Ciência Animal Brasileira
Brazilian Animal Science

DOI: 10.1590/1809-6891v26e-79129E

e-ISSN 1809-6891
Animal Science | Research article

Growth and senescence of mavuno, marandu, ipyporã and mulato II grasses subjected to stockpiling

Crescimento e senescência das gramíneas mavuno, marandu, ipyporã e mulato II submetidas ao diferimento

Bruno Humberto Rezende Carvalho[1], Gustavo Segatto Borges*[1], Dallety Haloma Alves Miler de Oliveira[1], Geovana Lopes Nascimento[1], Khazuê Ubagai Machado[1], Manoel Eduardo Rozalino Santos[1]

1 Universidade Federal de Uberlândia (UFU), Uberlândia, Minas Gerais, Brazil
*Corresponding author: gustavosegatto73@gmail.com

Received: April 23, 2024. Accepted: July 31, 2024. Published: February 04, 2025. Editor: Rondineli P. Barbero

Abstract: The objective of this study was to evaluate, during the stockpiling period, the growth and senescence of marandu, mavuno, ipyporã and mulato II grasses. The experimental design was completely randomized, with four replications. The experiment was repeated in 2 years (2020 and 2021). The leaf appearance (LApR) and elongation rate (LEIR), stem elongation rate, tiller population density, growth rates at canopy level, as well as canopy leaf senescence rate showed higher values at the beginning in relation to the end of the stockpiling period. The leaf life span showed an inverse response pattern. Among the cultivars, mavuno grass presented the highest LApR and total canopy growth rate. The LEIR and canopy leaf growth rate were higher in mavuno and marandu grasses than in mulato II and ipyporã grasses. The stem elongation rate was higher in mavuno and ipyporã grasses compared to mulatto II and marandu grasses. In general, the growth rate of individual tillers and canopy during the stockpiling period decreased in the following sequence: mavuno grass > marandu grass > ipyporã grass > mulatto II grass.

Keywords: leaf growth; morphogenesis; stem elongation; tiller; *Urochloa*.

Resumo: O objetivo com esse trabalho foi avaliar, durante o período de diferimento, o crescimento e a senescência dos capins marandu, mavuno, ipyporã e mulato II. O delineamento experimental foi inteiramente casualizado, com quatro repetições. O experimento foi repetido por dois anos (2020 e 2021). A taxa de aparecimento (TApF) e alongamento foliar (TAlF), a taxa de alongamento do colmo, a densidade populacional de perfilhos, as taxas de crescimento em nível de dossel, assim como a taxa de senescência foliar do dossel, foram superiores no início do que no fim do diferimento. A duração de vida da folha apresentou padrão de resposta inverso. Dentre as cultivares, o capim-mavuno apresentou maiores TApF e taxa de crescimento total do dossel, em relação aos demais. A TAlF e a taxa de crescimento foliar do dossel foram maiores nos capins mavuno e marandu, em relação aos capins mulato II e ipyporã. A taxa de alongamento do colmo foi maior nos capins mavuno e ipyporã, em comparação aos capins mulato II e marandu. De modo geral, a taxa de crescimento dos perfilhos individuais e do dossel durante o período de diferimento decresce na seguinte sequência: capim-mavuno > capim-marandu > capim-ipyporã > capim-mulato II.

Palavras-chave: alongamento de colmo; crescimento foliar; morfogênese; perfilho; *Urochloa*.

1. Introduction

In recent years, both public and private companies have started to invest more significantly in the improvement and release of new cultivars of forage grasses. However, little or no information exists on the development of these recent cultivars under conditions of stockpiling pasture. This strategy consists of delaying the use of the pasture at the end of the rainy season in order to obtain a stock of forage mass to be used, under grazing, in the dry period of the year [(1)]. In general, grasses of the *Urochloa* genus are suitable for stockpiling pastures given their naturally low height and good forage production in autumn [(2)]. Marandu grass has already been properly evaluated under stockpiling conditions [(3)]. Hybrids of the *Urochloa* genus may be promising for stockpiling, but this has not yet been investigated in those hybrids currently available.

The comparative study of hybrids available on the national market, such as ipyporã, mavuno, and mulato II grasses, with widely studied forage grasses, like marandu grass, would help demonstrate the possible aptitudes of forage plants for stockpiling. In this context, the evaluation of morphogenesis facilitates an understanding of the generation and expansion of the aerial organs of the plant in space [(4)] over the stockpiling period. Using such studies of morphogenesis, associated with evaluations of tiller population density and the generation of conversion factors for stem and leaf blades, we have been investigating the dynamics of growth and senescence of leaf and stems of forage grasses under stockpiling ([5,6]).

Our hypothesis for the current study was that there are differences in the growth and senescence of marandu, ipyporã, mavuno, and mulato II grasses when stockpiled. Therefore, this work was carried out with the objective of comparing the growth and senescence patterns of these grasses during the stockpiling period, leading to inferences about the suitability of these grasses for use in stockpiling pasture.

2. Material and methods

The study was conducted from October 2019 to June 2021, a period in which the same experiment was repeated in 2 consecutive years (Year 1, in 2020; and Year 2, in 2021). The first experimental year extended from October (2019) to June (2020), and the second experimental year from October (2020) to June (2021). The experiment took place at the Capim Branco Experimental Farm of the Federal University of Uberlândia, in Uberlândia, MG, Brazil (18°30′ S; 47°50′ W; 863 m altitude). The region's climate is Aw, tropical savannah, with a dry winter and a hot, humid summer [(7)]. Information regarding the climatic conditions during the experimental period was collected at the meteorological station located approximately 200 m from the experimental area (Figure 1).

The temperature and monthly rainfall were used to calculate the soil water balance [(8)], considering a soil water storage capacity of 50 mm (Figure 2).

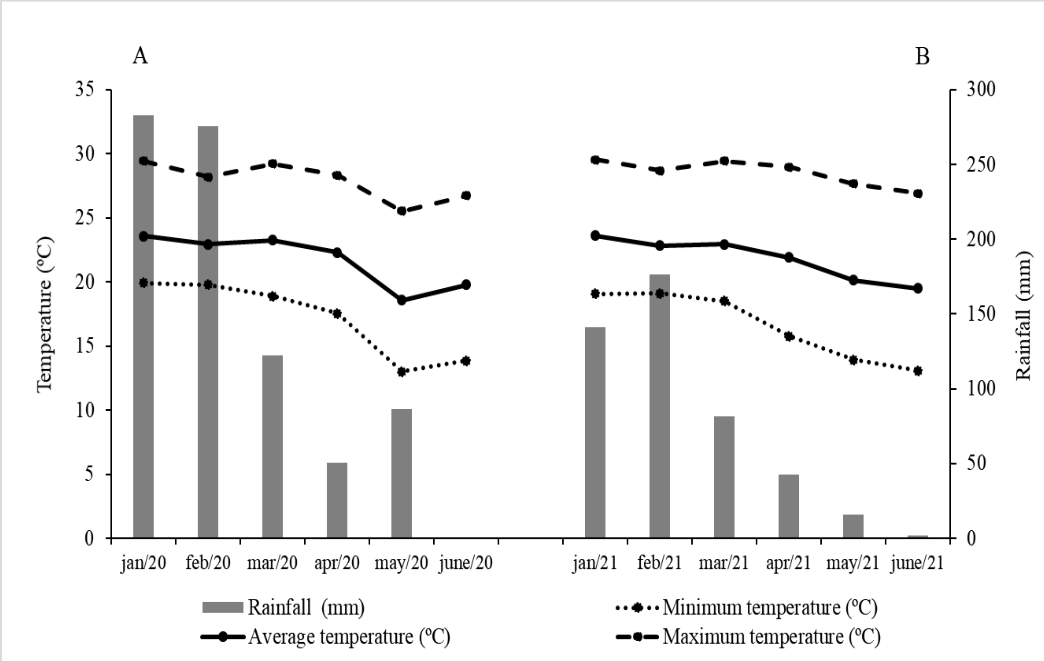

Figure 1. Average monthly temperatures and rainfall during the experimental period from January to June 2020 (A) and 2021 (B)

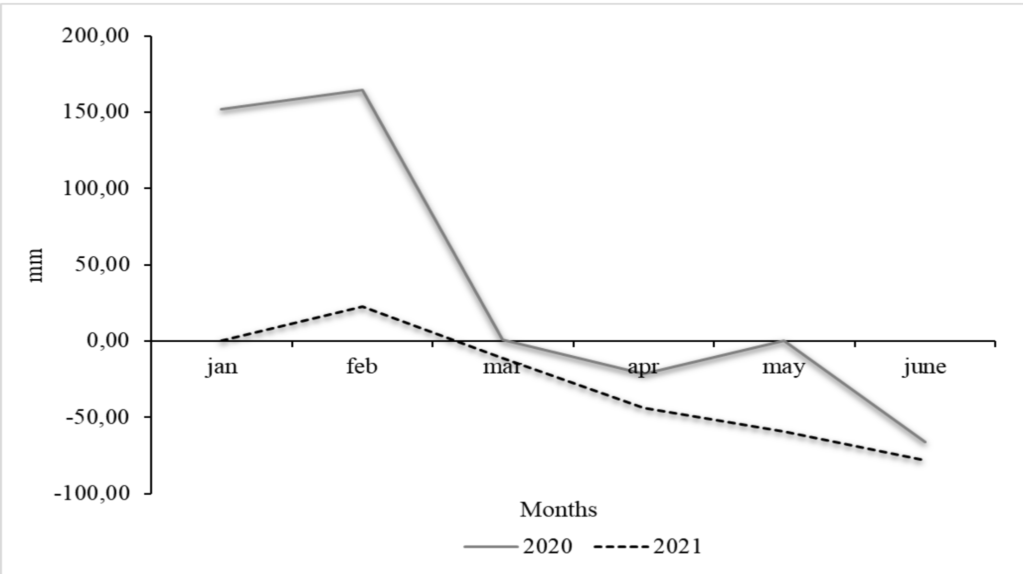

Figure 2. Soil water balance from January to June in 2020 and 2021.

The experimental area has a flat terrain and the soil is classified as Dark Red Latosol[9]. In September of both 2019 and 2020, soil samples were taken from the 0 to 20 cm layer using a probe for fertility analysis. The results in 2019 were: pH (in H_2O): 6.1; P: 4.6 mg dm^{-3} (Mehlich^{-1}); P rem: 10.1 mg dm^{-3}; K: 100 mg dm^{-3}; Ca^{2+}: 5.1 $cmol_c$ dm^{-3}; Mg^{2+}: 2.1 $cmol_c$ dm^{-3}; Al^{3+}: 0 $cmol_c$ dm^{-3} (KCl 1 mol L^{-1}); H + Al: 2.9 $cmol_c$ dm^{-3} and V: 72%. In 2020, the results were: pH (in

H_2O): 6.2; P: 23.2 mg dm^{-3} (Mehlich^{-1}); P rem: 6.9 mg dm^{-3}; K: 165 mg dm^{-3}; Ca^{2+}: 3.53 $cmol_c$ dm^{-3}; Mg^{2+}: 1.39 $cmol_c$ dm^{-3}; Al^{3+}: 0 $cmol_c$ dm^{-3} (KCl 1 mol L^{-1}); H + Al: 1.74 $cmol_c$ dm^{-3} and V: 75%. Based on these soil analysis results, as well as those of the forage grasses, there was no need for liming or potassium fertilization [10].

Nitrogen fertilization was divided into two applications in each of the two experimental years, on October 21st and February 19th, applying 50 kg ha^{-1} of N in the form of urea each time. Phosphate fertilizer was applied on October 21st of both years, with a single application of 50 kg ha^{-1} of P_2O_5 in the form of super-simple. All fertilizers were applied in the late afternoon and as a topdressing.

The experimental area consisted of 16 plots (experimental units) of 12.25 m^2 each. The grasses were established in 2018, at a sowing rate of 6.0 kg ha^{-1} of seeds with a cultural value of 64%. The sowing depth was 3 cm, with a spacing of 30 cm between rows. The experimental treatments consisted of four forage grasses: *Urochloa brizantha* cv. Marandu and the hybrids of *Urochloa* Mulato II, Mavuno, and Ipyporã. The experiment was conducted in a completely randomized design, with repeated measures over time and four repetitions. In both October 2019 and September 2020 (Year 1 and 2, respectively), a uniformity cut was performed on all forage canopies at a height of 5 cm, with all cut material removed from the plots. Subsequently, the plants continued to grow until they reached a height of 30 cm. This height was maintained until March in both years through weekly cuts using pruning shears, to mimic a steady-state condition under continuous stocking.

In both years, the stockpiling period started on March 9th and ended on June 9th, totaling 92 days. During the stockpiling period, the plants were left to grow freely without being cut. Throughout the stockpiling period, morphogenesis was evaluated in two 45-day cycles, with the first evaluation cycle (beginning of stockpiling) from March 9th to April 23rd and the second cycle (end of stockpiling) from April 24th to June 9th. In each evaluation cycle, six different tillers per plot were marked, spaced approximately 10 cm apart. New tillers with at least two expanded leaves and one leaf in expansion were chosen. The tillers were identified with numbered plastic clips. In Year 1, measurements for each tiller were taken every 15 days to minimize contact between evaluators during the COVID-19 pandemic, while in Year 2, measurements were taken weekly.

Using a graduated ruler, measurements were made of the length of the leaf blades and the stem of the marked tillers. The length of expanded leaves was measured from the tip of the leaf to its ligule. In the case of expanding leaves, the same procedure was adopted, but the ligule of the last expanded leaf was considered as a reference for measurement. For leaves in senescence, the length was measured from the ligule of the leaf to where the senescence process had advanced. The size of the stem was measured as the distance from the soil surface to the ligule of the youngest fully expanded leaf.

Based on the methodology, the following variables were calculated: leaf appearance rate, stem elongation rate, leaf elongation rate, and leaf senescence rate (sum of leaf blade senescence divided by the evaluation period of each tiller). The values of these characteristics are presented as means of tiller groups and separately for each evaluation cycle. The first cycle corresponded to the beginning, and the second cycle to the end of the stockpiling period [11]. For the evaluation of tiller population density (TPD), basal and living tillers were counted within a rectangle of 0.125 m^2 at two points in each plot at the beginning, middle, and end of the stockpiling period. The rectangles were allocated in a position parallel to the planting lines.

To express the growth and senescence rates of leaf blades and stems at the forage canopy level, 30 tillers per plot were harvested at the soil surface level on the last day of each morphogenic evaluation cycle. The length of the leaf blades and stems of the tillers was measured in a similar way as done in the field. Subsequently, all leaf blades and stems (including sheaths) were separated and placed in an oven at 65°C for 72 hours. After drying, the morphological components were weighed, and their masses were divided by their respective total lengths. In this way, conversion factors for live leaf blades to live stems (in $mg.cm^{-1}$) were obtained, and these were used to transform the values obtained from the readings in the field (in $cm.tiller^{-1}.day^{-1}$) into the unit of $mg.tiller^{-1}.day^{-1}$. This latter value was multiplied by the mean population density of live tillers ($tiller.ha^{-1}$) to obtain the rates (in $kg.ha^{-1}.day^{-1}$) of leaf blade, stem, and total growth, as well as the leaf blade senescence rate [5]. It is important to note that the TPD used in the initial phase of stockpiling was the average of the TPD at the beginning and middle of the stockpiling period, while the TPD for the final period of stockpiling was the average of the TPD at the middle and end of the stockpiling period.

For the statistical analysis, the average data of the two evaluation cycles were used, using the SAS 9.0 program and the PROC ANOVA, with the value of the means estimated by the MEANS. The variables were analyzed for their fit with a normal distribution. Among the response variables analyzed, three (final lengths of the stem and leaf blade and number of dead leaves per tiller) needed to be transformed to meet the assumptions of analysis of variance. For the comparison of means, a type I error of 5% was considered, and the Tukey test was used.

3. Results

Out of the ten response variables, 80% were influenced by the evaluated forage grasses; 60% differed between the years of evaluation, and 90% were influenced by the stockpiling period. The leaf senescence rate (LSeR) and tiller population density (TPD) were influenced by the interaction between year and stockpiling period. Moreover, the leaf (LElR) and stem (SElR) elongation rates showed an interaction between stockpiling period and forage grass. With the exception of TPD, the other characteristics evaluated at the forage canopy level were not influenced by the interactions between the evaluated factors (Table 1).

Table 1. Response variables and their respective P-values for each factor studied

Variable[1]	Grass[2]	Year	Grass x Year	Period[3]	Year x Period	Grass x Period	Grass x Year x Period
			At individual tiller level				
LApR	0.0039	<0.0001	0.3044	<0.0001	0.4047	0.4859	0.2964
LElR	<0.0001	0.0005	0.2562	<0.0001	0.5686	0.0124	0.9037
SElR	<0.0001	0.1992	0.7049	<0.0001	0.0835	0.0042	0.3214
LSeR	0.0330	0.9738	0.1872	0.1987	0.0108	0.2495	0.5105
LLS	0.4874	0.4552	0.7196	<0.0001	0.1032	0.4655	0.9974
			At forage canopy level				
TDP	0.0122	<0.0001	0.2108	<0.0001	0.0003	0.9259	0.9024
LGR	0.0207	<0.0001	0.6261	<0.0001	0.1935	0.3605	0.9051
SGR	0.0118	<0.0001	0.4407	<0.0001	0.1433	0.2980	0.8744
TGR	0.0110	0.08701	0.1235	<0.0001	0.2720	0.1194	0.7625
LSR	0.3011	<0.0001	0.2209	<0.0001	0.4847	0.8017	0.5711

LApR: leaf appearance rate (leaf tiller^{-1}.day^{-1}); LElR: leaf elongation rate (cm tiller^{-1}.day^{-1}); SElR: stem elongation rate (cm tiller^{-1}.day^{-1}); LSeR: leaf senescence rate (cm tiller^{-1}.day^{-1}); LLS: leaf lifespan (day); TPD: tiller population density (tiller m^{-2}); LGR: leaf growth rate (kg ha^{-1} day^{-1} of DM); SGR: stem growth rate (kg ha^{-1} day^{-1} of DM); TGR: total growth rate (kg ha^{-1} day^{-1} of DM); LSR: leaf senescence rate (kg ha^{-1} day^{-1} of DM). Values in bold differ by the Tukey test (P<0.05).

The leaf lifespan (LLS) and canopy level leaf senescence rate (LSR) did not vary among the forage grasses (Table 2). However, the leaf appearance rate (LApR) was higher in mavuno grass compared to the other grasses. Marandu and mavuno grasses had higher leaf elongation rates (LElR) when compared to mulato II and ipyporã grasses. The stem elongation rates (SElR) of mavuno and ipyporã grasses were superior to those of marandu and mulato II grasses. Regarding the leaf senescence rate (LSeR), marandu grass had a higher value compared to ipyporã grass, with the other grasses having similar values to the other grasses (Table 2). The tiller population density (TPD) was higher for mulato II grass compared to mavuno grass (Table 2).

Table 2. Morphogenic characteristics of individual tillers and growth and senescence rates of the canopies of marandu, mavuno, ipyporã, and mulato II grasses during the two evaluation years in two distinct periods: beginning and end of stockpiling

Variable	Grass				Year		Stockpiling period	
	Mavuno	Ipyporã	Marandu	Mulato II	2020	2021	Beginning	End
				At individual tiller level				
LApR	0.05a	0.04b	0.04b	0.04b	0.05a	0.04b	0.07a	0.02b
LElR	0.76a	0.39b	0.75a	0.45b	0.70a	0.57b	0.94a	0.23b
SElR	0.19a	0.14a	0.08b	0.07b	0.13	0.11	0.17a	0.06b
LSeR	0.61ab	0.52b	0.70a	0.54ab	0.59	0.59	0.62	0.56
LLS	82.78	99.27	93.06	99.73	96.98	90.43	70.53b	116.88a
				At forage canopy level				
TDP	1337b	1479ab	1414ab	1752a	2150a	841b	1719a	1272b
LGR	81.4a	49.5c	75.3a	62.6b	107.0a	27.4b	115.9a	18.5b
SGR	71.7a	50.1b	37.5bc	29.4c	72.9a	21.4b	82.4a	12.0b
TGR	153.1a	99.6c	112.8b	92.0c	179.9a	48.8b	198.2a	30.5b
LSR	58.5	50.4	57.3	57.5	79.8a	32.0b	71.4a	40.4b

LApR: leaf appearance rate (leaf tiller^{-1}.day^{-1}); LElR: leaf elongation rate (cm tiller^{-1}.day^{-1}); SElR: stem elongation rate (cm tiller^{-1}.day^{-1}); LSeR: leaf senescence rate (cm tiller^{-1}.day^{-1}); LLS: leaf lifespan (day); TPD: tiller population density (tiller m^{-2}); LGR: leaf growth rate (kg ha^{-1} day^{-1} of DM); SGR: stem growth rate (kg ha^{-1} day^{-1} of DM); TGR: total growth rate (kg ha^{-1} day^{-1} of DM); LSR: leaf senescence rate (kg ha^{-1} day^{-1} of DM). Means followed by different letters differ by the Tukey test (P<0.05).

Regarding the characteristics evaluated at the forage canopy level, the leaf growth rate (LGR) was higher in mavuno and marandu grasses, intermediate in mulato II grass, and lower in ipyporã grass. The stem growth rate (SGR) was higher in mavuno grass, intermediate in ipyporã grass, and lower in mulato II grass, with marandu grass showing similar values to ipyporã and mulato II grasses. Finally, the total growth rate (TGR) was higher in mavuno grass, intermediate in marandu grass, and lower in ipyporã and mulato II grasses (Table 2).

The variables SElR, LSeR, and LLS were not influenced by the evaluation year (Table 2). However, LApR, LElR, TPD, LGR, SGR, TGR, and LSR were higher in the first year (2020) compared to the second (2021) (Table 2). When comparing the initial and final periods of stockpiling, only LSeR was not influenced by this factor (Table 2). The LLS showed higher values at the end of stockpiling period, while the other variables showed the opposite response pattern (Table 2). LElR and SElR showed an interaction between stockpiling period and forage grass. LER was higher at the beginning compared to the end of stockpiling regardless of the forage grass. However, only in the initial period did mavuno and marandu grasses show higher values than mulato II and ipyporã grasses (Table 3).

Table 3. Leaf and stem elongation rates at the beginning and end of stockpiling period, in the two evaluation years for Mavuno, Ipyporã, Marandu, and Mulato II grasses.

Variable[1]	Year	Stockpiling period	Grass			
			Mavuno	Ipyporã	Marandu	Mulato II
LElR	-	Beginning	1.19Aa	0.63Ab	1.24Aa	0.71Ab
	-	End	0.33Ba	0.14Ba	0.27Ba	0.19Ba
SElR	-	Beginning	0.29Aa	0.18Ab	0.12Ab	0.09Ab
	-	End	0.08Ba	0.09Aa	0.04Aa	0.04Aa

[1] LER: leaf elongation rate (cm tiller^{-1}.day^{-1}); SER: stem elongation rate (cm tiller^{-1}.day^{-1}). Means followed by different letters, uppercase within the column and lowercase within the rows, differ by the Tukey test (P<0.05).

The SElR during the start of the stockpiling period was superior for Mavuno grass relative to the other grasses, with no difference among the grasses in the final stockpiling period. Only Mavuno grass had a higher SElR at the beginning compared to the end of stockpiling (Table 3). The LSeR and TPD were influenced by the interaction between the evaluation year and stockpiling period. The LSeR was higher at the beginning compared to the end of stockpiling only in the second year (2021). This same response pattern occurred with the TPD in the first evaluation year (Table 4). Furthermore, the TPD was higher in 2020 than in 2021 regardless of the stockpiling period (Table 4).

Table 4. Leaf senescence rate and tiller population density of forage grasses at the beginning and end of the stockpiling period over two experimental years

Variable[1]	Stockpiling period	Year	
		2020	2021
LSeR	Beginning	0.56Aa	0.68Aa
	End	0.62Aa	0.50Ba
TPD	Beginning	2549Aa	890Ab
	End	1751Ba	792Ab

[1]LSeR: leaf senescence rate (cm tiller^{-1}.day^{-1}); TPD: tiller population density (tiller m^{-2}). Means followed by different letters, uppercase within the column and lowercase within the rows, differ by the Tukey test (P<0.05).

4. Discussion

The LApR (Leaf Appearance Rate) was superior in Mavuno grass in relation to the other cultivars (Table 2). This result, associated with the superior LElR (Leaf Elongation Rate) of Mavuno and Marandu grasses at the beginning of the stockpiling period (Table 3), emphasizes the high growth potential of these cultivars during autumn, as LElR is responsible for the formation of the leaf area index [12] and is strongly correlated with the forage production of the canopy. Moreover, the superior SElR (Stem Elongation Rate) at the beginning of stockpiling only for Mavuno grass (Table 3) reinforces the higher growth potential of this grass. Indeed, when evaluated at the forage canopy level, Mavuno grass presented a superior LGR, SGR, and TGR (Table 2).

It should be emphasized that the magnitude of the LGR, SGR, and TGR values (Table 2) may have been overestimated due to the choice of younger tillers for the morphogenic evaluation. It is known that younger tillers have a higher growth rate than older tillers [13]. In this sense, since the estimate of the growth of forage canopies was based on the growth values of individual tillers from the morphogenic evaluation, the LGR, SGR, and TGR values may have been overestimated. As a consequence of the higher LElR, the highest values of SGR occurred in Mavuno and Marandu grasses in 2020 (Table 3). Indeed, the greater cellular elongation in plant organs, especially in the year with a climate more favorable for pasture growth (2020), would have contributed to the increased production of these organs [14]. The high TGR of Mavuno grass may have increased the shading within the canopy. In such conditions, there is a higher SElR in order to expose the younger leaves in the upper part of the canopy, where the brightness is higher. As a result, the highest SGR in Mavuno grass is natural (Table 2). However, the SGR of Ipyporã grass was even higher, above that of Mavuno grass, although Ipyporã grass had a lower LGR (Table 2). This is because during stockpiling, a large proportion of the tillers of Ipyporã grass flowered, as its blooming time (April) coincided with the stockpiling period. During flowering, there is the gradual emission of smaller leaves and there is also greater elongation of the stem to expose the seeds in the upper canopy of the pasture, increasing the probability of their dispersion [15].

The stem is an important structural characteristic of the canopy, as it interferes with the processes of competition for light [16] and the ingestive behavior of grazing animals. In general, larger and more productive plants have heavier and longer stems. In this context, the higher SGR of Mavuno grass is consistent with its high growth potential, characterized by its high values of LApR, LElR, and SElR (Table 2).

The tiller population density (TPD) was 23.4% higher in Mulato II grass than in Mavuno grass, and the Ipyporã and Marandu grasses presented values similar to the other grasses (Table 2). The low TGR of Mulato II grass (Table 2) resulted in a lower height of its stockpiled canopy. As a result, there may have been a higher incidence of light at the base of the plant, stimulating the basal buds to develop into new tillers (17). On the other hand, the higher growth rates of Mavuno grass (Table 2) tended to increase the height and, as a result, the shading within the canopy. Under such conditions, a greater amount of assimilates is allocated for the growth of existing tillers, to the detriment of the development of new tillers in a shading situation. This size/population density compensation mechanism for tillers whereby higher population densities are associated with smaller tillers (16).

The lower LSeR (leaf senescence rate) of Ipyporã grass, when compared to Marandu grass (Table 2), is possibly due to the fact that Ipyporã grass has a thinner stem and narrower leaves (15), which may have minimized the competition for light inside the canopy, enabling older leaves and those with a lower level of insertion in the tiller to receive enough photoassimilates to postpone leaf senescence.

With the exception of leaf lifespan (LLS), all other variables presented higher values at the beginning compared to the end of the stockpiling period. The highest LApR occurred at the beginning of stockpiling, due to the fertilization carried out prior to stockpiling. Fertilization before stockpiling increases the population density (TPD) and the relative participation of young tillers in the canopy, which have a higher LApR compared to old tillers (18). Moreover, at the beginning of stockpiling, the environmental conditions were favorable for the growth of forage plants (Figure 1 and 2). These favorable climatic and management conditions were such that at the beginning of stockpiling there were higher growth rates at the forage canopy level (Table 2). Moreover, at the beginning of the stockpiling period, the canopies may have been constituted by a higher percentage of young tillers, which have a higher growth rate (13,3). The more active growth of the grasses also triggers greater self-shading within the canopies, which explains the higher TSF at the beginning of the stockpiling period (Table 2).

In addition, according to Alves et al. (18) and Brito et al. (3), the LElR responds immediately to changes in temperature within the environment in such a way that the production of tissues follows its seasonal variations. Thus, as the climatic conditions became more limiting from the beginning to the end of the stockpiling period, the LElR (Table 3) and the growth rates evaluated at the forage canopy level (Table 2) declined.

The highest SElR also occurred during the initial period of stockpiling, concomitant with the highest LApR and LElR, due to the better environmental conditions during this period (Figure 1). This same response pattern was found in stockpiled Marandu grass pasture (18). The increase in tiller population density at the beginning of stockpiling can also increase intraspecific competition for light and, as a result, increase stem elongation. Moreover, as a result of the higher SElR, higher SGR values were found at the beginning of the stockpiling period (Table 2).

The highest LLS occurred at the end of stockpiling in response to the intensification of water deficiency at this time of year (Figure 2), which limits the absorption of nutrients by the plant. Under such conditions, the high LLS allows the retention of nutrients in the plant for a longer time, increasing its conservation in a situation of scarce nutritional resources [16]. The high LLS in times of limitation of growth factors, as at the end of the stockpiling period and in 2021 (Figure 1 and 2), explains the lower rates of leaf senescence, both at the tiller level (LSeR), and at the canopy level (LSR), at the end relative to the beginning of the stockpiling period in 2021 (Table 2).

The highest values of leaf appearance rate (LApR), leaf elongation rate (LElR), tiller population density (TPD), and growth rates at the forage canopy level (LGR, SGR, and TGR) occurred in 2020, this being attributed to the more limiting climatic conditions in 2021 compared to 2020 (Figure 3). Indeed, the rainfall from March to June (deferment period) was 45.4% lower in 2021 than in 2020, resulting in lower values of the characteristics related to plant growth. In this context, the water deficit reduces plant growth, as it depends, among other factors, on the physical action of water entering the cells, resulting in the expansion of plant structures [19].

The more favorable climate for plant growth explains the higher TPD in 2020 than in 2021, as well as the higher values of TPD at the beginning compared to the end of the stockpiling period in 2020 (approx. 31.3% higher). However, in 2021, the climatic conditions were more limiting to plant growth from the beginning of stockpiling, which is why there was no difference in TPD between the stockpiling periods (Table 4). The results of this study indicate that Mavuno grass has great potential for forage production during the stockpiling period (autumn). However, its high stem elongation rate may compromise the structure of the stockpiled pasture, with a negative effect on grazing. Therefore, a shortening of the stockpiling period or a reduction in the height of the pasture at the beginning of stockpiling should be carried out to mitigate this stem elongation [20].

Marandu grass was the next most promising hybrid for leaf production during the stockpiling period. In the case of Ipyporã grass, its intense flowering during stockpiling resulted in high stem growth and low leaf growth, making this grass less suitable for use under stockpiling. In general, Mulato II grass is a suitable option for stockpiling, although with a lower growth potential compared to Mavuno and Marandu grasses. The results of this study also demonstrate that the magnitudes of the growth responses of the tillers and forage canopies are strongly dependent on environmental conditions, which can vary between years and also throughout the stockpiling period.

5. Conclusion

The grasses marandu, mavuno, ipyporã, and mulato II show suitability for use in stockpiling, however, when stockpiled, mavuno grass showed a higher tiller and forage canopy growth rate, followed by marandu grass, compared to ipyporã and mulato II grasses. Ipyporã grass showed an apparent limitation for use under stockpiling, as its tillers have higher stem growth and less leaf growth during the stockpiling period compared to the other grasses.

Conflict of interest statement

The authors declare no conflict of interest.

Data availability statement

The data will be provided upon request.

Author contributions

Conceptualization: D. H. A. M. Oliveira. Data curation: B. H. R. Carvalho and G. S. Borges. Formal analysis: B. H. R. Carvalho and G. S. Borges. Methodology: M. E. R. Santos. Investigation: D. H. A. M. Oliveira, G. L. Nascimento and K. U. Machado. Supervision: M. E. R. Santos. Validation: D. H. A. M. Oliveira, G. L. Nascimento and K. U. Machado. Writing (review and editing): D. H. A. M. Oliveira and M. E. R. Santos.

Acknowledgments

To FAPEMIG for research funding (PPM-00519-17).

References

1. Carvalho BHR, Pereira LET, Sbrissia AF, Rocha GO, Santos MER. Height and mowing of pasture at the end of winter modulate the tillering of Marandu palisadegrass in spring. Tropical Grasslands - Forrajes Tropicales., v. 9, n. 1, p. 13-22, 2021a. https://doi.org/10.17138/tgft(9)13-22

2. Santos MER, Moraes FR, Rocha GO, Oliveira DM, Cleef FOSV, Carvalho BHR. How does the condition of the pasture in late winter influence the plant and animal responses in the subsequent seasons? Revista Bioscience, Uberlândia, MG, v. 38, p. e38022, 2022. https://doi.org/10.14393/BJ-v38n0a2022-54042

3. Brito AA, Adorno LC, Novais VS, Borges GS, Borges BG, Gois KB, Santos MER. Morphogenesis of age groups of marandu palisadegrass tillers during the stockpiling period. Acta Scientiarum. Animal Sciences., v. 44, p. e53901, 2022. https://doi.org/10.4025/actascianimsci.v44i1.53901

4. Chapman DF, Lemaire G. Morphogenic and structural determinants of plant regrowth after defoliation. In: Baker MJ (Ed.). Grasslands for our world. Wellington: SIR, 1993. p. 55-64.

5. Luz LA, Rodrigues PHM, Souza WD, Santos MER, Silva SP. Acúmulo de forragem do capim-marandu diferido com alturas variáveis. Enciclopédia Biosfera., v. 11, n. 21, p. 23-35, 2015. https://conhecer.org.br/ojs/index.php/biosfera/article/view/1723

6. Pinheiro SC, Monteiro LS, Carmo MS, Rocha CO, Pereira LET, Herling VR. Características morfogênicas de pastos de capim-marandu submetidos à alturas de diferimento. Brazilian Journal of Animal and Environmental Research, v. 2, n. 5, p. 1667-1684, 2019. https://ojs.brazilianjournals.com.br/ojs/index.php/BJAER/article/view/3957

7. Alvares CA, Stape JL, Sentelhas PC, Gonçalves JLM, Saparovek G. Köppen's climate classification map for Brazil. Meteorologische Zeitschrift., v. 22, n. 6, p. 711-728, 2013. https://doi.org/10.1127/0941-2948/2013/0507

8. Thornthwaite CW, Mather JR (Ed). The water balance. Centerton - NJ: Drexel Institute of Technology – Laboratory of climatology, 1955. 104p. (Publications in Climatology, v. VIII, n.1)

9. EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA. Sistema brasileiro de classificação de solos. 5.ed. Brasília-DF: Embrapa Solos, 2018, 356p.

10. Cantarutti RB, Martins CE, Carvalho MM. Pastagens. In: Ribeiro AC, Guimarães PTG. Alvarez VVH (Ed). Comissão de Fertilidade do Solo do Estado de Minas Gerais Recomendação para o uso de corretivos e fertilizantes em Minas Gerais. Brasil: Viçosa – 5ª Aproximação. 1999. p. 332-341.

11. Santos MER, Fonseca DM, Gomes VM, Gomide CAM, Junior DN, Queiroz DS. Capim-braquiária sob lotação contínua e com altura única ou variável durante as estações do ano: Dinâmica do perfilhamento. Revista Brasileira de Zootecnia/Brazilian Journal of Animal Science, v. 40, n. 11, p. 2332-2339, 2011. https://doi.org/10.1590/S1516-35982011001100007

12. Gomide CAM, Gomide JA. Morfogênese de cultivares de Panicum maximum. Rev. Bras. de Zootec./Braz. Jour. of Ani. Scie., v. 29, n. 2, p. 341-348, 2000. https://doi.org/10.1590/S1516-35982000000200004

13. Paiva AJ, Da Silva SC, Pereira LET, Caminha FO, Pereira PM, Guarda VDA. Morphogenesis on age categories of tillers in marandu palisadegrass. Scientia Agrícola., v. 68, n. 6, p. 626-631, 2011. https://doi.org/10.1590/S0103-90162011000600003

14. Santos MER, Fonseca DM, Gomes VM, Silva SP, Silva GP, Castro MRS. Correlações entre características morfogênicas e estruturais em pastos de capim-braquiária. Ciênc. Anim. Bras., v.13, n. 1, p. 49-56, 2012. https://doi.org/10.5216/cab.v13i1.13041

15. Barrios SCL, Carromeu C, Silva MAI, Matsubara ET, Valle CB, Jank L, Santos MF, Assis GML, Crivellaro LL, Goncalves TDT, Junior JMQ, Candido AR, Machado WKR, Gouveia BT, Nobre AAA, Zanella AL. Pasto Certo version 2.0 – An application about Brazilian tropical forage cultivars for mobile and desktop devices. Tropical Grassland – Forrajes Tropicalles., v. 8, n. 2, p. 162-166, 2020. http://dx.doi.org/10.17138/TGFT(8)162-166

16. Sbrissia AF, Da Silva SC. Compensação tamanho: Densidade populacional de perfis em pastos de capim-marandu. Revista Brasileira de Zootecnia, v. 37, n.1, p. 35–47, Jan. 2008. https://doi.org/10.1590/S1516-35982008000100005

17. Carvalho BHR, Martuscello JA, Rocha GO, Silva NAM, Borges GS, Santos MER. Tillering dynamics in spring and summer of marandu palisade grass pastures previously used under deferred grazing. Arq. Bras. de Med.Veter. e Zootec., v. 73, n. 6, p. 1422-1430, 2021b. https://doi.org/10.1590/1678-4162-12333

18. 18. Alves LC, Santos MER, Pereira LET, Carvalho AN, Rocha GO, Carvalho BHR, Vasconcelos KA, Ávila AB. Morphogenesis of age groups of Marandu palisade grass tillers deferred and fertilised with nitrogen. Semina. Ciências Agrárias., v. 40, n. 6, p. 2683-2692, 2019. https://doi.org/10.5433/16790359.2019v40n6p2683

19. 19. Haberman E, Oliveira EAD, Contin DR, Delvecchio G, Viciedo DO, Moraes MA, Prado RM, Costa KAP, Braga MR, Martinez CA. Warming and water deficit impact leaf photosynthesis and decrease forage quality and digestibility of a C4 tropical grass. Physiologia Plantarum. v. 165, n. 2, p. 383–402, 2019. https://doi.org/10.1111/ppl.12891

20. 20. Santos MER, Rocha GO, Carvalho BHR, Borges GS, Adorno LC, Oliveira DM. Does the lowering strategy before the stockpiling period modify the marandu palisade grass production and structure? Arquivo Brasileiro Medicina Veterinária e Zootecnia, Botucatu-SP, v. 73, n. 6, p. 1403-1412, 2021. https://doi.org/10.1590/1678-4162-12330