renovation and before the establishment of the experiment. The soil showed the following parameters: pH (H_2O) = 5.2; organic material (Walkley-Black) = 20 g kg^{-1}; P (Mehlich-1) = 11.7 mg dm^{-3}; Al^{3+} (KCl 1 mol L^{-1}) = 2.2 mmol$_c$ dm^{-3}; H+Al ($Ca(OAc)_2$ 0.5 mol L^{-1}) = 28.0 mmol$_c$ dm^{-3}; K^+ (Mehlich-1)=1.3mmol$_c$dm^{-3};Ca^{2+}(KCl1molL^{-1})=19.5mmol$_c$dm^{-3} and Mg^{2+} (KCl 1 mol L^{-1}) = 6.8 mmol$_c$ dm^{-3}. Based on these results, the calculated sum of bases (SB) was 27.6 mmol$_c$ dm^{-3}, and the base saturation (V%) was 49%. In summary, the soil exhibited moderate acidity and organic material; average P, K^+, Ca^{2+}, Mg^{2+}, SB and V% levels; and low Al^{+3} and H+Al levels (TEIXEIRA; OLIVEIRA; VEIGA, 2007).

A granulometric analysis was performed according to the pipette method of Gee and Bauder (1986). The results showed that the soil consisted of 667 g kg^{-1} sand, 149 g kg^{-1} silt and 184 g kg^{-1} clay.

The experiment used randomized blocks in a split-plot design with four replicates. The experimental design incorporated three factors: 1 – sampling season (plots), 2 – phosphorus application rate (subplots) and 3 – liming (sub-subplots).

The plots represented three plant and soil sampling seasons (1: March 2008; 2: September 2008; 3: January 2009). The subplots (5.0 × 8.0 m) consisted of three phosphorus application rates (0, 30 and 60 kg ha^{-1} P_2O_5) in the form of triple superphosphate. The sub-subplots (2.25 × 8.0 m) were defined by the presence or absence of liming (854 kg ha^{-1} of dolomitic limestone). Triple superphosphate was used because it contains the highest proportion of water-soluble phosphorus (41%) and is ready available. Dolomitic limestone was chosen for its acid-neutralizing effect and because it adds Mg to the soil (RAIJ et al., 1997).

Liming was performed in December 2007 by applying dolomitic limestone (75%) to the pasture surface without incorporation after a uniform cutting at 0.25 m from the soil surface. The limestone was applied to achieve 60% base saturation, as recommended for Marandu grass (WERNER et al., 1997).

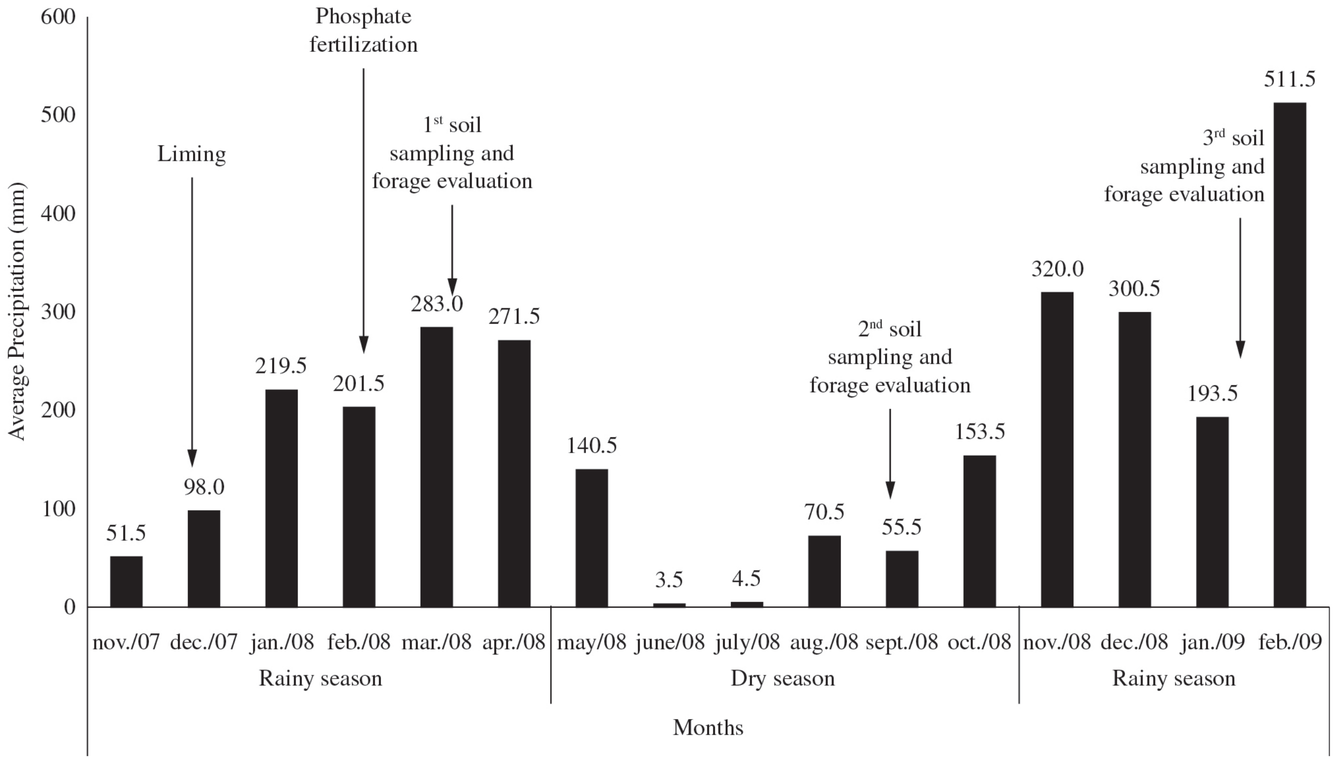

Figure 2. Rainfall during the experimental period (November 2007 to February 2009) in Parauapebas, Pará.

Phosphorus fertilization was performed in February 2008. The fertilizer was placed as close as possible to the base of each clump of plants. The phosphorus application rates were calculated according to the fertilization recommendations for Pará State, Brazil (TEIXEIRA; OLIVEIRA; VEIGA, 2007): 60 kg P_2O_5 for soil P concentrations of 11 to 20 mg dm^{-3}. The phosphorus application rates were 0, 30 (half the recommended dose) and 60 kg ha^{-1} P_2O_5, applied as a single dose.

The effects of the treatments on pasture productivity were evaluated at three time points, 3 (March 2008), 9 (September 2008) and 13 months (January 2009) after liming. These dates corresponded to 1, 7 and 11 months after phosphorus application. Importantly, the March 2008 and January 2009 cuttings corresponded to the rainy season, while the September 2008 cutting corresponded to the dry season.

At each test cutting, the sub-subplots were uniformly cut at the grazing point for Marandu-grass forage (a canopy height of 0.40-0.45 m). The aboveground portion of the forage within a 0.5-m^2 square was collected and separated into green leaves and stems. The samples were then dried at 65 °C for 72 hours. Subsequently, the dry mass of the leaves and stems was determined, and the total dry mass (leaves + stems) was calculated (MACHADO; KICHEL, 2004). Following dry-mass determination, the N, P, K, Ca and Mg concentrations in the aboveground dry matter (leaves + stems) were determined, and the uptake of each element was calculated.

The nutrient uptake was calculated using the following formula: nutrient uptake (kg ha^{-1}) = 0.001 × [dry material (kg ha^{-1}) x nutrient concentration (g kg^{-1})]. The crude-protein (CP) percentage was calculated using the following formula: CP (%) = N concentration (g kg^{-1}) × 0.1 × 6.25 (NATIONAL RESEARCH COUNCIL, 2000).

Concurrently with the forage sampling (March 2008, September 2008 and January 2009), soil samples were collected using an auger-type probe to monitor the soil fertility. Soil samples were taken from the 0-0.05-, 0.05-0.10-, 0.10-0.20- and 0.20-0.40-m soil layers in the usable area of each sub-subplot. Each sample consisted of five individual samples for each of the four soil layers. The samples were labeled and taken to the laboratory for chemical analysis. The soil pH (H_2O) and P, K^+, Ca^{2+}, Mg^{2+} and Al^{3+} concentrations were analyzed and the V% was calculated according to the methods of Silva (2009).

The data were subjected to analysis of variance. For the sampling season and liming factors, Tukey's test was applied with a significance threshold of 5%. The interaction between liming and P_2O_5 application rate was analyzed using linear regression. The SISVAR 5.3 statistical software was used for the statistical analyses.

3 Results and Discussion

No interaction ($p > 0.05$) between cutting, liming and P_2O_5 application rate was observed for the dry-matter forage productivity of Marandu grass. However, the leaf, stem and total dry mass and the leaf-stem ratio varied significantly among cuttings (Table 1).

Table 1. Dry-matter production of Marandu grass leaves, stems and total plants and the leaf-stem relationship at three test cuttings.

Cutting	DM			Leaf-stem ratio
	Leaves	Stems	Total	
	t ha^{-1}			
1	3.1 b	1.7 b	4.9 b	2.0 a
2	4.7 a	7.2 a	11.9 a	0.7 b
3	2.8 b	0.7 b	3.5 b	5.2 a
Average	3.6	3.2	6.80	2.7
CV (%)	16.0	26.0	13.0	17.0

Averages followed by the same letter within columns do not differ significantly between cuttings according to Tukey's test ($p < 0.05$). Cutting 1: March 2008; Cutting 2: September 2008; Cutting 3: January 2009.

The absence of an effect of fertilization and liming can be explained by the hardiness of this forage species, which is moderately tolerant to soil acidity and can grow well in soils with low to medium fertility (WERNER et al., 1997). The soil in the experimental area shows adequate levels of P, exchangeable bases and base saturation (V%), as reported below.

The average leaf dry mass in the three cuttings (3.6 t ha^{-1}) was greater than the value considered sufficient for cattle consumption in pastures (0.75 t ha^{-1}) (EUCLIDES; EUCLIDES FILHO, 1998).

At cutting 2, the pasture produced a greater dry mass of stems than of leaves, thus yielding a lower leaf-stem ratio. The leaf-stem ratio in pastures planted with forage grasses must be greater than or equal to 1 because a larger quantity of leaves provides better nutritional value. Compared to stems, leaves contain higher crude fiber concentrations, lower fiber content and higher digestibility, meeting the nutritional requirements of the ruminants and ensuring greater weight gain or milk production by these animals (JAYME et al., 2009).

The average total dry-mass productivity in the three test cuttings was within the reported productivity potential of the species. This result is similar to those obtained by Euclides et al. (2007), who observed a forage productivity of 6.5 t ha^{-1} of total dry mass at the beginning of the dry season from *Brachiaria brizantha* cultivated on a Dystrophic Red Latosol in an Awi-Cfa transitional climate in Campo Grande, MS, Brazil. However, the total dry-mass production varied among cuttings. The largest total dry-mass production of Marandu grass was observed at the second cutting due to the intense formation of offshoots from the basal buds, with a corresponding increase in the stem dry-mass production during this period (GOMIDE et al., 1988). Additionally, the forage at cutting 2 had attained the cutting height (0.40-0.45 m) established for sampling after 90 days of regrowth. Thus, as the plants aged, more of the photoassimilates produced in the leaves were remobilized to the stems, which are the primary organs responsible for storing the products of photosynthesis (SANTOS et al., 2009).

Other authors have observed increased forage dry-matter productivity with increasing plant age. In Minas Gerais State, Brazil, Jayme et al. (2009) observed a total dry mass of 3.04 to 11.47 t ha^{-1} with increasing plant maturity for Marandu grass cultivated on a Red Latosol and evaluated at four ages (28, 56, 84 and 112 days). In an experiment performed in southcentral Bahia, Brazil, *Brachiaria decumbens* was subjected to different doses of N (0, 100, 200 and 300 kg ha^{-1}) and P (0, 50 and 100 kg ha^{-1}). After 28 days of regrowth, the leaf and stem production was similar. This result confirms that with increasing pasture age, the leaf-stem ratio increases, leading to greater total dry-matter production and strongly affecting pasture quality (MAGALHÃES et al., 2007).

No interaction effect ($p < 0.05$) between cutting, liming and P_2O_5 application rate was observed for the nutrient concentrations in the aboveground plant tissue. However, the P, Ca and Mg concentrations in the aboveground dry matter varied significantly among cuttings, showing values greater than the critical values for this species (Table 2).

The concentrations considered adequate for Marandu grass vary from 0.8 to 3 g kg^{-1} P, from 3 to 6 g kg^{-1} Ca and from 1.5 to 4 g kg^{-1} Mg (WERNER et al., 1997). Based on these values, the experimental Marandu grass pasture did not show nutritional limitation for these nutrients; the soil in the experimental area contained adequate concentrations of these elements.

The N concentration in the aboveground dry matter was below the critical level (13 g kg^{-1}), affecting the crude-protein percentage of the aboveground dry matter. These protein values were below the percentage considered adequate for this grass species. The typical values indicated for the activity of ruminal bacteria range from 6 to 8% (MERTENS et al., 1994). Benett et al. (2008) subjected Marandu grass cultivated on a Eutrophic Red Argisol to increasing N application rates (0, 50, 100, 150 and 200 kg ha^{-1} year^{-1}). In three test cuttings, these authors found CP percentages ranging from 11.56 to 16.08% in the aboveground dry matter of the forage. This result indicates that N fertilization tends to improve the nutritional value of the forage by increasing the protein concentration. Low N concentrations in the aboveground portion of the forage occur primarily due to low organic-matter concentrations in the soil and nitrogen loss during the denitrification process, which is mainly associated with prolonged periods of soil waterlogging that occur in the region during the rainy season, causing lower N availability for the plants (ELZENGA; VEEN, 2010).

Table 2. Nutrient concentrations and uptake and crude-protein percentages in the aboveground dry matter of Marandu grass pastures at three test cuttings.

Cutting	N	P	K	Ca	Mg	CP
	Content (g kg^{-1})					%
1	8.75 a	3.96 b	20.95 b	2.88 b	4.81 b	5.5
2	7.19 b	2.63 c	9.18 c	4.30 a	6.64 a	4.5
3	9.31 a	6.26 a	24.56 a	2.94 b	6.33 a	5.8
Average	8.42	4.28	18.23	3.38	5.93	5.3
CV (%)	14.0	11.8	14.6	9.0	14.6	14.0
	Uptake (kg ha^{-1})					
1	43.3 b	19.8 b	104.6 a	14.6 b	24.1 b	
2	85.6 a	31.9 a	110.4 a	49.9 a	79.6 a	
3	32.5 c	21.5 b	84.6 b	10.2 b	21.9 b	
Average	53.8	24.4	99.9	24.9	41.9	
CV (%)	11.1	19.5	11.9	16.0	23.6	

Averages followed by the same letter within columns do not differ significantly between cuttings according to Tukey's test ($p < 0.05$). Cutting 1: March 2008; Cutting 2: September 2008; Cutting 3: January 2009.

The K concentrations in the aboveground dry matter at the first and third cuttings were within the critical range for the species, which extends from 12 to 30 g kg^{-1} (WERNER et al., 1997). However, at the second cutting, the K concentration was reduced due to dilution in the plant as a result of the increased total dry-matter production at this cutting.

The largest quantities of nutrients were extracted during the second cutting period, in proportion to the increase in total dry mass during this period. Nitrogen and potassium were extracted in the largest quantities, followed by magnesium, calcium and phosphorus (Table 2). Primavesi et al. (2006) have reported the nitrogen and potassium requirements of Marandu grass cultivated on a Dystrophic Red Latosol in São Carlos, SP, Brazil, after 42 days of regrowth. These authors observed an aboveground dry-matter production of 6,650 kg ha^{-1} and N, P, K, Ca and Mg extraction levels of 112, 23, 196, 30 and 25 kg ha^{-1}, respectively.

Based on these results, we conclude that to significantly increase and maintain the forage production of Marandu grass pastures in southeastern Pará State, special attention must be paid to replacing the N and K nutrients extracted in forage removal through nitrogen and potassium fertilization (TEIXEIRA; OLIVEIRA; VEIGA, 2007).

Three months after application, surface liming and phosphorus addition did not affect the dry-matter production and nutrient extraction of Marandu grass. Therefore, post-fertilization management is an important component of productive pasture maintenance. This management must include practices that decrease excessive forage losses and mitigate the decline in nutritional value due to an increasing proportion of stems relative to leaves as the pasture growth rate increases. (DIAS-FILHO, 2011).

Although our results show no interaction between cutting season, liming and P_2O_5 application rate, we emphasize that limestone application not only helps to correct the soil acidity but also provides Ca and Mg, while phosphorus addition increases the P concentration in the soil. Thus, the chemical quality of the soil is improved. Consequently, the pasture productivity and quality are also improved from the perspective of animal nutrition (PEREIRA et al., 2009). Calcium and phosphorus absorbed by plants and consumed by animals constitute more than 70% of the minerals present in the bodies of the animals, especially in the bones (NATIONAL RESEARCH COUNCIL, 2000). Additionally, from an economic point of view, the need for mineral supplementation of the animal diet is reduced.

Regarding modifications in the chemical attributes of the soil, the pH, Al, Ca, Mg, K and V% values were not affected ($p > 0.05$) by the interaction between sampling season, liming and P_2O_5 application rate. Liming affected the chemical attributes of the soil ($p < 0.05$) only observed in the 0- to 5-cm and 5- to 10-cm layers (Table 3).

Limestone application affected ($p < 0.05$) the pH values of the 0- to 5-cm and 5- to 10-cm layers until the third sampling. The soil pH increased after liming due to the dissolution of the limestone, which promotes the liberation of anions (OH^{-} and HCO^{3-}) in acidic soil. These anions then react with the acidic

Table 3. Soil chemical attributes at different depths 3, 9 and 13 months after limestone application.

Attribute	Depth (cm)	Liming					
		Without	With	Without	With	Without	With
		3 months		9 months		13 months	
pH	0-5	5.2 b	5.4 a	5.2 b	5.5 a	5.4 a	5.5 a
	5-10	5.2 a	5.2 a	5.2 a	5.3 a	5.3 b	5.5 a
Al (mmol$_c$ dm^{-3})	0-5	2.1 a	1.5 b	2.3 a	1.8 b	1.8 a	1.6 b
	5-10	2.3 a	2.0 a	2.5 a	2.0 a	2.0 a	2.0 a
Ca (mmol$_c$ dm^{-3})	0-5	22.8 b	25.4 a	23.5 b	26.1 a	18.4 b	23.8 a
	5-10	19.2	20.0	22.3	23.3	16.7	15.9
Mg (mmol$_c$ dm^{-3})	0-5	24.4 b	27.3 a	13.2	17.2	8.2 b	11.7 a
	5-10	19.7	23.1	11.8	12.9	6.2	6.2
K (mmol$_c$ dm^{-3})	0-5	3.3	3.6	2.7 b	3.1 a	2.8	3.1
	5-10	2.2	2.7	1.9 b	2.4 a	2.4	2.7
V (%)	0-5	58.7 b	61.8 a	54.5 b	59.7 a	40.5 b	51.3 a
	5-10	56.8	58.3	53.2	54.5	39.7	41.5

Averages followed by different letters within rows and sampling seasons differ significantly according to Tukey's test at the 5% level.

cations in the soil solution, such as H$^+$ and Al^{3+} (SOUZA; MIRANDA; OLIVEIRA, 2007). The observed soil-pH values indicated moderate acidity (CRAVO; VIÉGAS; BRASIL, 2007).

Due to limestone application and the resulting increase in soil pH, the Al^{3+} concentration in the 0- to 5-cm layer decreased at the first and second sampling. The Al^{3+} concentration decreased to a level considered low (<2.0 mmol$_c$ dm^{-3}) according to Cravo, Viégas and Brasil (2007). The reduction of Al^{3+} by liming is proportional to the quantity of limestone applied and the reaction time for the neutralization of Al^{3+} (CAIRES et al., 2008). Thus, due to the increase in pH, Al^{3+} precipitates as Al(OH)$^{2+}$, Al(OH)$_2^+$ and Al(OH)$_3$ (SOUZA; MIRANDA; OLIVEIRA, 2007), reducing the Al^{3+} concentration in the soil exchange complex (FIDALSKI; AULER, 2008).

At the first sampling, the exchangeable Ca and Mg concentrations in the soil increased in the 0- to 5-cm layer. The effect of liming on the 0- to 5-cm layer persisted until the third sampling. The Ca^{2+} concentrations were within the moderate range (16 to 45 mmol$_c$ dm^{-3}), while those of Mg^{2+} were moderate to high (5 to > 15 mmol$_c$ dm^{-3}) (CRAVO; VIÉGAS; BRASIL, 2007).

The exchangeable K concentration in the soil increased only at the second sampling in the 0- to 5-cm and 5- to 10-cm layers. The increased K concentration in the 5- to 10-cm layer was related to the increased saturation of Ca^{2+} and Mg^{2+} ions in the 0- to 5-cm layer, which displaced the K$^+$ from the exchange complex of the soil solution and consequently increased the K concentration in the deeper layer (DONAGEMMA et al., 2008). The exchangeable K concentration was within the high range (>2 mmol$_c$ dm^{-3}) according to Cravo, Viégas and Brasil (2007).

The results for base saturation were similar to those observed for Ca and Mg; limestone application affected this parameter only in the 0- to 5-cm layer at the three samplings. In a Red Hapludox in Botucatu, SP, Brazil, Soratto and Crusciol (2008) observed that 18 months after the application of 71.2% limestone at 0, 1 100, 2 700 and 4 300 kg ha^{-1}, the chemical attributes of the soil were modified only in the surface layer in an area where a direct-planting system had been recently implemented.

Because limestone application had no direct effect on the subsurface layers, it is possible that insufficient time had passed for the operation of the mechanisms involved in correcting the subsoil acidity, such as the formation and migration of Ca(HCO$_3$)$_2$ and Mg(HCO$_3$)$_2$ (OLIVEIRA; PAVAN, 1996), the mechanical displacement of limestone particles through channels formed by dead roots and kept intact by the lack of soil preparation (SIDIRAS; PAVAN, 1985), the movement of exchangeable Ca and Mg from the soil and the reduction of exchangeable Al through the formation of water-soluble organic complexes in the subsoil (FRANCHINI et al., 1999).

Neither the sampling season nor the interaction of sampling season, liming and phosphorus application rate affected (p > 0.05) the available P concentration in the soil. However, the available P concentration in the 0- to 5-cm soil layer was influenced ($p < 0.05$) by the interaction between liming and P$_2$O$_5$ application rate (Figure 3).

The phosphorus concentration increased with increasing phosphate-fertilizer application rate when limestone was also applied. This interaction occurred because liming decreases the concentration of exchangeable Al and consequently promotes the formation of aluminum-phosphate complexes, releasing the phosphorus in an available form for plant absorption (SOUZA; MIRANDA; OLIVEIRA, 2007). Another important factor contributing to the increased concentration of available phosphorus in the soil is the seasonal occurrence of excess water in soils with deficient drainage (B-textured soils). Excess water increases phosphorus availability to plants due to the occurrence of iron-reduction sites and the resulting solubilization of P-Fe precipitates (SOUZA; MIRANDA; OLIVEIRA, 2007). These conditions can contribute to a weaker response to phosphate fertilization in pastures subject to periodic

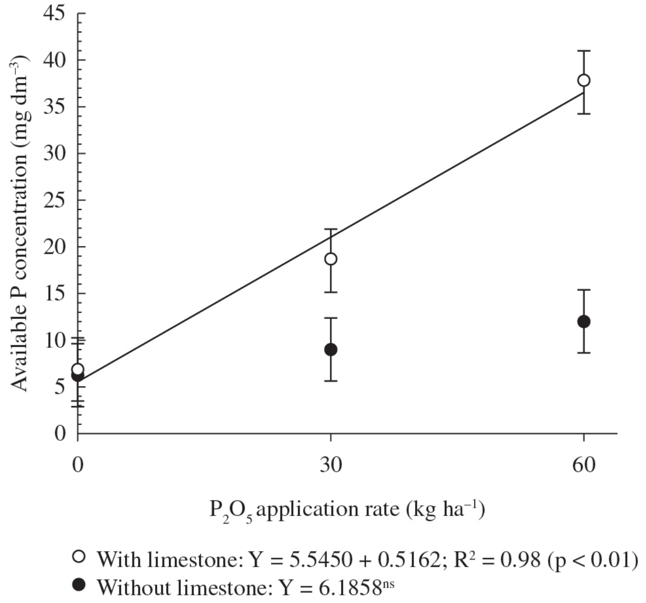

Figure 3. Available-phosphorus concentrations in the 0- to 5-cm soil layer 3 months after limestone application and 1 month after P_2O_5 fertilization in a Marandu-grass pasture. $p < 0.01$: significant at the 1% level; ns: not significant.

waterlogging. Because the P availability was high (>20 mg dm^{-3}) (CRAVO; VIÉGAS; BRASIL, 2007), the concentration of this element was above the critical concentrations required for the maintenance of Marandu grass (3.3 to 4.8 mg dm^{-3}) (MACEDO, 2004).

Thus, in pastures in the maintenance phase, where the calcium, magnesium and phosphorus levels are adequate and the Al concentrations are not limiting for Marandu grass, pasture management practices that improve nutrient cycling, decrease nutrient losses and promote nutrient inputs through fertilization and periodic corrections based on soil-fertility monitoring are important strategies for the productive maintenance and longevity of Marandu grass pastures in southeastern Pará State (DIAS-FILHO, 2011).

4 Conclusion

The productivity of Marandu grass did not increase after surface liming and phosphorus application. The nutrients extracted by Marandu grass in large quantities are K and N. At the three test cuttings, the crude-protein percentages in the aboveground plant tissues were below the levels considered adequate for this species. Thirteen months after surface liming, the soil chemical attributes were modified only in the surface layers.

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References

BENETT, C. G. S.; BUZETTI, S.; SILVA, K. S.; BERGAMASCHINE.; FABRICIO, J. A. Produtividade e composição bromatológica do capim-marandu a fontes e doses de nitrogênio. *Ciência e Agrotecnologia*, v. 32, n. 5, p. 1629-1636, 2008. http://dx.doi.org/10.1590/S1413-70542008000500041

BRASIL. Projeto RADAM. *Folha SB.22 Araguaia e parte da folha SC.22 Tocantins; geologia, geomorfologia, solos, vegetação e uso potencial da terra*. Rio de Janeiro: Departamento Nacional de Produção Mineral, 1974. 516 p.

CAIRES, E. F.; PEREIRA FILHO, P. R. S.; ZARDO FILHO, R.; FELDHAUS, I. C. Soil acidity and aluminium toxicity as affected by surface liming and cover oat residues under a no-till system. *System Use and Management*, v. 24, n. 3, p. 302-309, 2008.

CRAVO, M. S.; VIÉGAS, I. J. M.; BRASIL, E. C. *Recomendações de adubação e calagem para o Estado do Pará*. Belém: Embrapa Amazônia Oriental, 2007. 262 p.

DIAS-FILHO, M. B. *Degradação de pastagens*: processos, causas e estratégias de recuperação. 4. ed. Belém: Embrapa Amazônia Oriental, 2011. 215 p.

DONAGEMMA, G. K.; RUIZ, H. A.; ALVAREZ V, V. H.; FERREIRA, P. A.; CANTARUTTI, R. B.; SILVA, A. T.; FIGUEIREDO, G. C. Distribuição do amônio, nitrato, potássio e fósforo em colunas de latossolos fertirrigadas. *Revista Brasileira de Ciência do Solo*, v. 32, n. 6, p. 2493-2504, 2008. http://dx.doi.org/10.1590/S0100-06832008000600026

ELZENGA, J. T. M.; VEEN, H. Watterlogging and plant nutriente uptake. In: MANCUSO, S.; SHABALA, S. (Eds.). *Waterlogging Signalling and Tolerance in Plants*. Berlim: Springer-Verlag, 2010. p. 23-35. http://dx.doi.org/10.1007/978-3-642-10305-6_2

EMBRAPA. *Sistema Brasileiro de Classificação de Solos*. Rio de Janeiro: Embrapa – CNPS, 2006. 306 p.

EUCLIDES, P. B. E.; M.; FLORES, R.; MEDEIROS, R. N.; OLIVEIRA, M. P. Diferimento de pastos de braquiária Basilik e Marandu, na região do Cerrado. *Pesquisa Agropecuária Brasileira*, v. 42, n. 2, p. 273-280, 2007. http://dx.doi.org/10.1590/S0100-204X2007000200017

EUCLIDES, V. P. B.; EUCLIDES FILHO, K. *Using animals for forage evaluation*. Campo Grande: Embrapa/CNPGC, 1998. 59 p.

FIDALSKI, J.; AULER, P. A. M. Alterações químicas temporais nas faixas de adubação e entrelinhas do pomar, nutrição e produção de laranja após calagem superficial. *Revista Brasileira de Ciência do Solo*, v. 32, n. 689-696, 2008.

FRANCHINI, J. C.; MIYAZAWA, M.; PAVAN, M. A.; MALAVOLTA, E. Dinâmica de íons em solo ácido lixiviado com extratos de resíduos de adubos verdes e soluções puras de ácidos orgânicos. *Pesquisa Agropecuária Brasileira*, v. 34, n. 12, p. 2267-2276, 1999. http://dx.doi.org/10.1590/S0100-204X1999001200014

GEE, G. W.; BAUDER, J. W. Particle-size anaylis. In: KLUTE, A. (Ed.). *Methods of soil analysis, Part 1. Physical and mineralogical methods*. 2. ed. Madison: American Society of Agronomy, Soil Science Society American, 1986. p. 383-411. (Agronomy Series, n. 9).

GOMIDE, J. A. Fisiologia das plantas forrageiras e manejo das pastagens. *Informe Agropecuário*, v. 13, n. 153-154, p. 11-18, 1988.

INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA - IBGE. *Censo agropecuário 2006.* Disponível em: <http://www.ibge.gov.br>. Acesso em: 03 set. 2013.

JAYME, C. G.; MOLINA, L. R.; GONÇALVES, L. C.; JAYME, D. G. PIRES, D. A. A.; BORGES, I. Determinação do momento de colheita de *Brachiaria brizantha* (Hochest.) Stapf.cv. marandu para produção de silagem. *Ciência e Agrotecnologia*, v. 33, n. 2, p. 586-591, 2009. http://dx.doi.org/10.1590/S1413-70542009000200035

LIMA, E. V.; TAVARES, J. C. S.; SILVA, E. C.; LEITÃO-LIMA, P. S. Superfosfato triplo como via de distribuição de sementes de *Brachiaria brizantha* para renovação de pastagens na Amazônia. *Revista Brasileira de Zootecnia,* v. 38, n. 5, p. 796-800, 2009. http://dx.doi.org/10.1590/S1516-35982009000500003

MACEDO, M. C. M. Adubação fosfatada em pastagens cultivadas com ênfase na região dos Cerrados. In: YAMADA, T.; ABDALLA, S. R. S. (Ed.). *Fósforo na agricultura brasileira*. Piracicaba: Potafos, 2004. p. 359-400. PMid:16197842.

MACHADO, L. A. Z.; KICHEL, A. N. *Ajuste de lotação no manejo de pastagens.* Dourados: Embrapa Agropecuária Oeste; Campo Grande: Embrapa Gado de Corte, 2004. 55 p. (Embrapa Agropecuária Oeste. Documentos, n. 62).

MAGALHÃES, A. F.; PIRES, A. J. V.; CARVALHO, G. G. P.; SILVA, F. F.; SOUSA, R. S.; VELOSO, C. M. Influência nitrogênio e fósforo na produção de capim-braquiária. *Revista Brasileira de Zootecnia*, v. 36, n. 5, p. 1240-1246, 2007. http://dx.doi.org/10.1590/S1516-35982007000600004

MATTOS, C. A.; SANTANA, A. C.; PINTO, W. S.; CARDOSO, A. J. G.; COSTA, N. L. Características socioeconômicas e ambientais dos sistemas de produção da pecuária do Estado do Pará. *Revista de Ciências Agrárias, v.* 53, n. 2, p. 150-158, 2010. http://dx.doi.org/10.4322/rca.2011.021

MERTENS, D. R. Regulation of forage intake. In: FAHEY JUNIOR, G. C. (Eds.). *Forage quality, evaluation and utilization*. Madison: American Society of Agronomy, 1994. p. 450-493.

NATIONAL RESEARCH COUNCIL. *Nutrient requirements of beef cattle*. 5. rev. ed. Washington: National Academy Press, 2000. 281 p.

OLIVEIRA, E. L.; PAVAN, M. A. Control of soil acidity in no-tillage system for soybean production. *Soil Tillage Research,* v. 38, n. 1-2, p. 47-57, 1996. http://dx.doi.org/10.1016/0167-1987(96)01021-5

PEREIRA, A. L.; CAMPOS, M. C. C.; SOUZA, Z. M.; CAVALCANTE, I. H. L.; SILVA, V. A.; MARTINS FILHO, M. V. Atributos do solo sob pastagem em sistema de sequeiro e irrigado. *Ciência e Agrotecnologia*, v. 33, n. 2, p. 377-384, 2009. http://dx.doi.org/10.1590/S1413-70542009000200003

PARAUAPEBAS. Prefeitura Municipal. Coordenadoria de Informática – SEFAZ. Assessoria de Comunicação Social. *Informações, turismo e diversão*. 2009. Disponível em: <http://www.parauapebas.pa.gov.br>. Acesso em: 03 out. 2012.

PRIMAVESI, A. C.; PRIMAVESI, O.; CORRÊA, L. A.; SILVA, A. G.; CANTARELLA, H. Nutrientes na fitomassa de capim-marandu em função de fontes e doses de nitrogênio. *Ciência e Agrotecnologia*, v. 30, n. 3, p. 562-568, 2006. http://dx.doi.org/10.1590/S1413-70542006000300024

RAIJ, B.; CANTARELLA, H.; QUAGGIO, J. A.; FURLANI, A. M. C. *Recomendações de adubação e calagem para o Estado de São Paulo*. 2. ed. Campinas: Fundação IAC, 1997. p. 263-274 (IAC. Boletim Técnico, n. 100).

SANTOS, M. E. R.; FONSECA, D. M.; BALBINO, E. M.; MONNERAT, J. P. I. S.; SILVA, S. P. Capim-braquiária diferido e adubado com nitrogênio: produção e características da forragem. *Revista Brasileira de Zootecnia*, v. 38, n. 4, p. 650-656, 2009. http://dx.doi.org/10.1590/S1516-35982009000400009

SIDIRAS, N. PAVAN, M.A. Influência do sistema de manejo do solo no seu nível de fertilidade. *Revista Brasileira de Ciência do Solo*, v. 9, n. 3, p. 249-254, 1985.

SILVA, F. C. *Manual de análises químicas de solos, plantas e fertilizantes*. Brasília: Embrapa Informação Tecnológica, 2009. 627 p.

SORATTO, R. P.; CRUSCIOL, C. A. C. Atributos químicos do solo decorrentes da aplicação em superfície de calcário e gesso em sistema de plantio direto recém-implantado. *Revista Brasileira de Ciência do Solo*, v. 32, n. 2, p. 675-688, 2008. http://dx.doi.org/10.1590/S0100-06832008000200022

SOUZA, D. M.; MIRANDA, L. N.; OLIVEIRA, S. A. Acidez do solo e sua correção. In: NOVAIS, R. F.; ALVAREZ V, V. H.; BARROS, N. F.; FONTES, R. L.; CANTARUTTI, R. B.; NEVES, J. C. L. (Eds.). *Fertilidade do solo*. Viçosa: UFV, 2007. p. 205-274.

TEIXEIRA, L. B.; OLIVEIRA, R. F.; VEIGA, J. B. Recomendação de Adubação e Calagem para pastagens e gramados. In: CRAVO, M. S.; VIÉGAS, I. J. M.; BRASIL, E. C. (Eds.). *Recomendações de adubação e calagem para o Estado do Pará*. Belém: Embrapa Amazônia Oriental, 2007. p. 257-262.

WERNER, J. C.; PAULINO, V. T.; CANTARELLA, H.; ANDRADE, N. O.; QUAGGIO, J. A. Forrageiras. In: RAIJ, B.; CANTARELLA, H.; QUAGGIO, J. A.; FURLANI, A. M. C. (Eds.). *Recomendações de adubação e calagem para o Estado de São Paulo*. 2. ed. Campinas: Fundação IAC, 1997. p. 263-274 (IAC. Boletim Técnico, n. 100).