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Morphogenesis and productivity of Pioneiro elephant grass under different residual heights and light interceptions

Eleuza Clarete Junqueira de Sales[1*], Carlos Ramon Santiago Saraiva[2], Sidnei Tavares dos Reis[1], Vicente Ribeiro Rocha Júnior[1], Daniel Ananias de Assis Pires[1] and Cláudio Manoel Teixeira Vitor[3]

*[1]Departamento de Ciências Agrárias, Universidade Estadual de Montes Claros, Avenida Reinaldo Viana, 2630, 39440-000, Bico da Pedra, Janaúba, Minas Gerais, Brazil. [2]Instituto Federal de Educação, Ciência e Tecnologia Baiano, Guanambi, Bahia, Brazil. [3]Universidade Federal de São João Del Rei, São João Del Rei, Minas Gerais, Brazil. *Author for correspondence. E-mail: eleusa.sales@unimontes.br*

ABSTRACT. The aim of this study was to assess two residual heights and two light interceptions on morphogenetic, structural and productive characteristics of *Pennisetum purpureum* Schum. cv. Pioneiro. The experiment was a factorial randomized block design with four replications. We evaluated morphogenetic characteristics in three basal tillers tagged in each plot, in different tussocks. Tiller population density was evaluated in marked areas in all experimental units. The interaction between the factors significantly influenced the leaf and pseudostem elongation rate, the leaf appearance rate, phyllochron, number of leaves per tiller, green leaves per tiller, final leaf blade length, leaf area index and biomass yield. There were no changes in the leaf senescence rate, number of senescent leaves per tiller and tiller density. Most morphogenetic variables was affected by the interactions between factors which also influenced the productivity, allowing to set the treatment with 50 cm residual height and cut to reach values near 95% light interception as the one with the best results for the variables analyzed.

Keywords: *Pennisetum purpureum*, elongation rate, appearance rate, phyllochron.

Morfogênese e produtividade de capim–elefante, cultivar Pioneiro sob diferentes alturas de resíduos e interceptações luminosas

RESUMO. O objetivo deste trabalho foi avaliar o efeito de duas alturas de resíduo e duas interceptações luminosas sobre as características morfogênicas, estruturais e produtivas do *Pennisetum purpureum* Schum. cv. Pioneiro. O delineamento experimental utilizado foi em blocos casualizados em esquema fatorial com quatro repetições. Avaliaram-se variáveis morfogênicas em três perfilhos basais marcados em cada parcela, em touceiras diferentes. As densidades populacionais de perfilhos foram avaliadas em áreas marcadas em todas as unidades experimentais. A interação entre os fatores influenciou significativamente as taxas de alongamentos foliar e do pseudocolmo, a taxa de aparecimento foliar, filocrono, números de folhas por perfilho, de folhas verdes por perfilho, comprimento final da lâmina foliar, índice de área foliar e produtividade de biomassa. Não houve alterações nas variáveis taxa de senescência foliar, número de folhas senescentes por perfilho e densidade populacional de perfilhos. Observou-se que a maior parte das variáveis morfogênicas foi afetada pelas interações entre os fatores, o que também influenciou a produtividade, permitindo definir o tratamento com a altura de resíduo de 50 cm e corte efetuado ao atingir valores próximos a 95% de interceptação luminosa, aquele com os melhores resultados para as variáveis analisadas.

Palavras-chave: *Pennisetum purpureum*, taxa de alongamento, taxa de aparecimento, filocrono.

Introduction

Elephant grass has attracted cattlemen in tropical countries because of its high dry matter production per hectare, good growth, high animal productivity per hectare and for supporting high stocking rate. However, there is a need to add more information regarding the pasture responses to environmental conditions (MÍSSIO et al., 2006).

Morphogenesis is the formation and development of successive phytomers, making possible the appearance of leaves, which, in turn, determine the flow dynamics of tissues in forage plants. Thus, if for each new leaf emerged there is an axillary bud able to originate a new tiller, leaf appearance can be considered the central feature of morphogenesis, and biomass accumulation is the sum of the yields of individual tillers forming the pasture. Therefore, to correctly characterize the pasture is essential to understand the morphogenetic responses of forage plants to the cutting or grazing management, which consequently contributes to the development of more appropriate strategies for exploiting its potential (GOMIDE et al., 2009).

According to Andrade et al. (2005), among all variables related to growth and production of plants, the leaf area, light interception, photosynthesis and light environment are of paramount importance, since 90% of the dry weight of plants is due to the photosynthetic carbon assimilation. The 95% light interception is the point at which plants modify their dynamics of dry matter accumulation, reducing the accumulation of leaf blades and rapidly increasing the accumulation of stems and dead material. Both the cutting interval and the residual height may influence the accumulation and morphological composition of forage produced, and their relative importance vary with the season and phenological stage of plants (PENA et al., 2009).

In this context, this study aimed to evaluate the influence of different combinations of residual heights with different light interceptions on morphogenetic, structural and production characteristics of Pioneiro elephant grass in the northern Minas Gerais State.

Material and methods

The experiment was conducted between November 2008 and June 2009 at the Experimental Farm of the State University of Montes Claros–Unimontes, Campus Janaúba, located in the irrigated perimeter of Gorutuba in northern Minas Gerais State, 15° 47' South latitude, 43° 18' West longitude, and 516 m altitude.

The local climate is tropical mesothermic, almost megathermic because of the altitude, with characteristics of subhumid and semiarid, with erratic rainfall, leading to long dry periods. In accordance with Köppen, the typical climate is Aw, i.e. typical of savannah with dry winter and average air temperature of the coldest month above 18°C. According to data provided by the Agricultural Research Company of Minas Gerais (Epamig), the average annual rainfall in the municipality is 877 mm.

The soil of the experimental area is classified as clayey dystrophic red-yellow. The chemical characteristics of soil samples taken at 0-20 cm layer: pH in H_2O = 6.1; P = 3.9 (Mehlich-1) and K = 260 mg.dm^3; Ca^{+2} = 3.7; Mg^{+2} = 1.0; Al^{+3} = 0.1; H $^+$ Al = 2.6; cation exchange capacity = 7.4; sum of bases = 4.9 cmol$_c$ dm^{-3} and base saturation: 65%. In the 0-40 cm layer: pH in H_2O = 6.0; P = 6.0 (Mehlich-1) and K = 147 mg.dm^3; Ca^{+2} = 2.2; Mg^{+2} = 0.7; Al^{+3} = 0.2; H $^+$ Al = 3.6; cation exchange capacity = 6.9, sum of bases = 3.3 cmol$_c$ dm^{-3} and base saturation: 47%.

As topdressing, after the standardization cut, 200 kg ha^{-1} nitrogen were applied in the form of ammonium sulfate [$(NH_4)_2SO_4$], subdivided in four applications after each cut.

Based on data from another experiment conducted by Mota et al. (2010) with Pioneiro elephant grass in the same experimental farm, irrigations were made three times a week. In each irrigation, 18.88 mm water per square meter were sprayed, making a total of 56.64 mm per week. The treatments consisted of two residual heights, 30 and 50 cm, and the times of the cuts were set when reached one of two different light interceptions, 95 and 100%, depending on the treatment, which led to different intervals between cuts. Treatments were assigned to 7 x 9 m experimental units, with working area of 5 x 7 m, in a randomized complete block design with a 2 x 2 factorial arrangement with four replications, totaling 16 experimental units, spaced 1.5 m between blocks.

Assessments of light interception and leaf area index were performed using the equipment AccuPAR PAR/LAI Ceptometer LP-80 (DECAGON Devices), by following the instructions in the Operator's Manual Version 6.

Pre-cut forage mass was measured by collecting three 0.25 m^2 samples per experimental unit, harvested at the residual level of the treatment of the plot in question. Representative aliquots of these samples were taken for assessment of morphological components of forage. This aliquot was separated into the fractions (leaf blade), pseudostem (stem+sheath) and total (blade+pseudostem), which were weighed and dried in a forced air oven at 55°C to constant weight.

For determining the dry matter accumulation rate per day (kg DM ha^{-1} day^{-1}), values of forage mass harvested were divided by the number of days between cuts of each cycle.

The number of tillers was evaluated using three tussocks per plot, 0.25 m^2 each. At the beginning of the trial, all tillers contained in tussocks were counted and tagged with colored plastic-coated wire. In the immediate pre-cut, tillers emerged after the start of the cycle were counted. With each new sampling, which occurred in the post-cut, new tillers were tagged with a different color. Thus, we obtained an estimated population of tillers.

In the early first regrowth period, three basic random tillers were tagged on different tussocks in each plot (total of 48 tillers) for evaluation of morphogenetic and structural characteristics of the canopy during the growing period of the grass in the experimental area. Tillers were marked with plastic rings. At each new cycle, a new basal tiller was marked in the same tussock with a different color. Assessments were held every 15 days during the summer and every seven days during the fall.

The lengths of leaf blades and the height of the base of tillers (at ground level) were measured to the ligule of the last expanded leaf (pseudostem length), and we registered the number of new leaves that emerged in each of tillers and in each evaluation date. The leaves whose ligules were not yet exposed had its length evaluated from the last exposed ligule (the same used to measure the pseudostem length). Senescence was also measured and fully senesced leaves were counted.

The variables were grouped by their nature. We calculated the mean value for each cycle between cuts and then the mean of cycles for each of the variables, aiming to obtain information about the mean values between cycles at high temperature and long photoperiod and cycles at milder temperature and short photoperiod.

Discrete quantitative variables (from counting data) were tested by the General Linear Model procedure, namely: additivity by analysis of covariance of the squared predicted values; normality through the Univariate procedure, with the W statistics (Shapiro-Wilk), the homogeneity of variance by Bartlett's test.

The variable number of leaves per tiller did not satisfy the additivity. In this way, we used the non-parametric Wilcoxon test for this variable.

Once confirmed the lack of significance of these tests, indicating that the assumption of additivity of the residue, residual normality and homogeneity of variances were met, the remaining variables were subjected to analysis of variance and, whenever the F-test was significant, we compared the means to each other, at 5% probability, according to the following statistical model:

$$Yijk = \mu + B_i + R_j + I_k + RI_{jk} + e_{ijk}$$

where:

Yijk = Observed value of the residual height “j”, submitted to the block “i”;

μ = a constant associated with all observations;

B_i = Effect of block “i”, with i = 1, 2, 3, 4;

R_j = Effect of residual height “j”, with j = 1 and 2;

I_k = Effect of light interception “k”, with k = 1 and 2;

RI_{jk} = Effect of the interaction between residual “j” and light interception “k”;

e_{ijk} = Effect of uncontrolled factors (experimental error), which by definition has a normal distribution, zero mean and variance σ^2.

Results and discussion

The durations of the cycles, in days, and the number of cycles during this experiment were affected by residual heights and light interceptions used in the study. The treatment with 50 cm residual height and cut held when reached 95% light interception (treatment 50/95) presented one more grazing cycle than others during the experimental period.

The mean duration of cycles for the treatment 50/95 was 41.5 days. For the treatments 50/100, 30/95 and 30/100, the mean durations of cycles were, respectively, 49, 51.5 and 58.5 days.

Similar results were described by Barbosa et al. (2007) on *Panicum maximum* Jacq. cv. Tanzania in residual two heights and three light interceptions, and also by Carnevalli et al. (2006) with *Panicum maximum* Jacq. cv. Mombasa, whose number of grazing cycles was also reduced when the light interception increased from 95 to 100%.

The leaf appearance rate was significantly influenced ($p < 0.05$) by the treatment 30/100, showing the lowest value as seen in Table 1.

Table 1. Mean values of variables subjected to two residual heights held at two different light interceptions, for the cultivar Pioneiro, Janaúba, Minas Gerais State.

Residual height (cm)	Light interception (%)		Light interception (%)	
	95	100	95	100
	[1]leaf appearance rate		[6]number of green leaves per tiller	
30	0.148 Aa	0.118 Bb	5.90 Ba	8.58 Aa
50	0.158 Aa	0.140 Aa	6.26 Aa	7.31 Aa
	[2]phyllochron		[7]final leaf blade lenght	
30	8.76 Aa	10.41 Aa	22.65 Ab	23.53 Ab
50	6.73 Ab	8.08 Ab	31.51 Aa	31.16 Aa
	[3]leaf elongation rate		[8]leaf area index	
30	0.960 Aa	1.108 Aa	3.19 Ab	3.28 Ab
50	1.110 Aa	0.750 Bb	4.38 Aa	4.50 Aa
	[4]pseudostem elongation rate		[9]kilograms DM day^{-1}	
30	1.663 Ab	1.725 Ab	29.78 Aa	24.70 Aa
50	2.450 Aa	2.475 Aa	43.58 Ab	40.33 Ab
	[5]number of leaves per tiller		[10]tons DM in 30 $days^{-1}$	
30	9.08 Ab	9.31 Ab	0.89 Aa	0.74 Aa
50	11.53 Aa	10.53 Aa	1.31 Ab	1.21 Ab

Mean values followed by the same letter, uppercase and lowercase letters, in the rows and columns respectively, are not significantly different by F-test ($p > 0.05$). [1]CV (%) = 9.20; [2]CV (%) = 13.96; [3]CV (%) = 21.14; [4]CV (%) = 17.24; [5]CV (%) = 6.65; [6]CV (%) = 11.72; [7]CV (%) = 13.43; [8]CV (%) = 13.32; [9]CV (%) = 23.78; [10]CV (%) = 23.78.

According to Pontes et al. (2003), if on one hand the leaf elongation rate is directly related to the final leaf length, on the other hand, shorter leaves are related to higher leaf appearance rate, which was not found in this experiment. This can be because the leaf appearance rate is strongly influenced by temperature (PENA et al., 2009) and other environmental factors (RODRIGUES et al., 2012). Seasonal fluctuations are caused not only by temperature but also by changes in light intensity, photoperiod and availability of water and nutrients in the soil. As in almost the entire second half of the experimental period, temperatures were slightly warmer than normal and the photoperiod was shorter compared to that found in the summer, this may be the reason why plants had no increased leaf appearance rate.

Pena et al. (2009), working with *Panicum maximum* Jacq. cv. Tanzania also have detected significant differences ($p = 0.0001$) in the leaf appearance rate, reporting that this was affected by the interaction of residual height x cutting interval x cutting date (season).

Regarding the phylochron, resulting from the inverse of leaf appearance rate, it is related to the time interval between the appearance of two successive leaves, significant differences ($p < 0.05$) were found according to the residual height. The treatments with 50 cm residue exhibited lower values for the phyllochron. The light interceptions had no significant influence ($p > 0.05$) on this variable (Table 1).

Andrade et al. (2005) reported mean phyllochron for basal tillers of elephant grass cv. Napier of 7.1 days. In the present study, the treatments 50/95 and 50/100 showed results close to those: 6.73 and 8.08 days leaf^{-1}, respectively. In turn, the treatments 30/95 and 30/100 presented values of 8.76 and 10.41 days sheet^{-1}, respectively.

The treatment 50/100 had a significant ($p < 0.05$) influence on the leaf elongation rate, which showed the lowest mean, as seen in Table 1. These results contrast with those reported by Pontes et al. (2003), who registered important increases in this rate depending on the residual height, observing a linear increase in this rate with increasing height of the ryegrass pasture. The author relates this effect to greater residual height and greater amount of senescent material in the treatments of greater height, providing greater remobilization of nutrients. In the present study, the only variation was observed for the treatment with 50 cm residue and 100% light interception which despite having the highest residual height showed the lowest rate of leaf elongation. It could be expected a significant and positive difference, that is, a higher leaf elongation rate, as recorded by Pontes et al. (2003).

A significant effect of residual heights was observed ($p < 0.05$) on pseudostem elongation rate, however there was no effect of light interception on this rate (Table 1).

Higher rates of pseudostem elongation, compared to leaf elongation rates, are due to the fact that data were collected during a period including short photoperiod, when the Pioneiro elephant grass, as typically occurs with tropical forage grasses, started the reproductive stage (from April 2nd, 2009), characterized by the rapid growth of reproductive structures.

Pena et al. (2009) worked with *Panicum maximum* Jacq. cv. Tanzania and pointed out that the pseudostem elongation rate was not affected by the residual height ($p = 0.3154$). Therefore, our results contrast greatly with the work cited, since the pseudostem elongation rate was significantly different depending on the residual height, as shown in Table 1.

Although the stem elongation favors increased dry matter production per area, it can negatively influence the efficiency of grazing and nutritional values of forage produced (CARNEVALLI et al., 2006; DIFANTE et al., 2009), besides increasing the phyllochron.

The leaf senescence rate was not affected ($p > 0.05$) by the treatments, with a mean value of 0.25 cm dia^{-1}.

Similarly to our results, Paciullo et al. (2003), working with *Pennisetum purpureum* Schum., and Andrade et al. (2005), in an experiment with the cultivar Napier irrigated and under different levels of fertilization, did not report significant differences in the leaf senescence rate.

Different from that observed in this experiment, a work developed with *Panicum maximum* Jacq. cv. Tanzania by Pena et al. (2009) verified that the leaf senescence rate was influenced by the interaction interval x height x cutting ($p = 0.0147$), which may be partially due to the much shorter cutting intervals (two, three and four leaves) compared to experiment described in this research. Nevertheless, similar to results described herein, Andrade et al. (2005), in an experiment with Napier elephant grass irrigated and under different levels of fertilization, did not report significant differences in the rate.

It was found a significant effect ($p < 0.05$) of residual heights on the number of leaves per tiller, and the 50 cm residue led to the the highest values (Table 1).

In agreement with Skinner and Nelson (1995), the process of internode elongation, which elevates apical meristem along the pseudostem, also results in a rapid emergence of leaves of higher insertion level. Furthermore, longer length of the vegetative stem, as a rule, is shown associated with higher number of leaves. This explains the positive relationship in the results of this experiment on the relationship between stem length and number of leaves per tiller.

As for the number of green leaves per tiller, there is a significant effect ($p <0.05$) of the 30 cm residual height with 95% light interception, with fewer leaves (Table 1). In this case, the number of green leaves per tiller measured in the experiment with 100% light interception is higher than those recorded by Andrade et al. (2005) with *Pennisetum purpureum* Schum. cv. Napier, fertilized and irrigated. Under these conditions, after 55 regrowth days, the basal tillers had on average 6.1 leaves per tiller. In the present study, treatments with 95% light interception showed values similar to Andrade et al. (2005) therefore lower than those achieved with 100% light interception. This fact contradicts, at least in part, the 95% light interception as the moment from which the grasses modify its dynamics of dry matter accumulation, reducing thus the accumulation of leaf blades and rapidly increasing the accumulation of stems.

For 100% light interception, the number of green leaves per tiller was similar to that measured by Rezende et al. (2008), working with *Pennisetum purpureum* Schum. cv. Cameroon. However, the number of green leaves per tiller registered for 95% light interception is lower than that found by Rezende et al. (2008), which is related to the length of the pseudostem. These features maintain a close relationship with a smaller number of green leaves per tiller.

The number of senescent leaves per tiller, as well as the leaf senescence rate, was not significantly affected ($p > 0.05$) by the treatments. It was recorded a mean value of 3.1 senescent leaves per tiller. Paciullo et al. (2003) analyzed *Pennisetum purpureum* Schum. and also reported no significant differences in this respect.

The final length of the leaf blade was significantly influenced ($p < 0.05$) by residual heights, but not by light interceptions. The residual height of 50 cm led to a greater length (Table 1).

The leaf area index depends, among other characteristics, on leaf area, and this, in turn, also depends on leaf length, and our results confirmed the expected: the leaf area index was significantly affected ($p < 0.05$) by residual heights, similar to that verified with the final leaf blade length (Table 1). The 50 cm residual height showed a higher value of leaf area index.

Considering the highest mean values of final leaf blade length, Gomide and Gomide (2000) stated that the intermediate portion of the stem has the leaves of greater length in the tiller. Thus, since a longer stem has proportionally a longer intermediate portion, it justifies the higher mean values of final length of leaf blade registered for the 50 cm residual height. Notably, the lowest values of final leaf blade length were found for the 30 cm residual height. This is a response to more severe cuts (lower residual height), resulting in reduced length of the leaf sheath, probably a consequence of reduced cell multiplication, leading to a lower final leaf blade length, while the opposite is also true.

Silva et al. (2002) analyzed 17 genotypes of elephant grass in three grazing cycles, and obtained mean values of leaf area index of 4.60, 2.39 and 2.69, respectively for the three cycles. The authors argued that the differences between the values of this index were also resulting from climatic conditions according to the grazing period, providing a greater value in the first cycle due to more favorable environmental conditions at that time. Mean values of leaf area index of that work (3.23) showed no significant difference from that found in the present experiment for the 30 cm residual height: 3.19 with 95% light interception and 3.28, with 100% light interception. But the 50 cm residual height had different values: 4.38, with 95% light interception, and 4.50 with 100% of light interception. This is due to the fact that the residual height used by Silva et al. (2002) is close to the lowest of this experiment, 30 cm.

Critical values of leaf area index, close to those of the present study, were demonstrated by Viana et al. (2009), working with repeatability and determination of coefficients with cultivars of *Pennisetum purpureum* Schum. of small size under sheep grazing and by Mello and Pedreira (2004), evaluating Tanzania grass pastures (*Panicum* *maximum* Jacq.) in response to different levels of defoliation under intermittent stocking and using irrigation. The authors reported critical values of leaf area index of 4.5 (97.1% LI), 4.0 (96.1% LI) and 3.6 (94.6% LI), respectively, for increasing grazing intensities.

The leaf: pseudostem ratio was not affected ($p > 0.05$) by any of the treatments, with a mean of 1.60. This was lower than those found by Mota et al. (2010) with Pioneiro elephant grass in different levels of irrigation and nitrogen fertilization, which verified ratios ranging from 1.98 to 3.30, according to the treatments

The different treatments had no significant effect on tiller population ($p > 0.05$). The results achieved, compared to other experiments with *Pennisetum purpureum* Schum. (CUNHA et al., 2007; FREITAS et al., 2003; PACIULLO et al., 2003; REZENDE et al., 2008), appear to be within the higher rates reached, as this study reported an average of 310 tillers, and it is rarely found more than a total of 300 tillers per m^2.

The residual height significantly ($p < 0.05$) affected the dry matter production per hectare per day (kg DM day^{-1}) and the 50 cm residue showed the highest productivity. The light interceptions had no influence ($p > 0.05$) on this productivity rate. Consequently, the same was observed for the dry matter production per hectare within 30 days (ton DM 30 $days^{-1}$), with the 50 cm residual height resulting in higher productivity. Productivity data are shown in Table 1.

Carvalho et al. (2007) point the optimal leaf area index as the one recorded when the sward reaches the maximum growth rate (balance between photosynthesis and respiration), but the forage production is maximized when the balance between growth and senescence is maximum, a situation associated with canopy condition in which 95% of the incident photosynthetically active radiation (PAR) is intercepted. Other recent study with tropical grasses agree with these statements, also showing a strong relationship between sward height and its light interception in the pre-grazing condition and, consequently, with the critical leaf area index (BARBOSA et al., 2007; CARNEVALLI et al., 2006; PEDREIRA et al., 2007). Therefore, it is observed that the sward height can be used as a reliable feature for controlling the time for the beginning of grazing.

Conclusion

In summary, under the conditions of the northern Minas Gerais State, for the Pioneiro elephant grass fertilized and irrigated it is recommended cutting when the sward reaches values close to 95% light interception, in a post-cutting residual height of 50 cm.

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