



## Growth dynamics and morphogenesis of *Trachypogon plumosus* under soil fertility correction levels and regrowth ages<sup>1</sup>

### *Dinâmica de crescimento e morfogênese de Trachypogon plumosus sob níveis de correção da fertilidade do solo e idades de rebrotação*

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**Abstract** - The effects of soil fertility correction levels (control, liming, fertilization and liming + fertilization) and regrowth ages (21, 28, 35, 42, 49, 56, 63, 70, 77 and 84 days) on growth dynamics, forage yield and morphogenetic and structural characteristics of *Trachypogon plumosus* were assessed in Roraima's savannas. Dry matter yields (DMY), absolute growth rate (AGR), tiller population density (TPD), number of live leaves (NLL), final leaf length (FLL), leaf area index (LAI), leaf elongation rate (LER) and leaf senescence rate (LSR) increased consistently with regrowth age, while average growth rate (AvGR), and leaf appearance rate (LAR) were inversely proportional to regrowth age. The grass showed high responsiveness to the soil fertility improvement. Liming + fertilization or fertilization alone promoted higher DMY (2,116 and 1,759 kg ha<sup>-1</sup>), AGR (40.5 and 33.6 kg ha<sup>-1</sup>.day), AvGR (32.5 and 27.9 kg ha<sup>-1</sup>.day), NLL (5.5 and 4.9 leaf tiller<sup>-1</sup>), LAR (0.119 and 0.109 leaf day<sup>-1</sup> tiller<sup>-1</sup>), LER (2.53 and 2.06 cm day<sup>-1</sup> tiller<sup>-1</sup>), FLL (22.1 and 18.9 cm), LAI (2.64 and 2.83) and TPD (762 and 725 tillers m<sup>-2</sup>). To maximize the forage use efficiency and to prevent losses to leaves senescence, it is recommended a regrowth period between 56 to 63 days for fertilization and liming + fertilization, and 63 to 70 days for control or liming pastures.

**Key words** - Dry matter. Growth rate. Leaves. Tillering.

**Resumo** - Avaliaram-se os efeitos de níveis de correção da fertilidade do solo (testemunha, calagem, adubação e calagem + adubação) e da idade de rebrotação (21, 28, 35, 42, 49, 56, 63, 70, 77 e 84 dias) sobre a dinâmica de crescimento, rendimento de forragem e características morfológicas e estruturais de *Trachypogon plumosus* nos cerrados de Roraima. O aumento da idade de rebrotação resultou em maiores rendimentos de matéria seca (MS), taxa absoluta de crescimento (TAC), densidade populacional de perfilhos (DPP), número de folhas vivas (NFV), comprimento final de folhas CFF, índice de área foliar (IAF) e taxas de alongamento (TAIF) e senescência foliar (TSF), ocorrendo o inverso quanto às taxas médias de crescimento (TMC) e taxa de aparecimento foliar (TApF). A gramínea apresentou alta responsividade à melhoria da fertilidade do solo. A calagem + adubação ou a adubação proporcionaram maiores rendimentos de MS (2.116 e 1.759 kg ha<sup>-1</sup>), TAC (40,5 e 33,6 kg ha<sup>-1</sup> dia<sup>-1</sup>), TMC (32,5 e 27,9 kg ha<sup>-1</sup> dia<sup>-1</sup>), NFV (5,5 e 4,9 folhas perfilho<sup>-1</sup>), TApF (0,119 e 0,109 folhas dia<sup>-1</sup> perfilho<sup>-1</sup>), TAIF (2,53 e 2,06 cm dia<sup>-1</sup> perfilho<sup>-1</sup>), CFF (22,1 e 18,9 cm), IAF (2,64 e 2,83) e DPP (762 e 725 perfilhos m<sup>-2</sup>). Visando maximizar a eficiência de utilização da forragem produzida e reduzir as perdas por senescência foliar da gramínea, o período mais adequado de utilização de suas pastagens, durante o período chuvoso, situa-se entre 56 e 63 dias com o uso de adubação e calagem + adubação e, 63 a 70 dias para a testemunha e a calagem.

**Palavras-chave** - Matéria seca. Folhas. Perfilhamento. Taxa de crescimento.

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## Introduction

In the Roraima's savannas, the native pastures represent the most economical source for cattle feeding. Despite qualitative and quantitative limitations due to low natural fertility of soils, historically, native pastures provided food support to the livestock that became, over the years, as the main economic activity of Roraima (COSTA *et al.*, 2012). The continuous grazing with variable stocking rate, extensive and unrelated to the seasonal rhythm of pastures, has direct contribution to the low levels of herd production (MATA *et al.*, 1996). Over-stocking rate and non-replacement of the extracted nutrients are the main causes of depletion of soil fertility of the ecosystem and, consequently, of the carrying capacity reduction and productive potential of natural grasslands (SARMIENTO, 1992).

In plain and flood-proof areas of native pastures, where the grass *Trachypogon plumosus* constitutes between 80 and 90% of its botanical composition, animal production may be very low, requiring from 6 to 10 ha for each mature cow, which makes livestock activity economically unfeasible, unless practices for improvement are implemented (MATA *et al.*, 1996). The grass presents perennial cycle, caespitose growth habit, plants with 40 to 80 cm of height, and hairy leaves. However, there is little information about the productive potential and about the response of grass to improvement of the production environment conditions, remarkably regarding the correction of soil fertility in order to propose more sustainable management practices (COSTA *et al.*, 2012).

The grass forage accumulation rate is closely related to its growth stage, as a consequence of morphological and physiological changes that affect the balance between production and senescence of tissues, with effects on the chemical composition, regrowth ability and persistence of pasture regrowth (LEMAIRE *et al.*, 2011). Therefore, it is desirable seek the balance between productivity and quality, in order to ensure the nutritional requirements of animals, while ensuring maximum efficiency of the uses processes and conversion of produced forage.

The knowledge of the morphogenetic and structural characteristics provides a preview of the seasonal curve of forage production and an estimate of its quality (ZANINE, 2005), besides allowing the proposal of specific management practices for each forage grass (LEMAIRE *et al.*, 2011). The morphogenesis of a grass during its vegetative growth can be described by three variables: leaf appearance rate, leaf elongation rate, and leaf lifespan, which, despite their genetic nature, are strongly influenced by environmental conditions (temperature, light, water, and soil fertility) and management practices. The interactions between these variables determine the structural characteristics: number of live leaves tiller<sup>-1</sup> (NLL), final leaf length (FLL) and tiller density, which will determine the leaf area index (LAI), i.e., the apparatus used for the radiation interception by the pasture sward. NLL is due to the appearance rate and to leaf lifespan, being genetically determined, while the leaf elongation rate determines the FLL (LEMAIRE *et al.*, 2011).

In this study, the effects of correction levels of soil fertility, and regrowth age on forage production, and morphogenetic and structural characteristics of *Trachypogon plumosus* were evaluated in the savannas of Roraima.

## Material and methods

The experiment was conducted in a native pasture of *T. plumosus*, located in Boa Vista, Roraima (60°43' west longitude; 2°45' north latitude and 88 m of altitude above sea level), which was not under any management practice. The climate, according to Köppen, is Aw, with annual rainfall of 1,600 mm, and 80% occur within six months of the rainy season (April-September). The experimental period was from May to August 2011, which corresponds to rainy season (Table 1).

The soil of the experimental area was a Yellow Latosol, medium texture, with the following chemical characteristics at 0-20 cm depth:  $\text{pH}_{\text{H}_2\text{O}} = 5.1$ ;  $\text{P} = 1.1 \text{ mg dm}^{-3}$ ;  $\text{Ca} + \text{Mg} = 0.51 \text{ cmol}_c \cdot \text{dm}^{-3}$ ;  $\text{K} = 0.03 \text{ cmol}_c \cdot \text{dm}^{-3}$ ;

**Table 1** - Rainfall, minimum, maximum, and mean temperatures, and solar radiation recorded during the experimental period. Boa Vista, Roraima. 2011

Months	Rainfall (mm)	Temperature (°C)		Solar radiation	
		Minimum	Maximum	Mean	MJ/m <sup>2</sup>
May	692.9	23.0	30.8	26.9	376.9
June	383.8	22.7	31.7	27.2	381.8
July	389.2	22.2	32.1	27.1	432.4
August	234.8	23.8	32.9	28.4	458.8

Al = 0.39 cmol<sub>c</sub>dm<sup>-3</sup>; H+Al = 2.43 cmol<sub>c</sub>dm<sup>-3</sup>; Organic matter = 10.6 g dm<sup>-3</sup>; Cation exchange capacity = 2.97 cmol<sub>c</sub>dm<sup>-3</sup> and Base saturation = 18.2%. The experimental design was in randomized blocks with three replications and the treatments were arranged in a 4 × 10 factorial. Four correction levels of soil fertility (control, liming, fertilization and liming + fertilization) and ten regrowth ages (21, 28, 35, 42, 49, 56, 63, 70, 77 and 84 days after the uniform pasture to 5.0 cm above ground) were evaluated. The plot size was 5.0 × 4.0 m, with a utile area of 12 m<sup>2</sup>. Liming was performed 30 days before the pasture lowering, aiming to raise to 40% the bases saturation (600 kg ha<sup>-1</sup> liming - RNV = 100%). Fertilization consisted of 50 kg ha<sup>-1</sup> of N (urea), 50 kg ha<sup>-1</sup> of P<sub>2</sub>O<sub>5</sub> (triple superphosphate), 50 kg ha<sup>-1</sup> of K<sub>2</sub>O (potassium chloride) and 30 kg ha<sup>-1</sup> of S (elemental sulfur), applied after pasture lowering.

The dry matter yields (DMY) were estimated through mechanical cuts performed at a height of 5.0 cm above the ground. The collected material was weighed and left to dry in forced-ventilation oven at 65 °C for 72 hours. The absolute growth rate (AGR) was obtained by dividing the DM yield by the respective period of regrowth. The average growth rate (AvGR) was calculated according to Benincasa (2003):  $AvGR = \frac{P_2 - P_1}{T_2 - T_1}$  (kg ha<sup>-1</sup> day<sup>-1</sup> of DM), where, P<sub>2</sub> and P<sub>1</sub> and T<sub>2</sub> and T<sub>1</sub>, respectively represent DM production (kg ha<sup>-1</sup>) and the time interval (days) between two samplings.

To determine the morphogenetic and structural characteristics, four tussocks/plot were selected and three tillers/tussock were tagged, using plastic colored thread. The measurements were taken every three days, when the appearance, elongation and aging of leaves were computed. The leaf elongation rate (LER) and leaf appearance rate (LAR) were calculated by dividing the accumulated length of leaves and the total number of leaves on the tiller, respectively, by the regrowth period. The final leaf length (FLL) was determined by dividing the total tiller elongation by its number of leaves. For the calculation of leaf area, in each regrowth age, samples were collected from fully expanded green leaves, aiming to obtain an area between 200 and 300 cm<sup>2</sup>, estimated with the aid of an optical electronic planimeter (Li-Cor, model LI -3100C). Subsequently, the samples were taken to forced-ventilation oven at 65 °C until they reached constant weight, obtaining the leaf DM. Specific leaf area (SLA) was determined by the ratio between area of green leaves and its DM (m<sup>2</sup>/g of leaf DM). The leaf area index (LAI) was determined from the product between the total DM of green leaves (g of MS/m<sup>2</sup>) by SLA (m<sup>2</sup>/g of leaf DM). The leaf senescence rate (LSR) was obtained by dividing the length of the leaves that presented yellow staining or necrosis by regrowth age. The tiller population density (TPD) was estimated using metal frames of 0.25

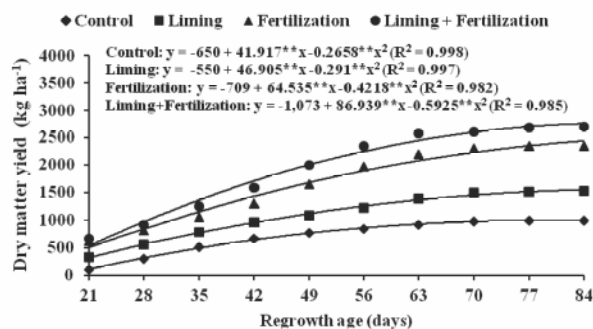
m<sup>2</sup> (50 × 50 cm), divided in four points at random in each plot; every tiller, in each regrowth age, was computed.

The data were submitted to analysis of variance and regression considering the significance level of 5% of probability, using Sisvar program. The identity test curves were performed according to the methodology proposed by Regazzi (1993). To estimate the response of the parameters evaluated at regrowth, in function of the levels of correction of soil fertility, the choice of regression models was based on the significance of the linear and quadratic coefficients through the Student "t" test at the level 5% of probability.

## Results and discussion

The effect of regrowth age was fitted to the quadratic model and the maximum yields were recorded at 78.9 (1,003 kg ha<sup>-1</sup>); 80.6 (1,340 kg ha<sup>-1</sup>); 76.5 (1,759 kg ha<sup>-1</sup>) and 73.4 days (2,116 kg ha<sup>-1</sup>), respectively for control, liming, fertilization and liming + fertilization (Figure 1). In the initial regrowth phase, the biomass increment is mainly due to the expanded leaves and developed tillers. However, as the sward closes intercepting most of the incident light, the process of senescence and death of older leaves is enhanced at the same time when the tiller is inhibited, processes that contribute to the stabilization of productivity DM. Similar trends were reported by Mata *et al.* (1996) for pastures of *Trachypogon* spp., under different cutting intervals (1,654; 2,309; 2,631 and 2,455 kg ha<sup>-1</sup> of DM, respectively for cuts every 28; 49; 63 and 77 days). To *T. vestitus*, Rippstein *et al.* (2001) obtained higher DM yields with cuts at 56 (3,349 kg ha<sup>-1</sup>) or 63 days (3,124 kg ha<sup>-1</sup>), comparatively to 84 days (2,867 kg ha<sup>-1</sup>).

Although adapted to low fertility soils of savannas, the native grasses appear to be responsive to the improvement of the production environment, mainly for fertilization, while the effects of lime alone were few

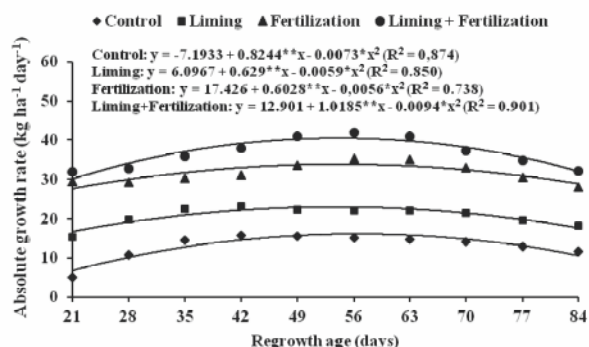


**Figure 1** - Dry matter yield of *Trachypogon plumosus* affected by regrowth age within each soil fertility correction level

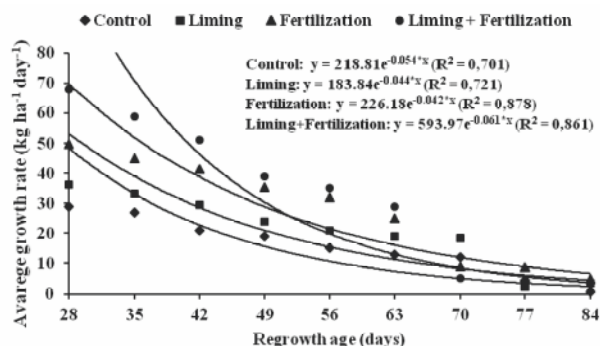
pronounced. In *Trachypogon vestitus* pastures fertilized with 50 kg ha<sup>-1</sup> of N, 50 kg ha<sup>-1</sup> of P<sub>2</sub>O<sub>5</sub>, 50 kg ha<sup>-1</sup> of K<sub>2</sub>O, 120 kg ha<sup>-1</sup> of dolomitic limestone and 20 kg ha<sup>-1</sup> of S, Rippstein *et al.* (2001) estimated a yield 4,550 kg ha<sup>-1</sup> of DM, comparatively with 2,840 and 3,111 kg ha<sup>-1</sup> of DM, respectively, in the absence of N or fertilization. Sarmiento *et al.* (2006) reported an increase of 256% in DM yield of *Axonopus purpusii* fertilized with 150, 100, 100 and 30 kg ha<sup>-1</sup>, respectively, for N, P, K and S (2,488 kg ha<sup>-1</sup> of DM) in relation to the unfertilized pasture (698 kg ha<sup>-1</sup> of DM).

The highest AGR and AvGR were recorded with liming + fertilization (40.5 and 33.6 kg ha<sup>-1</sup> day<sup>-1</sup> of DM) (Figures 2 and 3). The regrowth age effect on the AGR was adjusted to a quadratic regression model and the maximum values were obtained at 56.5 (16.1 kg ha<sup>-1</sup> day<sup>-1</sup> of DM); 53.3 (22.9 kg ha<sup>-1</sup> day<sup>-1</sup> of DM); 53.8 (33.6 kg ha<sup>-1</sup> day<sup>-1</sup> of DM) and 54.2 days (40.5 kg ha<sup>-1</sup> day MS), respectively, for control, liming, fertilization and liming + fertilization. For the AvGR, the adjustment was exponential and the highest values were observed in period of 28 (45.7 kg ha<sup>-1</sup> day<sup>-1</sup> of DM) and 42 days (35.7 kg ha<sup>-1</sup> day<sup>-1</sup> of DM), which were higher than those estimated by Tejos (2002) for *A. purpusii* (35.7 kg ha<sup>-1</sup> day<sup>-1</sup> of DM) and *Panicum laxum* (7.2 kg ha<sup>-1</sup> day<sup>-1</sup> of DM). Rippstein *et al.* (2001) showed that the AGR of *T. vestitus* were inversely proportional to regrowth period (10.4; 10.6 and 8.9 kg ha<sup>-1</sup> day<sup>-1</sup> of DM, respectively for 14, 28 and 56 days).

The high growth rates, during early regrowth, represent an adaptive mechanism of the grass, because it reduces the time for maximum light interception and promotes better use of water due to fast soil shading, which furthers its intraspecific competitiveness (LEMAIRE *et al.*, 2011). Parsons and Chapman (2000) suggest as the most appropriate period of the pasture utilization those in which the AGR and RGR are equivalent, in order to maximize the forage liquid accumulation and to avoid losses by senescence when AGR is diminishing and the variations



**Figure 2** - Absolute growth rate of *Trachypogon plumosus* affected by regrowth age within each correction level of soil fertility.



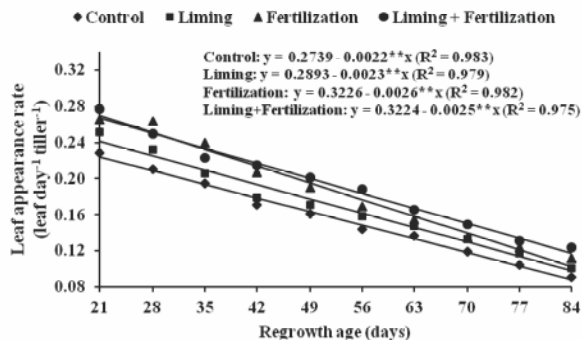
**Figure 3** - Average growth rate of *Trachypogon plumosus* affected by regrowth age within each soil fertility correction level.

in the AvGR are small. In this context, the period between 56 to 63 days with the use of fertilization and liming + fertilization, and 63 to 70 days for control and liming, would be recommended for pasture, optimizing the AGR and the AvGR of the grass. Moreover, it remarks the positive effect of improving soil fertility in anticipation pasture utilization.

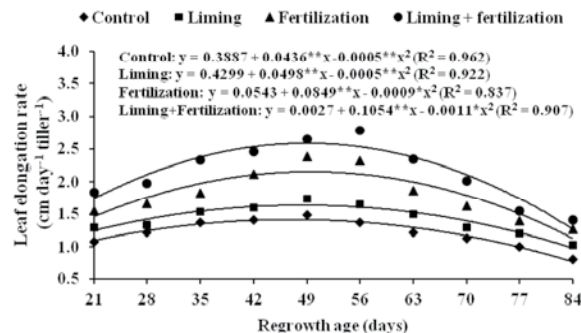
In all correction levels of soil fertility, the LAR was negative and linearly affected by the regrowth age (Figure 4). Liming + fertilization resulted in greater LAR (0.119 leaf day<sup>-1</sup> tiller<sup>-1</sup>), followed by fertilization (0.109 leaf day<sup>-1</sup> tiller<sup>-1</sup>) and lime (0.101 leaf day<sup>-1</sup> tiller<sup>-1</sup>), which were similar to each other ( $P > 0.05$ ) and higher than the control (0.088 leaf day<sup>-1</sup> tiller<sup>-1</sup>). In the absence of water and nutrient limitations, the plant produces leaves at a rate genetically determined based on the direct action of ambient temperature on the apical meristem (LEMAIRE *et al.*, 2011). Oliveira *et al.* (2007) evaluating the effects of N (300 kg ha<sup>-1</sup>), P (90 kg ha<sup>-1</sup> P<sub>2</sub>O<sub>5</sub>) and K (60 kg ha<sup>-1</sup> de K<sub>2</sub>O) in *P. maximum* cv. Tanzânia, reported significant increases in LAR with the application of N + P (0.21 leaves day<sup>-1</sup>), K + N (0.20 leaves day<sup>-1</sup>) and N + P + K (0.18 leaves day<sup>-1</sup>), while fertilization with K + P (0.14 leaves day<sup>-1</sup>) did not differ ( $P > 0.05$ ) from the control (0.13 leaves day<sup>-1</sup>). However, Andrade *et al.* (2005) and Quadros *et al.* (2005) found no significant effects of N, P or K doses on the LAR of *Pennisetum purpureum* cv. Napier and *Paspalum urvillei*, respectively.

The LAR is the most important morphogenetic characteristic because it directly affects the structural components of the pasture (FLL, TPD and NLL) and even under adverse environmental or management conditions it would be the last to be penalized by the plant (SOUSA *et al.*, 2010; LEMAIER *et al.*, 2011). The LAR results from the balance between the length of the sheath that surrounds the apical meristem and LER which, respectively, determine the distance that the leaf has to cover to emerge





**Figure 4** - Leaf appearance rate of *Trachypogon plumosus* affected by regrowth age within each soil fertility correction level



**Figure 5** - Leaf elongation rate of *Trachypogon plumosus* affected by regrowth age within each soil fertility correction level.

and how fast it travels that distance (LEMAIRE *et al.*, 2011). The LAR and LER present a negative correlation, indicating that the higher the LAR, the time available for the elongation of the leaves is shorter, which reflects negatively on the FLL (DIFANTE *et al.*, 2011). In this experiment, the correlation between LAR and LER was negative and nonsignificant ( $r = -0.3334$ ;  $p = 0.0728$ ), while with FLL, it was negative and significant ( $r = -0.5618$ ;  $p = 0.0012$ ).

LER was affected ( $P < 0.05$ ) by improving soil fertility and the higher values recorded with liming + fertilization ( $2.14 \text{ cm day}^{-1} \text{ tiller}^{-1}$ ). The LER responded quadratically to regrowth ages, and maximum values were observed at 43.6 ( $1.34 \text{ cm day}^{-1} \text{ tiller}^{-1}$ ), 49.8 ( $1.67 \text{ cm day}^{-1} \text{ tiller}^{-1}$ ), 47.2 ( $2.06 \text{ cm day}^{-1} \text{ tiller}^{-1}$ ) and 47.9 days ( $2.53 \text{ cm day}^{-1} \text{ tiller}^{-1}$ ) for control, liming, fertilization and liming + fertilization, respectively (Figure 5). The values obtained were higher than those reported by Sarmiento (1992) for *T. plumosus* subjected to cutting frequencies of 7 ( $0.70 \text{ cm day}^{-1} \text{ tiller}^{-1}$ ), 14 ( $0.91 \text{ cm day}^{-1} \text{ tiller}^{-1}$ ) or 28 days ( $1.07 \text{ cm day}^{-1} \text{ tiller}^{-1}$ ). Difante *et al.* (2011) reported that LER of *Brachiaria brizantha* cv. Marandu was inversely proportional to the defoliation frequency. Oliveira *et al.* (2007) showed higher LER in *P. maximum* cv. Tanzânia fertilized with N + K ( $2.68 \text{ cm day}^{-1} \text{ tiller}^{-1}$ ) or N + P ( $1.69 \text{ cm day}^{-1} \text{ tiller}^{-1}$ ), compared with treatment without fertilization ( $0.98 \text{ cm day}^{-1} \text{ tiller}^{-1}$ ). With the same grass, Patês *et al.* (2007) obtained more than 100% increase in LER with the combined application of N ( $100 \text{ kg ha}^{-1}$ ) and P ( $100 \text{ kg ha}^{-1}$ ), in comparison with isolated application of P ( $2.11 \times 0.98 \text{ cm day}^{-1} \text{ tiller}^{-1}$ ).

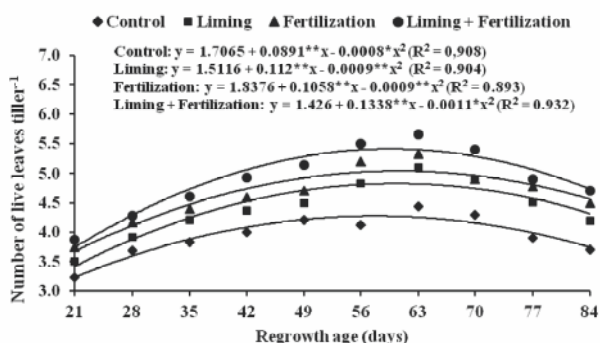
LER, when responding to better supply of nutrients, acts as a modifier of the LAR, especially with the emission of successive leaves on very similar levels of integration. For *P. purpureum* cv. Napier pastures, fertilized with  $100 \text{ kg ha}^{-1}$  of N and  $80 \text{ kg ha}^{-1}$  of K, LER was  $8.25 \text{ cm day}^{-1} \text{ tiller}^{-1}$  and increased to  $11.64 \text{ cm day}^{-1} \text{ tiller}^{-1}$  doubling the

doses (ANDRADE *et al.*, 2005). However, Quadros *et al.* (2005) found no positive effects of P and K fertilization on the LER of *P. urvillei*. The LER is the morphogenetic variable that, isolated, correlates the most with DM yield, acting as an appropriate estimator of regrowth vigor, because along with the LAR, it determines the size of the photosynthetic surface of the sward, directly through the FLL and indirectly through the TPD. Despite the genetic nature, LER responds differently to environmental conditions, especially temperature, water availability, soil fertility and light. With the progress of the regrowth age there is greater competition for photo-assimilates in the development of new tillers or reproductive structures, which contributes to the reduction in LER of individual leaves (ZANINE, 2005). Sousa *et al.* (2011) observed that LER was positively correlated with tiller in NLL remaining after defoliation, and the size of the tiller was responsible for the longer duration of LER. The capacity of the plant to expand its leaves is dependent on the elongation rate of the intercalary meristem, zone of cell division, location and metabolically active high nutrient demand (OLIVEIRA *et al.*, 2007). Increase in LER, based on the nutrient supply is assigned to the increase in cell division without effect on the final size of the cell or elongation rate of epidermal cells (DIFANTE *et al.*, 2011).

The NLL was affected ( $P < 0.05$ ) by improving soil fertility; the higher values ( $P < 0.05$ ) were observed with liming + fertilization ( $4.93 \text{ leaves tiller}^{-1}$ ). The effect of liming application ( $4.38 \text{ leaves tiller}^{-1}$ ) was nearly to the control ( $3.91 \text{ leaves tiller}^{-1}$ ) demonstrating the small effect of calcium and magnesium on this morphogenetic characteristic (Figure 6). Fertilized plants reach maximum NLL earlier, compared with the non-fertilized, enabling more frequent harvests in order to avoid losses due to leaf senescence. Oliveira *et al.* (2007) found higher NLL in *Panicum maximum* cv. Tanzânia with the application of N + K ( $3.5 \text{ leaves tiller}^{-1}$ ), while fertilization with K + P ( $2.6 \text{ leaves tiller}^{-1}$ ) or N + P + K ( $2.9 \text{ leaves tiller}^{-1}$ ) did

not differ from control (2.7 leaves tiller<sup>-1</sup>). The effect of regrowth age on NLL was quadratic and the maximum values were achieved at 55.7 (4.2 leaves tiller<sup>-1</sup>), 61.1 (5.0 leaves tiller<sup>-1</sup>), 58.8 (4.9 leaves tiller<sup>-1</sup>) and 60.8 days (5.5 leaves tiller<sup>-1</sup>), respectively for control, liming, fertilization and liming + fertilization. Similar trends were reported by Andrade *et al.* (2005), for *P. purpureum* cv. Napier, and Ferlin *et al.* (2006), with *P. maximum* cv. Tanzânia, who estimated higher NLL to 82 (3.1 leaves tiller<sup>-1</sup>), and 23 days of regrowth (3.8 leaves tiller<sup>-1</sup>), respectively. NLL is a structural feature with strong genetic influences and stable in the absence of water or nutritional deficiencies. The NLL, constant from the moment that the LSR equals LAR, constitutes objective and practical criteria to setting periods of rest in rotational stocking and grazing intensity in continuous stocking. In this context, the conditions of this study, the grazing period would be more appropriate between 63 and 70 days for the control and liming and 56 to 63 days for fertilization and liming + fertilization, in order to maximize the NLL, the harvesting efficiency and quality of forage produced.

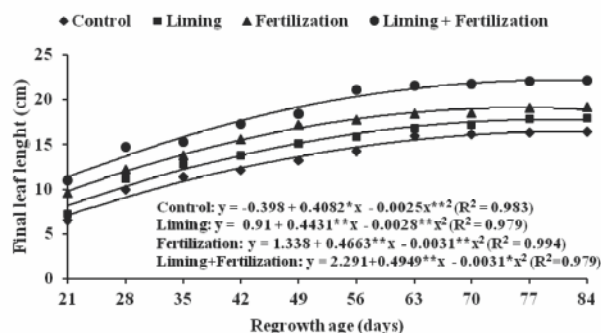
The effect of regrowth age on FLL was fitted to the quadratic model and maximum values were recorded at



**Figure 6** - Number of live leaves/tiller of *Trachypogon plumosus* affected by regrowth age within each soil fertility correction level.

81.6 (16.2 cm); 77.3 (17.6 cm); 75.3 (18.9 cm) and 79.8 days (22.1 cm) for control, liming, fertilization and liming + fertilization (Figure 7), respectively. The combination of liming + fertilization resulted in higher FLL (22.1 cm). The high response to this characteristic morphogenetic to calcium and magnesium application reflects the low mobility of these nutrients within the plant and its importance in the formation of cell walls and chlorophyll, respectively (LEMAIRE *et al.*, 2011).

On pastures of *Axonopus aureus*, Costa *et al.* (2012) found a similar trend, with the FLL positively related to the period of regrowth, and the highest value was observed at



**Figure 7** - Final leaf length of *Trachypogon plumosus* affected by regrowth age within each soil fertility correction level.

56 days (18.6 cm). The values obtained were higher than those reported by Machado (2010) for *A. affinis* (5.9 cm), *A. lateralis* (9.9 cm) and *Paspalum notatum* (6.9 cm), native grasses of South America. Oliveira *et al.* (2007) observed significant increases in FLL of *P. maximum* cv. Tanzânia with the application of N + P (30.1 cm), N + K (32.5 cm) and N + P + K (36.3 cm) in relation to the control (14.1 cm). In environmental conditions non-limiting to grass growth, cell division is favored, allowing greater blades for an equal sheath length. Fertilization, by stimulating the production of new cells, enables increase in LER, which is a strategy for changes in FLL (SOUSA *et al.*, 2011). Moreover, cell division is the primary engine of growth of the leaf blade, unlike that of the sheath which arises from the cell elongation (LEMAIRE *et al.*, 2011). The high response to this characteristic morphogenetic to calcium and magnesium application reflects the low mobility of these nutrients within the plant and its importance in the formation of cell walls and chlorophyll, respectively (SOUSA *et al.*, 2010).

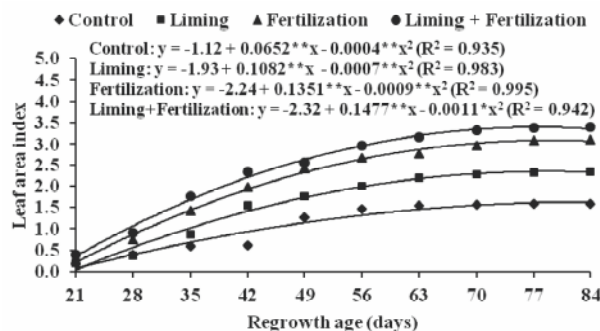
FLL and the angle of insertion of leaves have as consequences distribution and quality of light inside the sward, affecting the modulation of plant growth through production of photo-assimilated compounds in sources and their allocation to the sinks (LEMAIRE *et al.*, 2011). The leaves of *T. plumosus* have an average insertion angle between 45 and 60° and light extinction coefficient between 0.52 and 0.65, which facilitates greater penetration of red light instead of extreme-red, resulting in better quality of light for leaves photosynthesis at the lower portion of the plant, and delay or attenuation senescence process (SARMIENTO, 1992). The reduction of FLL is a strategy used by native grasses of the savannas for acquisition and conservation of water, offsetting water stress by reducing water loss by transpiration (SARMIENTO, 1992; BARUCH *et al.*, 2004). The determinant factors of FLL are the LAR and LER. Despite the changes that occurred between these two characteristics, according to the

regrowth age, the correlation analysis showed a positive association between FLL and LER ( $r = 0.7767$ ;  $p = 0.0165$ ) and a negative with LAR ( $r = -0.5618$ ;  $p = 0.0002$ ). Sheath height is another important factor because it defines the extent of growth zone to be travelled by the expanding blade and, the greater its length, the greater the phase of cell multiplication, the longer leaf will be protected from direct light by the sheath and, consequently, the greater the leaf expansion rate and FLL (LEMAIRE *et al.*, 2011). For *T. plumosus*, Sarmiento (1992) found an increase of 1.76 cm in FLL for each inch of height of the sheath.

The LAI was influenced ( $P < 0.05$ ) by liming + fertilization (2.42) and fertilization (2.59), while liming (2.25) and control (1.53) showed the lowest values (Figure 8). As the LAI represents the synthesis of grass morphogenetic and structural characteristics, it reflects the balance of the processes that determine the supply (photosynthesis) and demand (respiration, reserve accumulation, synthesis and senescence of tissues) of photo-assimilates, which determine the pasture growth *rhythm* (ZANINE, 2005). The action of soil fertility improvement on the LER, the FLL and the TPD is expressed directly on pasture LAI (SOUSA *et al.*, 2011). The effect of regrowth age on the LAI was quadratic and the highest values were recorded at 81.5 (1.54), 77.3 (2.25), 75.1 (2.83), and 67.1 days (2.64), respectively for control, liming, fertilization and liming + fertilization. The LAI values obtained were higher than those reported by Baruch *et al.* (2004) for *T. plumosus* (1.31) and Tejos (2002) for *A. purpusii* (1.54), *Hymenachne amplexicaulis* (1.02) and *P. laxum* (0.72), native grasses of Venezuela's savannas. For grasses with caespitose growth habit, the critical LAI, where 95% of incident light would be intercepted, usually varies between 3.0 and 5.0 (SARMIENTO, 1992); this condition was observed at 70 to 63 days of regrowth with the application of fertilization and lime + fertilization, respectively.

LAI was negatively correlated with LAR ( $r = -0.6491$ ;  $p = 0.0052$ ) and positively correlated with LER ( $r = 0.7814$ ,  $p = 0.0165$ ) and FLL ( $r = 0.9073$ ;  $p = 0.0001$ ), showing the antagonism between LER and LAR and synchrony between LER and FLL. Grasses with greater competitive ability are those that develop a more efficient architecture in light interception through the fast expansion of leaf area and colonization of the upper part of the sward, due to the elongation of the sheath and stem internodes (LEMAIRE *et al.*, 2011).

The highest LSR ( $P < 0.05$ ) were observed with liming + fertilization ( $0.261 \text{ cm day}^{-1} \text{ tiller}^{-1}$ ) and fertilization ( $0.245 \text{ cm day}^{-1} \text{ tiller}^{-1}$ ), and the lowest with liming ( $0.228 \text{ cm day}^{-1} \text{ tiller}^{-1}$ ) and control ( $0.212 \text{ cm day}^{-1} \text{ tiller}^{-1}$ ) (Figure 9). Until 63 days of regrowth, the use of lime provided smaller LSR compared to the control treatment, while from 70 days of age, higher LSR were

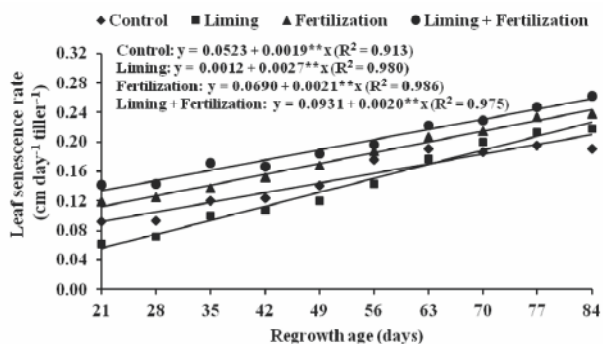


**Figure 8** - Leaf area index of *Trachypogon plumosus* affected by regrowth age within each soil fertility correction level.

recorded with use of lime. Possibly such behavior may be associated with increased flow of tissues with the use of lime, which provided greater forage yield and consequently greater number of green leaves which shadowed those inserted in the lower portion of the plant (LEMAIRE *et al.*, 2011). In the absence of fertilization, plants remain more time with their live leaves, to the detriment of the appearance or expansion of new leaves, which contributes to delaying the aging process (ANDRADE *et al.*, 2005). Oliveira *et al.* (2007) estimated higher LSR in *P. maximum* cv. Tanzânia fertilized with N + P ( $0.109 \text{ cm day}^{-1} \text{ tiller}^{-1}$ ), N + K ( $0.114 \text{ cm day}^{-1} \text{ tiller}^{-1}$ ) N + or P + K ( $0.100 \text{ cm day}^{-1} \text{ tiller}^{-1}$ ) compared with control ( $0.060 \text{ cm day}^{-1} \text{ tiller}^{-1}$ ). In *P. purpureum* cv. Napier, fertilized with  $200 \text{ kg ha}^{-1}$  of N and  $160 \text{ kg ha}^{-1}$  of K, LSR was  $5.91 \text{ cm day}^{-1} \text{ tiller}^{-1}$ , reduced to  $4.22 \text{ cm day}^{-1} \text{ tiller}^{-1}$  using half of the doses (ANDRADE *et al.*, 2005). The relationship between LSR and regrowth ages was linear and positive and the process of senescence was verified from 21 days (Figure 9). Oliveira *et al.* (2000) found that the LSR of *Cynodon* spp. was directly proportional to regrowth period (1.24, 1.18 and  $1.29 \text{ cm day}^{-1} \text{ tiller}^{-1}$  for 56, 63 and 70 days, respectively).

Senescence is a natural process that characterizes the last stage of leaf development, which begins after full expansion, whose intensity is enhanced progressively with the increase of LAI and the FLL, due to the shading of the leaves inserted in the lower portion and due to the low supply of photosynthetically active radiation (SOUSA *et al.*, 2011). When the tiller reaches a certain NLL, balance between LAR and senescence of leaves that have exceeded their duration of life occurs, so that the emergence of a new leaf implies senescence of the leaf that preceded it, maintaining the NLL relatively constant (ZANINE, 2005). The correlations between LSR and LAI ( $r = 0.8842$ ;  $p = 0.0001$ ) and FLL ( $r = 0.9056$ ;  $p = 0.0021$ ) were positive and significant, showing the depressive effect of low light, which was pronounced at higher regrowth ages. Despite the adverse effect on the quality of forage, senescence



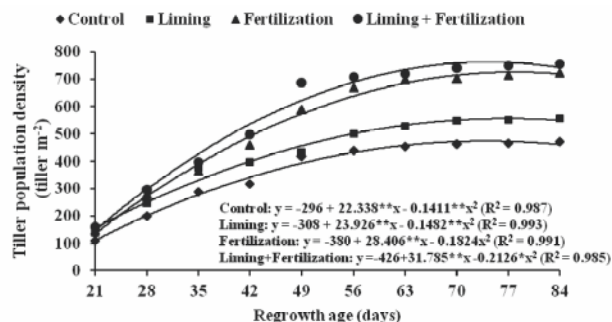


**Figure 9** - Leaf senescence rate of *Trachypogon plumosus* affected by regrowth age within each soil fertility correction level.

represents an important physiological process in the grass tissues flow, since about 50% carbon and 80% of nitrogen can be recycled from senescent leaves for the production of new leaf tissues (LEMAIRE *et al.*, 2011).

The effect of regrowth age on the TPD was quadratic and the highest values were observed at 79.2 (588 tillers  $m^{-2}$ ); 80.7 (657 tillers  $m^{-2}$ ); 77.8 (725 tillers  $m^{-2}$ ); and 74.7 days (762 tillers  $m^{-2}$ ); respectively for the control, liming, fertilization and liming + fertilization (Figure 10). However, Sarmiento (1992) found a reduction in TPD of *T. plumosus* with regrowth age (650, 430 and 410 tillers  $m^{-2}$  for 7, 14 and 28 days, respectively). The grass tillering results from the speed of the emergence of leaves, which will produce buds that can potentially give rise to new tillers, depending on environmental conditions and management practices (LEMAIRE *et al.*, 2011). Tillering gradually establishes a limiting condition to the light penetration, shading the lower leaves and promoting leaf senescence. When light penetrates the sward, the light red is diminished and that reaching lower strata is predominantly extreme light red, characterized as photosynthetically inefficient, reducing the production of tillers (LEMAIRE *et al.*, 2011). Shading reduces the proportion of buds which will effectively become new tillers (site filling), with negative and direct reflects in the TPD, NLL and LAR and indirect in LER and FLL (ZANINE, 2005). The TPD was negatively correlated with LAR ( $r = -0.8086$ ;  $p = 0.0001$ ), demonstrating the restrictive effect of light on the activation of basal buds, which was accentuated with increasing regrowth length.

In low fertility soils, photo-assimilate may be insufficient to supply the demand of expanding leaves and the plant limits the number of active meristems, reducing the TPD and prioritizing the leaves growth of mature tillers (LEMAIRE *et al.*, 2011). In *P. maximum* cv. Tanzânia, Oliveira *et al.* (2007) reported a significant effect of fertilization with N + P (10.3 tillers  $plant^{-1}$ ) or N + P + K (9.9 tillers  $plant^{-1}$ ) compared with non-fertilized treatment (2.3 tillers  $plant^{-1}$ ).



**Figure 10** - Tiller population density of *Trachypogon plumosus* affected by regrowth age within each soil fertility correction level.

## Conclusions

The grass presents responsiveness to improvement of production conditions environment.

The correction levels of soil fertility and regrowth ages affect the yield and pattern of forage accumulation, growth rates, and grass morphogenetic and structural characteristics.

The use of fertilization or liming + fertilization anticipates the period of pasture utilization.

## Scientific literature cited

- ANDRADE, A. C.; FONSECA, D. M.; LOPES, R. S.; NASCIMENTO JÚNIOR, D.; CECON, P. R.; QUEIROZ, D. S.; REIS, S. T. Características morfogênicas e estruturais do capim-elefante 'Napier' adubado e irrigado. **Ciência e Agrotecnologia**, v.29, n.1, p.150-159, 2005.
- BARUCH, Z.; NASSAR, J. M.; BUBIS, J. Quantitative trait, genetic, environmental, and geographical distances among populations of *Trachypogon plumosus* in Neotropical savanna. **Diversity and Distributions**, v.10, p.283-292, 2004.
- BENINCASA, M. M. P. **Análise do crescimento de plantas: noções básicas**. Jaboticabal: FUNEP, 2003. 2ed. 41p.
- COSTA, N. de L.; MORAES, A.; GIANLUPPI, V.; BENDAHAN, A. B.; MAGALHÃES, J. A. Rendimento de forragem e morfogênese de *Axonopus aureus*, durante o período seco, nos cerrados de Roraima. **Revista Agro@ambiente On-line**, v.6, n.1, p.59-66, 2012.
- DIFANTE, G. S.; NASCIMENTO JÚNIOR, D.; SILVA, S. C.; EUCLIDES, V. P. B.; MONTAGNER, D. B.; SILVEIRA, M. C. T.; PENA, K. S. Características morfogênicas e estruturais do capim-marandu submetido a combinações de alturas e intervalos de corte. **Revista Brasileira de Zootecnia**, v.40, n.5, p.955-963, 2011.



- FERLIN, M. B.; EUCLIDES, V. P. B.; LEMPP, B.; GONÇALVES, M. C.; CUBAS, A. C. Morfogênese e dinâmica do perfilhamento de *Panicum maximum* cv. Tanzânia sob pastejo. **Ciência e Agrotecnologia**, v.30, n.2, p.344-352, 2006.
- LEMAIRE, G.; HODGSON, J.; CHABBI, A. **Grassland productivity and ecosystem services**. Wallingford: CABI, 2011. 287p.
- MACHADO, J. M. **Morfogênese de gramíneas nativas sob níveis de adubação nitrogenada**. Santa Maria: UFSM, 2010. 78p. Dissertação de Mestrado em Zootecnia.
- MATA, D.; HERRERA, P.; BIRBE, B. Sistemas de producción animal con bajos insumos para las sabanas de *Trachypogon* sp. **Ecotropicos**, v.9, n.2, p.83-100, 1996.
- OLIVEIRA, A. B.; PIRES, A. J. V.; MATOS NETO, U.; CARVALHO, G. G. P.; VELOSO, C. M.; SILVA, F. F. Morfogênese do capim-tanzânia submetido a adubações e intensidades de corte. **Revista Brasileira de Zootecnia**, v.36, n.4, p.1006-1013, 2007.
- OLIVEIRA, M. A.; PEREIRA, O. G.; GOMIDE, J. A.; HUAMAN, C. A. M.; GARCIA, R.; CECON, P. R. Análise de crescimento do capim-bermuda 'Tifton 85' (*Cynodon* spp.). **Revista Brasileira de Zootecnia**, v.29, n.6, p.1930-1938, 2000.
- PARSONS, A. J.; CHAPMAN, D. F. The principles of pasture growth and utilization. In: HOPKINS, A. (Ed.). **Grass, its production and utilization**. London: Blackwell Science, p.31-89, 2000.
- PATÊS, N. M. S.; PIRES, A. J. V.; SILVA, C. C. F.; SANTOS, L. C.; CARVALHO, G. G. P. Características morfogênicas e estruturais do capim-tanzânia submetido a doses de fósforo e nitrogênio. **Revista Brasileira de Zootecnia**, v.36, n.6, p.1736-1741, 2007.
- QUADROS, F. L. F.; BANDINELLI, D. G.; PIGATTO, A. G. S.; ROCHA, M. G. Morfogênese de *Lolium multiflorum* Lam. e *Paspalum urvillei* Steud sob níveis de adubação de fósforo e potássio. **Ciência Rural**, v.35, n.1, p.181-186, 2005.
- REGAZZI, A. J. Teste para verificar a identidade de modelos de regressão e a igualdade de alguns parâmetros num modelo polinomial ortogonal. **Revista Ceres**, v.40, n.228, p.176-195, 1993.
- RIPPSTEIN, G.; ESCOBAR, G.; MOTTA, F. **Agroecología y biodiversidad de los Llanos Orientales de Colombia**. Cali, Colombia: CIAT, 2001. 302p.
- SARMIENTO, G. Adaptive strategies of perennial grasses in South American savannas. **Journal of Vegetation Science**, v.3, p.325-336, 1992.
- SARMIENTO, G.; SILVA, M. P.; NARANJO, M. E.; PINILLOS, M. Nitrogen and phosphorus as limiting factors for growth and primary production in a flooded savanna in the Venezuelan Llanos. **Journal of Tropical Ecology**, v.22, p.203-212, 2006.
- SOUSA, B. M. L.; NASCIMENTO JÚNIOR, D.; RODRIGUES, C. S.; MONTEIRO, H. C. F.; SILVA, S. C.; FONSECA, D. M.; SBRISSIA, A. F. Morphogenetic and structural characteristics of xaraes palisadegrass submitted to cutting heights. **Revista Brasileira de Zootecnia**, v.40, n.1, p.53-59, 2011.
- SOUSA, B. M. L.; NASCIMENTO JÚNIOR, D.; DA SILVA, S. C.; RODRIGUES, C. S.; MONTEIRO, H. C. F.; RODRIGUES, C. S.; FONSECA, D. M.; SBRISSIA, A. F. Morphogenetic and structural characteristics of andropogon grass submitted to different cutting heights. **Revista Brasileira de Zootecnia**, v.40, n.1, p.2141-2147, 2010.
- TEJOS, R. **Pastos nativos de sabanas inundables: caracterización y manejo**. Barquisimeto, Venezuela: Megagraf, 2002. 111p.
- ZANINE, A. M. Resposta morfofisiológica em pasto sob pastejo. **Colloquium Agrariae**, v.1, n.2, p.50-59, 2005.