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Forage productivity and morphogenesis of *Axonopus aureus* under defoliation levels

Produtividade de forragem e morfogênese de *Axonopus aureus* sob níveis de desfolhação

Productividad de forraje y morfogénesis de *Axonopus aureus* bajo niveles de defoliación

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Abstract
The effect of defoliation levels (5, 10, 15, 20, 25 and 30 cm above soil level) on dry matter (DM) yield and morphogenetic and structural characteristics of *Axonopus aureus* was evaluated under field conditions in Roraima´s savannas. The effects of defoliation levels on the DM yields, absolute growth rate, number of leaves/plant, medium blade length, leaf area, leaf appearance and elongation rates were quadratics and maximum values recorded with cutting at 19.2; 17.5; 20.7; 27.2; 24.3; 20.5 e 25.9 cm above soil level. The population tiller density was directly proportional to the level of defoliation, while the opposite occurred for to leaf senescence rate. Apical meristem removing percentage was higher with increasing defoliation level. Aftermath regrowth showed close negative correlation with defoliation level. Pastures of *A. aureus* managed under residues between 15 and 25 cm above the ground provide greater productivity and efficiency of forage use, greater tissue renewal and a more favorable canopy structure for grazing.
Keywords: Leaves; Dry matter; Tiller; Senescence.

Resumo
O efeito de níveis de desfolhação (5, 10, 15, 20, 25 e 30 cm acima do solo) sobre a produção de forragem e características morfogênicas e estruturais de *Axonopus aureus* foi avaliado sob condições naturais nos cerrados de Roraima. Os efeitos dos níveis de desfolhação sobre a produção de matéria seca, taxa absoluta de crescimento, número de folhas/perfilho, tamanho médio de folhas, área foliar e taxas de aparecimento e expansão de folhas foram quadráticos e os máximos valores registrados com cortes a 19,2; 17,5; 20,7; 27,2; 24,3; 20,5 e 25,9 cm acima do solo, respectivamente. A densidade populacional de perfilhos foi diretamente proporcional ao nível de desfolhação, ocorrendo o inverso quanto à taxa de senescência foliar. A eliminação de meristemas apicais foi incrementada com o aumento do nível de desfolhação. O vigor de rebrota foi direta e negativamente correlacionado com o nível de desfolhação. Pastagens de *A. aureus* manejadas sob resíduos entre 15 e 25 cm acima do solo proporcionam maior produtividade e eficiência de utilização da forragem, maior renovação de tecidos e estrutura do dossel mais favorável ao pastejo.
Palavras-chave: Folhas; Matéria seca; Perfilhamento; Senescência.

Resumen
Se evaluó el efecto de los niveles de defoliación (5, 10, 15, 20, 25 y 30 cm sobre el suelo) sobre la producción de forraje y las características morfogénicas y estructurales de *Axonopus aureus* en condiciones naturales en la sabanas de Roraima. Los efectos de los niveles de defoliación sobre la producción de materia seca, tasa absoluta de crecimiento, número de hojas macollas^{-1}, tamaño promedio de hoja, área foliar y tasas de aparición y expansión de hojas fueron cuadráticos y los valores máximos se registraron con cortes a 19,2; 17,5; 20,7; 27,2; 24,3; 20,5 y 25,9 cm sobre el suelo, respectivamente. La densidad de población de macollas fue directamente proporcional al nivel de defoliación, ocurriendo lo contrario con respecto a la tasa de senescencia de las hojas. La eliminación de meristemos

apicales se incrementó con el aumento del nivel de defoliación. El vigor de rebrote se correlacionó directa y negativamente con el nivel de defoliación. Las pasturas de *A. aureus* manejadas bajo residuos entre 15 y 25 cm sobre el suelo proporciona mayor productividad y eficiencia en el uso del forraje, mayor renovación de tejidos y una estructura de dosel más favorable para el pastoreo.
Palabras clave: Hojas; Materia seca; Macolla; Senescencia.

1. Introduction

In the soils under savanna vegetation of Roraima, the native pastures represent the most important and economical source for the feeding of the herds (Braga, 1998; Gianluppi et al, 2001). Among the various forage grasses that make up the ecosystem, *Axonopus aureus* is one of the most important, representing between 30 and 40% of its botanical composition (Costa et al., 2019). The productivity and longevity of pastures derive, among other factors, from the ability to reconstitute and maintain the leaf area after defoliation, which affects the canopy structure, determines its growth rate, forage accumulation, chemical composition and persistence (Gianluppi et al, 2001). The defoliation intensity indicates the proportion of plant tissue removed by the animal in relation to that available for grazing, strongly impacts the remaining photosynthetically active leaf area, the remobilization of organic reserves and the removal of apical meristems (Lemaire et al., 2011; Andrade et al., 2016).

The morphogenesis of a grass during its vegetative growth is characterized by three factors: the appearance rate, the expansion rate and the longevity of the leaves. The appearance rate and the duration and life of the leaves affect the number of live leaves/tiller, which are genetically determined and can be affected by environmental factors and management practices adopted (Lemaire et al., 2011; Santos et al., 2012; Rizato et al., 2019). The number of live leaves per tiller, constant for each species, constitutes an objective criterion in the definition of grazing systems to be impose in the management of forages. Thus, studies on the dynamics of leaf and tiller growth of perennial forage grasses are important for the definition of specific and sustainable management strategies (Sarmiento et al., 2016).

In this work, the effect of defoliation levels on forage production and morphogenic and structural characteristics of *Axonopus aureus* pastures in the Roraima's savannas was evaluated.

2. Methodology

The research was performed under field natural conditions using the quantitative method. As there are still gaps about the effect of the defoliation intensity on the productive performance of native tropical forage pastures, it was choose to use the hypothetical-deductive method (Pereira et al., 2018).

The experiment was carried out in the Experimental Field of Embrapa Roraima, located in Boa Vista, from May to September 2016, which corresponded to an accumulated precipitation of 1,416 mm and average monthly temperature of 24.8ºC. The soil of the experimental area is a Yellow Latosol, medium texture, biome savanna, with the following chemical characteristics, at a depth of 0- 20 cm: pH_{H2O} = 4.9; P = 2.1 mg kg^{-1}; Ca + Mg = 0.83 $cmol_c.dm^{-3}$; K = 0.012 $cmol_c.dm^{-3}$; Al = 0.67 $cmol_c.dm^{-3}$; H+Al = 2.85 $cmol_c.dm^{-3}$ and Sum of Bases = 0.842 $cmol_c.dm^{-3}$. The experimental design was completely randomized with three repetitions. The treatments consisted of six defoliation intensities (5; 10; 15; 20; 25 and 30 cm above the soil ground). The size of the plots was 3.0 x 3.0 m, with a useful area of 4.0 m^2. During the experimental period, three cuts were performed at 45-day intervals.

The parameters evaluated were green dry matter yield (GDM), absolute growth rate (AGR), tiller density population (TDP), number of leaves $tiller^{-1}$ (NLT), leaf appearance rate (LAR), leaf expansion rate (LER), leaf senescence rate (LSR), average leaf size (ALS) and tiller leaf area (TLA). The AGR was obtained by dividing the GDM yield, at each defoliation age, by the respective regrowth period. LAR, LER and TLA were determined only in live tillers. LAR and LER were calculated by dividing the accumulated leaf length and the total number of leaves in the tiller, respectively, by the regrowth period.

To calculate the leaf area, samples of completely expanded green leaves were collect, trying to obtain an area between 200 and 300 cm^2. The samples were digitalized and the leaf area estimated with the aid of an electronic optical planimeter (Li-Cor 3100C). Subsequently, the sample was dried in a forced air over at 65ºC until they reached constant weight, to obtain the leaf GDM. Specific leaf area (SLA) was determined by the relationship between green leaf area and its GDM (m^2/g leaf GDM). The estimate of tiller density was determined at 1.0 linear meter in each plot. The TLA was determined from the product of the total green leaf GDM (g GDM/m^2) by SLA (m^2/g leaf GDM). The LSR was obtained by dividing the length of the leaf that was yellowish or necrotic by age of regrowth. The survival of apical meristems was estimate by relating to the total number of tillers those with truncated new leaves, seven days after defoliation of the plants. Regrowth vigor was evaluated through GDM production at 21 days after defoliation at the age of the first cut.

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

3. Results and Discussion

The GDM yields and AGR were affect by the levels of defoliation, and the relationships were quadratic and described, respectively, by the equations: $Y = 164.7 + 215.82 X - 5.4164 X^2$ ($R^2 = 0.953$) and $Y = 4.7047 + 6.1663 X - 0.1548 X^2$ ($R^2 = 0.941$). Maximum values were estimate with defoliation at 19.2 and 17.5 cm, respectively for GDM yield and AGR (Table 1). The first effect of defoliation is a plastic response of the plant to adapt to changes in its environment and through the escape mechanism there are morphogenic and architectural adaptations that reduce the accessibility of leaves to animal grazing. At higher defoliation intensity, competition for light is attenuated due to the greater removal of leaf area, however, in this condition plants tend to develop shorter leaves and less forage accumulation (Lemaire et al., 2011; Barbero et al., 2015).

Tabel 1. Green dry mater yield (GDM - kg ha^{-1}), absolute growth rate (AGR - kg ha^{-1} day^{-1}), removal of apical meristems (RAM - %), tiller density population (TDP - tiller m^2), number of live leaf $tiller^{-1}$ (NLT), average leaf size (ALS - cm), tiller leaf area (TLA - cm $tiller^{-1}$), leaf appearance rate (LAR - cm $tiller^{-1}$ day^{-1}), leaf expansion rate (LER - cm $tiller^{-1}$ day^{-1}) and leaf senescence rate (LSR - cm $tiller^{-1}$ day^{-1}) of *Axonopus aureus*, as affected by defoliation level.

Defoliation Level (cm)	GDM[1]	AGR	RAM	TDP	NLT	ALS	TLA	LAR	LER	LSR
5	1,121 c	32.0 e	85.7 a	829 a	5.11 e	14.92 c	20.01 c	0.121 d	2.28 c	0.123 e
10	1,698 b	48.5 d	73.6 b	781 ab	5.80 d	18.83 b	23.08 c	0.138 c	2.59 bc	0.153 d
15	2,287 a	65.3 ab	63.4 bc	731 bc	6.92 b	18.60 b	32.09 b	0.157 b	3.06 ab	0.165 c
20	2,377 a	67.9 a	56.5 cd	689 cd	7.93 a	21.10 a	41.67 a	0.171 a	3.56 a	0.195 b
25	2,009 a	57.4 bc	51.9 d	634 de	7.12 ab	20.56 a	36.49 b	0.159 b	3.47 a	0.264 a
30	1,835 b	52.4 cd	40.7 e	611 e	6.42 c	21.42 a	35.87 b	0.143 c	3.41 a	0.277 a

- Means followed by the same letter do not differ (P >0.05) by Tukey's test. 1 - Total of three cuts. Source: Research data.

The reduction in the level of defoliation ensures the retention of greater photosynthetically active leaf area and greater remobilization of nutrients, about 50% of the nitrogen and 80% of the carbon, from the senescent leaves for the production of new leaf tissues, resulting in a greater speed of recovery, and shorter interval between grazing (Cruz et al., 2021). Palhano et al. (2005) and Costa et al. (2019) estimated higher GDM yields for *Panicum maximum* cv. Mombasa and *Brachiaria brizantha* cv. Xaraés, respectively, maintained under residues of 60 (5,328 kg ha^{-1}) or 25 cm (5,240 kg ha^{-1}), compared to 120 (1,399 kg ha^{-1}) or 15 cm (2,540 kg ha^{-1}). Costa et al. (2019) found a negative linear relationship between AGR and pasture height of *Trachypogon vestitus* (68.3, 51.4 and 44.1 kg of GDM ha^{-1} day^{-1}, respectively for 10, 20 and 30 cm above the soil ground).

Removal of apical meristems was inversely proportional to the level of defoliation (Y = 91.667 - 1.6971 X - R^2 = 0.983). Costa et al. (2019), in pastures of *P. maximum* cv. Centenário, reported greater removal of apical meristems with cuts at 20 cm above the ground (79.3%), compared to 30 (50.7%) or 40 cm (36.1%), which was negatively correlated with production of forage.

Regrowth vigor was affected by defoliation levels, the relationship was linear and described by the equation Y = 179.6 + 16.909 X (R^2 = 0.958). Similar behavior was obtained by Costa et al. (2019) for *Andropogon gayanus* cv. Planaltina pastures, with regrowth vigor directly proportional to the level of defoliation (671, 921 and 1,132 kg of GDM/21 days, respectively for 10, 20 and 30 cm above the ground).

For NLT, TLA and ALS the relationships were adjust to the quadratic regression model and define, respectively, by the equations: Y = 2.96 + 0.4301 X - 0.0104 X^2 (R^2 = 0.891), Y = 6.0905 + 2.6178 X - 0.0537 X^2 (R^2 = 0.871) and Y = 12.471 + 0.6419 X - 0.0118 X^2 (R^2 = 0.901) with the maximum values obtain with defoliations at 20.7; 24.3 and 27.2 cm above the ground. The correlations between GDM yield and TDP (R = 0.9281; P=0.0025) and NLT (R = 0.9548; P=0.0016) were positive and significant, which explained in 86.1 and 91.2%, respectively, the increments verified in the forage yields of the grass, in function of the levels of defoliation. The values recorded in this study for NLT, ALS and TLA were higher than those reported by Costa et al. (2018) for *A. aureus* pastures maintained under 20 cm residue, which estimated 4.7 leaves tiller^{-1}; 9.3 cm leaf^{-1} and 17.8 cm^2 tiller^{-1}. The TDP was inversely proportional to the level of defoliation, the relationship being linear and described by the equation: Y = 869.8 - 8.9886 X (R^2 = 0.992). The TLA represents the synthesis of the morphogenic and structural characteristics of the grass and reflects the balance of processes that determine the supply (photosynthesis) and demand (respiration, accumulation of reserves, synthesis) of photoassimilates, which establish the rhythm of growth of the pasture (Nabinger & Carvalho, 2009; Pereira, 2018).

The tiller potential of a genotype, during the vegetative stage, depends on its leaf emission rate, which will produce buds capable of producing new tillers, depending on the environmental conditions (light, photoperiod, water and temperature), hormonal balance, flowering and the management practices adopted (Silva & Nascimento Júnior, 2007; Zanine et al., 2012). The relationships between levels of defoliation, LAR and LER were adjusted to the quadratic regression model and described, respectively, by the equations: Y = 0.082 + 0.0082 X - 0.0002 X^2 (R^2 = 0.941) and Y = 1.514 + 0, 1507 X - 0.0029 X^2 (R^2 = 0.951) (Table 1). LAR and LER present a negative correlation, indicating that the higher the LAR, the shorter the time available for leaf elongation (Rodrigues et al., 2012; Costa et al., 2019; Santos et al., 2012). In this work, the correlation between these two variables was positive and significant (R = 0.9123; P=0.0072), possibly as consequence of the higher soil fertility, which contributed positively to the maximization of the morphogenic characteristics of the grass. Lemaire et al. (2011) observed that LER was positively correlated with the amount of green leaves remaining on the tiller after defoliation, with tiller size being responsible for the long duration of LER. In this work, the correlation was positive and significant (R = 0.9835; P=0.0036), evidencing the synchrony between these two variables.

The relationship between defoliation levels and LSR was linear and defined by the equation: Y = 0.0829 + 0.0065 X (R^2 = 0.948). The values recorded in this study were lower than those reported by Costa et al. (2018) for *Axonopus aureus*, a native grass of Roraima's savanna, who estimated a LSR of 0.281 cm tiller^{-1} day^{-1}, for plants evaluated at 45 days of regrowth. Costa et al. (2019) reported higher LSR for *Paspalum secans* FCAP-12 pastures maintained under residues of 30 cm (0.176 cm tiller^{-1} day^{-1}), compared to 20 cm (0.154 cm tiller^{-1}day^{-1}) or 10 cm (0.109 cm tiller^{-1} day^{-1}). Senescence is a natural process that characterizes the last stage of a leaf's development, which begins after the complete expansion of the first leaves, whose intensity progressively increases with the increase of the leaf area, which implies the shading of the leaves inserted in the lower portion of the stem (Lemaire et al., 2011; Santos et al., 2012; Barbero et al., 2015). Despite the negative effect on forage quality, senescence represents an important physiological process in grass tissue flow, as around 35; 68; 86 and 42% of nitrogen, phosphorus, potassium and magnesium, respectively, can be recycled from senescent leaves and used for the production of new leaf tissues (Sarmiento et al., 2016).

4. Final Considerations

The level of defoliation affects dry matter yields, absolute growth rate and structural characteristics of the grass.

The elimination of apical meristems was directly proportional to the level of defoliation, with the opposite occurring in relation to regrowth vigor.

The maintenance of *Axonopus aureus* pastures under residues between 15 and 25 cm promoted greater productivity and, efficiency of forage use, greater tissue renewal and a more favorable canopy structure for grazing.

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