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Phosphorus fertilization in the implantation of a silvopastoral system: morphogenic and structural characteristics of Mombaça grass

Adubação fosfatada na implantação de sistema silvipastoril: características morfogênicas e estruturais do capim Mombaça

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RESUMO

Objetivou-se avaliar o efeito da adubação fosfatada nas características morfogênicas e estruturais do capim Mombaça sob condições de implantação de sistema silvipastoril com eucaliptos e monocultivo no ecótono Amazônia/Cerrado. O experimento foi conduzido na UFT-EMVZ, nas estações chuvosas dos anos agrícolas de 2016/2017 e 2017/2018. Área experimental foi subdividida em dois sistemas de cultivo, Monocultivo de capim Mombaça, com 0,25 hectare e Silvipastoril com consórcio de eucalipto e capim Mombaça com área de 0,75 hectare. O delineamento utilizado foi um Delineamento inteiramente casualizado em esquema fatorial 4 a 2 sendo quatro doses de fósforo (0; 50; 100; 200 kg. ha^{-1} de P_2O_5. ano-¹) e dois sistemas de cultivo (monocultivo e silvipastoril), com três repetições. Foram avaliados três ciclos por período de descanso médio de 21 dias. Semanalmente foram realizadas as medições para avaliação das características estruturais e morfogênicas das plantas. De forma geral, fatores testados como adubação fosfatada, sistema de cultivo e ano de condução (implantação e ano seguinte) apresentaram

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influência, alterando o desenvolvimento do capim Mombaça, refletindo nas características morfogênicas e estruturais. As variáveis: densidade populacional de perfilhos, taxa de crescimento cultural, índice de área foliar, obtiveram interações entre a adubação fosfatada e os sistemas de cultivos analisados (P<0,05). A adubação fosfatada utilizada na implantação momento este de a de maior requerimento da planta, refletiu no desenvolvimento da forrageira aumentando a taxa de crescimento cultural, aparecimento foliar, bem como alongamento de folhas e colmo nos dois sistemas avaliados.

Palavras-chave: *Eucalyptus urograndis*, Fósforo, Integração pecuária-floresta, *Megathyrsus maximum*.

ABSTRACT

The objective of this study was to evaluate the effect of phosphate fertilization on morphogenic and structural characteristics of Mombasa grass under conditions of implantation of silvopastoral system with eucalyptus and monoculture in the Amazon/Cerrado ecotone. The experiment was conducted at UFT-EMVZ during the rainy seasons of the 2016/2017 and 2017/2018 agricultural years. The experimental area was subdivided into two cultivation systems, Mombaça grass monoculture, with 0.25 hectare and silvopastoral system, intercropping eucalyptus with Mombaça grass, with 0.75 hectare area. The design used was a 4 x 2 factorial IHD with four doses of phosphorus (0; 50; 100; 200 kg.ha $^{-1}$ P_2O_5 year-^{1}) and two cultivation systems (monoculture and silvopastoral) with three repetitions. Three cycles were evaluated for an average rest period of 21 days. Weekly measurements were taken to evaluate structural and morphogenic characteristics of plants. In general, factors tested such as phosphorus fertilization, cultivation system and year (implantation and following year) showed influence, altering the development of Mombaça grass, reflecting on the morphogenic and structural characteristics. Tiller population density, crop growth rate, leaf area index showed interactions between phosphorus fertilization and the cultivation systems analyzed (P <0.05). Phosphorus fertilization used in the implantation, moment of greatest requirement of the plant, influenced forage development by increasing the crop growth rate, leaf appearance, as well as leaf and stem elongation in the two evaluated systems.

Keywords: *Eucalyptus urograndis*, Livestock-forest integration, Phosphorus, *Megathyrsus maximum*,

INTRODUCTION

Phosphorus is found in extremely low concentrations in the vast majority of Brazilian soils including the soils of the Amazon /Cerrado ecotone, especially considering the Quartzarênico Neosol. Phosphorus has low mobility and high adsorption capacity with clays typical of low slope areas such as kaolinites. Phosphorus is considered the very limiting nutrient for biomass production in Brazilian tropical soils (SANTOS et al., 2011).
The application of phosphate fertilizers has been used to meet the deficiencies in P, so that the demand for phosphate fertilizers in Brazil has increased

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significantly in recent years, from 1,522 thousand tons in 2011, to 5,126 thousand tons in 2017 (ANDA, 2017).

The supply of phosphorus for crops such as pastures will depend on their concentrations in the soil solution, in addition to the soil ability to maintain adequate nutrient levels for the plant. Since the increased need for P in Quartzarênico Neosol is related to low concentrations of organic matter and clay, making it impossible to retain large amounts of P applied (SILVA et al., 2016).

The recovery of pastures through silvopastoral systems (Ssp's) appears as a possible alternative for the expansion of Brazilian livestock, especially in the Amazon/Cerrado ecotone region (DIAS FILHO, 2011). Currently, Ssp's are one of the tools to solve the problem of depletion of natural resources, as these systems have a tree-pasture-animal combination in the same ecosystem. This can result in greater cycling in contrast to the loss of resources (EMBRAPA, 2015). The increase in OM concentration in soils is one of the advantages attributed to Ssp's and as soluble phosphate fertilizers have their efficiency increased in soils with a higher concentration of OM.

In the Amazon/Cerrado ecotone, studies of tissue flow in pastures by means of morphogenic processes have become an important tool for the evaluation, use and increase in the production of leaves and tillers. In the last decades, management of tropical forage plants has undergone constant changes. In an energetic system, which seeks the interaction between the components of these pastures (Soil, Plant and Animal), the forage plant started to be studied as part of this system (CARVALHO et al., 2014).

Thus, the goal was to evaluate the effect of phosphorus fertilization on the morphogenic and structural characteristics of Mombaça grass under conditions of implantation of a silvopastoral system with eucalyptus and in monoculture.

MATERIAL AND METHODS

The experiment was conducted at the Federal University of Tocantins - Campus de Araguaína, at the School of Veterinary Medicine and Animal Science, at latitude, longitude and altitude of 07°05’43’’S, 48°12’13’’W and 226 m, respectively. The climate of the region, according to the Köppen classification (1948), is Aw (hot and humid). The experiment was conducted in the rainy seasons of the agricultural years 2016/2017 and 2017/2018. The meteorological data of the experimental periods were recorded in the meteorological station, located 900 m from the experimental area (Table 1).

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Table 1: Maximum and minimum temperatures, relative humidity and rainfall in the experimental period.

Months	Max temperature (ºC)	Min temperature (ºC)	Humidity (%)	Rainfall (mm)
December 2016	25.9	24.8	83.5	99.4
January 2017	25.4	24.3	86.0	289.0
February 2017	25.3	24.3	87.4	348.0
March 2017	25.9	24.7	86.6	235.2
April	26.1	24.8	86.1	204.0
Average year 1	27.7	24.5	85.9	235.0
December 2017	25.1	24.4	86.3	64.8
January 2018	25.2	24.0	85.9	251.4
February 2018	25.3	24.2	87.3	255.2
March 2018	25.8	24.7	85.9	341.8
Average year 2	25.3	24.3	86.3	228.3

Source: INMET, 2019.

The soil of the area was a typical Quartzarênico Órtico Neosol (EMBRAPA, 2014). The studied area was 1.0 ha, divided into two systems, the first was a monoculture of *Megathyrsus maximus* cv. Mombaça with 0.25 ha, and the second, a silvopastoral, system intercropping eucalyptus (*Eucalyptus urograndis*) with Mombaça grass, with an area of 0.75 ha in the Amazon/Cerrado ecotone.

The soil was sampled at a depth of 0 to 20 cm in November of each year evaluated, performing chemical analysis (Table 2) according to the methodology proposed by EMBRAPA (2013).

Table 2: Soil chemical characteristics in the 0-20 cm deep layer of the experimental area

System	pH	OM	P	K^+	Ca^{++}	Mg^{++}	H+Al	Al^{++}	SB	CEC	V
	$CaCl_2$	$g.kg^{-1}$	$mg.dm^{-3}$	-----------------Cmolc.dm^{-3}---------------					%	Cmolc.dm^{-3}	%
Year (2016)											
Mono	4.28	1.13	1.42	0.12	1.55	0.55	5.17	0.33	2.22	7.72	28.75
Ssp	4.58	1.23	1.42	0.14	1.45	0.65	5.19	0.35	2.24	7.78	28.79
Year (2017)											
Mono	4.58	1.54	2.70	0.08	1.14	0.38	4.36	0.22	1.60	6.18	25.88
Ssp	4.80	1.54	2.74	0.08	1.17	0.40	4.34	0.25	1.65	6.24	26.44
Year (2018)											
Mono	4.10	2.90	1.47	0.10	0.91	0.91	3.38	0.50	1.52	5.4	28.14
Ssp	4.08	2.43	1.66	0.10	0.81	0.81	3.34	0.30	1.21	4.85	24.94

Mono: monoculture of *Megathyrsus maximus cv.* Mombaça; Ssp: Silvopastoral system; pH: potential of hydrogen; $CaCl_2$: Calcium chloride; OM: Organic matter; P: phosphorus in the soil in milligrams per cubic decimeter using the Mehlich method[1]; K: Potassium in milligrams per cubic decimeter using the Mehlich method[1]; Ca: Calcium; Mg: Magnesium; H + Al: hydrogen plus aluminum; Al: Aluminum; SB: sum of bases; V: Base saturation, CEC: Total cation exchange capacity; cmolc. dm^{-3}: centimol of charge per cubic decimeter.

Two months before implementing the experiment, liming was performed to correct the soil, and dolomitic limestone with 80% PRNT was incorporated with the aid of a plow harrow. Application of limestone in Quartzarênico Neosol is justified because this soil is a sediment with high depth and predominance of medium and coarse sand, the concentration of organic matter is very low, and mineralization is very intense due to the characteristics of the region (CARNEIRO et al., 2009). Allied to this, the implanted crops have their extraction particularities, such as eucalyptus with its rapid development and nutritional

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requirements, and Mombaça due to the large number of cycles, demand a lot from the soil. And the soil due to the very low load takes the characteristics mentioned and these pastures after each cycle are exported to other sites and leading to an annual decrease in CEC.

In the silvopastoral system, 350 seedlings of *E. urograndis* were planted on 15/12/2016, in pits 40 cm deep, in the East-West direction, allowing greater light incidence in the understory, with 9.0 m spacing between double rows, 2 m between plants, and 3m between single rows. Nutrition gel was used to plant eucalyptus, 300 mL per plant. On 18/12/2016, Mombaça grass was sown broadcast using 4.5 kg pure viable seeds per hectare, in both systems.

After forage establishment, in which it reached 3 to 4 leaves per tiller, in March 2017 the standardization cut was performed.

The design used was completely randomized (DIC), although unusual, it was used because the experimental area of Quartzarênico Neosol was homogeneous in depth, slope. The DIC with repeated measures over time agricultural years (2016/2017 and 2017/2018), the main plot arranged in a 2 x 4 factorial arrangement, with two cultivation systems (monoculture and silvopastoral) and four levels of phosphorus (0; 50; 100; 200 kg P_2O_5 ha^{-1} $year^{-1}$), with three repetitions per plot, in three cycles per experimental period.

The source of phosphorus was single superphosphate, broadcast applied by hand only once a year. At the beginning of each regrowth period, nitrogen (N) and potassium (K_2O) fertilization was carried out with 150 kg ha^{-1} of the formula 30:00:30 (30% N, 0% of ??? and 30% K_2O) per cycle, with 21 rest days per cycle. This fertilization is in accordance with the recommendation for management systems of medium technological level and for a demanding forage like Mombaça grass (CFSEMG, 1999). In the following year 2017/2018, the standardization cut and the phosphate, nitrogen and potassium fertilization were repeated.

Grass height was monitored and controlled every seven days; canopy height was measured at 30 points at random, using a graduated ruler (SANTOS et al., 2011).

Evaluations of morphogenic and structural characteristics were studied in relation to the growth and death dynamics of the plants measured at the level of tiller individually, using the technique of marked tillers, according to Davies (1993), in which the readings started, three days after fertilization, every 7 days. Leaf lengths, expanding and expanded, senescent parts, as well as the length of the stems (height from the ground to the last expanded leaf) were measured and tillers counted by area ($tiller.m^{-2}$) using a frame 0.15 m x 1.00 m (0.15 m^2). In addition, new leaves that appeared during each cycle were recorded. From this information, morphogenic variables were calculated: leaf appearance rate (TApF, leaf. $Tiller^{-1}$. Day^{-1}); leaf elongation rate (TAlF, cm leaf. $Tiller^{-1}$. Day^{-1}); phyllochron (days. $Leaf^{-1}$. $Tiller^{-1}$); stem elongation rate (TAlC, cm stem. $Tiller^{-1}$. Day^{-1}).

Leaf area index (IAF) was estimated from a leaf sub-sample. Segments with 10 cm were cut, and the sum of the average width of all segments was multiplied by 10 cm, thus estimating the leaf area of the sub-sample (IAF, m^2 leaf/m^2 soil) according to Alexandrino et al. (2005).

For the evaluation of the structural characteristics, we evaluated tiller

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population density (DPP); leaf/stem ratio, percentage of leaves and stems in the total dry mass; crop growth rate (TCC), which was estimated by dividing the mass of green forage by the length of the rest period.

The statistical model adopted was:
$\mathbf{Y_{ijk} = \mu + P_i + S_j + PS_{ji} + e_{ijk(a)}\ A_l + AP_{li} + e_{ijkl(b)}}$
where:
"μ" is the overall mean.
"P_i" is the effect of levels of phosphorus i, i = 0, 50, 100 and 200 kg ha^{-1} P_2O_5.
"S_j" is the effect of forage production systems j, j = monoculture and silvopastoral.
"PS_{ji}" is the effect of the system vs. fertilization interaction.
"A_l" is the effect of the agricultural year 1, 1 = 2016/2017 and 2017/2018.
"AP_{lj}" is the effect of the year vs. phosphorus interaction.
"$e_{ijk(a)}$" is the $error_{(a)}$.
"$e_{ijkl(b)}$" is the $error_{(b)}$.
The variables were subjected to the tests of normality (SHAPIRO-WILK, 1965) and homoscedasticity (COCHRAN, 1941). For variables with normal data distribution and with homogeneous variances, analysis of variance was applied, followed by an F-test on ANOVA parameters. For the comparison of the years and systems studied, Student's t-test was run for comparison of means, and for the levels of phosphorus, regression analysis was carried out observing the linear, quadratic and deviation from linearity effects, adopting the significance of 5% for probability of type I error.

RESULTS AND DISCUSSION

In general, factors tested, such as: phosphorus fertilization, production system and year (implantation and following year) of the study, showed significant influence, altering the development of Mombaça grass, reflecting on the morphogenic and structural characteristics. There was no interaction between phosphorus fertilization and the production system analyzed, only in relation to the variables: (TAPF), (TALF), (TALC), phyllochron and (DVF), with $P>0.05$ (Table 3).
Phosphorus fertilization provided greater root development, which reflected significantly in the development of the aerial part, providing a positive correlation between TAPF and TALF (0.70), thus enabling greater growth of the leaf fraction (OLIVEIRA et al., 2014).
Torres et al. (2016) evaluated phosphorus doses in the early development and forage production of *Megathyrsus maximus* cultivars, and found a quadratic effect for doses from 48 to 50 kg ha^{-1}, with maximum points of 56 kg ha^{-1}; these authors still infer that doses above the maximum point decrease leaf elongation, as the plant responds positively up to 56 $kg.ha^{-1}.year^{-1}$ P, and from that point on, there is a drop in production, thus interrupting the leaf elongation and growth, observations that corroborate the present study at doses greater than 140 kg $ha^{-1}.year^{-1}$ P_2O_5.
TALC was affected by the production system, in which the silvopastoral system presented a higher TALC than the monoculture system. Such results occurred, possibly, due to the competition for light, space and nutrients among the young tillers; they tend to increase the elongation of stems to achieve a greater exposure to light, in addition, the stem elongation was greater at the reproductive phase than at the vegetative phase, since the transition from vegetative to

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reproductive development is marked by an increase in the frequency of cell divisions within the central zone of the apical meristem of the stem, resulting in stem elongation (TAIZ & ZEIGER, 2009).

Table 3. Morphogenic characteristics of Mombaça grass under the effect of phosphorus fertilization in cultivation systems

Systems	Phosphorus** (kg ha^{-1}. $year^{-1}$) 0	50	100	200	Means	P* Systems	Phosphorus EL	EQ	DL	System x Phosphorus	CV (%)
TAPF (leaf. $tiller^{-1}$. day^{-1})											
Mono	0.394	0.494	0.428	0.456	0.443 B		0.300	0.214	0.019		
Ssp	0.475	0.498	0.500	0.492	0.491 A	0.013	0.678	0.472	0.831	0.335	9.91
Means[1]	0.435	0.496	0.464	0.474	0.467		0.380	0.174	0.058		
TALF (cm. $tiller^{-1}$.day^{-1})											
Mono	3.126	3.656	4.771	4.349	3.975 A		0.088	0.165	0.412		
Ssp	3.147	3.939	5.033	4.586	4.176 A	0.576	0.601	0.102	0.507	0.992	5.90
Means[2]	3.136	3.797	4.902	4.682	4.076		0.018	0.043	0.301		
TALC (cm. $tiller^{-1}$. day^{-1})											
Mono	0.249	0.390	0.197	0.243	0.270 B		0.479	0.819	0.051		
Ssp	0.293	0.609	0.481	0.384	0.442 A	0.003	0.936	0.013	0.043	0.292	7.16
Means[3]	0.271	0.500	0.339	0.314	0.356		0.653	0.044	0.010		
Phyllochron (days.$leaf^{-1}$.$tiller^{-1}$)											
Mono	8.450	7.443	6.912	6.634	7.280 A		0.000	0.001	0.645		
Ssp	8.136	7.477	6.966	6.540	7.360 A	0.402	0.000	0.033	0.911	0.492	7.45
Means[4]	8.293	7.460	6.939	6.587	7.320		0.000	0.001	0.804		
DVF											
Mono	16.696	10.518	10.514	10.066	11.949 A		0.081	0.138	0.397		
Ssp	12.617	12.478	11.568	12.652	12.329 A	0.797	0.990	0.726	0.812	0.392	7.01
Means[5]	14.657	11.498	11.041	11.359	12.139		0.195	0.193	0.659		
IAF											
Systems	0	50	100	200	Means	Systems	EL	EQ	DL	System x Phosphorus	CV (%)

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Mono	3.326 B	3.500 B	5.340 B	3.620 B	3.946		<0.001	<0.001	0.234		
Ssp	5.176 A	5.426 A	6.633 A	5.623 A	5.714	<0.001	<0.001	<0.001	0.187	0.001	6.65
Means[6]	4.251	4.463	5.986	4.621	4.830		<0.001	<0.001	0.210		

Mono: monoculture of *Megathyrsus maximus cv.* Mombaça; Ssp: Silvopastoral system; P*: Probability of type I error; Phosphorus **: P_2O_5 doses; TAPF: tiller leaf appearance rate. Tiller. Day^{-1}; TAPF: leaf appearance rate cm leaf. Tiller. Day^{-1}; TAPF: leaf appearance rate cm stem. $Tiller^{-1}$. Day^{-1}; DVF: leaf life days; IAF: Leaf area index; EL: Linear effect; EQ: Quadratic effect; DL: Deviation from linearity; CV: coefficient of variation; mean values followed by different uppercase letters, in the same column, or lowercase letters, in the same row, are significantly different ($P<0.05$) by Student's t-test. Equations: 1 - $\hat{y} = 0.467$; 2 - $\hat{y} = 3.028534 + 0.025760X - 0.000092X^2$ ($R^2 = 92.00\%$); 3 - $\hat{y} = 0.356$; 4 - $\hat{y} = 8.298573 - 0.018905X + 0.0000514X^2$ (R^2 99.97); 5 - $\hat{y} = 12.136$.

The increase in phosphorus fertilization provides greater productivity of the dry mass of the aerial part of Mombaça grass and the rapid renewal of plant tissues, which was demonstrated by phyllochron, which responded at the level of 183.54 kg $ha^{-1}.year^{-1}$ P_2O_5 providing less time for the appearance of the set of Mombaça grass leaves. Costa et al. (2016) verified a quadratic relationship and the maximum estimated value with the application of 91.3 kg $P_2O_5.ha^{-1}$, confirming the efficiency observed in the following work, that the application of phosphorus results in good leaf production in grasses.

There was a negative correlation between the phyllochron and DVF (-0.22), this relationship indicates the mechanics of pasture growth related to the condition of the medium, which if favorable, the expression is maximum of its genetic potential, responding to the high fertility of the soil, due to the fertilization used, allowing the plant a greater speed in leaf replacement. The lower the phyllochron, the more efficient the grass is at intercepting and converting light energy into leaf tissue, since this variable increases with plant age, due to the longer time for the leaf to travel the distance between the apical meristem and the end of the pseudostem formed by the sheaths of older leaves (LUNA et al., 2012).

Leaves have a limited life span, which is determined by genetic traits, which are influenced by environmental factors and management practices (LEMAIRE et al., 2008). As the present study shows similarity in the characteristics (nutritional, environmental and management used) of the production systems, there was no effect of the tested parameters for DVF.

The action of phosphorus fertilization in improving soil fertility on leaf elongation, leaf length and tiller population density is directly expressed on the IAF of the pasture, which can be demonstrated by the positive correlation of IAF with other variables, such as TAPF, TALF and DPP, resulting in greater forage production (PONTES et al., 2010). IAF values between 3.4 and 4.8 were reported by Duarte et al. (2019), who analyzed tropical grass managed under intermittent stocking, fertilized with phosphorus sources with different solubilities, combined or not with nitrogen; the authors also report that the higher amounts of P in the soil enable greater growth and accumulation of leaves, which resulted in increased IAF, a fact observed in the present study.

There was an effect ($P < 0.05$) of phosphorus fertilization and the production system on DPP and TCC (Table 4). There was a quadratic effect of phosphorus fertilization on DPP, with the maximum point for this parameter being 132.80 and 119.40 kg ha^{-1}. $year^{-1}$ P_2O_5 for monoculture and Ssp, respectively.

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Table 4. Structural characteristics of Mombaça grass under the effect of phosphorus fertilization in cultivation systems

Systems	Phosphorus** (kg ha^{-1} $year^{-1}$) 0	50	100	200	Means	P* Systems	Phosphorus EL	EQ	DL	System x Phosphorus	CV (%)
DPP (tillers per m²)											
Mono[1]	30.795A	35.964B	64.879A	49.428A	45.267		<0.001	<0.001	0.209		
Ssp[2]	30.956A	43.362A	60.864B	43.501B	44.671	0.344	<0.001	<0.001	0.313	<0.001	8.15
Means	30.875	39.663	62.872	46.464	44.969		<0.001	<0.001	0.645		
TCC (Kg $ha^{-1}.day^{-1}$)											
Mono[2]	124.7A	146.760B	262.504A	202.091A	184.033		<0.001	<0.001	0.087		
Ssp[3]	126.3A	176.973A	247.259B	177.934B	182.140	0.441	<0.001	<0.001	0.067	<0.001	7.85
Means	125.584	161.867	254.882	190.013	183.086		<0.001	<0.001	0.245		
Leaf: stem ratio											
Mono	0.721	0.813	0.831	0.715	0.774 B		0.096	<0.001	0.507		
Ssp	0.864	0.929	0.925	0.903	0.905 A	<0.001	0.362	0.086	0.068	0.081	5.44
Means[s4]	0.792	0.871	0.878	0.809	0.825		0.564	<0.001	0.110		

Mono: monoculture of *Megathyrsus maximus cv.* Mombaça; Ssp: Silvopastoral system; P*: Probability of type I error; Phosphorus **: P_2O_5 doses; DPP: tiller population density per m²; TCC: crop growth rate; CV: coefficient of variation; EL: Linear effect; EQ: Quadratic effect; DL: Deviation from linearity; mean values followed by different uppercase letters, in the same column, or lowercase letters, in the same row, are significantly different (P<0.05) by Student's t-test. Equations: 1 - $\hat{y} = 26.853941 + 0.483421X - 0.001820X^2$ (R^2 = 72.80 %); 2 - $\hat{y} = 109.142671 + 1.951163X - 0.007302X^2$ (R^2 = 73.77 %); 3 - $\hat{y} = 119.056545 + 1.963974X - 0.008287X^2$ (R^2 = 91.10 %); 4 - $\hat{y}$= 0.825.

From these applied phosphorus levels, there was a decrease in tiller population for both systems. Tillering is dependent on internal and external conditions to the plant, being regulated mainly by the genotype, hormonal balance, flowering, light, temperature, photoperiod, water, mineral nutrition, mainly phosphorus, since it acts directly on grass tillering (LANGER, 1972).

Similar values of tiller production were found by Torres *et al.* (2016), who studied phosphorus at the initial development and forage production of cultivars of *Megathyrsus maximus*, with higher tillering of Mombaça grass at a dose of 60 kg P_2O_5. ha^{-1}. Dias et al. (2015) evaluated the production of *Brachiaria brizantha* cv. BRS Piatã submitted to sources of phosphorus, and obtained greater response in tiller density when a high level of soluble sources was applied. These results are possibly explained by the intense meristematic activity promoted by the supply of phosphorus at the initial stage of forage regrowth.

Fertilization influenced the TCC, with a quadratic effect of 133.60 and 118.50 $ha^{-1}.year^{-1}$ P_2O_5 for monoculture and Ssp, respectively; from this plateau a decrease in the growth of the culture was found,

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independent of the production system. There was a positive correlation between DPP and TCC (0.99) in relation to the increase in phosphate fertilization, which reflect increases in the rates of leaf elongation, leaf appearance and tiller production. This occurred due to greater tissue renewal, associated with the main effect of the nutrient in increasing the rate of cell production and tillering, thus enabling a higher forage growth rate (ROMA *et al*., 2012).

The absence of interactions in the present study for the leaf: stem ratio can be related to the fact that the cut management was the same, generating similarity in the responses found. Nevertheless, it is inferred that phosphorus fertilization was able to provide increases in forage productivity in the implantation and establishment phase, generating positive gains in the leaf fraction, being observed that the SSP obtained higher TALF and TAPF, which increased this fraction (leaf) in relation to the stem, generating a high-quality forage. The largest leaf fraction in the forage improves the nutritional value of the grass, as it is the fraction most selected by animals; TALF is a determining characteristic for productive genotypes, even when they are under different management conditions (LARA; PEDREIRA, 2011).

There were no interactions of phosphorus levels with the year of implantation and the following year for the variables: TAPF, TALF, TALC; Phyllochron, DVF, DPP, TCC, leaf: stem ratio, with P <0.05 (Tables 5 and 6). This higher TAPF and TALF in the second year is possibly because the grass metabolism is more efficient in capturing photoassimilates in the year following implantation, as well as, better root development, which allowed the emergence of more tillers and new leaves (CARNEIRO *et al*., 2017).

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Table 5. Morphogenic characteristics of Mombaçaa grass under the effect of phosphorus fertilization in the experimental years.

TAPF (leaf. tiller^{-1}. day^{-1})											
Year	**Phosphorus** (kg.ha^{-1} year^{-1}) **0**	**50**	**100**	**200**	**Means**	**P* Year**	**Phosphorus EL**	**EQ**	**DL**	**Year x Phosphorus**	**CV (%)**
2016/2017	0.399	0.438	0.411	0.442	0.422 B		0.200	0.863	0.158		
2017/2018	0.470^{a}	0.554	0.517	0.505	0.511 A	0.003	0.605	0.412	0.051	0.273	13.80
Means[2]	0.435	0.496	0.464	0.474	0.467		0.380	0.174	0.058		
TALF (cm. tiller^{-1}.day^{-1})											
Year	**Phosphorus** (kg ha^{-1} year^{-1}) **0**	**50**	**100**	**200**	**Means**	**P* Year**	**Phosphorus EL**	**EQ**	**DL**	**Year x Phosphorus**	**CV (%)**
2016/2017	2.739	3.367	4.062	3.679	3.462 B		0.209	0.204	0.701		
2017/2018	3.534	4.227	5.742	5.256	4.689 A	0.031	0.036	0.095	0.273	0.832	47.26
Means[2]	3.136	3.797	4.902	4.682	4.076		0.018	0.043	0.301		
TALC (cm. tiller^{-1}. day^{-1})											
Year	**Phosphorus** (kgha^{-1} year^{-1}) **0**	**50**	**100**	**200**	**Means**	**P* Year**	**Phosphorus EL**	**EQ**	**DL**	**Year x Phosphorus**	**CV (%)**
2016/2017	0.250	0.588	0.385	0.421	0.411 A		0.190	0.010	0.001		
2017/2018	0.293	0.411	0.293	0.206	0.301 B	0.013	0.037	0.096	0.067	0.279	35.42
Means[2]	0.271	0.5000	0.339	0.314	0.356		0.653	0.044	0.010		
Phyllochron (days.leaf^{-1}.tiller^{-1})											
Year	**Phosphorus** (kg ha^{-1} year^{-1}) **0**	**50**	**100**	**200**	**Means**	**P* Year**	**Phosphorus EL**	**EQ**	**DL**	**Year x Phosphorus**	**CV (%)**
2016/2017	8.287	7.441	6.971	6.689	7.359 A		0.000	0.000	0.571		
2017/2018	8.2997	7.479	6.906	6.485	7.279 A	0.210	0.000	0.000	0.983	0.648	2.83
Means[2]	8.293	7.460	6.939	6.587	7.320		0.000	0.001	0.804		
DVF											
Year	**Phosphorus** (kgha^{-1} year^{-1}) **0**	**50**	**100**	**200**	**Means**	**P* Year**	**Phosphorus EL**	**EQ**	**DL**	**Year x Phosphorus**	**CV (%)**
2016/2017	12.414	11.982	11.483	11.945	12.206 A		0.150	0.142	0.540		
2017/2018	11.511	11.260	11.009	10.774	11.065 A	0.210	0.717	0.743	0.987	0.682	66.35
Means[2]	12.657	11.498	11.041	11.359	12.139		0.195	0.193	0.659		
IAF											
Year	**Phosphorus** (kg ha^{-1} year^{-1}) **0**	**50**	**100**	**200**	**Means**	**P* Year**	**Phosphorus EL**	**EQ**	**DL**	**Year x Phosphorus**	**CV (%)**
2016/2017	4.029 B	4.415 A	5.761 B	4.536 B	4.685		0.001	<0.001	0.136		
2017/2018	4.473 A	4.511 A	6.212 A	4.706 A	4.975	0.010	0.005	<0.001	0.431	0.001	6.17
Means[2]	4.251	4.463	5.986	4.621	4.830		<0.001	<0.001	0.210		

Year: 2016-2017(planting) 2017-2018(following planting); Probability of type I error; Phosphorus **: P_2O_5 doses; TAPF: tiller leaf appearance rate. Day^{-1}; TAPF: leaf appearance rate cm leaf. Tiller. Day^{-1}; TAPF: leaf appearance rate cm stem. Tiller^{-1}. Day^{-1}; DVF: leaf life days; IAF: Leaf area index; EL: Linear effect; EQ: Quadratic effect; DL: Deviation from linearity; CV: coefficient of variation; mean values followed by different uppercase letters, in the same column, or lowercase letters, in the same row, are significantly

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different ($P<0.05$) by Student's t-test. Equations: 1 - $\hat{y} = 0.467$. 2 - $\hat{y} = 3.028534 + 0.025760X - 0.000092X^2$ ($R^2 = 92.00\%$); 3 - $\hat{y} = 0.356$; 4 - $\hat{y} = 8.298573 - 0.018905X + 0.0000514X^2$ (R^2 99.97); 5- - $\hat{y} = 12.136$; %); 6 - $\hat{y} = 3.843916 + 0.027157X - 0.00012X^2$ ($R^2 = 75.05\%$); 7- $\hat{y} = 4.203824 + 0.026413X - 0.000117X^2$ ($R^2 = 56.98\%$).

There was a difference ($P<0.05$) for TALC, the year 2016/2017 presented a higher value for this variable, possibly because the plant is expressing its genetic potential to the maximum and the shading at the base of the clump allows an increase in TALC because when shading occurs on new tillers, they tend to increase stem elongation, in search of light and the emergence of new leaves, since the plant seeks to intensify the development of existing tillers at the expense of new tillers, thus increasing TALC (SILVEIRA JUNIOR et al., 2017).

There was no significant difference ($p<0.05$) in phyllohron between years, however, there was a quadratic effect for the fertilization levels in the years evaluated 181.59 kg ha^{-1} $year^{-1}$ P_2O_5.

There was no effect of phosphorus levels on DVF in the years. This can be justified because the planted grass shows similarity in the cultural treatments and cut management adopted for the experimental years. Leaf life span consists of a limited process and once reached its final size, leaves remain in the tillers for a certain period, enter senescence and die; this growth dynamics is an important characteristic and can be used as management tool, functioning as an indicator for determining grazing intensity and the maximum resting time between grazing (MARTUSCELLO et al. 2006).

Phosphorus fertilizer applied in the experimental years favored a greater IAF, a greater response of the plant, presenting a physiological development superior to the initial year, with a larger volume of root, leaves and stems, being the result of this interaction expressed in the present study (Table 5). The importance of nutritional replacement via fertilization is reported by Duarte et al. (2016), since its absence or even its inefficiency can lead the plant to use the phosphorus available in the solution only for maintenance, which can stop the emergence of tillers, new leaves and interrupting their development and production. In the present experiment, since phosphorus is replaced each year, greater production occurred in the year following implantation.

The structural characteristics did not show any interaction between the years of experimental evaluation and the fertilization used, due to nutritional replacement in cycles and annually, provided similarity in the response of the grass in the years (Table 6).

The similarity of values found in DPP, TCC and leaf: stem ratio can be verified in Dias et al. (2015), who, when evaluating the production of Piatã palisadegrass subjected to different sources of phosphorus, obtained a greater response in tiller density, when increasing levels of soluble phosphorus fertilizers were applied. These authors argue that this occurred due to the intense meristematic activity promoted by the supply of phosphorus at the early regrowth phase of the forage, exactly as in the present study, in which there was mineral replacement via phosphorus fertilization at the beginning of each year, allowing forage response in the study years. The same behavior can be observed for TCC, which responds to DPP gains and, consequently, interferes with the leaf: stem ratio, resulting in a forage with a higher proportion of

RBSPA Revista Brasileira de Saúde e Produção Animal

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leaves, of good quality and high production over the years.

Table 6. Structural characteristics of Mombaça grass under the effect of phosphorus fertilization in the experimental years.

DPP (tillers per m²)

Year	Phosphorus** (kg ha^{-1} year^{-1}) 0	50	100	200	Means	P* Year	Phosphorus EL	EQ	DL	Year x Phosphorus	CV (%)
2016/2017	29.933	40.116	63.884	45.828	44.940 A		<0.001	<0.001	0.365		
2017/2018	31.817	39.210	61.860	47.101	45.007 A	0.700	<0.001	<0.001	0.168	0.066	1.80
Means[1]	30.875	39.663	62.872	46.464	44.969		<0.001	<0.001	0.645		

TCC (Kg ha^{-1}.day^{-1})

Year	Phosphorus** (kg ha^{-1} year^{-1}) 0	50	100	200	Means	P* Year	Fósforo EL	EQ	DL	Year x Phospho	CV (%)
2016/2017	121.479	163.036	257.325	187.259	182.275 A		<0.001	<0.001	0.265		
2017/2018	129.688	160.698	252.439	192.766	183.897 A	0.175	<0.001	<0.001	0.150	0.077	3.01
Means[2]	125.584	161.867	254.882	190.013	183.086		<0.001	<0.001	0.245		

Leaf: stem ratio

Year	Phosphorus** (kgha^{-1} year^{-1}) 0	50	100	200	Means	P* Year	Phosphorus EL	EQ	DL	Year x Phosphorus	CV (%)
2016/2017	0.777	0.837	0.825	0.788	0.770 B		0.809	0.012	0.160		
2017/2018	0.808	0.905	0.831	0.830	0.880 A	0.252	0.652	0.026	0.631	0.241	6.40
Means[3]	0.792	0.871	0.828	0.809	0.825		0.564	<0.001	0.110		

Year: 2016-2017(planting) 2017-2018(following planting); DPP: tiller population density per m²; TCC: crop growth rate; EL: Linear effect; EQ: Quadratic effect; DL: Deviation from linearity; CV: coefficient of variation; mean values followed by different uppercase letters, in the same column, or lowercase letters, in the same row, are significantly different ($P<0.05$) by Student's t-test. Equations: %); 1 - $\hat{y} = 27.982 + 0.484812X – 0.001924X^2$ ($R^2 = 81.38$ %) 2 - $\hat{y} = 114.231257 + 1.957634X – 0.007823X^2$ ($R^2 = 82.01$ %) 3- $\hat{y}= 0.825$.

Thus, it can be concluded that phosphorus fertilization used for implantation, moment of highest requirement for the nutrient, favored the morphogenic and structural modifications in the plant, which reflected in the development of the forage, increasing the crop growth rate, the leaf appearance rate, leaf and stem elongation rates.

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