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Canopy structure and forage mass of mixed pastures of Marandu palisadegrass and the legume *Macrotyloma axillare* managed under rotational stocking

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ABSTRACT - The objective of this study was to evaluate the use of grazing management strategies (GMS) in rotational stocking to improve the canopy structure in mixed pastures of Marandu palisadegrass (*Brachiaria brizantha* cv. Marandu) and legume *Macrotyloma axillare*. Treatments consisted of combinations of defoliation frequencies (pre-grazing heights of 30 and 40 cm) and intensities (post-grazing heights of 15 and 20 cm) in a 2 × 2 factorial arrangement, corresponding to four GMS: 30-15, 30-20, 40-15, and 40-20 cm, allocated to 16 experimental units (paddocks) in a completely randomized block design with four replicates. Pastures managed with 30-20, 40-15, and 40-20 cm had the highest pre-grazing legume masses (P = 0.0378), but for all GSM, there was a reduction of legume in the forage mass over time (P<0.0001). In Summer 1, legume was observed in the upper strata of the pre-grazing profile for all GMS, but in Summer 2, it was only detected in the 20-25 cm stratum of the 30-20 and 40-20 cm GMS. Pastures managed with 30-20 cm had a high pre-grazing bulk density of total forage, grass, and legume leaf (P<0.05), and a high post-grazing grass leaf mass and bulk density. The highest pre- and post-grazing stem mass and bulk density occurred in pastures with a pre-grazing height of 40 cm (P<0.05). The lower defoliation frequencies (pre-grazing height of 40 cm) had no benefits for the canopy structure. Among the GMS evaluated, a pre-grazing height of 30 cm and a post-grazing height of 20 cm resulted in the most suitable canopy structure for grazing.

Keywords: *Brachiaria brizantha* cv. Marandu, canopy height, grass-legume pastures, mixed pastures, *Urochloa brizantha* cv. Marandu

1. Introduction

The combination of forage legumes with tropical grasses is used for intensification of livestock production (Braga et al., 2020; Pereira et al., 2020; Santos et al., 2023). In addition, this combination increases the sustainability of pastoral systems, reduces the emission of greenhouse gases (Cardoso et al., 2016), and increases the capacity for biological fixation of atmospheric nitrogen in pastoral systems, which can be equivalent to the application of 120 to 150 kg N/ha (Pereira et al., 2020; Santos et al., 2023).

Marandu palisadegrass (*Brachiaria brizantha* cv. Marandu syn. *Urochloa brizantha* cv. Marandu) is the most common grass used in Brazilian pastures because of its great productive potential (Da Silva et al., 2013; Antunes et al., 2022). It can also be used in mixed swards with some forage legumes such as *Arachis pintoi* (Gomes et al., 2018; Pereira et al., 2020), *Calopogonium mucunoides* (Alviarez et al., 2020; Depablos et al., 2021), and *Desmodium ovalifolium* (Santos et al., 2023). Legumes of the Macrotyloma genus can fix atmospheric nitrogen, have high nutritional value (Batista et al., 2019), and have the potential to reduce the emission of enteric methane by grazing animals (Lima et al., 2018; Oliveira, 2023). Under continuous stocking, the combination of Marandu palisadegrass and Macrotyloma had benefits, such as great animal performance, less enteric methane emissions, and legume proportion varying from 5 to 32% in total herbage mass (Oliveira, 2023). However, no studies have investigated these plants under rotational stocking.

The GMS for forage quality and livestock production with Marandu palisadegrass in monoculture under rotational stocking is the use of 25 to 33 cm pre-grazing height (average 30 cm) and 15 cm post-grazing height (Gimenes et al., 2011; Antunes et al., 2022). On the other hand, a lower defoliation frequency can increase forage accumulation, the number of branches and leaves per plant, and the number and weight of nodules in tropical forage legumes (Silva et al., 2010). According to Mero and Udén (1997), legumes, including Macrotyloma, adapt better to longer defoliation intervals (lower defoliation frequencies) than grasses. This finding suggests that the inclusion of legumes in mixed pastures may be favored by lower defoliation frequencies in comparison with single-species grass pastures.

Our hypothesis was that the GMS would influence canopy structure, and the use of a lower frequency of defoliation (40 cm) compared with 30 cm pre-grazing height would increase legume (*Macrotyloma axillare*) mass and improve forage bulk density and mass vertical distribution in the forage canopy. Therefore, the objective of this study was to evaluate grazing management effects on the canopy structure of Marandu palisadegrass and the legume *Macrotyloma axillare* in mixed pastures under rotational stocking.

2. Material and methods

2.1. Experimental site

The experiment was conducted at the Centro de Pesquisa e Desenvolvimento de Pastagens e Alimentação Animal of the Instituto de Zootecnia, Nova Odessa, São Paulo, Brazil (22°42' S and 47°18' W, altitude of 528 m). The average temperatures are higher than 22 °C during the warmer months and lower than 18 °C in the coldest month. About 30% of the average annual precipitation, which is 1,270 mm in the municipality, occurs from May to September. The data on temperature and precipitation during the experimental period were collected at the meteorological station of the Instituto de Zootecnia (Figure 1). Climate data were used to calculate the water balance (Thornthwaite and Mather, 1955) considering soil water storage capacity of 50 mm (Figure 2).

The soil in the experimental area is classified as an Ultisol. Soil chemical characteristics in the 0-20 cm layer were: pH $CaCl_2$ = 4.5; OM= 13.5 g/dm^2; P = 10.2 mg/dm^3; Ca = 2.2 cmolc/dm^3; Mg = 1.2 cmolc/dm^3; K = 0.08 cmolc/dm^3; H + Al = 1.6 cmolc/dm^3; sum of bases = 3.5 cmolc/dm^3; cation exchange capacity = 5.5 cmolc/dm^3; and base saturation = 66.5%. For overseeding of Macrotyloma in September 2017, 27 kg P/ha were used in the form of simple superphosphate. To maintain the pastures during the experimental period, in December 2017, potash (83 kg K/ha) and simple superphosphate (35 kg P/ha) were applied, and in February 2018, simple superphosphate (33 kg P/ha) and potassium chloride (83 kg K/ha) were applied, according to the recommendations of Quaggio et al. (2022) for mixed pastures.

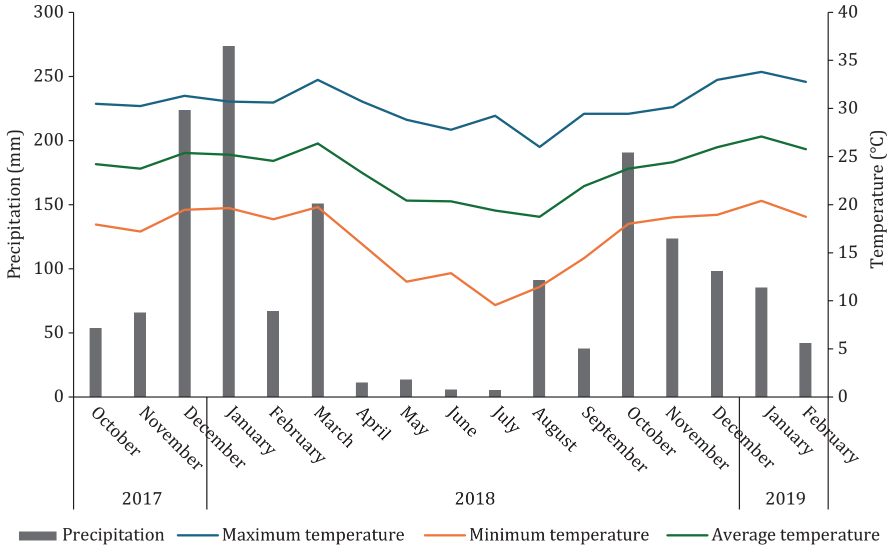

Figure 1 - Monthly precipitation and temperature in Nova Odessa, Brazil, from October 2017 to February 2019.

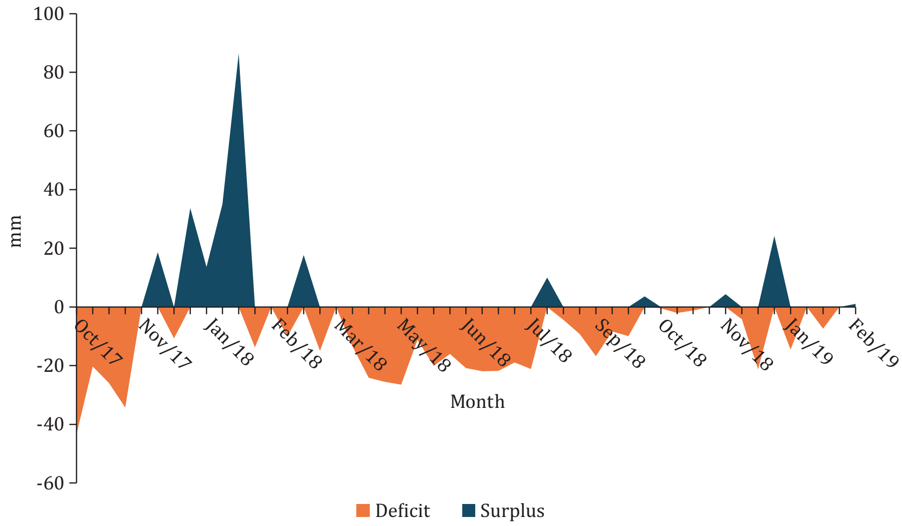

Figure 2 - Monthly water balance from October 2017 to February 2019, considering a soil water storage capacity of 50 mm.

2.2. Area history

The experimental area was established with Marandu palisadegrass [*Brachiaria brizantha* cv. Marandu syn. *Urochloa brizantha* (Hochsct. A. Rich) Stapf.] in 1997 and maintained under continuous stocking until legume overseeding [*Macrotyloma axillare* E. Mey (Verdc), accession no. 279 of the Germplasm Bank of the Instituto de Zootecnia] in February 2014 and December 2016, 10 kg of Macrotyloma seeds/ha were used for each sowing. Before sowing the legume in 2014, the Marandu palisadegrass pasture was lowered, and glyphosate [N-(phosphonomethyl)glycine] herbicide was applied at 5 L/ha of a commercial product (445 g/L of active ingredient) to reduce competition from the grass. Sowing was carried out with a direct planting implement, with a spacing between lines of 0.5 m in February 2014. The establishment management included cattle grazing, maintaining the sward height at around 20 cm. The legume was well established, but in 2015, there was an attack by hares in the experimental area that consumed and injured the legumes, and three severe frosts in the fall/winter of 2016, reducing its participation in the forage mass. For these reasons, the legume was reseeded in December 2016, and the establishment period lasted until February 2017.

2.3. Treatments and pasture management

The treatments were a combination of defoliation frequencies (corresponding to 30 and 40 cm pre-grazing heights) and defoliation intensities (15 and 20 cm post-grazing heights) in a 2 × 2 factorial arrangement [30-15, 30-20, 40-15, and 40-20 cm] with the following percentages of forage canopy height reduction (proportion of canopy height removed by grazing): 33% (30-20 cm), 50% (30-15 and 40-20 cm), and 60% (40-15 cm). The treatment combinations were allocated to 16 experimental units (paddocks) measuring 300 m^2 each, in a completely randomized block design with four replicates, totaling approximately 0.5 ha of the experimental area. In addition, 10 ha of pastures were reserved for regulator animals when they were not in the experimental paddocks.

The experimental period lasted from October 2017 to February 2019, totaling 17 months. Since the grazing intervals were variable due to the previous definition of the treatments based on forage canopy height, data collection was divided into three seasons of the year according to climate conditions (Figures 1 and 2) and phenology of the legume: Summer 1 (October 2017 to February 2018), Autumn (March and April 2018), and Summer 2 (October 2018 to February 2019). There was no grazing from May to September 2018 since the grass did not grow due to the water deficit and low temperatures (Figures 1 and 2).

Jersey heifers (*Bos taurus taurus*), with approximately 220 ± 25.0 kg body weight and initial age of 8 to 14 months, grazed the pastures in a rotational stocking system with variable stocking rates, according to the pre- and post-grazing heights established for the experimental treatments. The "mob-grazing" technique was used as a forage management strategy, which consists of using high grazing pressure for a short period to remove the forage quickly. Groups of animals were used for rapid defoliation (from 4 to 20 h) (Allen et al., 2011), with 8 to 12 animals per paddock. As the animals grazed, height measurements were taken until the canopy reached the post-grazing height target of 20 or 15 cm.

2.4. Experimental evaluations

2.4.1. Canopy height, forage mass, and forage accumulation rate

Canopy height was monitored with a sward stick once or twice a week, depending on weather conditions, throughout the experimental period (Barthram, 1985) at 30 sites per paddock in transect lines. Every time the pasture reached the pre-grazing target height, the animals were transferred to the paddocks for grazing until lowering to the post-grazing target height. A grazing cycle was defined as every time the animals were transferred to the paddocks. The interval, in days, between two grazing cycles was defined as the pasture resting period.

Forage samples were collected before and after grazing by cutting at ground level at three points to calculate the average pasture heights, using a 0.25 m^2 square (0.5 × 0.5 m) as described by Ongaro et al. (2023). The total pre- and post-grazing forage mass values were calculated based on fresh mass and dry mass of the sub-sample and were used to calculate the forage bulk density, the ratio between forage mass, and the average pasture height (kg/ha cm). A similar procedure was used to calculate the bulk density of the morphological components based on the mass of each morphological component and canopy height.

The forage accumulation rate was calculated as the difference between the pre-grazing herbage mass in cycle n and post-grazing herbage mass in cycle n-1, divided by the number of days in this growth period and expressed as kg DM/ha day.

2.4.2. Canopy vertical distribution of forage mass

The vertical distribution of the botanical and morphological components of the pasture was determined in pre-grazing conditions and using the inclined point quadrat method (Warren Wilson, 1960), as described by Alviarez et al. (2020). At least 30 touches were performed per experimental unit (120 touches per treatment). The data obtained were expressed as percentages of the different morphological components in the different vertical strata for each grazing management strategy and season.

2.5. Statistical analysis

Data were subjected to analysis of variance according to the following model:

$$yijkl = \mu + \rho l + \alpha i + \beta j + \gamma k + (\alpha\beta)ij + (\alpha\gamma)ik + (\beta\gamma)jk + (\alpha\beta\gamma)ijk + ijkl$$

in which α = defoliation frequency factor (frequency), β = defoliation intensity factor (intensity), γ = season factor (season); $yijkl$ = observation regarding the effect of the i-th level of factor frequency, j-th level of factor intensity, k-th level of factor season, and l-th block; $(\alpha\beta)ij$ = effects of the interaction between the i-th level of factor frequency and j-th level of factor intensity; $(\alpha\gamma)ik$ = effects of the interaction between i-th level of factor frequency and k-th level of factor season; $(\beta\gamma)jk$ = effects of the interaction between j-th level of factor intensity and k-th of factor season; $(\alpha\beta\gamma)ijk$ = effects of the interaction between the i-th, j-th, and k-th levels of factors frequency, intensity, and season, respectively; ρl = effect of the l-th block; μ = constant; and $ijkl$ = the error.

Statistical analysis was performed using PROC MIXED of SAS (Statistical Analysis System, v.9.4). The Akaike information criterion was used to construct the variance and covariance matrix (Wolfinger, 1993), which permitted detecting the effects of the main causes of variation: grazing frequency (pre-grazing height), grazing intensity (post-grazing height), season, and their interactions [grazing frequency × grazing intensity (GMS), grazing frequency × season, grazing intensity × season, and grazing frequency × grazing intensity × season]. The effects of grazing frequency and intensity, season, and their interactions were considered to be fixed, and the effect of blocks was considered random (Littell et al., 2000). Treatment means were estimated using LSMEANS and compared by the probability of difference (PDIFF) option using the Student's *t* test, and an experimental error probability of 5% was adopted.

3. Results

3.1. Canopy height, grazing cycles, resting period, and forage accumulation rate

Mean pre-grazing (Figure 3) and post-grazing (Figure 4) heights during the experimental period for the different GMS were, respectively, 31.5 and 17.1 cm (30-15 cm), 30.2 and 19.2 cm (30-20 cm), 40 and 16.9 cm (40-15 cm), and 40.2 and 19.5 cm (40-20 cm).

The number of grazing cycles was affected by defoliation frequency and intensity ($P<0.0001$) and was higher for the grazing management strategies involving higher defoliation frequencies (pre-grazing height of 30 cm) and lower defoliation intensities (post-grazing height of 20 cm). Mean numbers were 11.4 and 6.8 days for pre-grazing heights of 30 and 40 cm, respectively, and 9.5 and 8.6 days (±0.26) for post-grazing heights of 20 and 15 cm, respectively. The resting period differed only between defoliation frequencies ($P = 0.0043$) and was longer for the pre-grazing height of 40 cm [62.7 (±9.26) days] compared with the pre-grazing height of 30 cm [32.0 (±7.60) days].

There were no effects of GMS, season, and their interaction on the forage accumulation rate ($P>0.05$), with an average of 27.7±7.25 kg DM/ha day for the entire experimental period.

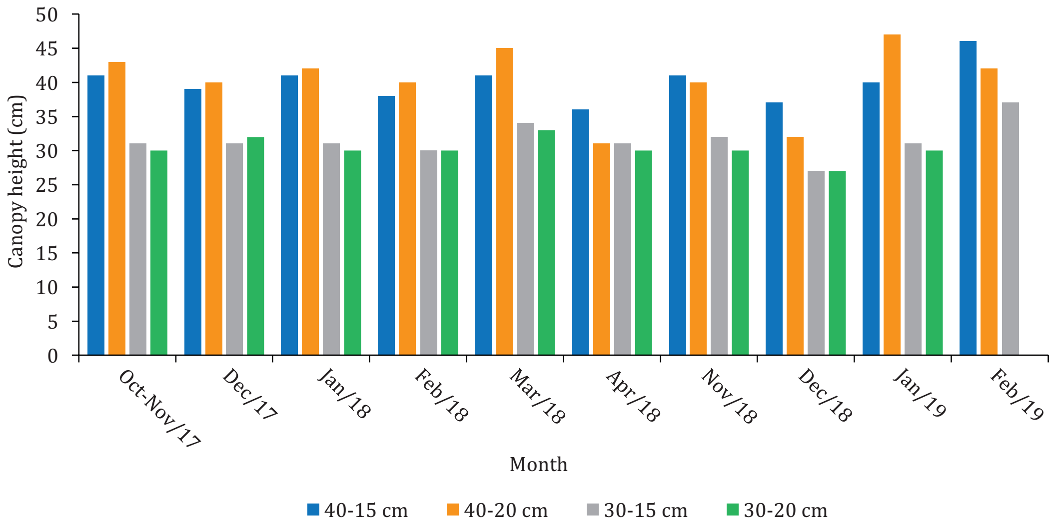

Figure 3 - Pre-grazing canopy heights in components in mixed pastures of Marandu palisadegrass and Macrotyloma legume under grazing management strategies and seasons.

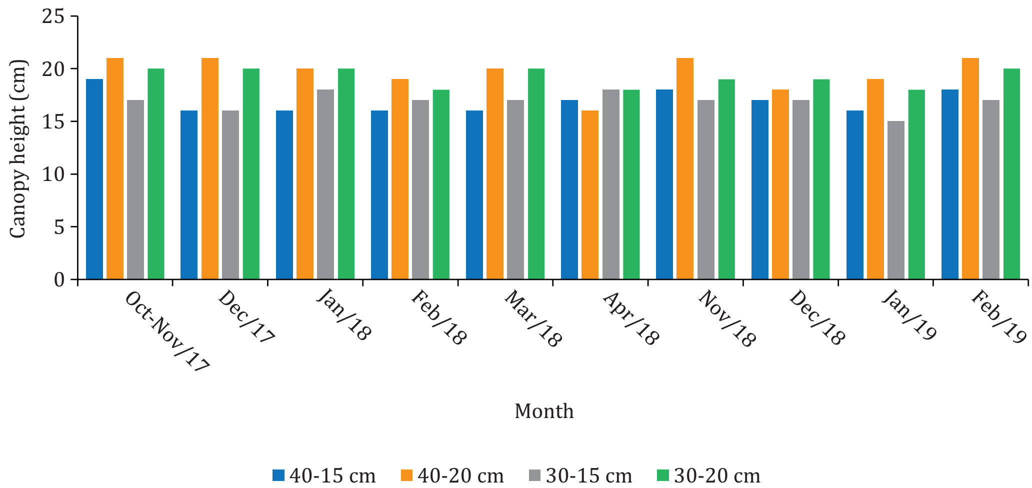

Figure 4 - Post-grazing canopy heights components in mixed pastures of Marandu palisadegrass and Macrotyloma legume under grazing management strategies and seasons.

3.2. Pre-grazing

3.2.1. Forage mass

For pre-grazing total forage mass, an interaction was observed between grazing frequency × season (P = 0.0119). Pastures managed at a pre-grazing height of 40 cm had higher pre-grazing forage mass in Summer 1 (6,190 kg DM/ha) and Summer 2 (5,793 kg DM/ha) than pastures with a pre-grazing height of 30 cm. The grass mass did not differ between the variables analyzed, with a mean forage mass of 3,700±327 kg DM/ha. For grass leaf mass, there were interactions between intensity × frequency of grazing × season (Table 1). The highest leaf mass was observed for pastures subjected to the 40-15, 40-20, and 30-15 cm treatments in Summer 1 and Autumn, while in Summer 2, the highest values occurred in the 30-15 and 40-20 cm pastures. Stem mass was affected by the interactions between grazing intensity × season (P = 0.0304) and grazing frequency × season (P = 0.023). The lowest stem mass values occurred in Summer 2 for pre-grazing height of 30 cm (960 kg DM/ha) and post-grazing height of 20 cm (1,041 kg DM/ha) compared with the other treatments.

For legume mass and legume leaf mass, interactions were observed between grazing intensity × frequency (Table 1). In general, the 30-20, 40-15, and 40-20 cm GMS provided higher legume forage and leaf mass and differed from the 30-15 cm treatment (Table 1). Higher legume and legume leaf masses were obtained in Summer 1 than in Summer 2 and Autumn (Table 1). Legume branch mass was influenced by the interaction grazing intensity × season (P = 0.0015) and was higher in Summer 1 at both post-grazing heights (15 and 20 cm) and lower in Autumn and Summer 2. For dead material, there was an interaction between grazing frequency × season (P = 0.0068), with a reduction in dead material mass in Summer 2 for pastures managed at a pre-grazing height of 30 cm (919 kg DM/ha), while the mass of this component remained the same throughout the year for pastures measuring 40 cm (1,441 kg DM/ha).

Table 1 - Pre-grazing forage mass (kg DM/ha) in mixed pastures of Marandu palisadegrass and Macrotyloma legume under grazing management strategies (GMS) and seasons

Season	Grazing management strategy (cm)				Average	SEM	P-value		
	30-15	30-20	40-15	40-20			GMS	Season	GMS × Season
	Pre-grazing total forage mass								
Summer 1	4977	5587	6151	6228	5736A	319.61	0.3750	0.0079	0.2401
Autumn	5008	5139	4732	5456	5084B				
Summer 2	4775	3740	5816	5770	5025B				
Average	4920	4822	5566	5818					
	Pre-grazing grass mass								
Summer 1	3101	3253	4005	3917	3569	327.36	0.5546	0.1661	0.6590
Autumn	3248	3270	3694	4072	3571				
Summer 2	3821	2855	4786	4410	3968				
Average	3390	3126	4162	4133					
	Pre-grazing grass leaf mass								
Summer 1	1804Bb	1892Aab	2419Aa	2416Ba	2133	195.63	0.1369	0.0136	0.0246
Autumn	1758Bb	1928Aab	2495Aa	2490Ba	2168				
Summer 2	2691Aa	2064Ab	2389Aa	3118Aa	2565				
Average	2084	1961	2434	2674					
	Pre-grazing grass stem mass								
Summer 1	1297	1360	1585	1500	1436	220.74	0.6268	0.9694	0.1533
Autumn	1490	1342	1199	1574	1400				
Summer 2	1129	790	2397	1292	1402				
Average	1306	1164	1727	1455					
	Pre-grazing legume mass								
Summer 1	398	801	672	759	658A	97.79	0.0378	<0.0001	0.9831
Autumn	67	190	114	0	86B				
Summer 2	0	0	290	0	72B				
Average	155b	330a	358a	243ab					
	Pre-grazing legume leaf mass								
Summer 1	197	336	385	417	334A	53.78	0.0466	<0.0001	0.9473
Autumn	25	116	48	0	44B				
Summer 2	0	0	146	0	36B				
Average	74b	150a	193a	134a					
	Pre-grazing legume branch mass								
Summer 1	200	465	287	342	324A	33.16	0.0272	<0.0001	0.1410
Autumn	41	74	65	0	43B				
Summer 2	0	0	0	0	0B				
Average	80a	180a	117b	111b					

Different uppercase letters denote statistical differences (P<0.05) by seasons (column) and lowercase letters by grazing management strategies (row).

3.2.2. Bulk density

The total pre-grazing forage bulk density varied according to season, with the highest values observed in Summer 2 compared with the other seasons (Table 2). The pre-grazing grass bulk density varied according to season (Table 2) and grazing frequency (P = 0.0451), with the highest densities in pastures with a pre-grazing height of 30 cm (106.7 kg DM/ha cm) compared with those managed at 40 cm (96.1 kg DM/ha cm). The pre-grazing grass stem bulk density was influenced by grazing intensity × season (P = 0.0495) and grazing frequency × season (P = 0.0314). Pastures with pre-grazing height of 40 cm (42.6 kg DM/ha cm) and post-grazing height of 15 cm (48.6 kg DM/ha cm) had the highest densities. The pre-grazing legume bulk density varied according to season and was affected by the interaction intensity × frequency of grazing (Table 2). Pastures managed at heights of 30-15 and 40-20 cm had the lowest legume bulk density, and those managed at heights of 40-15 and

Table 2 - Pre-grazing forage bulk density (kg DM/ha cm) components in mixed pastures of Marandu palisadegrass and Macrotyloma legume under grazing management strategies (GMS) and seasons

Season	Grazing management strategy (cm)				Average	SEM	P-value		
	30-15	30-20	40-15	40-20			GMS	Season	GMS × Season
	Pre-grazing total forage bulk density								
Summer 1	165.7	179.2	153.9	156.4	163.8B	21.22	0.6141	0.0407	0.2137
Autumn	164.1	153.5	137.8	169.1	156.2B				
Summer 2	206.4	198.5	217.2	144.7	191.3A				
Average	178.8	177.0	169.7	156.6					
	Pre-grazing grass bulk density								
Summer 1	102.8	104.1	92.0	96.1	98.8B	7.69	0.3153	0.0237	0.1590
Autumn	104.8	103.6	86.5	87.1	95.5B				
Summer 2	126.6	98.0	109.7	105.4	109.9A				
Average	111.4	101.9	96.0	96.2					
	Pre-grazing grass leaf bulk density								
Summer 1	52.8	60.2	60.5	59.0	58.1	5.78	0.8258	0.2003	0.5737
Autumn	61.2	60.9	58.7	54.6	58.9				
Summer 2	59.6	70.8	55.3	74.6	65.1				
Average	57.9	63.9	58.2	62.7					
	Pre-grazing grass stem bulk density								
Summer 1	43.3	43.9	39.6	37.1	41.0	5.18	0.8998	0.7028	0.5763
Autumn	48.3	42.7	27.8	31.4	37.5				
Summer 2	42.8	27.2	54.3	30.8	38.8				
Average	44.8	37.9	40.6	33.1					
	Pre-grazing legume bulk density								
Summer 1	12.6	25.2	16.9	18.6	18.3A	2.91	0.0053	<0.0001	0.6662
Autumn	2.1	5.97	2.6	0	2.6B				
Summer 2	0	0	14.9	0	3.7B				
Average	4.9b	10.4a	11.5a	6.1b					
	Pre-grazing legume leaf bulk density								
Summer 1	16.7	10.4	9.7	10.1	11.8A	4.26	0.5318	<0.0001	0.8695
Autumn	10.0	3.6	1.1	0	3.6B				
Summer 2	11.6	0.0	7.6	0	4.8B				
Average	12.8	4.6	6.1	3.2					
	Pre-grazing legume branch bulk density								
Summer 1	6.7	14.8	7.2	8.4	9.3A	1.40	0.0043	<0.0001	0.5359
Autumn	1.3	2.3	1.5	0	1.2B				
Summer 2	0	0	7.3	0	1.8B				
Average	2.6b	5.7a	5.3a	2.7b					

Different uppercase letters denote statistical differences (P<0.05) by seasons (column) and lowercase letters by grazing management strategies (row).

30-20 cm had the highest densities (Table 2). The legume leaf bulk density varied according to season (Table 2) and was affected by the interaction grazing intensity × season (P = 0.0327). Legume leaf bulk densities were lower in Autumn and Summer 2 compared with Summer 1 at both post-grazing heights (Table 2); in Summer 2, the bulk density was higher in pastures managed at a post-grazing height of 15 cm at 20 cm. Legume branch bulk density was influenced by the interactions grazing frequency × season (P = 0.0101) and grazing intensity × season (P = 0.0016). Branch bulk density was lowest in Autumn and Summer 2 for all pre-grazing and post-grazing heights (Table 2). In Summer 2, pastures with a pre-grazing height of 30 cm and a post-grazing height of 20 cm had lower branch densities compared with the other GMS (Table 2). Dead material bulk density was affected by the interaction grazing frequency × season (P = 0.0326), with higher values for 40 cm (36.5 kg DM/ha cm) in Summer 2 and for 30 cm in Autumn (53.9 kg DM/ha cm).

3.2.3. Canopy vertical distribution of forage mass

For all GMS, there was a concentration of grass leaf above the 15 cm stratum and a concentration of dead material and stems in the stratum below 15 cm in Summer 1 and Autumn (Figures 5 and 6). On the other hand, in Summer 2, there was a concentration of grass leaf above 10 cm in the 30-20 cm pastures and above 20 cm in the 40-20 cm pastures (Figure 7). The proportion of stems was low in the vertical profile, and stems were concentrated in the lower strata at all times evaluated; 40-15 cm pastures had stems in the higher stratum compared with the other GMS (above 25 cm) (Figures 5, 6, and 7). In Summer 1, the presence of legume (leaves and branches) was observed in the upper strata of the pre-grazing profile for all grazing managements, with emphasis on the 30-20 and 40-15 cm strata, in which legumes were positioned at the top of the canopy (30 to 40 cm stratum) above the grass. The legumes were also situated in intermediate strata (15 to 25 cm) in the 30-15 and 40-20 cm GMS (Figure 5). In Autumn, the percentages of legume leaves were higher in the 30-20 cm treatment compared with the other GMS (Figure 6). In Summer 2, the percentage of legumes in the forage canopy strata was low, with their presence only being detected in the 20-25 cm stratum of the 30-20 and 40-20 cm GMS, below the grass components.

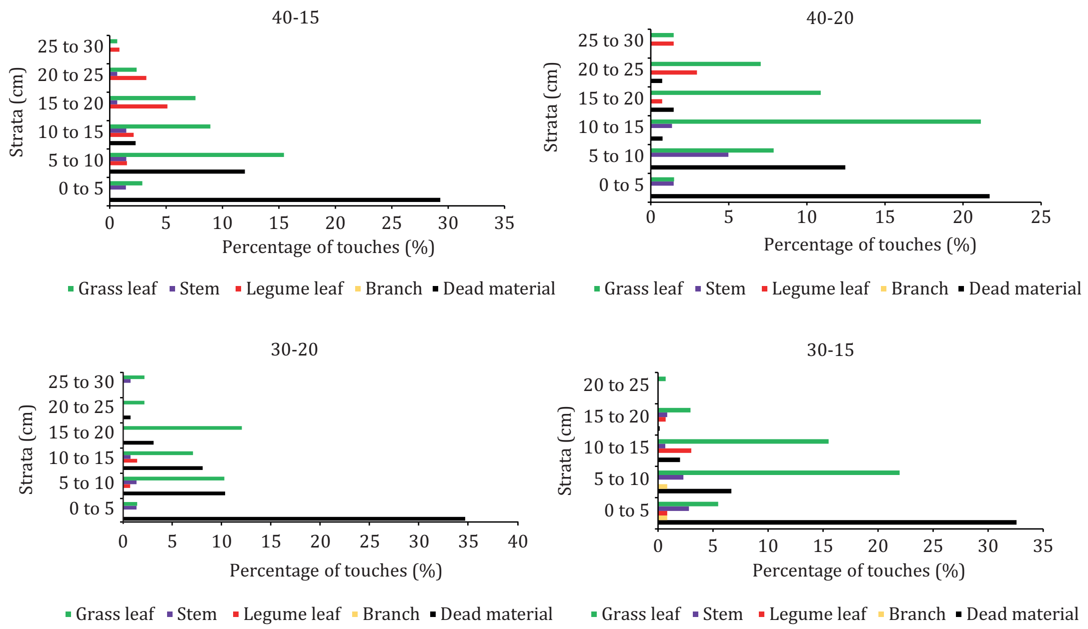

Figure 5 - Pre-grazing vertical distribution of botanical and morphological components in mixed pastures of Marandu palisadegrass and Macrotyloma legume under grazing management strategies in Summer 1.

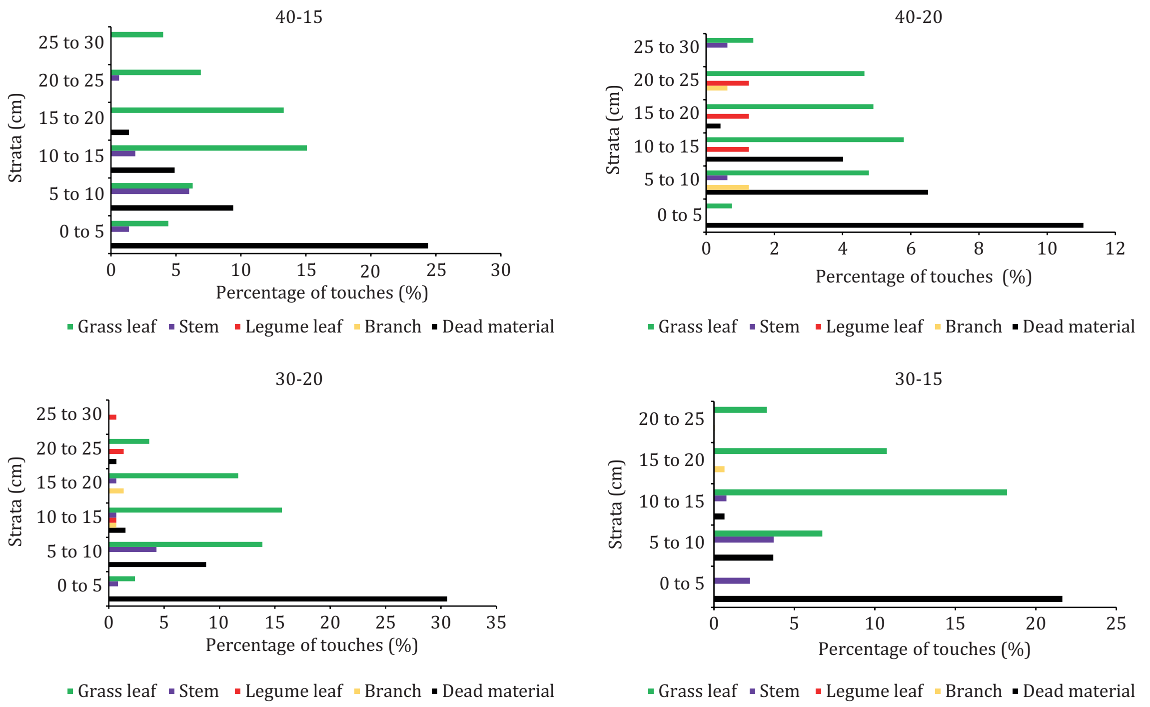

Figure 6 - Pre-grazing vertical distribution of botanical and morphological components in mixed pastures of Marandu palisadegrass and Macrotyloma legume under grazing management strategies in Autumn.

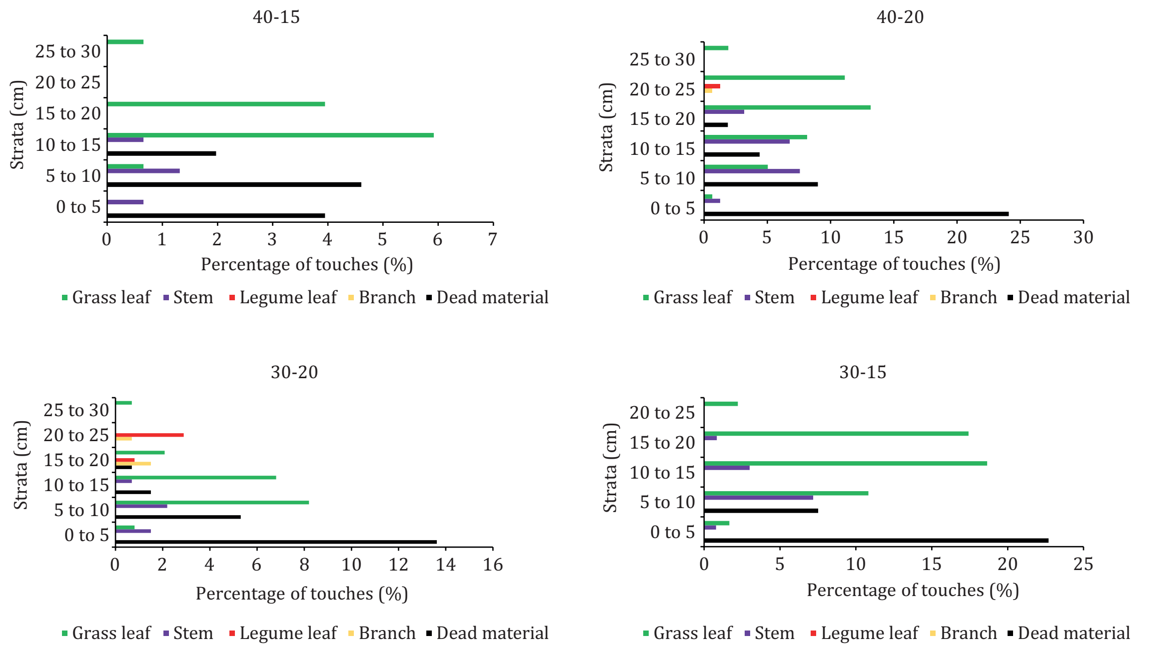

Figure 7 - Pre-grazing vertical distribution of botanical and morphological components in mixed pastures of Marandu palisadegrass and Macrotyloma legume under grazing management strategies in Summer 2.

3.3. Post-grazing

3.3.1. Forage mass

Total post-grazing forage mass was affected by the interaction grazing frequency × grazing intensity × season, with a lower mass for 30-20 cm in Summer 2 compared with the other treatments (Table 3). The post-grazing grass mass varied according to season, with a higher value in Autumn compared with Summer 1 and 2 (Table 3). Grass leaf mass varied according to grazing intensity (P = 0.0072), with higher values observed at the post-grazing height of 20 cm (1,056 kg DM/ha) than at 15 cm (898 kg DM/ha), and was influenced by the interaction grazing frequency × season (P = 0.0146), with higher values in pastures managed at a pre-grazing height of 30 cm in Summer 1 and 2 (1,143 and 992 kg DM/ha, respectively) compared with 40 cm (1,050 and 706 kg DM/ha). Grass stem mass varied according to

Table 3 - Post-grazing forage mass (kg DM/ha) components in mixed pastures of Marandu palisadegrass and Macrotyloma legume under grazing management strategies (GMS) and seasons

Season	Grazing management strategy (cm)				Average	SEM	P-value		
	30-15	30-20	40-15	40-20			GMS	Season	GMS × Season
	Post-grazing total forage mass								
Summer 1	2410	2187	2081	2797	2369	186.42	0.0794	0.0511	0.2462
Autumn	2530	2252	2678	2503	2491				
Summer 2	2207	2131	2026	2302	2166				
Average	2382	2190	2262	2534					
	Post-grazing grass mass								
Summer 1	2410	2187	2081	2797	2369	185.36	0.0627	0.0578	0.2725
Autumn	2530	2252	2678	2503	2491				
Summer 2	2207	2131	2026	2302	2166				
Average	2382	2190	2262	2040					
	Post-grazing grass leaf mass								
Summer 1	1189	1097	848.0	1252	1096.9A	84.32	0.1654	0.0140	0.1475
Autumn	782	889	1099	1170	985.6AB				
Summer 2	866	1118	602	811	849.5B				
Average	945.9	1035	850	1078					
	Post-grazing grass stem mass								
Summer 1	1297Aa	1090Ab	1585Ba	1545Aa	1272	128.74	0.6003	0.8120	0.0202
Autumn	1490Aa	1342Aa	1199Ba	1574Aa	1325				
Summer 2	1129Ab	790Ab	2397Aa	1292Ab	1324				
Average	1306	1164	1727	1456					
	Post-grazing legume mass								
Summer 1	139	215	109	155	155A	37.84	0.4397	<0.0001	0.8000
Autumn	0	0	80	7	22B				
Summer 2	0	0	0	0	0.01B				
Average	46	71	63	54					
	Post-grazing legume leaf mass								
Summer 1	47	42	24	41	38.8A	6.23	0.4511	<0.0001	0.3156
Autumn	0	0	6	5	2.6B				
Summer 2	0	0	0	0	0.01B				
Average	15	14	10	15					
	Post-grazing legume branch mass								
Summer 1	92	147	85	114	109A	25.34	0.4646	<0.0001	0.8726
Autumn	0	0	40	2	10B				
Summer 2	0	0	0	0	0B				
Average	31	49	41	39					

Different uppercase letters denote statistical differences (P<0.05) by seasons (column) and lowercase letters by grazing management strategies (row).

the interaction GMS × season. In Summer 2, 40-15 cm pasture had the highest value differing from the others and also differed from 40-15 cm in Summer 1 and Autumn (Table 3). Legume forage and leaf and branch mass varied according to season, being higher in Summer 1 that in the other seasons (Table 3). There was a difference in dead material mass among seasons, which was higher in Summer 2 (2,322 kg DM/ha) compared with Summer 1 (1,933.4 kg DM/ha) and Autumn (1,923 kg DM/ha).

3.3.2. Bulk density

The post-grazing forage bulk density varied according to post-grazing height and was higher at 15 cm (249.4 kg DM/ha cm) compared with 20 cm (213.2 kg DM/ha cm). There was an interaction of grazing intensity × grazing frequency × season for grass bulk density, in which the 30-15, 40-15, and 40-20 cm pastures had the highest values in Summer 1 and the 40-15 cm pastures in Autumn and in Summer 2 did not differ from each other (Table 4). An interaction of grazing intensity × grazing

Table 4 - Post-grazing forage bulk density (kg DM/ha cm) components in mixed pastures of Marandu palisadegrass and Macrotyloma legume under grazing management strategies (GMS) and seasons

Season	Grazing management strategy (cm)				Average	SEM	P-value		
	30-15	30-20	40-15	40-20			GMS	Season	GMS × Season
	Post-grazing total forage bulk density								
Summer 1	255.8	223.9	241.8	239.9	240.4	19.43	0.7886	0.1820	0.1127
Autumn	222.8	225.6	295.9	212.2	239.2				
Summer 2	243.6	153.0	236.6	224.8	214.4				
Average	240.8	258.0	200.2	225.6					
	Post-grazing grass bulk density								
Summer 1	140.3Aa	113.7Ab	123.6Bab	134.1Aab	127.9	8.8669	0.8513	0.0722	0.0173
Autumn	113.7Bb	116.4Ab	167.9Aa	133.5Ab	132.9				
Summer 2	121.5ABa	118.8Aa	121.5Ba	111.6Aa	118.8				
Average	125.2	116.07	137.7	126.4					
	Post-grazing grass leaf bulk density								
Summer 1	76.3Aa	56.7Ab	49.4Bb	59.8ABab	60.1	3.838	0.5734	0.0550	0.0374
Autumn	41.5Bb	45.5Ab	68.5Ba	62.1Ba	54.4				
Summer 2	55.2Bab	63.8Aa	38.6Bb	41.3Bb	49.7				
Average	57.7	55.3	52.2	54.4					
	Post-grazing grass stem bulk density								
Summer 1	70.3	56.9	74.1	74.2	68.9	7.632	0.6174	0.3759	0.1049
Autumn	64.9	70.9	99.3	71.4	76.6				
Summer 2	74.9	54.2	82.9	69.6	70.4				
Average	70.0	60.7	85.4	71.7					
	Post-grazing legume bulk density								
Summer 1	6.9	10.8	6.07	7.3	7.8A		0.3453	<0.0001	0.7793
Autumn	0	0	4.72	0.35	1.3B				
Summer 2	0	0	0	0	0.0B				
Average	2.3	3.6	3.6	2.5					
	Post-grazing legume leaf bulk density								
Summer 1	8.4	3.4	1.3	1.9	3.8	2.89	0.1948	0.4375	0.8414
Autumn	10.1	0	2.4	0.2	3.2				
Summer 2	8.25	0	0	0	2.0				
Average	8.9	1.4	1.2	0.6					
	Post-grazing legume branch bulk density								
Summer 1	5.7	7.4	4.7	5.4	5.8A	1.34	0.4846	<0.0001	0.8672
Autumn	0	0	0	0.1	0.6B				
Summer 2	0	0	0	0	0.0B				
Average	1.9	2.3	2.3	1.8					

Different uppercase letters denote statistical differences (P<0.05) by seasons (column) and lowercase letters by grazing management strategies (row).

frequency × season was also observed for grass leaf bulk density (Table 4). Pastures managed at heights of 30-15 and 30-20 cm had higher values in Summer 1 and in Summer 2, respectively, while the 40-15 cm pastures had higher values in Autumn (Table 4). Stem bulk density varied according to grazing intensity (P = 0.0316) and grazing frequency (P = 0.0177). Pastures managed at a pre-grazing height of 40 cm (78.1 kg DM/ha cm) and post-grazing height of 15 cm (77.7 kg DM/ha cm) had higher stem bulk densities than pastures managed at 30 cm (65.4 kg DM/ha cm) and 20 cm (66.2 kg DM/ha cm). Legume leaf bulk density was similar between the variables evaluated, with an average DM of 3.0±2.9 kg/ha cm. Dead material bulk density varied according to grazing intensity (P = 0.0329), with pastures managed at a post-grazing height of 15 cm having higher density of dead material (125.6 kg DM/ha cm) than those managed at 20 cm (104.5 kg DM/ha cm).

4. Discussion

The forage canopy heights were close to the pre-established treatment targets (Figures 2 and 3). In fact, the use of a higher pre-grazing height (40 cm) resulted in the desired contrast with 30 cm, including a smaller number of grazing cycles and a longer resting period compared with the recommended height (30 cm). For mixed pastures with Marandu palisadegrass and the legume *Calopogonium mucunoides*, the resting periods also varied according to the frequencies of defoliation during the rainy season in periods of 44, 63, and 113 days for light interception of 90, 95, and 100%, respectively (Depablos et al., 2021). Longer resting periods for tropical grasses provide greater forage mass and forage components in the pre-grazing forage canopy, with emphasis on increase in mass and proportion of stems above residue (Gomes et al., 2018) and total forage mass (Gimenes et al., 2011), in addition to a reduction in digestible organic matter intake (Gomes et al., 2018), intake and retention of N and its utilization efficiency by animals (Depablos et al., 2021), as well as in individual weight gain (Gimenes et al., 2011).

The absence of difference in the forage accumulation rate among treatments indicated that all GMS were in a range of canopy heights where the plasticity of the plant community is sufficient to adjust to grazing management. In the pre-grazing condition, the highest forage mass occurred in the highest pastures (40 cm) as described in the literature (Gimenes et al., 2011; Antunes et al., 2022; Barbosa et al., 2021). The balance between defoliation frequency and intensity (50% lowering) provided a high proportion of leaves in the forage mass.

Pastures subjected to grazing managements of 30-20, 40-15, and 40-20 had greater legume mass than 30-15 cm. However, in the present study, the hypothesis that reducing the frequency of defoliation would increase the presence of legumes in the forage mass was not confirmed, as Macrotyloma was reduced both at pre-grazing heights of 30 and 40 cm.

Gomes et al. (2018) found that the highest proportions of peanut legumes mixed with Marandu palisadegrass occurred at the highest defoliation frequencies (95 and 90% light interception, corresponding to pre-grazing heights of 29 and 24.5 cm, respectively) compared with the tallest pastures (100% light interception, corresponding to a pre-grazing height of 38.4 cm), indicating that differences in grazing management may exist between legumes used in mixture with grasses. This difference compared with the present study in which Macrotyloma had mass in both pre-grazing pastures can be explained by the difference in the growth habit of these legumes. Macrotyloma has a twining growth habit, while *Arachis pintoi* shows a more prostrate growth habit. Macrotyloma forage mass (155 to 359 kg/ha) was lower than that reported for mixed pastures with other legumes such as *Arachis pintoi*, ranging from 293 to 493 kg/ha (Gomes et al., 2018; Pereira et al., 2020), and *Stylosanthes*, ranging from 200 to 1,000 kg/ha (Braga et al., 2020), and Macrotyloma with Marandu palisadegrass under continuous stocking (200 to 2.325 kg/ha) (Oliveira, 2023).

Facing the reduction of Macrotyloma presence in forage mass over time, we can observe that, in some regions, annual overseeding legumes in established grass pastures is a common practice, ensuring the presence of these species during periods of lower grass growth (Garzon et al., 2024) and increasing forage production (Rama et al., 2022) relative to grass monoculture. This may be an alternative for maintaining in pastures also twinning growth habit legumes, such as Macrotyloma. However, there are still few studies of annual overseeding forage legumes in tropical areas.

In this study, the pre-grazing height of 30 cm provided the highest pre-grazing bulk density of total forage, grass, and grass leaves; while the highest pre- and post-grazing stem bulk density values occurred in pastures with a pre-grazing height of 40 cm, highlighting the high percentage of stems in the upper stratum of the 40-15 cm GMS in Summer 2 (Figure 5). The bulk density of grass leaves and stems, mainly in the upper strata, are directly related to bite size and forage intake, and, consequently, animal performance (Benvenutti et al., 2009; Boval and Sauvante, 2021). Canopy height and bulk density are important indicators of pastures suitable for biting (Boval and Sauvante, 2021). According to Ferreira et al. (2022), a greater pre-grazing stem mass negatively influences forage intake, and the presence of leaves and stems in the upper stratum is an important factor in determining the ingestive behavior of grazing animals. Legume bulk density was reduced over time, that is in line with the decrease in legume mass and with the reduction in its proportion in the vertical distribution of pastures during these periods (Figures 5, 6, and 7).

In the post-grazing condition, pastures managed at 30-20 cm exhibited lower forage mass, which can be explained by the lower stem and dead material mass compared with the other treatments, since they had the highest grass leaf mass. The post-grazing leaf mass is related to the residual leaf area and directly affects the speed of pasture regrowth during the resting period (Pedreira et al., 2007; Gimenes et al., 2011). Furthermore, in pastures with pre-grazing height at or below 95% light interception, there is a greater presence of leaves in the animals' diet at the final stage of pasture lowering, while the presence of stem mass indicates the difficulty faced by the animals to consume forage and lower the pasture in this final stage (Da Silva et al., 2015). The highest post-grazing leaf mass and density occurred in pastures with a pre-grazing height of 30 cm, increasing the photosynthetic apparatus and the presence of leaves in the feed of grazing animals. On the other hand, the highest post-grazing stem mass and density occurred in pastures with a pre-grazing height of 40 cm. The proportion of stems in the treatments increased over time, mainly in pastures subjected to the 40-15 cm GSM. Post-grazing legume bulk density decreased during the grazing periods, probably because of the reduced presence of legumes in the lower stratum.

Pastures with a smaller lowering percentage (less than 50%), for example, the 30-20 cm GMS, are characterized by shorter resting periods, a larger number of grazing cycles, and a higher proportion of grass leaves in the post-grazing mass, permitting the intake of higher quality forage by the animals compared with pastures with a greater lowering percentage (Barbosa et al., 2021).

5. Conclusions

The management strategies employed influenced the canopy structure. Lower defoliation frequencies (pre-grazing height of 40 cm) have no benefits for canopy structure compared with pastures with a pre-grazing height of 30 cm, and in all GMS, there is a reduction in the presence of the legume Macrotyloma in the forage mass over time. Among the GMS evaluated, a pre-grazing height of 30 cm and a post-grazing height of 20 cm result in the most appropriate canopy structure for grazing.

Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Author contributions

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Conflict of interest

The authors declare no conflict of interest.

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