









Structural characteristics and forage biomass accumulation of dwarf elephant grass genotypes at two stubble heights

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ABSTRACT - The objective was to evaluate the structural traits and forage accumulation of elephant grass genotypes under two stubble heights. The experiment was conducted in a factorial scheme, with five genotypes (P 2022 S1, 1810, 2111, 2035 and BRS Kurumi) and two stubble heights (25 and 45 cm), in a randomized block design, with three replications, considering the rainy and dry periods. Forage accumulation of the rainy period was higher for genotype 2111 ($P < 0.05$) compared to P 2022 S1 and BRS Kurumi. The 1810 and 2035 genotypes showed forage accumulation similar to 2111. In the dry period, forage accumulation values were approximately 35% of those observed in the rainy period, with the BRS Kurumi and P 2022 S1 genotypes presenting lower values ($P < 0.05$) compared to the others. The stubble height of 25 cm resulted in lower canopies (82 cm) than that at 45 cm (96 cm). The genotypes P 2022 S1 and 2111 had a higher percentage of leaves and a lower percentage of stem at the stubble height of 45 cm. The genotypes 2111 and 1810 were superior to BRS Kurumi for the percentage of leaf blade and stem at the defoliation height of 45 cm. In the dry season, the genotype 2111 showed the highest leaf-stem ratio. The genotypes 1810, 2111, 2035 and BRS Kurumi showed the highest leaf and lowest stem percentage. The defoliation height of 45 cm resulted in higher forage density. The genotypes 2035, 2111 and 1810 stood out for the high forage accumulation and leaf percentage at both stubble heights during the rainy season. Management with a defoliation height of 45 cm increases the leaf blade percentage and the leaf-stem ratio and reduces the proportion of stem in the forage harvested above the residue.

Keywords: canopy height, forage density, leaf blade percentage, leaf-stem ratio

1. Introduction

Cenchrus purpureus (Schumach.) Morrone (*Pennisetum purpureum* Schumach.), commonly known as elephant grass, stands out as a forage grass due to its high biomass accumulation, nutritional quality, and good acceptance by animals (Silva et al., 2021). Despite the strong incentive to use this species for

grazing cattle, its adoption has been limited by management difficulties associated with its tall size and rapid stem elongation, which impact the canopy structure (Carnevali et al., 2021) and reduce the grazing efficiency, requiring frequent mowing (Gomide and Gomide, 2013). Consequently, these factors increase field labor requirements and production costs, which is why most milk production systems based on elephant grass pastures in Brazil have not persisted over the years (Pereira et al., 2021).

The launch of the BRS Kurumi cultivar in 2012 has contributed to reversing these difficulties, due to its ease of management under grazing because of the short internode that results in a low canopy height (Pereira et al., 2021). In 2022, the total area planted with BRS Kurumi in Brazil was estimated at 10,900 ha (Embrapa, 2023), mainly benefiting small and medium-sized farms.

Another factor that makes it difficult to use elephant grass for grazing in large areas is the propagation mechanism. Currently, there are no seed-propagated cultivars on the market, which increases implementation costs (Anandhinatchiar et al., 2020; Camelo et al., 2021). There are still a few dwarf cultivars, but all are vegetatively propagated, making it crucial to evaluate new genotypes to identify more productive plants with better nutritional value and tolerance to environmental stresses (Pereira et al., 2021).

The elephant grass breeding program continues to select promising genotypes for grazing. The genotypes selected for this study showed, during the initial phases of the breeding program, greater forage production potential than BRS Kurumi (1810, 2111, and 2035) or seed propagation mode (P 2022 S1). However, these genotypes, despite being dwarf cultivars, exhibit morphological variations.

The evaluation of structural characteristics is essential to understand the dynamics of plant growth in response to growth factors and/or defoliation intensity (Chapman and Lemaire, 1993). Based on this knowledge, it is possible to establish management goals that allow the use of genetic potential and provide forage in the quantity and quality needed for use in grazing. Although growth dynamics are genetically controlled, factors such as defoliation height can interfere with the structure of the forage canopy (Gomide and Gomide, 2013; Carnevali et al., 2021).

The critical leaf area index, corresponding to the interception of 95% of incident radiation by the canopy (Parsons et al., 1983), is used to define the ideal moment to stop regrowth, thus optimizing sunlight capture and photosynthesis while avoiding the accumulation of dead stems and leaves. (Gurgel et al., 2021; Martins et al., 2021). The time to stop grazing has been less studied and may vary depending on the species or even the cultivar, in addition to being associated with the residual leaf area after defoliation.

The residual leaf area index, and its relationships with regrowth and productive capacity, may vary depending on the defoliation height, which may promote an increase or reduction in stem elongation and leaf senescence and may influence the persistence of the genotype in situations where defoliation intensity is excessive (Lee et al., 2008; Martins et al., 2021; Rosa et al., 2023).

The objective of this study was to evaluate the effect of two stubble heights under the structural characteristics and the forage accumulation of genotypes of dwarf elephant grass selected by the breeding program based on their forage production potential (1810, 2035 and 2111) and/or seed propagation mode (P 2022 S1).

2. Material and methods

2.1. Experimental site

The experiment was conducted at the José Henrique Bruschi Experimental Field, of Embrapa Gado de Leite, located in Coronel Pacheco, MG, Brazil (21°33'22" S, 43°06'14" W, 410 m altitude). The experimental period was from November 2021 to September 2023. The monthly data on accumulated precipitation and monthly maximum, average, and minimum temperatures during the experimental period are shown in Figure 1.

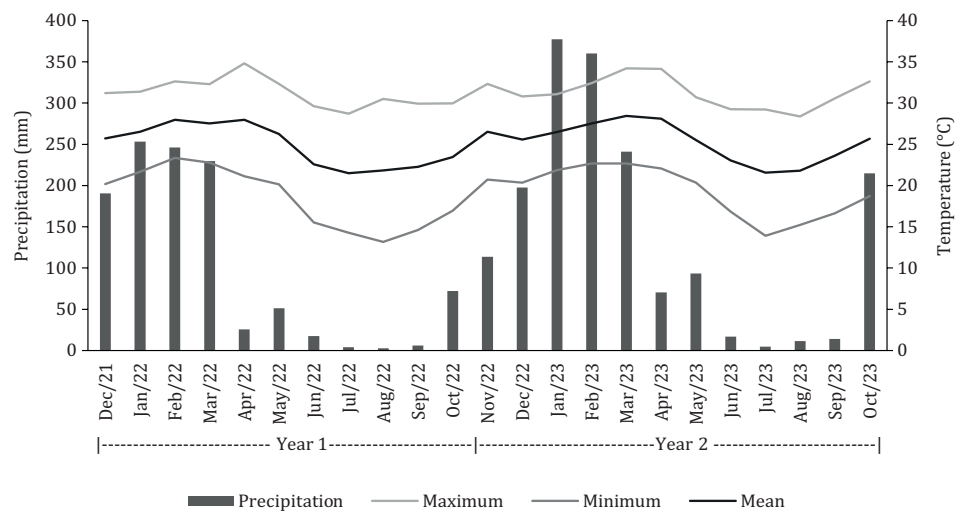


Figure 1 - Monthly accumulated precipitation (columns) and average, maximum and minimum monthly temperature (lines) from December 2021 to October 2023.

The soil of the experimental area is classified as Ferralsol (IUSS Working Group WRB, 2015) and had the following characteristics in the 0–20 cm layer: pH in water, 6.0; organic matter, 2.47 dag kg⁻¹; P (Mehlich-1), 7.1 mg dm⁻³; K, 41 mg dm⁻³; Ca, 2.42 cmol dm⁻³; Mg, 0.80 cmol dm⁻³; H+Al, 1.32 cmol dm⁻³; sum of bases, 3.32 cmol dm⁻³; effective cation exchange capacity, 3.32 cmol dm⁻³; total cation exchange capacity, 4.64 cmol dm⁻³; and base saturation, 71.6%.

To establish elephant grass plants in the plots (4 × 3 m), seedlings produced in 44 cm³ tubes were transplanted. The seedlings of the vegetative propagation genotypes were made from buds taken from each of the genotypes (clones). On September 22, 2021, was planted in each tube one stem bud and kept in an agricultural greenhouse. For the P 2022 S1 genotype, 4 seeds were sown per tube on September 6, 2021. After 7 days of sowing thinning was executed leaving only one seedling per tube. On November 24, 2021, transplantation was carried out for the experimental plots. Planting was conducted observing 50 cm between rows and between seedlings.

Planting and establishment fertilization was carried out as recommended for the BRS Kurumi cultivar (Gomide et al., 2015). Thus, the equivalent of 100 kg of P2O5/ha was placed in the planting furrow and, 40 days after planting, the equivalent of 40 kg ha⁻¹ of N and K2O was applied using the 20-00-20 (N-P-K) formulation as top dressing. Sixty days after transplantation, the standardization cut was carried out and the cuts for evaluation of the forages began on February 14, 2022.

2.2. Experimental design

Four genotypes from Embrapa's elephant grass breeding program and the BRS Kurumi cultivar (control) were evaluated. The genotypes were selected based on evaluations conducted in small plots (5 m²) under standardized cutting. When the plants reached an average height of 70–80 cm, an evaluation cut was performed (data not shown), leaving a 30-40 cm residue. Forage production, nutritional value, phenotypic vigor, tillering, leaf volumetric density, and pest and disease attack were evaluated. The best genotypes were selected for further evaluation in plots simulating management variations. Three genotypes were vegetatively propagated clones (1810, 2035, and 2111) and one genotype propagated by seeds (P 2022 S1).

Each genotype was cut to two stubble heights (25 and 45 cm) in a 5 × 2 factorial scheme in a randomized block design, with three replications per treatment, for two experimental years. The genotypes were evaluated during two rainy periods (February to April 2022 and November 2022 to April 2023) and two dry periods (May to October 2022 and May to September 2023).

During the rainy season, the cutting frequency was defined based on the achievement of 92–95% interception of photosynthetically active radiation (LI) by the canopy. This LI interval was chosen due to the rapid increase in LI as the critical leaf area index (LAI) for 95% LI was approached (Gomide and Gomide, 2013). Thus, we sought to prevent some plots from exceeding the recommended limit, which could cause the accumulation of stems and dead leaves (Carnevali et al., 2021). Such a condition could hide the effects of the stubble heights studied. During the dry season, due to the very long period to reach the LI, harvests were carried out at fixed intervals of 45 days. Forage samples were collected within 1.0 × 0.5 m frames positioned transversely to the planting rows. After harvest, the remainder of the plot was lowered to the respective predetermined heights with a backpack mower. During the rainy season, topdressing after each harvest was carried out with the equivalent of 50 kg ha⁻¹ of N and 50 kg ha⁻¹ of K₂O, using the 20-05-20 (N-P-K) formulation. The last topdressing was carried out in March of each year, taking advantage of the end of the rainy season.

LI monitoring in the canopy was performed weekly with an AccuPar Linear PAR/LAI ceptometer (METER Group, Inc., Pullman, WA, USA) at four points per experimental unit. The mean LI value of three replicates was used to determine the time of cutting in each treatment. Thus, the cutting interval varied among treatments according to the time required to reach 92–95% LI.

2.3. Variables evaluated

Canopy height was measured with a graduated ruler at the time of forage harvest, at five points per experimental unit. The cutting dates were recorded to calculate the period between harvests.

At the time of cutting, samples collected above the stubble height were taken to the forage laboratory and weighed. A subsample of approximately 400–500 g was separated to examine the morphological components. The samples were separated into leaf blade, stem, and senescent/dead forage fractions, which were weighed, identified, stored in paper bags and dried in an oven with forced air circulation at a temperature of 55 °C for 72 h (Detmann et al., 2012). They were reweighed after drying on a precision scale to determine the dry mass of each fraction and the proportions of each component and the leaf/stem ratios (LSR) were calculated. Forage volumetric density was estimated by dividing the total dry green forage biomass per ha, harvested above the stubble height, by the average canopy height minus the stubble height. Forage accumulation was calculated by the sum of the forage masses harvested above the stubble height for the rainy and dry periods of the year.

On at least two harvest dates during the rainy season, the number of tillers was estimated. For this three clumps representative of the average condition of the plot were chosen and the number of basal and aerial tillers per clump were counted seven days after harvesting and lowering of each plot. The total number of tillers was calculated by multiplying the number of tillers per clump by the number of clumps per plot. The density of tillers per m² was calculated by dividing the total number of tillers in the plot by the size of the plot area (12 m²).

2.4. Statistical analysis

The parameters for each variable within each treatment were averaged. The data were analyzed separately for the rainy and dry periods by using the SAEG-UFV software (2007). The sources of variation were genotype, stubble height, and year. The interactions of these factors were modeled by the following equation:

$$Y_{ijk} = \mu + \lambda_i + \alpha_j + \beta_k + (\alpha\beta)_{ij} + (\lambda\beta)_{ik} + (\lambda\alpha)_{ki} + (\lambda\alpha\beta)_{ijk} + (\omega_n/\lambda_i) + e_{ijk}$$

in which Y_{ijk} is the observed value corresponding to the k -th ijk repetition of the combination of the i -th genotype with the j -th stubble height, μ is the mean of all experimental units for the variable under study, λ_i is the effect of the i -th year on the observed value Y_{ijk} , α_j is the effect of the j -th genotype on the observed value Y_{ijk} , β_k is the effect of the k -th stubble height on the observed value Y_{ijk} , $(\alpha\beta)_{ij}$ is the effect of the interaction of the j -th genotype with the k -th stubble height, $(\lambda\beta)_{ik}$ is the effect of the interaction

of the i -th year with the k -th stubble height, $(\lambda\alpha)_{ij}$ is the effect of the interaction of the i -th year with the j -th genotype, $(\lambda\alpha\beta)_{ijk}$ is the effect of the interaction of the i -th year with the j -th genotype, with the k -th stubble height, ω_n is the effect of the n -th block on the observation Y_{ijk} , and e_{ijk} is the error associated with the observation.

The treatment means were compared, when appropriate, using Tukey's test at a 5% probability of error. The F-test was used to compare stubble heights.

3. Results

3.1. Rainy period

The genotypes 1810, 2035, 2011, and BRS Kurumi had a shorter average interval between cuts (24 days) and a higher number of harvests (seven), compared to P 2022 S1, which had a cut interval of 29 days and six harvests during the rainy period. Stubble height did not influence the interval between cuts and the number of harvests.

Forage biomass accumulation was influenced only by genotype (Table 1). Greater accumulation was observed for genotype 2111 than for P 2022 S1 and BRS Kurumi but did not differ from that for 1810 and 2035.

Table 1 - Forage accumulation (kg ha^{-1}) of elephant grass genotypes, in the rainy and dry period

Genotype	Rainy period	Dry period
1810	14,009ab	5,468a
P 2022 S1	12,134b	3,569b
2035	13,171ab	5,281a
2111	14,740a	5,611a
BRS Kurumi	12,659b	3,558b
SEM	975.8	217.1
CV (%)	12.6	21.9

Means followed by the same letter did not differ statistically by Tukey's test at 5% probability.

There was no effect of interaction among the studied factors ($P > 0.05$) on canopy height. However, there was a genotype effect ($P = 0.049$), with a higher canopy height for genotype 2111 (Table 2). There was also an effect of stubble height ($P < 0.001$) on the canopy height at the end of regrowth, with a higher value for plants cut at 45 cm. The year also influenced the canopy height, with a higher value in year 1.

The basal tillering was not influenced by any factor ($P > 0.05$). However, aerial tillering was influenced by genotype ($P < 0.001$) and year ($P < 0.001$; Table 2). BRS Kurumi had significantly greater aerial tillering. Greater aerial tillering occurred in the second year compared to the first year. Stubble height did not influence aerial tillering, with an average of 106 tillers m^{-2} .

The number of total tillers was influenced by the interaction genotype \times stubble height ($P < 0.001$) and by year ($P < 0.001$; Figure 2). The BRS Kurumi had significantly more tillers, at both stubble heights, than the other genotypes. The year also influenced the total tiller population, with more tillering in the second year (92 vs 118 tillers m^{-2}).

The percentage of dead biomass was not influenced by stubble height, genotype, or year ($P > 0.05$), with an average percentage of only 0.01%. However, an effect of the genotype \times stubble height interaction was observed for leaf blade percentage ($P = 0.004$) and stem percentage ($P = 0.002$; Table 3).

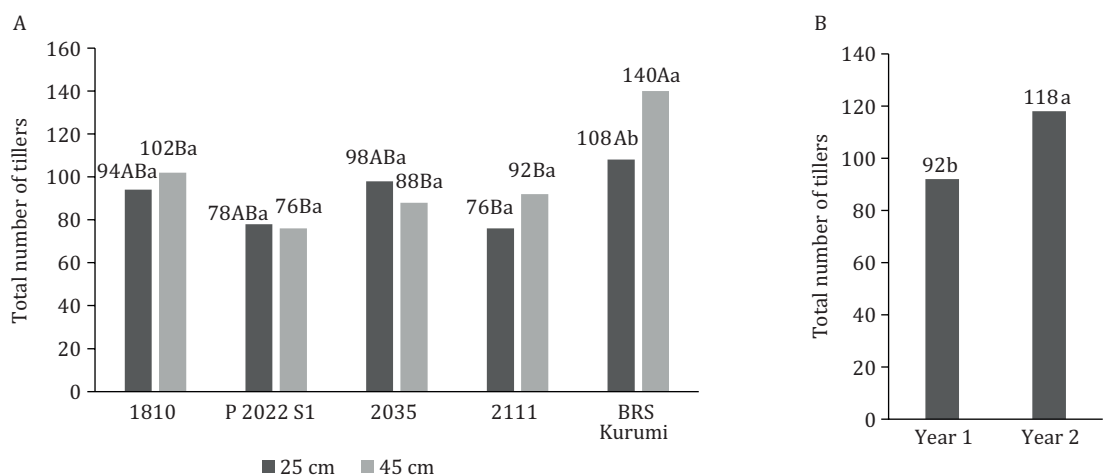
The leaf blade percentage varied among genotypes according to stubble height. The 25 cm stubble height resulted in a higher proportion of leaf blades for the genotypes 1810, 2035, and 2111 than for P 2022 S1. However, with a 45 cm stubble height, BRS Kurumi had a lower leaf blade percentage compared to all other genotypes.

The stem percentage was higher at a stubble height of 25 cm compared to 45 cm for genotype 2111 only (Table 3). Genotypes 2035, 1810, and 2111 cut at 25 cm had lower stem percentages in the harvested forage, whereas at 45 cm, the lowest stem percentages were observed for genotypes 2111 and P 2022 S1.

Table 2 - Mean values of canopy height and number of basal and aerial tillers per m² according to elephant grass genotypes, stubble height or year in the rainy season

	Height (cm)	Basal tiller	Aerial tiller
Genotype			
1810	88b	20	80b
P 2022 S1	88b	28	66b
2035	89b	28	80b
2111	95a	22	66b
BRS Kurumi	87b	18	120a
Stubble height			
25 cm	83b	24	104
45 cm	96a	22	108
Year			
Year 1	92a	22	94b
Year 2	87b	24	118a
SEM	1.31	1.34	3.95
CV (%)	7.78	44.7	21.9

Means followed by the same letter within the column did not differ statistically by Tukey's test at 5% probability.



Means followed by the same letter, uppercase in the comparison between genotypes, and lowercase in the comparison between defoliation heights or year, did not differ statistically by Tukey's test at 5% probability.

Figure 2 - Mean values of the number of total tillers m⁻² during the rainy season according to elephant grass genotypes at different stubble heights (A) and evaluation year (B) (CV 17.1% and SEM 1.94).

Table 3 - Mean values of leaf blade and stem percentage of harvested forage of elephant grass genotypes in the rainy period

Genotype	Stubble height			
	25 cm		45 cm	
	--- % Leaf blade ---		--- % Stem---	
1810	85ABa	88Aa	14BCa	11Ba
P 2022 S1	80Cb	88Aa	18Aa	12Bb
2035	88Aa	85ABa	11Ca	13ABa
2111	84ABCb	88Aa	15ABCa	11Bb
BRS Kurumi	81BCa	83Ba	17Aba	17Aa
SEM	0.0054		0.0051	
CV (%)	2.87		16.4	

Means followed by the same uppercase letter, within the column, and lowercase within the row, did not differ statistically by Tukey's test at 5% probability.

Leaf blade percentage ($P = 0.004$), stem percentage ($P = 0.003$), and the LSR ($P = 0.008$) were influenced by the genotype \times year interaction (Table 4). The genotypes 1810, P 2022 S1, 2035, and 2111 had higher leaf blade percentages than BRS Kurumi in the first year, but there were no differences among the genotypes in the second year. Comparing the years within each genotype, BRS Kurumi and P 2022 S1 had the lowest leaf blade percentages in the first year.

In the first year, genotypes 1810, 2111, 2035, and P 2022 S1, 2035 had lower stem percentages compared to BRS Kurumi. In the second year, only genotype 2035 had a lower stem percentage than BRS Kurumi.

There were no significant differences in LSR among genotypes in the first year. In the second year, genotype 2035 had the highest LSR. The year effect occurred only for the genotypes P 2022 S1 and 2035, which had the highest LSR in the second year.

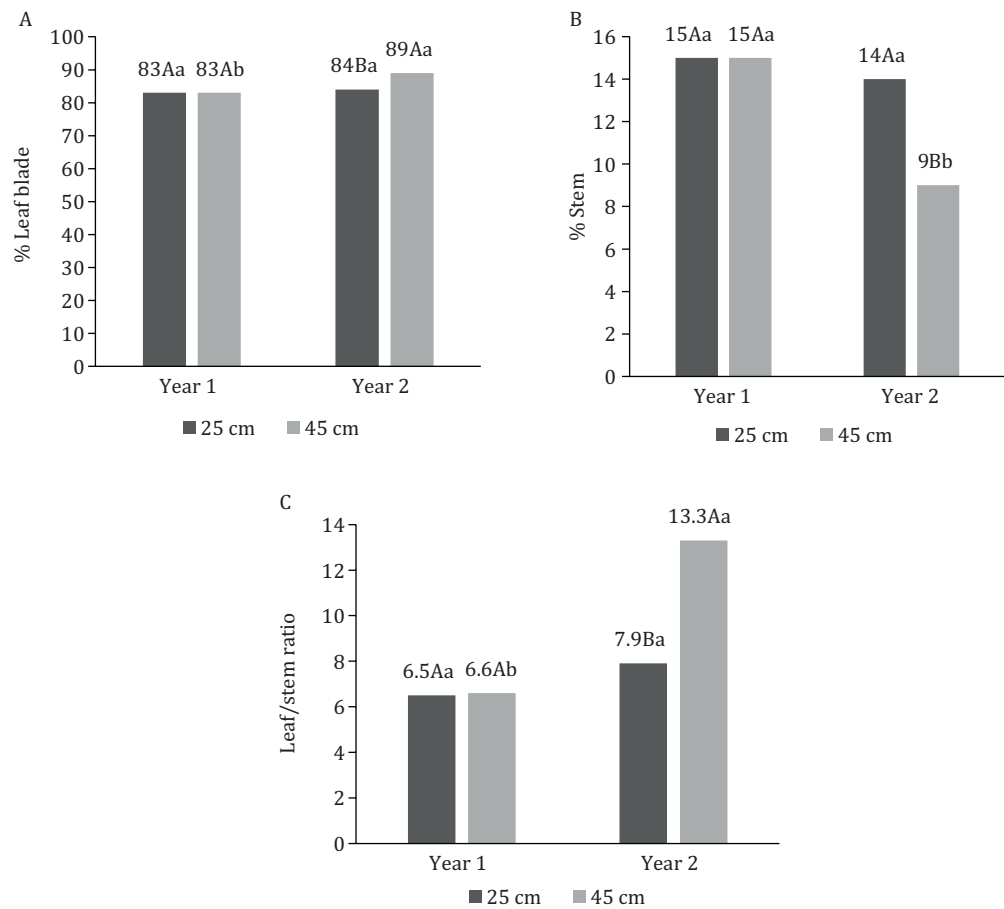
Leaf blade percentage ($P = 0.002$), stem percentage ($P = 0.001$), and the LSR ($P = 0.003$) were also significantly influenced by the interaction of stubble height \times year (Figure 3). No difference was observed between years when the plants were cut at 25 cm. When cut at 45 cm, leaf blade percentage was higher in the second year. When cut at 45 cm, stem percentages were lower in the second year. In the first year, there was no difference in the LSR in response to cuts at both levels. In the second year, the LSR was higher with a stubble height of 45 cm than at 25 cm.

Higher forage volumetric density was observed for the P 2022 S1 genotype ($P = 0.001$; Figure 4). There was also an effect by the stubble height \times year interaction ($P = 0.027$). Higher volumetric density was observed with stubble height at 45 cm in both years. A significant difference between years was observed only for the 45-cm stubble height, with dry matter reduced from 59 to 49 kg cm⁻¹ ha⁻¹ between the first and second year, respectively.

Table 4 - Mean values of leaf and stem percentage and leaf/stem ratio (LSR) in the rainy period of elephant grass genotypes according to genotype \times year interaction

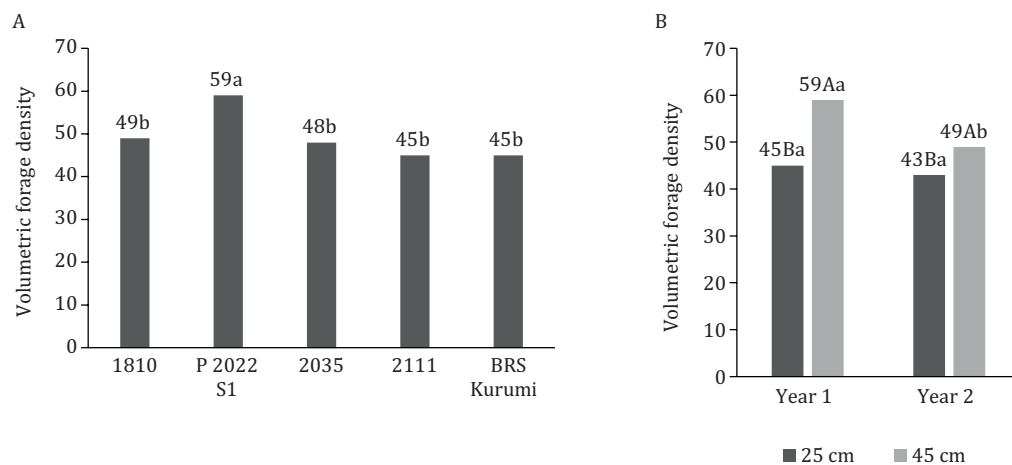
Genotype	Year 1		Year 2		Year 1		Year 2	
	--- % Leaf blade ---		--- % Stem---		--- LSR ---			
1810	84Aa	86Aa	13Ba	12ABa	8.7Aa	9.2Ba		
P 2022 S1	82ABa	84Aa	16Ba	14Aa	4.7Ab	10.4Ba		
2035	83Ab	89Aa	14Ba	9Bb	6.3Ab	16.1Aa		
2111	88Aa	84Aa	13Ba	12ABa	7.6Aa	9.1Ba		
BRS Kurumi	79Bb	86Aa	20Aa	13Ab	4.4Aa	8.1Ba		
SEM	0.0054		0.0051		0.5968			
CV (%)	2.87		16.4		36.4			

Means followed by the same uppercase letter within the column, and lowercase within the row, did not differ statistically by Tukey's test at 5% probability.



Means followed by the same letter, uppercase in the comparison between defoliation height, and lowercase in the comparison between year, did not differ statistically by Tukey's test at 5% probability.

Figure 3 - Mean values of the variables % leaf blade (A), % stem (B) and leaf/stem ratio (LSR) (C) of elephant grass genotypes during the rainy season submitted to two stubble heights in the two years of evaluation.



Means followed by the same letter, uppercase in the comparison between defoliation height, and lowercase in the comparison between year or genotype, did not differ statistically by Tukey's test at 5% probability.

Figure 4 - Mean values of volumetric forage density (kg ha⁻¹ cm⁻¹) during the rainy season according to elephant grass genotypes (A) and to the stubble heights and year interaction (B) (CV 21.2% and SEM 1.04).

3.2. Dry period

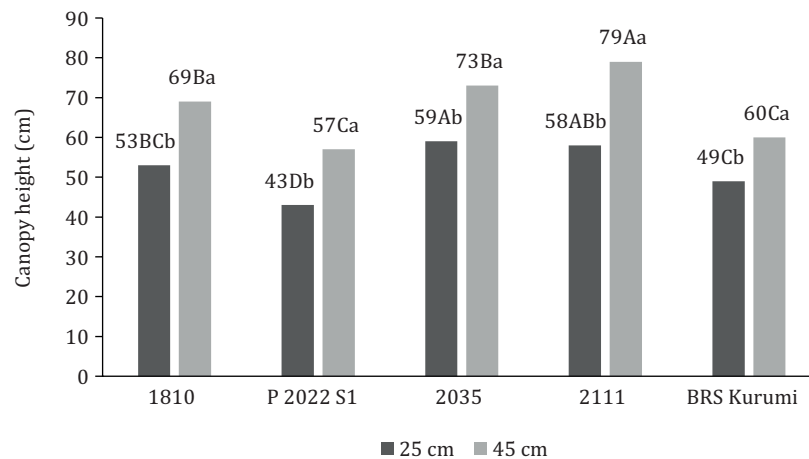
As observed in the rainy period, greater forage biomass accumulation ($P < 0.05$) in the dry period was observed for genotype 2111 compared to genotypes P 2022 S1 and BRS Kurumi. Genotypes 1810 and 20235 did not differ significantly from the other genotypes (Table 1).

There was an effect of the genotype \times stubble height interaction on canopy height ($P < 0.001$; Figure 5). Genotypes 2035 and 2111 had the highest canopy heights, at a stubble height of 25 cm, and genotype 2111 had the highest canopy height, at a stubble height of 45 cm. For all genotypes, higher stubble height resulted in higher canopy height.

There was no effect of year nor its interaction with other factors ($P > 0.05$) on canopy height.

There was no effect of stubble height ($P > 0.05$) nor its interaction with other factors ($P > 0.05$) on leaf blade and stem percentages, which averaged were 84% and 12%, respectively. The average percentage of dead biomass was 0.04% and was not influenced by any factor studied ($P > 0.05$).

An interaction effect between genotype \times year was observed on leaf blade and stem percentages ($P = 0.001$; Table 5). Genotypes 1810, 2035, 2111, and BRS Kurumi had the highest leaf blade



Means followed by the same letter, uppercase in the comparison between genotypes, and lowercase in the comparison between defoliation heights, did not differ statistically by Tukey's test at 5% probability.

Figure 5 - Mean values of canopy height of elephant grass genotypes in response to two stubble heights during the dry season (CV 18.8% and SEM 2.40).

Table 5 - Mean values of leaf blade and stem percentage in the dry period of elephant grass genotypes according to the evaluation year

Genotype	Year 1		Year 2	
	--- % Leaf blade ---		--- % Stem ---	
1810	90Aa	80Bb	6Bb	17Ba
P 2022 S1	80Ba	55Cb	16Ab	36Aa
2035	92Aa	89Aa	5Ba	7Ca
2111	92Aa	88Ab	5Bb	10Ca
BRS Kurumi	90Aa	85ABb	5Bb	11BCa
SEM	0.0127		0.0125	
CV (%)	4.4		31.4	

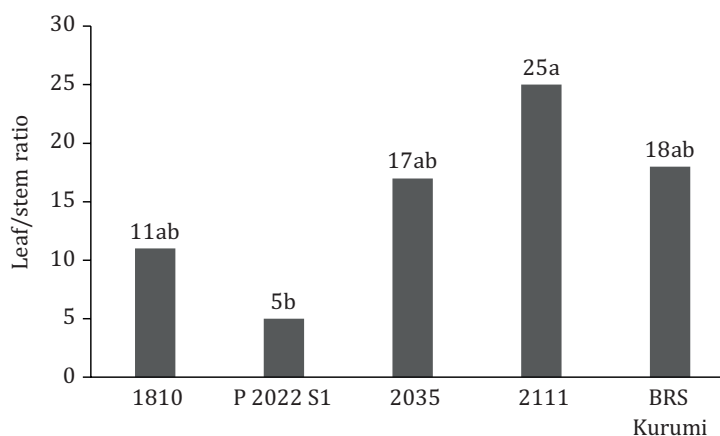
Means followed by the same uppercase letter within the column, and lowercase within the row, did not differ statistically by Tukey's test at 5% probability.

percentages in the first year. In the second year, genotypes 2035, 2111, and BRS Kurumi had higher leaf blade percentage compared to the other genotypes. Leaf blade percentages decreased in the second year for all genotypes except for 2035.

Genotype P 2022 had a higher stem percentage than the other genotypes in both years. The stem percentages of all genotypes except 2035 increased in the second year.

The LSR was influenced by genotype ($P = 0.034$) and year ($P < 0.001$). Genotype 2111 had a significantly higher LSR than P 2022, whereas BRS Kurumi, 2035, and 1810 were intermediate (Figure 6). A higher LSR was observed in the first year (LSR = 23) than in the second year (LSR = 8). There was no effect of stubble height nor its interaction with other factors ($P > 0.05$) on LSR, which averaged 14.

Volumetric forage density was significantly affected by the interactions of genotype \times stubble height ($P < 0.001$) and genotype \times year ($P = 0.001$; Table 6). BRS Kurumi had higher forage volumetric density at both stubble heights in both years. For all genotypes, the 45-cm stubble height provided higher volumetric forage density. In the first year, 1810 and P 2022 S1 had volumetric forage densities similar to that of BRS Kurumi. In the second year, the volumetric forage densities of P 2022 S1, 2035, and BRS Kurumi increased.



Means followed by the same letter did not differ statistically by Tukey's test at 5% probability.

Figure 6 - Mean values of the leaf/stem ratio of elephant grass genotypes during the dry season.

Table 6 - Volumetric forage density of elephant grass genotypes in the dry period in response to stubble heights and years

Genotype	Stubble height		Year	
	25 cm	45 cm	Year 1	Year 2
	--- Density (kg cm ⁻¹) ---			
1810	36ABb	44Ca	48Aa	43Ca
P 2022 S1	42Ab	73Ba	44Aa	60Ba
2035	34ABb	43Da	34Bb	43Ca
2111	30Bb	40Da	34Ba	34Ca
BRS Kurumi	42Ab	83Aa	43Ab	71Aa
SEM	1.1055			
CV (%)	38.1			

Means followed by the same uppercase letter within the column, and lowercase within the row, did not differ statistically by Tukey's test at 5% probability.

4. Discussion

4.1. Rainy period

The intensity and frequency of defoliation can influence grass growth rate, canopy structure, and tiller production and size and may interfere with the harvest interval and overall productivity (Venter et al., 2021). In this sense, it was expected that with a lower stubble height there would be faster achievement of the 95% LI, with a shorter interval between cuts. However, factors such as number, size, and weight of tillers, leaf angle, and canopy extinction coefficient affect the LI capacity. Mello and Pedreira (2004) studied the morphological response of Tanzania grass (*Megathyrus maximus* (Jacq.) B.K.Simon & S.W.L.Jacobs) to three defoliation intensities represented by residual masses of 1,000, 2,500, and 4,000 kg of dry matter ha⁻¹. Light interception of 95% was achieved about the 22nd day of regrowth, regardless of the residual mass, but with leaf area indices of 3.6, 4.0, and 4.6, respectively. According to the Mello and Pedreira (2004), the increase in grazing intensity resulted in canopies with more horizontal leaves, allowing the interception of more light per leaf area unit.

In our study, the average interval between harvests in the rainy period was shorter and more cuts were made with genotypes 1810, 2035, 2111, and BRS Kurumi (24 days between harvests and seven cuts) compared to P 2022 S1 (29 days between harvests and six cuts).

These results are similar to those of Chaves et al. (2013) who evaluated the dry matter production of elephant grass genotypes managed under intermittent stocking and observed six grazing cycles from December to April and an average of 24 days of rest, for BRS Kurumi. The longer interval between harvests of P 2022 S1, i.e., a longer period to reach 92–95% LI, and the lower number of harvests within the rainy period are associated with a slower regrowth capacity of this genotype after defoliation compared to the other genotypes.

The lower forage biomass accumulation of P 2022 S1 compared to 2111 is linked to the lower number of harvests performed in the rainy period (four vs six harvests). Although forage biomass per cut is highly correlated with longer intervals between cuts, with a strong contribution from stems in cespitose grasses (Gomide and Gomide, 2013), forage biomass accumulation within the growing season tends to be greater with cuts at shorter intervals. The sigmoidal response of the forage biomass accumulation curve (Parsons et al., 1983) as a function of regrowth time explains this phenomenon. Thus, harvests performed close to the maximal mean growth rate (Parsons and Penning, 1988) enhance forage biomass accumulation throughout the growing season.

The average canopy lowering percentages were 50% and 70% at stubble heights of 45 and 25 cm, respectively. Previous studies have shown a defoliation intensity of 50% as ideal (Costa et al., 2020; Rosa et al., 2023), allowing grazing animals to consume high quality forage with a predominance of leaves and adequate canopy regeneration. However, defoliation intensity may vary depending on the morphological and structural characteristics of each genotype (Schmitt et al., 2019; Martins et al., 2021), and higher intensities can be used to reduce stem elongation in upright or cespitose grasses (Gomide and Gomide, 2013; Carnevalli et al., 2021).

In our study, there was no significant variation in the number of harvests and the harvest intervals between stubble heights. However, leaf blade percentages were higher, and stem percentages were lower, for P 2022 S1 and 2111 cut to a stubble height of 45 cm compared to 25 cm, confirming that adaptation to defoliation intensity is variable among genotypes. Differences between the regrowth of elephant grass genotypes were also observed by Gomide et al. (2015), who observed slow regrowth of the CNPGL 00-1-3 genotype in relation to BRS Kurumi, with long intervals between grazing, even considering the achievement of 90% LI as the criterion for interrupting the regrowth period. Based on these results, the CNPGL 00-1-3 genotype was excluded from the evaluation process to obtain a new elephant grass cultivar (Gomide et al., 2015), revealing the importance of this type of study to support the selection of forage grasses for grazing. In this sense, the longer interval between harvests

of P 2022 S1 puts it at a disadvantage compared to other genotypes, although it is the only genotype propagated from seeds. The poor performance of P 2022 S1 compared to the vegetatively propagated genotypes was expected. P 2022 S1 was created by self-fertilization (crossing between plants of the same genotype) of the C2022 clone, giving rise to progeny with low vigor due to inbreeding depression (Silva et al., 2008).

Canopy height plays an important role in defining management strategies, as it has a high correlation with dry matter production (Costa et al., 2020) and has been used as a practical measure to determine the grazing/harvesting moment (Almeida et al., 2023). Moreover, canopy height is highly correlated with LI (Schmitt et al., 2019; Martins et al., 2021). As expected, cutting to a 25-cm stubble height resulted in lower canopy height compared to 45 cm (83 cm vs 96 cm) during the rainy period, indicating the need to adopt different management targets according to the post-grazing residue.

The lower percentage of leaves and higher percentage of stems observed in the first rainy period may be associated with lower growth rates due to lower rainfall in relation to the second rainy period and consequently smaller leaf growth and increased stem elongation (Habermann et al., 2019; Luo et al., 2020). In addition to the lower rainfall in the first year (996 mm) compared to the second year (1340 mm), rainfall distribution was more uniform in the second year (Figure 1), allowing the genotypes to express their genetic potential throughout the evaluation cycles. Another factor that may also explain this result is the fact that in the first year the plants were still in the establishment phase. Notably, genotypes 1810, P 2022 S1, 2035, and 2111 had better canopy structure (leaves blade percentage and LSR) in the first year than BRS Kurumi. This result may suggest a greater capacity to adapt to variations in the rainfall regime in the rainy period.

Volumetric forage density is an important structural characteristic, as it is related to the bite volume of grazing animals (Boval and Sauvant, 2021). In the rainy period, P 2022 S1 had the highest volumetric forage density ($49 \text{ kg cm}^{-1} \text{ ha}^{-1}$ of dry matter) (Figure 4). However, although this genotype had a higher forage density, it had a lower number of harvests and a longer interval between harvests, which highlights the importance of a broader evaluation for the selection of forage genotypes for grazing. Genotypes 1810, 2111, 2025, and BR Kurumi had similar forage densities but a higher number of harvests and a shorter interval between cuts, which may influence animal performance per area. Volumetric forage densities of $80\text{--}103 \text{ kg cm}^{-1} \text{ ha}^{-1}$ of dry matter for BRS Kurumi and $65\text{--}59 \text{ kg cm}^{-1} \text{ ha}^{-1}$ of dry matter for CNPGL 00-1-3 were observed by Gomide et al. (2015) when evaluating the defoliation intervals corresponding to 90 and 95% of IL, respectively. Based on this difference, Pereira et al. (2014) reported a high heifer bite weight for BRS Kurumi ($5.0 \times 1.4 \text{ g bite}^{-1}$ of dry matter).

The 45 cm stubble height resulted in higher volumetric forage density in both years compared to the 25 cm stubble height (Figure 4). The higher volumetric forage density may be associated with the greater total tillering of the genotypes at this stubble height. In addition to higher forage density, the 45 cm stubble height resulted in forage with a higher leaf blade percentage and a lower stem percentage.

The canopy height influences tillering through the activation of basal and axillary meristems, depending on the capacity of light penetration into the canopy (Butler and Briske, 1988). During the rainy period, there were no differences in basal tillering among genotypes (Table 2). The values found are close to those observed by Rosa et al. (2023) working with different stubble heights of BRS Kurumi (33 and 43 basal tillers m^{-2}). Aerial tillering was more intense in all genotypes compared to basal tillering. The high aerial tillering is associated with the removal of the apical meristem, which stimulates the development of axillary buds (Butler and Briske, 1988). Aerial tillering provides lighter tillers but can be very important in the production of forage biomass, representing 63% of the leaf biomass produced (Paciullo et al., 2003).

Among the evaluated genotypes, BRS Kurumi cut to a stubble height of 45 cm had the highest total tillering per m^2 , which can be attributed to its greater aerial tillering (Figure 2). The emission of aerial tillers is a mechanism to increase light capture capacity and maximize leaf area after defoliation.

However, high tiller recruitment after defoliation delays the recovery of the canopy LAI, impacting overall forage production and pasture persistence (Martins et al., 2021). Pereira et al. (2018), studying the contribution of basal and aerial tillers to the growth of elephant grass pasture under intermittent defoliation, observed that, although aerial tillering is an important adaptive response of this species, grazing management strategies that maximize aerial tillering do not result in greater leaf growth nor decrease stem growth rates. Sollenberger et al. (1988) pointed to the importance of basal tillering in the dwarf elephant grass cultivar "Mott" for forage production and pasture persistence.

4.2. Dry period

The water limitation of the dry period causes a decrease in leaf turgor pressure, resulting in the inhibition of cell expansion and differentiation. Drought also decreases the elongation rate but increases the duration of elongation in grasses, consequently reducing the vertical growth of plants and canopy height (Luo et al., 2020; Coussement et al., 2021).

The leaf is the morphological component of greatest interest in the forage canopy, as it has the best nutritional value and is preferred for consumption by grazing animals (Boval and Sauvant, 2021). In addition, the pasture structure and forage supply influence the forage capture capacity and bite volume (Januszkiewicz et al., 2019), so that stem elongation can interfere with the animals' consumption pattern and act as a vertical or horizontal barrier, interfering in the bite formation process and restricting forage intake (Mohammed et al., 2020). In this sense, the 25-cm stubble height for the genotypes P 2022 S and 2111 promoted an increase of the stem percentage in the harvested forage. For the other genotypes, there was no effect by stubble height, showing, in a way, greater management flexibility.

This pattern was not expected, since reducing the stubble height is a way to control the elongation of the stems of tropical grasses when attempting to attain 95% IL (Carnevali et al., 2021). However, in evaluations carried out only on forage harvested above the residue, when the stubble height is reduced, there is a tendency to harvest more stems proportional to the greater heights.

In the dry period, genotypes 1810, P 2022 S1, 2111, and BRS Kurumi had higher leaf blade percentages and lower stem percentages in the first year (Table 5). These results may be associated with the fact that there was less precipitation in the first year (110 mm) than in the second year (216 mm), as well as lower minimum temperatures (Figure 1). Plants under drought conditions exhibit reduced growth due to, among other factors, reduced photosynthetic efficiency (Flexas et al., 2006).

The higher LSR of genotype 2111 in the dry period (Figure 6) indicates that this genotype has forage with a better leaf proportion. According to Catunda et al. (2022), plants that are more tolerant of drought tend to have a higher LSR. Moreover, genotypes with a higher LSR tend to have forage with greater digestibility (Silva et al., 2023), a highly desirable characteristic for animal nutrition, especially in the dry period when the forage supply is low. The higher leaf blade percentage of 2111 may be an indication of better adaptability to the dry period compared to the other genotypes.

The impact of environmental conditions during the dry period led to a significant reduction in the growth of the genotypes, regardless of the stubble height. Although no statistical comparison was made between the rainy and dry periods, the forage biomass accumulation values in the dry period were, on average, 35% those observed in the rainy period. This reduction in the dry season was expected since elephant grass is highly affected by the climatic conditions of the dry season (Pereira et al., 2021). Paciullo et al. (2008) evaluated the forage mass in Napier elephant grass pasture and observed a strong concentration of production in the rainy season, with values of forage accumulation below 500 kg of dry matter ha⁻¹ in September, the peak of the dry season.

During the dry period, a 45-cm stubble height resulted in higher volumetric forage density. Genotype 2111 had low forage volumetric density, possibly in response to its greater canopy height, since volumetric forage density is the relationship between forage mass and height. With a higher stubble

height, a larger residual leaf area is expected (Rosa et al., 2023), as well as larger organic reserves at the base of the plants (Martins et al., 2021), which may benefit regrowth during the drought (Moot et al., 2021). The strategy of adopting more lenient grazing (higher stubble height) during the dry season may help maintain the pasture's perennality. However, a more precise assessment of these effects will be presented in a publication that will address several productive features of this study.

5. Conclusions

The genotypes 1810, 2035, and 2111 exhibit rapid regrowth capacity, high forage biomass accumulation, and high leaf blade percentage in the rainy and dry periods. The genotype P 2022 S1, propagated by seed, requires a longer interval between cuts and fewer harvests and has lower forage biomass accumulation than the other genotypes. A 25 cm stubble height results in lower pre-harvest canopy height in the rainy period, while a 45 cm stubble height increases the leaf blade percentage and the LSR and reduces the proportion of stem in the harvested forage. In the dry period, a 45 cm stubble height results in greater volumetric forage density.

Data availability

Data will be available upon request to the corresponding author.

Author contributions

Conceptualization: Gomide, C. A. M. and Lédo, F. J. S. **Data curation:** Silva, R. B.; Gomide, C. A. M.; Paciullo, D. S. C.; Paiva, L. E. F. and Souza, E. M. B. **Formal analysis:** Ribeiro, K. G.; Gomide, C. A. M.; Paciullo, D. S. C.; Lédo, F. J. S. and Cecon, P. R. **Funding acquisition:** Gomide, C. A. M. and Lédo, F. J. S. **Investigation:** Silva, R. B. and Ribeiro, K. G. **Methodology:** Gomide, C. A. M. and Paciullo, D. S. C. **Project administration:** Gomide, C. A. M. **Supervision:** Gomide, C. A. M. **Writing – original draft:** Silva, R. B.; Ribeiro, K. G.; Gomide, C. A. M.; Paciullo, D. S. C.; Lédo, F. J. S. and Souza, E. M. B. **Writing – review & editing:** Silva, R. B.; Ribeiro, K. G.; Gomide, C. A. M.; Paciullo, D. S. C. and Cecon, P. R.

Conflict of interest

The authors declare no conflict of interest.

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