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Forage productivity and morphogenesis of *Megathyrsus maximus* x *M. infestum* cv. Massai under phosphate fertilization

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Abstract. The effect of phosphorus fertilization (0, 30, 60, 90 and 120 kg of P_2O5 ha^{-1}) on green dry matter (GDM) yield and morphogenetic and structural characteristics of *Megathyrsus maximus* x *M. infestum* cv. Massai was evaluated under natural field conditions in Roraimas´s savannas. Phosphorus fertilization increased significantly (P<.05) GDM yields, P concentrations, tiller populational density (TPD), live leaf $tiller^{-1}$ number (LLTN), avarege leaf size (ALS), leaf area index (LAI), leaf senescence rate, leaf appearance rate (LAR) and elongation rates (LER). Maximum GDM yields, LAR, LER, TPD, LLTN, LAI and ALS were obtained with the application of 101.7; 62.5; 68.7; 80.8; 66.5; 91.7 and 74.1 kg of P_2O5 ha^{-1}, respectively. The P critic level, related to 80% of GDM maximum production, was estimated at 1.652 g kg^{-1}. The P efficiency utilization was inversely proportional to the P rates applied.

Keywords: Leaves, green dry matter, tillering, senescence

Produtividade de forragem e morfogênese de Megathyrsus maximus **x** M. infestum cv*. Massai sob fertilização fosfatada*

Resumo. O efeito da fertilização fosfatada (0, 30, 60, 90 e 120 kg de P_2O5 ha^{-1}) sobre a produção de forragem e características morfogênicas e estruturais de *Megathyrsus maximus* x *M. infestum* cv. Massai foi avaliado em condições naturais de campo nos cerrados de Roraima. A adubação fosfatada afetou positiva e significativamente (P<0,05) a produção de matéria seca verde (MSV), teores de fósforo (P), densidade populacional de perfilhos (DPP), número de folhas $perfilho^{-1}$ (NFP), tamanho médio de folhas (TMF), índice de área foliar (IAF) e taxas de aparecimento (TAF), expansão (TEF) e senescência das folhas. Os máximos rendimentos de MSV, TAF, TEF, DPP, NFP, IAF e TMF foram obtidos com a aplicação de 101,7; 62,5; 68,7; 80,8; 66,5; 91,7 e 74,1 kg de P_2O5 ha^{-1}, respectivamente. O nível crítico interno de P, relacionado com 80% da produção máxima de MSV, foi estimado em 1,652 g kg^{-1}. A eficiência de utilização de P foi inversamente proporcional às doses de P aplicadas.

Palavras-chave: Folhas, matéria seca verde, perfilhamento, senescência

Productividad de forraje y morfogénesis de Megathyrsus maximus *x M. infestum cv.* *Massai bajo fertilización fosfatada*

Resumen. El efecto de la fertilización fosfatada (0, 30, 60, 90 y 120 kg de P_2O5 ha^{-1}) sobre la producción de forraje y las características morfogénicas y estructurales de *Megathyrsus maximus* x *M. infestum* cv. Massai fue evaluado en condiciones naturales de campo en las sabanas de Roraima. La fertilización con fosfato afectó positiva y significativamente ($P<0.05$) la producción de materia seca verde (MSV), el contenido de fósforo (P), la densidad de población de macollas (DPM), el número de hojas de la $macolla^{-1}$ (NHM), el tamaño promedio de la hoja de la macolla (TPHM), índice de área foliar (IAF) y tasas de aparición (TAH), expansión (TEH) y tasas de senescencia de las hojas. Los rendimientos máximos de MSV, TAH, TEH, DPM, NHM, IAF y TPHM se obtuvieron con la aplicación de 101,7; 62,5; 68,7; 80,8; 66,5; 91,7 y 74,1 kg de P_2O5 ha^{-1}, respectivamente. El nivel crítico interno de P, relacionado con el 80% de la producción máxima de MSV, se estimó en 1,652 g kg^{-1}. La eficiencia de utilización de P fue inversamente proporcional a las dosis de P aplicadas.

Palabras clave: Hojas, materia seca verde, macollaje, senescencia

Introduction

Cattle ranching is a of the main economic activities in Roraima and the cultivated pastures represent the main forage resource for the herds feeding. The use of continuous grazing or minimum rest periods, high intensities defoliation and non-replacement of nutrients removed via animal production are factors that contribute to low availability and quality of forage, with negative effects on the zootechnical performance of animals (Costa et al., 2020a; Tesk et al., 2020).

In Roraima, soils under savanna vegetation are characterized by low natural fertility, characterized by high acidity, low cation exchange capacity and high levels of exchangeable aluminum, limiting the productivity and persistence of cultivated pastures, reflecting negatively on the performance herd zootechnics. In the formation and management of cultivated pastures, the knowledge of the nutritional factors that limit the growth of forage grasses becomes essential for the formulation of adequate fertilization practices (Costa et al., 2007; Lemaire et al., 2011).

In exploratory soil fertility trials carried out in Roraima, phosphorus (P) was considered the most limiting nutrient to the growth of several forage grasses, notably *Megathyrsus maximus* cvs. Centenario, Mombasa and Vencedor, whose deficiency implies in significant reductions in yields and in the quality of its forage, as it drastically affects the morphogenic characteristics (appearance rate, elongation rate and life duration of the leaves) and structural characteristics of the grass (density of tillers, number and average size of live leaves) (Costa et al., 2007; Costa et al., 2020b).

Phosphorus plays an important role in the development of the root system and in the tillering of grasses, being essential for photosynthesis, synthesis and degradation of carbohydrates, in addition to actively participating in cellular respiration, influencing the storage, transport and use of energy produced in the photosynthetic process, in addition to favor the growth of the root system, which contributes to greater absorption of water and nutrients (Pereira, 2013; Sarmiento et al., 2006). Considering the high investment in the acquisition of phosphate fertilizers and their relative importance in the composition of the production costs of livestock systems, it is necessary to ensure their efficiency, through the determination of the most adequate doses for the establishment and maintenance of pastures (Nabinger & Carvalho, 2009).

Pasture productivity is strongly influenced by environmental conditions (temperature, light, water and soil fertility) and management practices, while its longevity, among other factors, results from the ability to reconstitute and maintain the leaf area after defoliation, which affects the structure of the canopy, determining its growth speed, forage accumulation, chemical composition and persistence (Almeida, 2015; Cavalli, 2016; Nabinger & Carvalho, 2009; Souza, 2018).

In this work were avaluated the effects of phosphate fertilization on forage accumulation and morphogenesis of *Megathyrsus maximus* x *M. infestum* cv. Massai in the Roraima´s savannas.

Material and methods

The trial was conducted at the Embrapa Roraima Experimental Field, located in Boa Vista, from May to September 2016 and May to October 2017, which corresponded to an accumulated precipitation of 1,416 mm and 1,218 mm and average monthly temperature of 24.79ºC and 25.12ºC, respectively. The climate of the region, according to Köppen's classification is Awi, characterized by well-defined dry and rainy periods of approximately six months each. The soil of the experimental area is a Yellow Latosol, medium texture, savanna phase, with the following chemical characteristics, at a depth of 0-20 cm: pH_{H2O}=5.9; P=11.1 mg/kg; Ca + Mg = 1.21 $cmol_c.dm^{-3}$; K = 0.056 $cmol_c dm^{-3}$ and Al = 0.11 $cmol_c dm^{-3}$.

The experimental design was entirely randomized with three replications. The treatments consisted of five phosphorus levels (0; 30; 60; 90 and 120 kg of P_2O5 ha^{-1}), applied to broadcast after the pasture uniformormization and in the form of triple superphosphate.. The establishment fertilization consisted of the application of 90 kg of N ha^{-1} and 60 kg of K_2O ha^{-1}, in the form of urea and potassium chloride, respectively. The nitrogen fertilization was divided in two times, being 1/3 when clearing the pasture, at the beginning of the experiment, and 2/3 at 35 days. Nitrogen, phosphorus and potassium fertilizations were reapplied in May 2017, using the same doses as the previous year. The plots measured 2.0 x 2.0 m, with a useful area of 1.0 m^2. During the experimental period, eight cuts were performed at intervals of 35 days and 20 cm above the ground.

The parameters evaluated were green dry matter (GDM), phosphorus content, phosphorus efficiency use (PEU), tiller populational density (TPD), live leaf $tiller^{-1}$ number (LLTN), average leaf size (ALS), leaf area index (LAI), leaf appearance rate (LAR), leaf expansion rate (LER) and leaf senescence rate (LSR). LAR, LER and LAI were determined only in live tillers. LAR and LER were calculate by dividing the accumulated leaf length and the total number of leaves in the tiller, respectively, by the regrowth period. To calculate the leaf area, samples of completely expanded green leaves were collect, trying to obtain an area between 200 and 300 cm^2. The samples were digitalize and the leaf area estimated with the aid of an electronic optical planimeter (Li-Cor 3100C). Subsequently, the sample was take, to the greenhouse with forced air at 65ºC until they reached constant weight, obtaining the leaf GDM. Specific leaf area (SLA) was determine by the relationship between green leaf area and its GDM (m^2/g leaf GDM). The LAI was determined from the product of the total green leaf GDM (g GDM/m^2) by SLA (m^2/g leaf GDM). The LSR was obtained by dividing the length of the leaf that was yellowish or necrotic by age of regrowth. The levels of P were determined according to the methodology described by Silva (2009). The levels of P were quantified after nitroperchloric digestion and determined by colorimetry.

PEU was estimated by relating the GDM yield to the respective applied P level. The phosphorus internal critical level (PICL) was determined by adjusting the regression equation to GDM yield (dependent variable) and P levels (independent variable) (equation 1) and for P levels as a dependent variable of the P levels applied (equation 2). Using equation 1, the dose of P was calculated to obtain 80% of the maximum GDM yield, and this value is replaced in equation 2.

The data were subject to analysis of variance and regression considering the significance level of 5% probability. In order to estimate the response of the parameters evaluated to the phosphate fertilization, the choice of regression models was reason on the significance of the linear and quadratic coefficients, using the Student's “t”test, at the level of 5% probability.

Results and discussion

The GDM yields were affected by phosphate fertilization ($P < 0.05$), with the quadratic relationship and the maximum estimated value with the application of 101.7 kg of P_2O_5 ha^{-1} (3,99 kg of GDM ha^{-1}), the which was lower than those reported by Costa et al. (2007) for *M. maximus* cv. Centenario (138.9 kg of P_2O_5 ha^{-1}) (Table 1). In pastures of *M. maximus* cv. Massai, Volpe et al. (2008) estimated the P_2O_5 ha^{-1} dose for maximum GDM accumulation at 237 kg ha^{-1} and the economic dose at 185 kg ha^{-1}, for a soil base saturation of 39%.

The efficiency of phosphorus use was inversely proportional to the doses used (Table 1). However, the grass showed greater responsiveness than that reported by Costa et al. (2006) for pastures of *M. maximus* cv. Centenario (62.3, 48.6 and 30.1 kg of GDM/kg of P_2O_5 ha^{-1}, respectively for doses of 40, 80 and 120 kg of P_2O_5 ha^{-1}). The reported GDM yields were higher than those reported by Costa et al., (2007) for *M. maximus* cv. Tanzania, fertilized with 80 kg of P_2O_5 ha^{-1} and subjected to different cutting frequencies (1,856; 2,587 and 3,009 kg of GDM ha^{-1}, respectively for cutting every 21, 35 and 42 days).

The P contents were adjusted to the quadratic regression model and the maximum value was obtained with the application of 89.90 kg of P_2O_5 ha^{-1} (1.78 g kg^{-1}). The PICL, related to 80% of the maximum production of GDM, was estimated at 1.652 g kg^{-1} and obtained with the application of 40.1 kg of P_2O_5 ha^{-1}, being lower than those reported by Costa et al. (2007) for *M. maximus* cvs. Tobiatã (2.073 g kg^{-1}) and Tanzania (1.885 g kg^{-1}), showing high efficiency of P utilization in forage production, since the PICL represents the nutrient concentration below which yield is reduced and above which it is not presents an economic return (Ferreira et al., 2008; Nabinger & Carvalho, 2009; Oliveira et al., 2009; Silva et al., 2017).

Table 1. Green dry matter (GDM - kg ha^{-1}) yield, P content (g kg^{-1}), P efficiency use (PEU - kg GDM ha^{-1}/kg P_2O_5 ha^{-1}), tiller populational density (TPD - tiller m^{-2}), live leaf $tiller^{-1}$ number (LLTN), leaf area index (LAI), average leaf size (ALS - cm), leaf appearance rate (LAR - cm $tiller^{-1}$ day^{-1}), leaf expansion rate (LER - cm $tiller^{-1}$ day^{-1}) and leaf senescence rate (LSR - cm $tiller^{-1}$ day^{-1}) of *Megathyrsus maximus* cv. Massai, as affected by phosphate fertilization

Variables	Phosphorus levels (kg P_2O_5 ha^{-1})					Regression Equation
	0	30	60	90	120	
GDM	2,361	3,142	3,588	4,199	3,847	$Y = 2{,}314 + 32.981\ X - 0.1622\ X^2$ ($R^2 = 0{,}95$)
P content	1.39	1.57	1.72	1.85	1.77	$Y = 1.369 + 0.009352\ X - 0.000052\ X^2$ ($R^2 = 0{,}93$)
PEU	---	104.73	59.80	46.65	32.05	$Y = 117.7 - 0.7623\ X^2$ ($r^2 = 0{,}90$)
TPD	1,231	1,367	1,458	1,527	1,411	$Y = 1{,}219 + 6.7429\ X - 0.04171\ X^2$ ($R^2 = 0{,}91$)
LLTN	3.55	3.98	4.32	4.91	3.59	$Y = 3.41 + 0.03432\ X - 0.000258\ X^2$ ($R^2 = 0{,}89$)
LAI	2.35	2.97	3.54	4.42	3.59	$Y = 2.22 + 0.03764\ X - 0.000205\ X^2$ ($R^2 = 0{,}93$)
ALS	14.87	15.39	15.79	16.14	15.65	$Y = 14.81 + 0.02961\ X - 0.000211\ X^2$ ($R^2 = 0{,}90$)
LAR	0.079	0.085	0.096	0.109	0.083	$Y = 0.076 + 0.000763\ X - 0.0000061\ X^2$ ($R^2 = 0{,}87$)
LER	1.51	1.75	1.97	2.26	1.62	$Y = 1.43 + 0.01869\ X - 0.000136\ X^2$ ($R^2 = 0{,}91$)
LSR	0.091	0.112	0.136	0.152	0.161	$Y = 0.9744 + 0.000615\ X$ ($r^2 = 0{,}95$)

Source: Research data

For TPD, LLTN, IAF, ALS, LAR and LER the relationships were adjusted to the quadratic regression model and the maximum values obtained with the application of 80.8; 66.5; 91.7; 74.1; 62.5 and 68.7 kg of P_2O_5 ha^{-1}, respectively (Table 1). LAR and LER present a negative correlation, indicating that the higher the LAR, the shorter the time available for leaf elongation (Rosanova & Rebouças, 2009; Pereira, 2013). LER due to its high correlation with the production of GDM, has been used as a criterion for the selection of grasses in genetic improvement works (Benício et al., 2011; Nabinger & Carvalho, 2009), while LAR is the most prominent morphogenic trait, since it directly affects the three structural characteristics of the grassland: ALS, LLTN and TPD (Costa et al., 2006; Costa et al., 2008).

In pastures of *M. maximus* cv. Centenario, Costa et al. (2007) found a positive effect of phosphate fertilization on TDP, ALS, LER and LAI, with the maximum values obtained with the application of 80 to 120 kg of P_2O_5 ha^{-1}, however for LLTN the relationship was linear and negative. Patês et al. (2007) only detected positive effects of phosphate fertilization (50, 100 and 150 kg of P_2O_5 ha^{-1}) on the morphogenic characteristics of *M. maximus* cv. Tanzania with the simultaneous application of 100 kg of N ha^{-1}. The LAI represents the synthesis of the morphogenic and structural characteristics of the grass and reflects the balance of processes that determine the supply (photosynthesis) and demand (respiration, accumulation of reserves, synthesis and senescence of tissues) of photoassimilates, which establish the rhythm of growth from the pasture (Nabinger & Carvalho, 2009; Pereira, 2013). For *M. maximus* cv . Massai pastures, Benício et al. (2011) reported the low availability of P severely limited the tillering, which caused a lower forage production and delay in the development of plants. This resulted in a pasture deficient formation and caused the high appearance of weeds.

The LSR was directly proportional to phosphorus doses, reflecting the acceleration of the renewal process of tissues as a consequence of higher forage productivity (Table 1). Costa et al. (2007), evaluating *Megathyrsus* genotypes reported higher LSR with the application of 120 kg of P_2O_5 ha^{-1} (0.198 cm $tiller^{-1}day^{-1}$), compared to 30 kg of P_2O_5 ha^{-1} (0.107 cm $tiller^{-1}$ day^{-1}). Senescence reduces the quality of forage, however it is an important physiological process in the flow of grass tissues, since around 35; 68; 86 and 42% of nitrogen, phosphorus, potassium and magnesium, respectively, can be recycled from senescent leaves and used for the production of new leaf tissues (Sarmiento et al., 2006).

Senescence reflects the natural physiological process that characterizes the last stage of leaf development, started after its complete expansion and progressively accentuated with the increase in leaf area, due to the shading of the leaves inserted in the lower portion and the low supply of photosynthetically active radiation, characterized by intense competition for light, nutrients and water between the different strata of the plant (Lemaire at al., 2011).

Conclusions

Phosphate fertilization positively affects forage availability and morphogenic and structural grass characteristics. The phosphorus utilization efficiency is inversely proportional to the applied doses.

The maximum technical efficiency dose for the GDM yield was estimated at 101.7 kg of P_2O_5 ha^{-1} and the phosphorus internal critical level, related to 80% of the maximum GDM yield, in 1.652 g kg^{-1}.

The process of renewal and senescence of grass tissues is accelerated with increasing doses of phosphorus.

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