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Productive efficiency of mombasa grass in silvopastoral system under pasture deferment and nitrogen fertilizer

Eficiência produtiva do capim Mombaça em sistema silvipastoril sob diferimento do pasto e fertilização nitrogenada

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Abstract

This study aimed to evaluate the efficiency of Mombasa grass in a silvopastoral system and submitted to different nitrogen fertilization rates and pasture management strategies. Treatments consisted of four nitrogen fertilizer doses (0.0, 125.0, 187.5, and 250.0 kg N ha^{-1} $year^{-1}$) and three cutting heights (70, 90, and 105 cm). Plant agronomic and physiologic efficiencies, as well as nitrogen use and accumulation by plants, forage production, and increments of forage production, were verified for the application of nitrogen fertilizer. Nitrogen fertilization was only efficient for grasses cut at 105 cm, where 75% of the applied nitrogen at a dose of 125 kg ha^{-1} $year^{-1}$ was recovered. Yet the grasses cut at 70 and 90 cm presented low results for nitrogen fertilization, showing plants with low physiological and agronomic efficiencies. For Mombasa grass in a silvopastoral system, nitrogen fertilization is more efficient when applied at lower doses and for plants cut at higher heights.

Key words: *Megathyrsus maximus*. Agroforestry systems. Pre-grazing height. Post-grazing height.

Resumo

Objetivo de avaliar a eficiência do capim Mombaça manejado em sistemas silvipastoril submetido adubação nitrogenada e estratégias de manejo de corte do pasto. Avaliou-se o capim Mombaça manejado em sistema silvipastoril, com quatro doses de nitrogênio (0, 125; 187,5 e 250 kg ha^{-1} ano^{-1}) e três alturas de corte do capim (70, 90 e 105 cm). Verificando a eficiência da planta quanto a utilização do nitrogênio, eficiência agronômica, eficiência fisiológica, acúmulo de nitrogênio na planta, produção de forragem e o incremento de produção de massa de forragem com aplicação do adubo nitrogenado. A adubação nitrogenada foi eficiente somente para o capim manejado a 105 cm de altura de corte, onde foi possível obter nas doses de 125 kg ha^{-1} ano^{-1} recuperação de 75% do nitrogênio aplicado. Já o capim manejado a 70 e 90 cm apresentou baixo resultado com uso de adubação nitrogenada, com baixa eficiência fisiológica e agronômica. O capim Mombaça em sistema silvipastoril com uso de fertilizante nitrogenado é mais eficiente em baixos níveis de nitrogênio aplicado e nas maiores alturas de corte do pasto.

Palavras-chave: *Megathyrsus maximus*. Sistemas Agroflorestais. Altura pré-pastejo. Altura pós-pastejo.

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Introduction

The main challenge of ruminant livestock on pasture lies in the understanding and use of strategies to reverse the current low indexes of the Brazilian ranching sector. For this, the knowledge on new techniques becomes fundamental to maximize pasture productivity, sustainably and with low environmental impacts (REIS et al., 2012). Therefore, silvopastoral systems can bring great environmental and economic benefits, and recover the productive capacity of degraded or derelict lands, with rational use of natural resources (FERREIRA MAIA et al., 2008).

However, little knowledge exists about the productive potential of grasses in silvopastoral systems; this is mainly due to the restriction of light, which compromises the forage production, hindering the identification of the best management practices to ensure a satisfactory and efficient production. Thus, the productive potential of silvopastoral systems under natural soil conditions should be well understood, as well as its potential with fertilizers, particularly nitrogen.

Nitrogen fertilizers contribute to increasing productivity since this chemical element is one of the main nutrients to maintain forage grass productivity, being an essential constituent of proteins and directly linked to photosynthesis (MOREIRA et al., 2009; PRIMAVESI et al., 2006). By accelerating the development of the forage and ensuring a great contribution of photo-assimilates, nitrogen favors the maintenance of forage canopy and influences the persistence of pastures. Bernardino et al. (2011) reported that nitrogen deficiency in the understory of a silvopastoral system may restrict forage productivity; therefore, when used, nitrogen fertilizers can increase yield levels since these silvopastoral systems also have high demands for this nutrient; thus, the efficiency of nitrogen fertilizers on pastures deserves closer examinations.

Another contributor to pasture yields is the grass cut height. Different heights of cuts should be tested for efficiency in silvopastoral systems; thereafter, effective management practices and precise recommendations can ensure low environmental impacts and a reduced use of inputs (GUELFI-SILVA et al., 2011). In general, grasses are quite tolerant to grazing, presenting an adjustment according to defoliation intensity. In light-restricted environments, grazing height might directly affect plant efficiency, as well as its productivity. Changes in grazing pressure interfere with the demand for nutrients, what added to a light restriction by tree shading may interfere with forage responses.

Given the above background, the objective of this study was to evaluate the productive efficiency indices of Mombasa grass submitted to different nitrogen fertilizer rates and at varied pasture heights in a silvopastoral system.

Material and Methods

This study was conducted at the Federal University of Tocantins, campus in Araguaína, which is located near the geographic coordinates at latitude 7°06’21” South and longitude 48°11’21” West, with an altitude of about 227 m. The local climate is classified as an AW type, which stands for well-defined dry and rainy seasons, and a drought period of nearly 4 months, from June to September, and a rainy summer. The annual rainfall is 1800 mm per year on average. The study area presents soil classified as fertile, characterized as a ferric Red-Yellow Argisol (Ultisol), with abrupt textural changes, according to Embrapa (2013), (Table 1).

The analyzed area was established in 2011 with a silvopastoral system, mixing a secondary forest environment of babaçu (*Attalea speciosa*, Mart) and a pasture of *Megathyrsus maximus* cv. Mombasa, under 35% shade. Between 2012 and 2013, this system was used for sheep grazing with continuous stocking, grass height at 50 cm, and a variable animal load. Forage supply was set at 10% of live weight animal^{-1} day^{1}, with stocking adjustment every 14 days. From January to December 2014, the area was used for alternating grazing, occupied for six days, and remained in rest for 28 days during the rainy season and for 40 days in the dry period.

Table 1. Soil chemical analysis of the experimental area before the implementation of the experiment, in the 0-20 cm depth layer, December 2014.

pH	OM	P	K	Ca	Mg	Al	H+Al	SB	CEC	CEC_e	m	V
$CaCl_2$	g dm^{-3}	mg dm^{-3}	$cmol_c$ dm^{-3}								%	
4,6	56,9	1,73	0,03	4,96	1,73	0,10	1,30	6,90	8,02	6,90	1,47	83,79

SB = sum of bases; OM = organic matter; CEC = cation exchange capacity; CECe = effective cation-exchange capacity; m = aluminum saturation; V = base saturation.

The experiment started from November 2014 and lasted during the rainy season of 2014-2015. In November 2014, a standardization cut was performed, and soil samples were collected for chemical analysis. Based on this, 60 kg ha^{-1} year^{-1} of single superphosphate (P_2O_5) and 90 kg ha^{-1} year^{-1} of potassium chloride (K_2O) were applied.

The experiment was performed in a complete split-plot randomized block design with four replications, wherein each experimental unit had 12 m². Treatments were composed by four doses of nitrogen (urea as N source) equivalent to 0.0, 125.0, 187.5, and 250.0 kg ha^{-1} year^{-1}, and three cutting heights for the Mombasa grass at 70, 90, and 105 cm above soil level.

Nitrogen fertilization was managed in function of the time spent by grass to reach the cutting height, based on the harvest efficiency; in other words, the pasture condition after cutting was 45% of the biomass in relation to the canopy height. Thus, the residue from post-cutting of the grass managed at a cutting height of 70 cm was 30 cm, the grass managed at 90 cm was 40 cm, and the grass managed at 105 cm showed a post-cutting height of 50 cm as residue.

Forage was sampled according to cut point (70, 90, and 105 cm height) using a metal frame (0.5m x 1.0m) and collecting two samples per experimental unit. Only the material above the residue height (30, 40, and 50 cm) was collected. For dry mass measurements (kg ha^{-1}), samples were taken to an oven at 65 °C with forced ventilation for 72 hours or until constant weight, being then weighed, in addition to calculating the forage yield per hectare. An aliquot of the forage sample was grounded to determine the amount of nitrogen by the Kjeldahl method (EMBRAPA, 2005).

Data on forage mass and nitrogen in the plant were determined by the amount of nitrogen accumulated per hectare (kg ha^{-1}) and the content of accumulated crude protein (kg ha^{-1}). In addition, plant use efficiency and assimilation of nitrogen were calculated (FAGERIA, 1998):

✓ Nitrogen use efficiency =

$$\frac{\text{total dry mass (kg ha}^{-1}\text{)}}{\text{N accumulation in the plant (kg ha}^{-1}\text{)}}$$

✓ Efficiency of absorption =

$$\frac{\text{N accumulation with fertilization – N accumulation without fertilization (kg ha}^{-1}\text{)}}{\text{amount of N applied (kg ha}^{-1}\text{)}} x\ 100$$

✓ Agronomic Efficiency =

$$\frac{\text{dry mass with fertilization – dry mass without fertilization (kg ha}^{-1}\text{)}}{\text{amount of N applied (kg ha}^{-1}\text{)}}$$

✓ Physiologic Efficiency =

$$\frac{\text{dry mass with fertilization – dry mass without fertilization (kg ha}^{-1}\text{)}}{\text{N accumulation with fertilization – N accumulation without fertilization (kg ha}^{-1}\text{)}}$$

Forage mass production was verified through the increase in forage yield (%) when comparing the control group, without fertilization (0 kg N ha^{-1}

equal to 100%), with the different nitrogen doses and cutting heights. The increment added with the nitrogen doses in the forage production - 100 plus the increment in the production (%) with fertilizer use - represents the treatment without fertilization as 100% of the natural potential of the soil in forage production.

The Lineweaver and Burk (1934) kinetics saturation model was used to determine the maximum forage yield with minimum fertilizer utilization following the law of decreasing returns; the maximum use efficiency occurs at the lowest doses. The model developed by Lana et al. (2005) was followed. The linear regression analysis of the reciprocal pasture production in the different cutting managements was tested, and the amount of nitrogen fertilizer necessary to reach 50%, 60%, 70%, 80%, and 90% of the theoretical maximum forage production was determined based on the following model:

$$\frac{1}{Y} = a + b * (\frac{1}{X})$$

Where:

Y = forage production (kg ha^{-1} year^{-1});

a = intercept;

b = Coefficient of linear regression;

X = Amount of nitrogen (kg ha^{-1} year^{-1}).

The maximum estimated forage yield was obtained based on the previous model of the intercept reciprocal ($PF_{max} = 1/a$), and the amount of nitrogen needed to achieve 50%, 60%, 70%, 80%, and 90% of the maximum theoretical response was obtained by substitution of the Y in the equation by 1/ * percentage of response (LANA et al., 2005; LANA, 2009).

The data were submitted to the Shapiro-Wilk normality test to verify normal distribution and Bartlett's test for homoscedasticity to check homogeneity. The variables with normal distribution were submitted to analysis of variance and compared by the Tukey test at 5% level of significance, and the effect of the nitrogen doses compared to the means of regression equations, according to the model:

$$y_{jik} = \mu + \alpha_i + b_j + e_{ij} + \gamma_k + (\alpha\gamma)_{ik} + e_{ijk}$$

y_{jik} = observation in the j-th block, the i-th nitrogen level, and the k-th manage for grass height;

μ = overall average;

a_i = effect due to the i-th nitrogen level;

b_j = effect due to the j-th block;

e_{ij} = error associated with the plot (ij);

γ_k = effect due to the k-th manage height

$(\alpha\gamma)_{ik}$ = effect of interaction between nitrogen doses and manage height;

e_{ijk} = error associated with the subplot (ijk)

Results and Discussion

The plant's nitrogen utilization efficiency reflects the ability to produce forage mass for each unit of nitrogen absorbed. The process of breeding Mombasa grass benefits plants yield by absorbing and using nitrogen more efficiently. This fact was verified by the application of N ($P<0.01$), in which the plants with the best utilization efficiency were those receiving the lowest N doses (Table 2). This is due to the reduced efficiency of grass when responding with an increase of forage yield to the increase of N in the soil. Furthermore, higher doses permit N losses due to leaching, volatilization, denitrification, and absorption by the root system (COSTA et al., 2009, 2010).

Table 2. Nitrogen utilization efficiency, accumulation of nitrogen, and crude protein accumulated of Mombasa grass in a silvopastoral system with different nitrogen doses and three cutting height conditions, Araguaína - TO.

Height	Nitrogen (kg ha^{-1} year^{-1})				Average	Equation	CV
(cm)	0	125	187,5	250			
			Nitrogen utilization efficiency (kg DM kg N^{-1})				
70	52,45	45,78	40,45	39,28	44,49 B	$\hat{Y} = 52,3 - 0,055x$	
90	57,68	46,39	45,25	45,35	48,66 A	$\hat{Y} = 57,63 - 0,127x + 0,000313x^2$	3,7
105	56,87	51,44	46,98	44,14	49,85 A	$\hat{Y} = 57,14 - 0,052x$	
			Accumulation of nitrogen (kg ha^{-1})				
70	109,69	141,21	193,96	166,64	152,88	$\hat{Y} = 113,03 + 0,283x$	
90	119,10	165,12	187,05	170,61	160,47	$\hat{Y} = 118,07 + 0,63x - 0,0016x^2$	6,5
105	96,26	190,26	203,92	152,34	160,69	$\hat{Y} = 95,08 + 1,39x - 0,0046x^2$	
			Crude Protein (kg ha^{-1})				
70	685,14	882,59	1212,25	1041,51	955,37	$\hat{Y} = 706,4 + 1,773x$	
90	744,35	1032,02	1169,07	1054,38	999,96	$\hat{Y} = 737,6 + 4,010x - 0,0106x^2$	6,6
105	601,60	1189,14	1274,51	952,10	1004,34	$\hat{Y} = 594,27 + 8,70x - 0,0287x^2$	

Means followed by the same letter do not differ by Tukey test ($P < 0.05$).

Different from the observed in the silvopastoral system, Silva et al. (2011), studied Marandu grass without the effect of shading, and they verified an increase in the nitrogen utilization efficiency with the application of nitrogen fertilizer in the soil. The grass also presented greater capacity to accumulate and absorb N, which favored the maximum deposition in tissue with higher N doses. The silvopastoral system has other factors, such as competition for light, water, and other nutrients, limiting the maximum deposition on plant tissue; thereby, plants are more efficient when low doses of N are applied. Furthermore, with the reduced quantity of light reaching the understory, a reduction in the population of tillers is observed—64% fewer tillers in this area. The plants require less N per hectare since the plant population is smaller compared to those of areas receiving direct sunlight. In 2014, plants in direct sunlight presented of 533 tillers m^{-2}, while in the silvopastoral area presented 182 tillers m^{-2}.

Grass cutting height managements also influenced the nitrogen utilization efficiency ($P<0,01$); better responses were observed when grasses were managed at 90 cm and 105 cm cutting heights, presenting 10% more efficiency in accumulation of N in plant tissues than in the treatments using 70 cm of cutting height. This shows plants managed at these cutting heights require lower concentrations of N in their tissues to express maximum forage production (Table 2).

However, when the accumulation of N in the pasture is verified, there is no significant difference ($P=0.075$) in the different cutting heights tested. Thus, the grass managed at the lowest cutting height accumulates larger amounts of N (2.28% of N in dry mass for grass managed at 70 cm and 2.03% of N in dry mass for grass managed at higher altitudes) to express a maximum potential for production, meaning a lower nitrogen utilization efficiency (Table 2).

A dilution effect of available nitrogen per forage mass might have occurred since low-cut grasses had lower yields, however, the amount of deposited nitrogen was the same for both high- and low- cut plants. Such effect is common when comparing grasses grown under direct sunlight and plants under systems with light restriction, wherein the higher forage mass produced under direct sunlight provides a lower concentration of N in the plants. However, a similar accumulation of N is verified in both systems (SOARES et al., 2009; SOUZA et al., 2007).

Nitrogen accumulation ranged from 152.88 to 160.7 kg ha^{-1} on average in the grass, presenting an average of 2.13% N in the dry matter. Even compared to treatments without fertilization, N accumulation is significantly superior to other studies conducted in a silvopastoral system (CASTRO et al., 2009; LACERDA et al., 2009; ANDRADE et al., 2001). For instance, the research carried out by Bernardino et al. (2011) in areas of Marandú grass integrated with Eucalyptus, these authors verified N accumulation in pasture varying from 27.8 to 45.4 kg ha^{-1} of N to doses of 150 kg ha^{-1} $year^{-1}$, with N values inferior to 1% in the dry matter. Possibly, the high values of N in the dry matter of the grass may be associated with the high content of organic material (5.69%) and soil based saturation (V=83.79%), which directly reflect the chemical characteristics of the plant (Table 1).

A better adaptation of the Mombasa grass to an environment with light restriction may explain the higher values of N accumulation and protein in the pasture. This favored the photosynthetic efficiency and increased in the number of precursors responsible for the capture of light (SOARES et al., 2009).

The nitrogen doses applied in the soil affected the accumulation of N in the pasture ($P<0.01$). The pasture managed at 70 cm showed a linear effect with an increase of 28.3 kg ha of N accumulated in the pasture for each 100 kg N ha^{-1} $year^{-1}$ applied in the soil. A quadratic effect was observed in the plants managed at 90 and 105 cm of cutting heights, with better responses at 197 and 151 kg N ha^{-1} $year^{-1}$, which represents an accumulation of N in the pasture of 180, 200 kg ha^{-1} $year^{-1}$, respectively. The pasture managed at 105 cm requires less amount of nitrogen fertilizer; this shows a pasture with greater utilization efficiency of the applied fertilizer.

The behavior observed in the accumulation of N was similar for crude protein in the pasture, which had no significant difference in the cutting heights ($P>0.05$), but showed effects from the nitrogen fertilization. The increments of crude protein were verified for treatments managed with nitrogen fertilization at 105 cm cutting height. The pasture managed at 105 cm cutting height and 50 cm of residual height may have provided a more rapid regeneration of its biomass in the silvopastoral system for showing the largest amount of leaves remaining in the area. This favored an increase in the production of photoassimilates, which adjust easily to environments with light restriction (CASTRO et al., 2009; MACEDO et al., 2010; PACIULLO et al., 2011; CARDOSO et al., 2015).

An interaction was observed for cutting height and nitrogen fertilization when verifying the nitrogen absorption efficiency applied to the soil ($P<0.01$). The treatments managed at 105 cm showed better recovery of N in the doses of 125 and 187.5 kg ha^{-1} $year^{-1}$, with recovery doses of 75% and 57% of the nitrogen applied in the soil (Table 3). Certainly, the grass managed at higher cutting height presents a better utilization efficiency of the fertilizer, reflecting a maximum forage production. Higher doses of N applied to the soil reduce plant efficiency and negatively affect the use of fertilizer to increase the mass of forage (SILVA et al., 2011). In addition, with increasing doses of N, there are also higher losses (RODRIGUES et al., 2017).

Table 3. Efficiency of nitrogen absorption, agronomic and physiologic efficiency of Mombasa grass in a silvopastoral system, under nitrogen fertilizer and three cutting conditions, Araguaína - TO.

Height	Nitrogen (kg ha^{-1} $year^{-1}$)			Average	cv
(cm)	125	187,5	250		
		Efficiency of nitrogen absorption (%)			
70	25,22 d	44,94 bc	22,78 d	30,98	
90	36,82 cd	36,24 cd	20,61 d	31,22	18,2
105	75,21 a	57,42 b	22,43 d	51,69	
		Agronomic Efficiency (kg DM kg $N^{-1}_{applied}$)			
70	5,60 cd	11,20 c	3,17 d	6,66	
90	6,40 cd	8,53 cd	3,48 d	6,14	27,1
105	34,34 a	22,02 b	4,98 cd	20,44	
		Physiologic Efficiency (kg DM kg $N^{-1}_{accumulated}$)			
70	22,67 b	24,44 b	13,86 b	20,32	
90	16,70 b	23,25 b	16,83 b	18,93	22,1
105	45,69 a	37,57 a	20,77 b	34,67	

Means followed by the same letter do not differ by Tukey test ($P < 0.05$).

For plants cut at 70 and 90 cm, one of the factors responsible to reduce the nitrogen absorption efficiency might be related to the low efficiency of these plants to increase forage production. Hence, the amount of nitrogen to be used will be low, once the plant under these conditions has a poor conversion of nitrogen fertilizer into forage mass, which does not justify the application of high doses of nitrogen.

The reduction of plant efficiency may also be related to the post-cutting residual height because 45% of the height of the forage canopy remained after cutting, which represents 30 and 40 cm of residual height for the grasses managed at heights of 70 and 90 cm, respectively.

The low post-cutting residual height in a light restricted system may have affected the recovery of the pasture, possibly due to the lower remaining leaf area, which results in lower organic reserves, lower production of photoassimilates, and difficult recovery of its forage biomass with the use of nitrogen fertilizer (KIM et al., 2010; PACIULLO et al., 2008). In addition, a pasture with low residual mass implies a smaller leaf area remains, and with this, a lower transparent surface, resulting in a lower absorption of mass flow. Thus, there is a lower absorption of N, higher losses, and consequently, lower efficiency.

Agronomic efficiency may be a good indicator of nitrogen conversion in forage production since it reflects the amount of forage produced for each kg of applied nitrogen. Therefore, the agronomic efficiency interaction between cutting heights and nitrogen doses ($P<0.01$) was verified. The grass managed at 105 cm presented the best efficiency, requiring the lowest nitrogen concentrations in the soil and plant for a maximum forage production; such fact can be observed by the agronomic and physiological efficiency shown in Table 3.

The highest efficiency was observed at the lowest nitrogen doses for grasses cut at 105 cm. For the dose of 125 kg N ha^{-1} $year^{-1}$, agronomic efficiency of 34.34 kg of dry matter for each kg of N applied to the soil, and physiological efficiency of 45.7 kg of dry matter for each kg of N accumulated in the plant (Table 3).

Mombasa showed the best efficiency at low nitrogen doses, what highlights its high phenotypic plasticity since it adjusts to different concentrations of fertilizers to meet the plant physiological demands, responding satisfactorily with little N in the plant and soil (CABEZAS et al., 2011; SILVA et al., 2011; HIREL et al., 2007).

Castagnara et al. (2011) conducted a study in a Red Latosol using Tanzania, Mombasa, and Mulato grasses under four nitrogen doses (0, 40, 80, and 160 kg ha^{-1} year^{-1}). These authors observed a maximum agronomic efficiency at doses of up to 106 kg N ha^{-1} year^{-1} applied to the soil; this shows Tanzania, Mombasa, and Mulato grasses showed unsatisfactory responses to higher N doses. In addition, the Mombasa grass showed the lowest agronomic efficiency, and in soils with good fertility, the grass responds with a low increase in the production with the use of nitrogenous fertilizers, since the soil can supply a good part of the nutrients necessary for an increase in production.

In studies conducted by Silva et al. (2011), the agronomic and physiological efficiency presented reduction with N doses higher than 100 kg ha^{-1} year^{-1}applied to the soil. Even with increased forage production in larger doses, the plant has already reached its point of nitrogen saturation, since the increment of the dry mass of forage per unit of nitrogen applied and absorbed by the plant is reduced. Primavesi et al. (2006) point out the maximum efficiency occurs in lower doses of nitrogen, which was also verified in this present study.

Forage production was influenced by cutting heights ($P<0.001$) and nitrogen doses ($P<0.01$). The grasses managed at 90- and 105-cm cutting heights showed higher forage yields and an increase of 18% in forage production in relation to grass managed at 70 cm (Table 4).

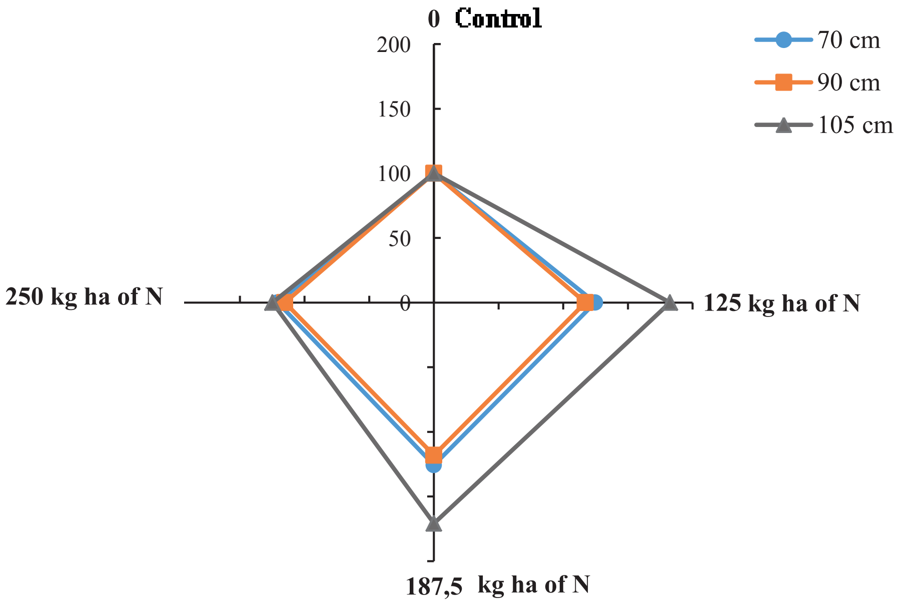
Table 4. Forage production of Mombasa grass in a silvopastoral system, under nitrogen fertilizer and three cutting conditions, Araguaína - TO.

Height	Nitrogen (kg ha^{-1} year^{-1})				Average	Equation	R²	CV
(cm)	0	125	187,5	250				
				Forage production (kg DM ha^{-1})				
70	5753,28	6453,68	7852,54	6546,28	6651,45 b	$\hat{Y} = 5660,44 + 16,95x - 0,049x^2$	0,54	
90	6891,17	7692,52	8455,48	7742,13	7695,33 a	$\hat{Y} = 6844,33 + 13,91x - 0,039x^2$	0,59	7,2
105	5508,04	9768,12	9604,42	6720,46	7900,26 a	$\hat{Y} = 5475,56 + 66,43x - 0,244x^2$	0,90	

Means followed by the same letter do not differ by Tukey test ($P < 0.05$).

Even grass managed at 90 cm and 105 cm cutting heights showed no difference in forage production, the amount of N in the grass managed at 90 cm express a maximum forage production 31% higher than the grass managed at 105 cm. This is due to the low efficiency to increase production; in other words, the increase in production caused by nitrogen fertilization in relation to the treatment without fertilization provided a small increase of forage for grasses managed at 90 cm (Figure 1), being only 30% of the applied fertilizer recovered by plants (Table 3). This caused the pasture to present low agronomic efficiency of 6.14 kg of dry matter produced for each 1 kg of N applied, while the grass managed at 105 cm presented efficiency of 20.4 kg of dry matter for each 1 kg of N applied in the soil.

Figure 1. Radar graph of the increment of forage yield (%) in relation to the control group (without fertilization, equal to 100% of the soil potential in forage production), and different nitrogen doses in three cutting heights for the Mombasa grass in a silvopastoral system.



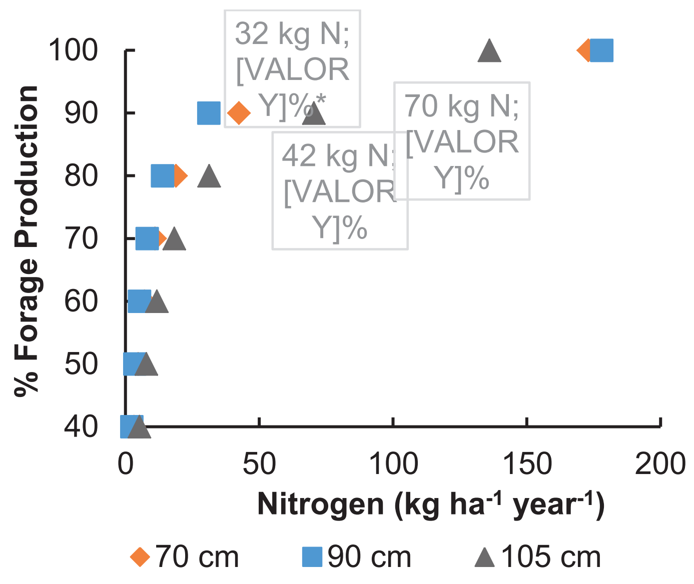
The grass managed at 105 cm shows better use of nitrogen, since there was an increase of production, higher than 80%, in relation to the control group (Figure 1). Certainly, the increment of the production is due to the higher utilization, absorption, agronomic, and physiological efficiency caused by the nitrogen fertilization in the silvopastoral system.

Although better yields are desired for production systems, there is a high demand for nitrogen to meet maximum organic production. Thus, finding the best productive response of pasture at the minimal use of fertilizers is necessary to reduce production costs and avoid soil losses (LANA, 2009; GUIMARÃES et al., 2011). In the majority of evaluated treatments, forage did not absorb more than 50% of the nitrogen applied in the soil.

The enzymatic saturation curve of Michaelis-Menten obtained through the Lineweaver-Burk model (LINEWEAVER; BURK, 1934) shows the relationship between the substrate concentration (nitrogen doses) and the increase of the substrate conversion into product (forage production), which is found in the saturation point of the nitrogen fertilizer reaching the point of maximum forage production (LANA, 2009). The minimum nitrogen dose expressing the maximum production of forage was obtained through the Lineweaver-Burk model (LANA, 2009; GUIMARÃES et al., 2011).

The Mombasa grass, managed at 70 cm, expressed a maximum forage yield with an application of 173 kg N ha^{-1} $year^{-1}$ (Table 4). In order to reach 90% of the maximum production (a reduction of 10% in maximum forage production), the grass managed at 70 cm required 42 kg N ha^{-1} $year^{-1}$, a reduction of 76% in the amount of N applied. The grass managed at 90 cm presented a maximum yield with an application of 178 kg N ha^{-1} $year^{-1}$, a reduction of 10% maximum forage production is achieved with the application of 32 kg ha^{-1} $year^{-1}$, and a reduction of 82% N applied. The grass managed at 105 cm showed the maximum forage production by applying 136 kg N ha^{-1} $year^{-1}$, with a 10% reduction in maximum production. Then, the amount of N applied becomes 70 kg ha^{-1} $year^{-1}$, providing a 49% reduction for nitrogen applied to the soil (Figure 2).

Figure 2. Percentage response in forage production of the Mombasa grass in function of the nitrogen fertilization and different cutting height in a silvopastoral system. Estimated production through data transformation by the Lineweaver-Burk model. *To obtain 90% of the maximum forage production need to apply 32, 42, and 70 kg N ha^{-1} $year^{-1}$.



Thus, the reduction in nitrogen saturation kinetic response curve of Mombasa grass provides a significant reduction for fertilizer applied, maintaining satisfactory levels of forage production. The reduction in the amount of N applied benefit the reduction of production costs, increase the plant efficiency, and reduce N losses (leaching, volatilization, denitrification), which contributes to the rational use of nitrogen fertilizers in the silvopastoral system (GUIMARÃES et al., 2011; COSTA et al., 2009, 2010).

Our data are in accordance with those observed by Guimarães et al. (2011), who reported better responses of corn and common beans to lower fertilizer amounts (NPK) after applying a kinetic saturation model. This outcome is due to smaller losses of fertilizers, lower costs of production, favoring a family farming system.

For the grass to be managed at 70 cm and 90 cm of cutting height, which expresses 80% of the maximum forage production, the amount of N applied was inferior to 15 kg N ha^{-1} $year^{-1}$ based on the response curve (Figure 2). In the pasture managed at 70 and 90 cm of cutting height, and in soil with conditions of high base saturation and organic matter, periodical nitrogen fertilization is considered unnecessary, under a silvopastoral system. This fact can be observed by the low-efficiency indexes in the use of nitrogen fertilizers. In addition, the soil was able to provide adequate amounts of nitrogen to the plant to express satisfactory forage production.

Conclusion

In a silvopastoral system, Mombasa grass responses to nitrogen fertilization are more efficient when low doses of N are applied to the soil.

The use of nitrogen is only efficient for grass cut at 105 cm height, with 90% of maximum forage production with an application of 70 kg N ha^{-1} $year^{-1}$.

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