

Establishment and recovery of *Brachiaria* hybrids subjected to nitrogen and phosphorus omission

Mateus Aparecido Casarotto, Dhovane Oliveira Araújo, Anna Cláudia Cardoso Paimel, Nathaly Soares Rodrigues, Eildson Souza de Oliveira Silva, Neferson Augusto Farias Leal, Eliza Geovana Novaes Neves Araújo, Camila Fernandes Domingues Duarte, Carla Heloisa Avelino Cabral, Carlos Eduardo Avelino Cabral +

Federal University of Rondonópolis

Abstract. Adequate fertilization is essential for the establishment of *Urochloa hybrids*, while nutritional limitations during establishment can affect the initial growth and response of plants after reestablishment of fertilization. This study aimed to evaluate the effects of nitrogen (N) and phosphorus (P) omission during establishment on *Urochloa* hybrids and their recovery after fertilization was restored, as well as to identify differences among hybrids in their responses to nutrient limitation. The experiment was carried out in a greenhouse in Rondonópolis, Mato Grosso state, in a completely randomized design in a 4 × 4 factorial scheme, with four replications. Four hybrids (Sabiá, Camello, Cayana and Mulato II) and four fertilization strategies at establishment (without N, without P, without NP and with NP) were evaluated. The combined supply of N and P increased the number of leaves and tillers and forage mass during establishment, whereas the omission of these nutrients limited the initial development of the plants. During recovery, the effects of the omission of N and P at establishment depended on the hybrid and the trait evaluated, persisting for the number of leaves, number of tillers and phyllochron. Sabiá maintained the number of tillers after the different nutritional omission conditions. The forage mass was not influenced by the previous omission of N or P after the reestablishment of fertilization and was greater in Mulato II, which indicates that the subsequent replacement of these nutrients allows the recovery of forage production, which is compromised during establishment. Therefore, the joint supply of N and P is essential for the establishment of hybrids, but after the reestablishment of fertilization, forage production can be recovered, although the effects on morphogenic and structural characteristics may persist differently among hybrids.

Keywords: *Brachiaria*, Phosphate fertilization, Nitrogen fertilization, Nutritional stress, Pasture establishment

Introduction

Pastures are highly important for ruminant production in tropical and subtropical regions of the world, where herd feeding is predominantly based on the direct consumption of forage produced in these systems. In this context, *Urochloa* spp. (syn. *Brachiaria* spp.) are widely used in livestock production systems because of their adaptability to different environmental conditions, high productivity, and persistence under grazing (CABRAL; DUARTE; AVELINO, 2024).

This set of characteristics contributed to their wide use and to the consolidation of these forage grasses in ruminant production systems in tropical pastures. However, despite their hardiness and adaptability, an adequate supply of nutrients is necessary to meet the requirements of these

grasses, increase the productivity and longevity of pastures, and reduce the risk of degradation.

In this context, an adequate supply of nitrogen and phosphorus is important for the establishment and longevity of pastures. Nitrogen is an essential nutrient for plant metabolism and is present mainly in organic compounds such as proteins and amino acids (SOUZA JUNIOR; MONTEIRO, 2026). Adequate N availability promotes plant growth and is associated with the characteristic dark-green color of leaves, whereas N deficiency causes chlorosis of older leaves and reduces productivity (FERREIRA; CRAVO; FERREIRA, 2020).

In addition to its structural function, nitrogen makes up the chlorophyll molecule, which is indispensable for photosynthesis. In pasture

ecosystems, this nutrient stimulates the rate of forage accumulation (CORRÊA et al., 2021) and, consequently, increases the supply of forage, increasing both the stocking rate and the efficiency of livestock systems (GOMIDE; PACIULLO; MARTINS, 2020).

Like nitrogen, phosphorus plays a fundamental role in the growth and establishment of forage plants, although it affects different metabolic processes. Phosphorus is involved in respiration, photosynthesis, and energy metabolism through ATP and is a structural component of nucleic acids and phospholipids (NASCIMENTO et al., 2024). The lack of this nutrient severely limits plant growth, generating dark green leaves with necrotic spots, thin stems, and a characteristic purplish color (TAIZ et al., 2017).

Although phosphate fertilizers represent the highest cost in the pasture establishment phase, reaching up to 80% of the investment in clay soils, nitrogen becomes one of the main limiting factors and cost components during maintenance and can constitute up to 80% of the fertilization costs in this phase (CABRAL et al., 2021). The efficiency of nitrogen fertilization also depends on the adequate availability of other nutrients, including potassium, whose response may be limited when it is applied without an adequate supply of N (LOPES et al., 2018) and which is involved in physiological processes such as enzyme activation, osmotic regulation, and assimilate transport (TAIZ et al., 2017; HASANUZZAMAN et al., 2018). However, the response to nutrient availability can vary across genetic materials, making it important to consider the characteristics of each cultivar when planning fertilization.

Fertilization planning becomes even more challenging in regard to hybrids of *Urochloa* spp., since these materials are developed from crosses among different genotypes, with the aim of gathering desirable agronomic characteristics (BRASIL, 1997; JAYME et al., 2022; GOUVEIA et al., 2022). The accessions used as parents may present genetic and agronomic variability, which may result in differences in nutritional requirements and responses to fertilization between these materials. This issue is particularly important in pastures, where the use of fertilizers is still reduced (BARCELLOS et al., 2008), in contrast to the main agricultural crops, which constitute a large part of the national consumption of these inputs (BRASIL, 2021).

In this scenario, information on how different hybrids respond to nutrient omission during establishment and, especially, whether they have the same recovery capacity after reestablishment of fertilization is scarce. Understanding these differences is essential for identifying materials that are more sensitive to nutritional deficiency and those with greater recovery capacity. Thus, the objective of this study was to evaluate the impact of nitrogen and phosphorus omission during establishment and the recovery capacity of *Urochloa* spp. hybrids after

fertilization reestablishment and to identify differences between hybrids in terms of their response to nutritional stress.

Materials and Methods

The experiment was carried out in a greenhouse at the Federal University of Rondonópolis (UFR), Mato Grosso (latitude 16°28' S, longitude 54°38' W and altitude of 284 meters). The experimental period ranged from January to June 2021.

The experimental design was completely randomized, with sixteen treatments, a 4x4 factorial scheme, and four replications. The treatments involved four hybrids of *Urochloa* spp.: Sabiá (*U. ruziziensis* × *U. brizantha*), Camello (*U. ruziziensis* × *U. brizantha* × *U. decumbens*), Cayana (*U. ruziziensis* × *U. brizantha*) and Mulato II (*U. ruziziensis* × *U. brizantha* × *U. decumbens*), and four nitrogen and phosphorus fertilization strategies: no nitrogen (- N), no phosphorus (- P), no nitrogen and phosphorus (- NP) and with both nutrients (+NP).

The soil used was classified as Red Latosol (Table 1), collected in the 0–20 cm layer, sieved and transferred to the pots. The experimental units were composed of pots with a capacity of 5.0 dm³, containing five plants per pot.

Twenty seeds of each hybrid were sown per pot, and thinning was performed 10 days after sowing, leaving five uniform plants per pot. At sowing, for the phosphorus treatments, P₂O₅ was applied at a dosage of 100 mg dm⁻³, using triple superphosphate as a source. Nitrogen fertilization was performed in nitrogen treatments at a dosage of 100 mg/dm³ in the form of urea when the plants reached 15 cm in height. Potassium fertilization was not performed, as the soil had 171 mg dm⁻³ of K, a value higher than the limit of 50 mg dm⁻³ established for the recommendation of potassium fertilization (VILELA; DE SOUSA; MARTHA JÚNIOR, 2007).

Thirty days after thinning, the first evaluation was carried out to measure the effect of nutrient omission on the establishment of *Urochloa* spp. hybrids. Plant height was measured, tillers were counted, and the forage was harvested at 15 cm of residue height. After the forage mass was harvested, the number of leaves was quantified. Height was measured with a graduated ruler. The harvested forage was placed in paper bags, dried in a forced-air oven at 55 ± 5 °C for 72 h, and weighed. The leaf appearance rate was calculated as the ratio between the number of leaves per tiller and the growth interval in days. Phyllochron was calculated as the reciprocal of the leaf appearance rate.

To evaluate the recovery of the hybrids after nutritional stress during establishment, after the first forage harvest, all the treatments were fertilized with 100 mg dm⁻³ of N and 100 mg dm⁻³ of P₂O₅, using urea and triple superphosphate as sources, respectively. Twenty days after the first evaluation, the same variables were measured during the second evaluation. The same procedure was repeated for two additional harvests, resulting in

three recovery evaluations. After the first recovery evaluation, in the two subsequent cycles, only N was applied at a dosage of 100 mg/dm³ in the form of urea.

In the last evaluation, residue and root dry masses were determined. The residue was obtained by cutting the remaining plant material at soil level, whereas the roots were recovered by sieving and

washing. The residue and the root mass were subsequently subjected to drying in an oven with forced air circulation at 55°C±5°C for 72 hours.

The data were subjected to analysis of variance, considering, for the establishment phase, the effects of hybrid, fertilization strategy, and the hybrid × fertilization interaction.

Table 1. Chemical and particle size characterization of a clayey red Latosol from the Cerrado

pH	P	K	Ca+Mg	Al	H	CTC	V	O.M.	Sand	Silte	Clay
CaCl ₂	mg/dm ³		cmolc/dm ³				%		g/kg		
4.9	4.4	171	4.3	0.0	3.0	7.7	61	24	515	110	375

pH: hydrogen potential; CaCl₂: calcium chloride; P: phosphorus; K: potassium; Ca+Mg: calcium+magnesium; Al+H: aluminum+hydrogen; CEC: cation exchange capacity; V: base saturation; O.M.: organic matter.

For the recovery phase, the effects of hybrid, fertilization strategy, and the hybrid × fertilization interaction were considered fixed effects, whereas regrowth was considered a random effect. When a significant effect was found, the means were compared by Tukey's test at 5% probability.

The statistical model adopted for the establishment phase was as follows:

$$Y_{ijk} = \mu + C_i + A_j + C_i A_j + \epsilon_{ijk}$$

where Y_{ijk} is the observed value; μ is the overall average; C_i is the effect of hybrid i ; A_j is the effect of fertilization strategy j ; $(CA)_{ij}$ is the effect of the interaction between hybrid and fertilization; and ϵ_{ijk} is the experimental error.

For the statistical analysis of recovery after nutrient omission, the following model was adopted:

$$Y_{ijkl} = \mu + C_i + A_j + (CA)_{ij} + R_k + \epsilon_{ijkl}$$

where R_k corresponds to the random effect of regrowth, and the other terms are defined according to the previous model.

Results and discussion

At establishment, fertilization influenced the number of leaves, the number of tillers and the forage mass, whereas the effect of hybrid was observed only for the number of tillers. Notably, no hybrid × fertilization interaction was detected for these variables (Table 2). The joint supply of N and P resulted in a greater number of leaves, greater number of tillers and greater forage mass (Table 3). With respect to the number of leaves and forage mass, the individual omission of N or P did not differ from the joint omission of both nutrients. With respect to the number of tillers, the individual omissions of N and P resulted in intermediate values, which were greater than those observed with the joint omission of NP and lower than those observed with the supply of both nutrients. Among the hybrids, the number of tillers was lower in Camello than in Cayana, Mulato II and Sabiá, while

the number of leaves and forage mass did not differ between the hybrids.

The greater number of leaves, tillers and forage mass with the joint supply of N and P demonstrates the simultaneous importance of these nutrients for the establishment of hybrids. The availability of only one of them was not sufficient to maintain the number of leaves and forage production at levels similar to those obtained with NP, indicating that the deficiency of both N and P limits the initial growth of plants. N is involved in the formation of organic compounds, such as amino acids and proteins, in addition to integrating chlorophyll molecules and promoting vegetative growth (TAIZ et al., 2017; FERREIRA; RANGPUR; FERREIRA, 2020). P, in turn, is involved in energy metabolism; the composition of nucleic acids, nucleotides, and phospholipids; and processes related to photosynthesis and plant growth (TAIZ et al., 2017; COCITO et al., 2025).

With respect to the phyllochron, the intensity of nutritional stress made it impossible to determine it in most combinations of hybrid and fertilization strategies (Table 4). In these cases, the plants did not produce forage mass above the residue height established for cutting; therefore, there was no leaf harvest that would allow the determination of the phyllochron. These results demonstrate that the omission of N and/or P compromised the establishment of hybrids, with insufficient growth for the determination of the phyllochron in all materials submitted to the omission of P or NP.

During establishment, the omission of nitrogen and phosphorus compromised the establishment of hybrids, reducing the number of leaves, the number of tillers, and the forage mass and, in most treatments, making it impossible to determine the phyllochron. These results highlight the importance of an adequate nutrient supply during the grass establishment phase. Among them, nitrogen plays a fundamental role in shoot growth and dry matter accumulation and is among the most important nutrients for pasture productivity and recovery (DIJKSTRA et al., 2024). Thus, the reduction in tillering, leaf appearance and,

consequently, forage mass observed under N omission is consistent with the limitation of vegetative growth caused by nutrient deficiency.

Table 2. Summary of the analysis of variance for the effects of hybrid, fertilization, and their interaction during establishment

Variable	Hybrid	Fertilization	Hybrid x fertilization	SEM
Number of leaves	0.1330	<0.0001	0.2331	2.1127
Number of tillers	0.0009	<0.0001	0.1523	0.8416
Forage mass	0.2192	<0.0001	0.3895	0.5090

SEM: standard error of the mean.

Table 3. Number of leaves, tillers and forage mass (FM) of *Urochloa* spp. hybrids submitted to N and P omission during establishment

Variable	Hybrid				Fertilization			
	Camello	Cayana	Mulato II	Sabiá	- NP	- N	- P	+ NP
Leaves (n°/pot)	6 A	12 A	11 A	13 A	0 b	5 b	1 b	35 a
Tillers (n°/pot)	8 B	12 A	13 A	12 A	7 c	11 b	11 b	16 a
FM (g/pot)	0.1 A	1.2 A	1.9 A	2.1 A	0.5 b	0.0 b	0.0 b	5.6 a

Averages followed by the same uppercase letter for each hybrid and a different lowercase for each type of fertilization did not differ according to the results of the Tukey test ($p>0.05$).

Table 4. Phyllochron (days/leaf) of *Urochloa* spp. hybrids submitted to N and P omission during establishment

Hybrid	Fertilization			
	- NP	- N	- P	+ NP
Camello	-	-	-	4.92 ± 0.68
Cayana	-	-	-	6.99 ± 0.91
Mulato II	-	-	-	8.89 ± 1.24
Sabiá	-	8.70 ± 0.56	-	6.75 ± 0.83

Phosphorus also plays an essential role in grass establishment because it is involved in plant energy metabolism as a component of adenosine triphosphate (ATP), nucleic acids, nucleotides, and phospholipids (TAIZ et al., 2017). Thus, its contribution is not restricted to the development of the root system, since P also participates in processes related to photosynthesis (COCITO et al., 2025) and can favor plant growth and tillering (GUIMARÃES et al., 2021). The lower emission of leaves and tillers and the reduced accumulation of forage observed in treatments with P restriction therefore reinforce the importance of phosphate fertilization during the establishment of hybrids.

Recovery after nutrient omission during establishment

During the recovery phase, the effects of the hybrid on the forage mass, residue mass, number of tillers and number of leaves were observed. Fertilization, in turn, affected only the number of tillers as a main effect. There was an interaction effect between hybrid and fertilization on the number of leaves, the number of tillers and the phyllochron, indicating that the response of the hybrids varied according to the fertilization strategy. For root mass, no main effects of hybrid or fertilization were observed (Table 5).

Table 5. Summary of the analysis of variance for the effects of hybrid, fertilization, and their interaction during the recovery phase.

Variables	Hybrid	Fertilization	Hybrid X Fertilization	SEM
Forage mass	<0.0001	0,2488	0,3244	0,4512
Number of leaves	0,0002	0,0979	0,0001	1,3408
Number of tillers	<0.0001	0,0001	0,0016	0,9667
Phyllochron	0,0804	0,5371	0,0024	0,5803
Root mass	0,1318	0,1326	0,7970	2,3721
Residue mass	0,0085	0,2745	0,7159	1,3540

SEM: standard error of the mean.

The interaction between hybrid and fertilization for traits related to shoot development demonstrated that the hybrids showed different

responses to nutritional stress during establishment, even after the reestablishment of fertilization. Thus,

the response and recovery capacity after N and P deficiency differed among the evaluated hybrids.

Sabiá did not differ in terms of the number of tillers between the nutritional conditions imposed during establishment, since there was no difference between the fertilization strategies for this hybrid (Table 6). In Camello, the highest tillering occurred with NP, whereas the lowest values were observed after the omission of N and NP. In Cayana, the omission of P or NP compromised tillering during recovery, whereas in Mulato II, there was no difference between the strategies.

These results reveal differences between the hybrids in terms of their response to N and P availability. Sabiá maintained tillering even after the omission of these nutrients during establishment, whereas Camello and Cayana showed greater dependence on the previous nutritional conditions for the recovery of this trait.

This characteristic is important, as high tillering favors the perennality of forage plants (CABRAL; DUARTE; AVELINO, 2024) and contributes to the maintenance of vegetation cover, which helps in competition with weeds and protection against erosive processes (AMORIM et al., 2025). From the point of view of management, however, tillering should not be considered in isolation, as the productive response of pastures also depends on canopy management, area sizing, and adjustment of the stocking rate to forage production conditions (CABRAL et al., 2021).

In terms of the number of leaves, differences were observed among the hybrids in terms of the residual effects of nutritional omission that occurred during establishment (Table 6). In Camello, the

number of leaves did not differ between the fertilization strategies. In Cayana, compared with the other strategies, the treatment with NP resulted in a greater number of leaves. In Mulato II, the number of leaves was greater in the treatment with NP than in the treatment without NP. In Sabiá, the number of leaves was greater after the omission of P than in the treatment with NP.

The differences observed between the hybrids demonstrate that the effects of nutrient omission during establishment on leaf emission can persist after the reestablishment of fertilization. In Cayana, this response was more evident because the number of leaves was greater with the supply of NP after establishment than under the three conditions of nutritional omission.

In Mulato II and Sabiá, the differences occurred only between some fertilization strategies, while Camello showed no differences among fertilization strategies. Therefore, the results indicate differences in the response to nutritional stress and in the recovery capacity of the hybrids evaluated.

This response may be related to the functions of N and P in plant growth. Phosphorus promotes root system development (COCITO et al., 2025), thereby enhancing soil exploration and nutrient uptake, whereas nitrogen directly affects the emergence of new leaves (MARTUSCELLO et al., 2019). Thus, limitations in the availability of these nutrients during establishment can compromise the formation of the structures necessary for regrowth and prolong their effects on subsequent growth cycles.

Table 6. Number of tillers, number of leaves, and phyllochron of *Urochloa* spp. hybrids during recovery after omission of N and P at establishment

Hybrid	Fertilization			
	- NP	- N	- P	+ NP
Tillers (n°/pot)				
Camello	27 Bb	25 Bb	29 ABab	35 Aa
Cayana	24 Cb	31 ABab	24 BCb	36 Aa
Mulato II	24 Ab	27 Aab	25 Ab	30 Aa
Sabiá	36 Aa	34 Aa	34 Aa	34 Aa
Leaves (n°/pot)				
Camello	39 Aab	41 Aab	36 Ab	42 Aa
Cayana	34 Bab	33 Bb	31 Bb	45 Aa
Mulato II	28 Bc	37 ABab	38 ABb	42 Aa
Sabiá	44 ABa	45 ABa	48 Aa	36 Ba
Phyllochron (days/leaf)				
Camello	15 Aa	14 Ab	17 Aa	17 Aab
Cayana	14 Ba	20 Aa	16 Ba	17 ABab
Mulato II	17 Aa	14 Ab	14 Aa	14 Ab
Sabiá	17 Aa	17 Aab	15 Ab	19 Aa

Means followed by the same uppercase letter in the row and the same lowercase letter in the column did not differ according to Tukey's test ($p > 0.05$).

With respect to phyllochron, no main effects of hybrid or fertilization were observed, but there was a hybrid $\times$ fertilization interaction, demonstrating that the response of the hybrids to the previous nutritional conditions varied for this characteristic (Table 6). In Cayana, the phyllochron after the omission of N was greater than that after the omission of P or NP but did not differ from that in the treatment with NP. For Camello, Mulato II and Sabiá, there was no difference between the fertilization strategies. Thus, the effects of nutritional omission during establishment on the phyllochron did not persist in a generalized way after the reestablishment of fertilization, and a response to previous nutritional conditions was observed only in Cayana, which indicates greater persistence of the effects of nutritional stress on the dynamics of leaf emission in this hybrid than in the other materials evaluated.

During the recovery phase, forage mass differed among hybrids, with greater forage mass observed for Mulato II, whereas no effect of fertilization strategy was detected (Table 7). The absence of this effect indicates that after the nutrient supply was reestablished, the hybrids recovered their forage production, regardless of the omission of N and P during establishment.

With respect to root mass, no effects of hybrid, fertilization strategy, or interactions between

these factors were observed (Table 5, Table 7). These results suggest that root mass may recover after fertilization is restored, which is important for plant persistence because roots are involved in water and nutrient uptake and serve as reserve organs during regrowth (RIGHI et al., 2024). However, the high variability observed for this trait (CV = 42.52%) requires caution in this interpretation and indicates the need for studies with greater experimental precision to evaluate root system recovery.

For the residue mass, there was a difference only between the hybrids (Table 7). Cayana had greater residue mass than Mulato II, whereas Camello and Sabiá had intermediate values. At the end of the recovery period, the residue mass was determined mainly by the differences between the genetic materials and not by the previous omission of N or P.

Residual mass plays an important role in the recovery of grasses after defoliation, since the amount of remaining leaf tissue interferes with their photosynthetic capacity and the use of reserves for the emission of new leaves and tillers (SILVA et al., 2025). Although residue height was not a factor evaluated in this study, differences in residual mass between hybrids may represent important characteristics for their regrowth capacity.

Table 7. Forage mass (FM), residue mass (RM) and root mass (RootM) of *Urochloa* spp. hybrids during recovery after omission of N and P at establishment

Variable	Hybrid				Fertilization			
	Camello	Cayana	Mulato II	Sabiá	- NP	- N	- P	+ NP
FM (g/pot)	5.6 B	6.3 B	8.6 A	4.6 B	6.0 a	6.1 a	5.9 a	6.9 a
RM (g/pot)	23.4 AB	26.4 A	18.8 B	22.9 AB	21.2 a	23.4 a	22.1 a	25.1 a
RootM (g/pot)	27.0 A	20.5 A	19.5 A	25.1 A	26.7 a	22.3 a	18.8 a	25.5 a

Averages followed by the same uppercase letter for each hybrid and a different lowercase for each type of fertilization did not differ according to the results of the Tukey test ($p > 0.05$).

In addition, the maintenance of residue and root mass is important for the regrowth capacity of grasses, as these structures participate in the storage and mobilization of reserves used after defoliation and in situations of stress (RIGHI et al., 2024). In this study, the effects of nutritional deficiency during establishment were more persistent for shoot characteristics than for root and residue mass.

In general, the results reinforce the importance of the joint supply of N and P during the establishment of pastures, since the deficiency of any of these nutrients compromises initial growth and can reduce the formation of adequate vegetation cover. Adequate establishment of forage is essential to express its productive potential and contribute to the maintenance of soil cover, reducing conditions that favor the degradation process.

In addition, although the hybrids evaluated share parental species of the genus *Urochloa*, distinct responses to omission and subsequent

reestablishment of N and P were identified, especially for the number of leaves, tillering and phyllochron. Sabiá maintained the number of tillers regardless of the previous nutritional condition, whereas the other hybrids showed distinct responses because of the omission of nutrients and the trait evaluated. These results demonstrate that the common interspecific origin does not imply similar agronomic responses and reinforce the importance of individually evaluating hybrids in terms of their response to nutritional deficiency and ability to recover after the reestablishment of fertilization.

Conclusion

The omission of nitrogen or phosphorus limits the establishment of *Urochloa* spp. hybrids, demonstrating that the joint supply of these nutrients is necessary for the initial formation of these plants. In the recovery phase, the effects of nutritional omission during establishment depend on the hybrid and the trait evaluated. With respect to tillering,

Sabiá maintains this trait regardless of the previous nutritional condition, whereas Camello and Cayana show residual effects of the previous nutrient omission. In terms of the number of leaves and the phyllochron, the response to nutrient replacement also varies among the hybrids.

The forage mass is not influenced by the previous omission of N or P after the reestablishment of fertilization and is greater in Mulato II, which indicates that the subsequent replacement of these nutrients allows the recovery of forage production, which is compromised by nutritional deficiency during establishment. Thus, the effects of the omission of N and P on forage production are reversible with the reestablishment of fertilization, while their effects on morphogenic and structural characteristics may persist differently among hybrids.

References

- Amorim, S. S.; Pires, A. J. V.; Fries, D. D.; Cruz, N. T.; Ribeiro, A. S.; Conceição, F. J.; Ferreira, E. P. L.; Da Silva, H. S. 2025. Effects of fertilization protocols on the morphological and productive characteristics of *Brachiaria brizantha* cv. Marandu. *Aracê* 7(3): 14576-14597. <https://doi.org/10.56238/arev7n3-256>
- Barcellos, A. O.; Ramos, A. K. B.; Vilela, L.; Martha Junior, G. B. 2008. Sustainability of animal production based on intercropped pastures and the use of exclusive legumes, in the form of a protein bank, in the Brazilian tropics. *Brazilian Journal of Animal Science* 37(Supl. Esp.): 51-67. <https://doi.org/10.1590/S1516-35982008001300008>
- Brazil. 1997. Ministry of Agriculture, Livestock and Supply. Decree No. 2,366, of November 5, 1997. Regulates Law No. 9,456, of April 25, 1997, which establishes the Protection of Plant Varieties, provides for the National Service for the Protection of Plant Varieties – SNPC, and provides for other provisions. Federal Official Gazette, Brasília, Brazil.
- Brazil. 2021. Special Secretariat for Strategic Affairs. National Fertilizer Plan 2050: a strategy for fertilizers in Brazil. SAE, Brasília, Brazil. 195 p.
- Cabral, C. E. A.; Cabral, C. H. A.; Santos, A. R. M.; Motta, A. M.; Mota, L. G. 2021. Technical-economic impacts of pasture fertilization. *Native* 9(2): 173-181. <https://doi.org/10.31413/nativa.v9i2.12047>
- Cabral, C. E. A.; Duarte, C. F. D.; Avelino, A. C. D. (org.). 2024. Easy Forragiculture. EdUFR, Rondonópolis, Brazil. 169 p.
- Cocito, D. C.; Silva, E. L.; Carmaneiro, F. C.; Jaski, J. M. 2025. The importance of phosphate fertilization in tropical pastures as an alternative in management and its application models. *Revista Temas* 3(18): 1-18. <https://doi.org/10.5281/zenodo.14914894>
- Corrêa, D. C. C.; Cardoso, A. S.; Ferreira, M. R.; Siniscalchi, D.; Gonçalves, P. H. A.; Lumasini, R. N.; Reis, R. A.; Ruggieri, A. C. 2021. Ammonia volatilization, forage accumulation, and nutritive value of Marandu palisade grass pastures in different N sources and doses. *Atmosphere* 12(9): 1179. <https://doi.org/10.3390/atmos12091179>
- Dijkstra, D. D.; Backes, C.; Santos, A. J. M.; Baião, D. C.; Teodoro, A. G.; Ribon, A. A. 2024. Recovery of *Brachiaria marandu* pasture with nitrogen and sulfur application. *Observatory of the Latin American Economy* 22(4): e3994. <https://doi.org/10.55905/oelv22n4-004>
- Ferreira, C. P.; Clove, M. S.; Ferreira, E. V. O. 2020. Mineral fertilizers. In: Brazil, E. C.; Clove, M. S.; Viégas, I. J. M. (eds.). Fertilization and liming recommendations for the state of Pará. 2nd ed. Embrapa Eastern Amazon, Brasília, Brazil. p. 73-91.
- Gomide, C. A. M.; Paciullo, D. S. C.; Martins, C. E. 2020. Timing of nitrogen fertilization in intensively managed pastures. Embrapa Dairy Cattle, Juiz de Fora, Brazil. 17 p. (Technical Circular, 125).
- Gouveia, B. T.; Mateus, R. G.; Barrios, S. C. L.; Valle, C. B.; Bueno Filho, J. S. S.; Rios, E. F.; Dias, A. M.; Nunes, J. A. R. 2022. Combining ability and selection for agronomic and nutritional traits in *Urochloa* spp. hybrids. *Grass and Forage Science* 77(1): 33-44. <https://doi.org/10.1111/gfs.12555>
- Guimarães, A. K. V.; Pinto, J. C.; Faquin, V.; Castro, E. M.; Boldrin, P. F.; Faria, M. R.; Marinho, J. V. N. 2021. Morphology, nutritive value, and anatomy of *Brachiaria brizantha* under phosphorus doses and cutoff ages. *Conjectures* 21(2): 246-259. <https://doi.org/10.53660/CONJ-145-236>
- Hasanuzzaman, M.; Bhuyan, M. H. M. B.; Nahar, K.; Hossain, M. S.; Mahmud, J. A.; Hossen, M. S.; Masud, A. A. C.; Moumita; Fujita, M. 2018. Potassium: A vital regulator of plant responses and tolerance to abiotic stresses. *Agronomy* 8(3): 31. <https://doi.org/10.3390/agronomy8030031>
- Jayme, D. G.; Gonçalves, L. C.; Ramirez, M. A.; De Menezes, R. A. 2022. Tropical forage grasses. 1st ed. FEPE, Belo Horizonte, Brazil. 328 p.
- Lopes, G. H. L.; Vilar, C. C.; Ushiwata, S. Y.; Reis, R. G. E.; Silveira, D. S.; Tafarel, A. H. 2018. Production of *Urochloa brizantha* cv. Marandu submitted to potassium fertilization of establishment. *Campo Digital Magazine* 13(1): 1-8.
- Martuscello, J. A.; Rios, J. F.; Ferreira, M. R.; Assis, J. A.; Braz, T. G. S.; Cunha, D. N. F. V. 2019. Production and morphogenesis of BRS Tamani grass under different nitrogen doses and defoliation intensities. *Animal Industry Bulletin* 76: 1-10. <https://doi.org/10.17523/bia.2019.v76.e1441>
- Nascimento, D. B.; Lopes, M. L. S.; Izidro, J. L. P. S.; Bezerra, R. C. A.; Gois, G. C.; De Amaral, T. N.

E.; Dias, W. S.; De Barros, M. M. L.; Oliveira, A. R. S.; De Farias Sobrinho, J. L.; Coêlho, J. J. 2024. Nitrogen, phosphorus, and potassium cycling in pasture ecosystems. Brazilian Animal Science 25: e-76743P. <https://doi.org/10.1590/1809-6891v25e-76743P>

Righi, R. S. M.; Gomes, L. D.; Mota, L. G.; Duarte, C. F. D.; Cabral, C. H. A.; Cabral, C. E. A. 2024. Tolerance of *Megathyrsus maximus* cultivars to water stress. Nativa 12(2): 249-254. <https://doi.org/10.31413/nat.v12i2.15729>

Silva, G. B. A.; Silva, R. B.; Duarte, C. F. D.; Cabral, C. H. A.; Cabral, C. E. A.; Moura, A. B. O. 2025. Residue height and interval between defoliation and nitrogen fertilization of Mombaça grass. Journal in Agribusiness and Environment 18: e12930. <https://doi.org/10.17765/2176-9168.2025v18e12930>

Souza Junior, J. C.; Monteiro, F. A. 2026. Sulfur improvements in growth, nutrient use efficiency, and photosynthesis depend on ammonium–nitrate nutrition in *Megathyrsus maximus*. Frontiers in Plant Science 17: 1828558. <https://doi.org/10.3389/fpls.2026.1828558>

Taiz, L.; Zeiger, E.; Møller, I. M.; Murphy, A. 2017. Physiology and plant development. 6th ed. Artmed, Porto Alegre, Brazil. 888 p.

Vilela, L.; Sousa, D. M. G.; Martha Júnior, G. B. 2007. Liming. In: Martha Júnior, G. B.; Vilela, L.; Sousa, D. M. G. (eds.). Cerrado: efficient use of correctives and fertilizers in pastures. Embrapa Cerrados, Planaltina, Brazil. p. 93-106.