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Morphological adaptations of signal grass in response to liming and cutting severities[1]

Adaptações morfológicas do capim-braquiária em resposta a calagem e severidades de corte

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ABSTRACT - Changes in morphological composition and in the plant population were evaluated during late spring, summer and autumn, in swards of *Brachiaria decumben*s cv. Basilisk in response to liming (C0.0, without liming; C0.7, limestone amount equivalent to 0.7 ton ha^{-1}; and C1.0, limestone amount equivalent to 1.0 ton ha^{-1}), which were subjected to severe or lenient cutting (40 or 60% of the pre-cutting height, respectively). Increased limestone doses did not result in higher herbage mass (HM), leaf area index (LAI) or proportion of leaves (%L) in the pre-harvest. However, lower proportion of dead material was registered in C0.7 treatment. The treatments C0.0 e C0.7 had higher %L during late spring and summer when associated to severe cutting regimes (R40%), although they reached the pre-harvest condition with lower HM and longer regrowth periods compared to lenient cuttings. The *Brachiaria decumbens* cv. Basilisk modifies its shoot architecture during the growth season, indicating that lower pre-harvest heights are required during autumn. The absence of liming led to a sharp decreasing of base saturation and levels of K, Ca and Mg in the soil. The minimum annual amount of limestone required for *B. decumbens* correspond to 0.7 ton ha^{-1}.

Key words: Soil acidity. Canopy height. Management strategies.

RESUMO - A composição morfológica e atributos da população de plantas foram avaliados nas épocas de final de primavera, verão e outono, com o objetivo de compreender os mecanismos de adaptação da *Brachiaria decumben*s cv. Basilisk em resposta a doses de calcário (C0.0, sem calagem; C0.7, aplicação de calcário equivalente a 0.7 ton ha^{-1}; e C1.0, aplicação de calcário equivalente a 1.0 ton ha^{-1}), e submetida a cortes severos ou lenientes (resíduo de 40% e 60% da altura pré-corte, respectivamente). Aumento nas doses de calcário não resultou em acréscimos em massa de forragem (MF), índice de área foliar (IAF) e proporção de folhas (%F) na condição pré-corte. Entretanto, menor proporção de material morto foi observada em C0.7. A adoção de cortes severos (R40%) em dosséis submetidos aos tratamentos C0.0 e C0.7, resulta em menor MF e maior período de rebrotação no verão, mas favoreceu a manutenção de maior %F nas épocas de final de primavera e verão. A *Brachiaria decumbens* cv. Basilisk possui habilidade de modificar a arquitetura da parte aérea ao longo da estação de crescimento, apontando para a necessidade de adoção de menores alturas pré-corte no outono. A ausência de calagem conduz a redução drástica na saturação por bases e nos teores de K, Ca e Mg do solo. A aplicação anual de 0.7 ton.ha^{-1} de calcário é a dose mínima recomendada para pastos de *B. decumbens*.

Palavras-chave: Acidez do solo. Altura do dossel. Estratégias de manejo.

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INTRODUCTION

Pasture-based livestock systems in Brazil are traditionally stablished on low fertility soils, which are subjected to a minimal frequency of nutrient replacement through fertilization or control of their acidity levels, and unsatisfactory grazing management techniques (VOLPE *et al.*, 2008). Therefore, liming is an essential agronomic practice for pH correction and neutralization of toxic aluminum, also promoting benefits to chemical, physical and biological soil properties, and contributing to the maintenance of productivity and persistency of pastures (BARCELOS *et al*., 2011).

Brachiaria decumbens cv. Basilisk is prominent among the perennial tropical grasses as it is considered tolerant to soil acidity (PEDREIRA; SILVA; ALONSO, 2015). It has high resistance to grazing, being able to provide an adequate vegetation cover and satisfactory dry matter yield even under poor soil fertility, a condition considered restrictive for growing and persistency of other plant species of the same genus (VALLE *et al.*, 2010). Despite being introduced in Brazil in 1968 and commonly used as pasture, its plasticity for adjustments in tiller population density and morphological traits in response to liming remain largely unknown, particularly when severe cuttings are adopted (PEDREIRA; BRAGA; PORTELA, 2017).

The grazing management aims the definition of targets compatible with the plasticity for the expression of morphological adaptations of the plant species, ensuring forage supply in quantity and quality for the animals and, at the same time, avoiding negative impacts for persistency of the vegetal community. Under rotational stocking, the light availability reaching the base of the canopy is considered a modulator of competition between plants. It has been observed expressive stem and dead material accumulation beyond the 95% of the canopy light interception (LI) during regrowth. Thus, the point in which swards reach 95% LI is considered the ideal time to interrupt the regrowth (PEDREIRA; PEDREIRA; SILVA, 2009; SILVA; SBRISSIA; PEREIRA, 2015). In the field, the canopy height has been used as the criterion to determine the pre-grazing condition (PEDREIRA; BRAGA; PORTELA, 2017; PEDREIRA; PEDREIRA; SILVA, 2007), once it has a high and positive correlation with the canopy light interception. However, in situations in which no liming is applied, plants can trigger morphological changes and adjustments in tiller weight and population density as a way to adapt to the soil conditions, affecting the relationships between the sward structural components, such as leaf area index (LAI), herbage mass and canopy height. Hence, the canopy height corresponding to 95% LI can vary according the amount of limestone applied.

Changes in morphological traits and sward structure are more pronounced under severe grazing (PORTELA; PEDREIRA; BRAGA, 2011), particularly in the absence of liming. In this situation, the low residual herbage mass and LAI could limit new tiller recruitment as well as the ability of adjustments in shoot architecture, and sward recovering might be largely dependent upon the organic reserves available in the roots and stubble, affecting sward's persistency in the long-term. Against this background, the aim of this study was to determine which changes in sward structure are triggered in *Brachiaria decumben*s cv. Basilisk pastures in response to the increased doses of limestone, when swards are subjected to severe or lenient cuttings.

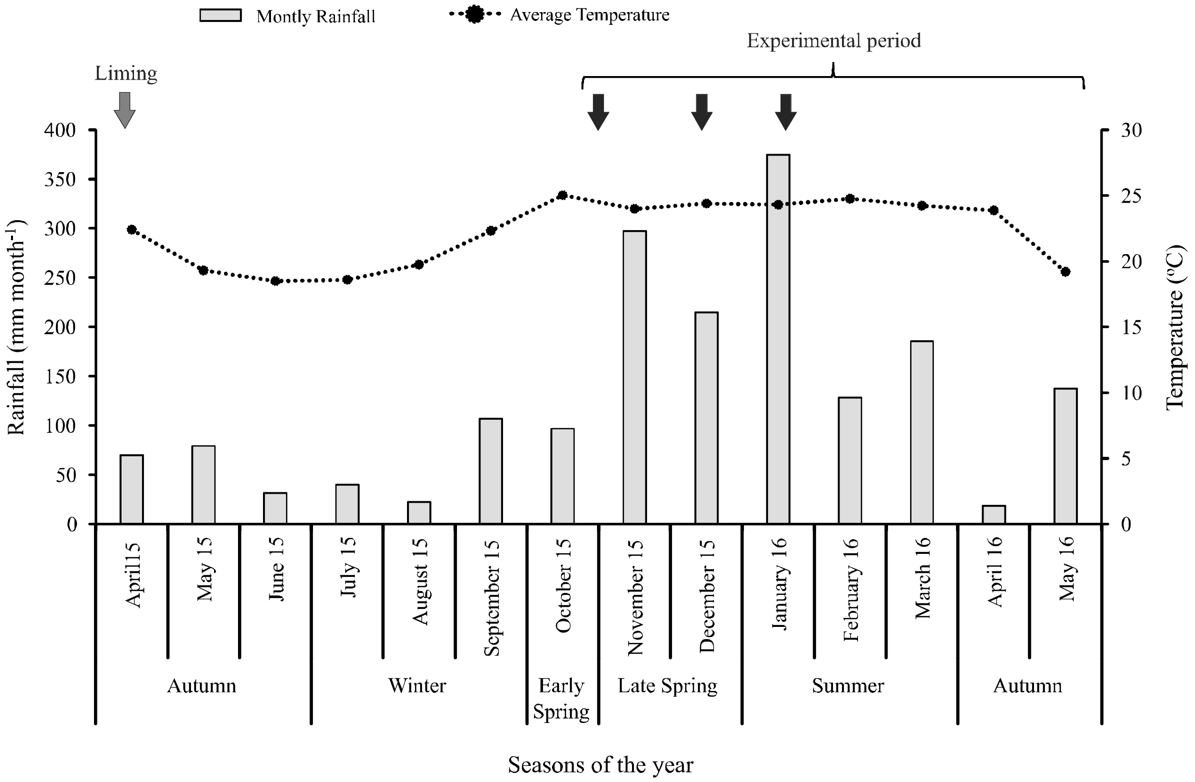
MATERIAL AND METHODS

The experiment was carried out at Faculty of Animal Science and Food Engineering (FZEA), University of São Paulo, Pirassununga, SP, Brazil (21º36'N, 47º15'W, 620 m a.s.l.). The slope is moderately undulating, and the soil was classified as an Oxisol (USDA Soil Taxonomy) or dystrophic Red Latosol according to Empresa Brasileira de Pesquisa Agropecuária (2013). The climate is Cwa (sub-tropical with dry winter), and the annual average rainfall is around 1,395 mm. The average temperatures during the experimental period (October 2015 to May 2016) ranged from 18.9 to 25 ^{o}C. Monthly average rainfall during late spring (October to December 2015), summer (January to March 2016) and autumn (late March to May 2016) were 203.4; 259.2 and 71.7 mm month^{-1}, respectively (Figure 1).

The experimental treatments resulted from the combination of three liming doses: C0.0; in which no limestone was applied, and liming rates equivalent to 0.7 ton ha^{-1} (C0.7) and 1.0 ton ha^{-1} (C1.0), and two severities of cutting, in which the stubble corresponded to 40% (R40%, severe) or 60% (R60%, lenient) of pre-harvest canopy height. The experimental area was comprised by 18 paddocks (80 m²) distributed in three blocks, according the soil slope. The experimental design was in a randomized complete block, and treatments were distributed in a factorial arrangement 3 x 2, with three replications.

Soil samples were collected in March 2015, and the average soil chemical characteristics of the 0–20 cm layer in the paddocks attributed to the treatments C0.0, C0.7 and C1.0 were, respectively: pH $CaCl_2$: 4.8, 5.1 and 5.3; organic matter = 20.5, 23.0 and 23.3 g kg^{-1}; P (resin) = 5.7, 7.3 and 11.2 mg dm^{-3}; Ca = 8.8, 12.7 and 19.3 mmol$_c$ dm^{-3}; Mg = 4.3, 5.5 and 6.2 mmol$_c$ dm^{-3}; K = 2.6, 2.5 and

Figure 1 - Monthly average raifall (mm month^{-1}) and daily average temperatures (^{o}C) from April 2015 to May 2016. Black arrows indicate the application of maintenance fertilizer. Meteorological data were obtained from the Experimental Station of the Agricultural Sciences Laboratory (USP/FZEA)



2.3 mmol$_c$ dm^{-3}; S= 8.5, 22.0 and 25.0 mg dm^{-3}; H + Al = 24.5, 24.2 and 24.3 mmol$_c$ dm^{-3}; sum of bases = 15.8, 20.6 and 27.8 mmol$_c$ dm^{-3}; cation exchange capacity (CEC) = 40.5, 44.8 and 52.0 mmol$_c$ dm^{-3}; soil base saturation = 39.1, 45.9 and 51.2%.

The limestone amount applied would correspond to the elevation of soil base saturation to 50 and 65% in the treatments C0.7 and C1.0, respectively (RAIJ *et al.*, 1997). Dolomitic limestone (89% TNRP) was applied after mowing (5 cm above ground) without incorporation in April 2015. The annual maintenance fertilization was equivalent to 106.5 kg ha^{-1} of N; 52.5 kg ha^{-1} of P_2O_5 and 35 kg ha^{-1} of K_2O, spplited in three applications: in November 2015 by applying the equivalent to 17.5; 52.5 and 35 kg ha^{-1} of N; P_2O_5 and K_2O (formulated fertilizer 5-15-10), respectively; and in 05 December 2015 and 26 January 2016 with the equivalent to 49.5 and 39.5 kg ha^{-1} of N by using ammonium nitrate (33% N). Less demanding grasses were considered for this dosage (RAIJ *et al.*, 1997), reflecting a low intensification state, the goal being to prevent any confusion between the influences due to limestone application and fertilization. A new soil sampling (0-20 cm soil depth) was made at the end of the experimental period (May/2016).

The period from May to October 2015 was considered an adaptation phase, during which the limestone was left to act in the soil. Monitoring of experimental conditions started immediately after mowing. The cuttings were carried out with a costal mower. The experimental period started in November 2015, and measurements were carried out until May 2016, comprising three seasons: late spring, summer and autumn.

The criterion to define the pre-harvest condition was the moment in which the swards intercepted 0.95 of the incoming photosynthetically active solar radiation ($LI_{0.95}$), (PORTELA; PEDREIRA; BRAGA, 2011). Measurements of LI were made during the post- and pre-cutting stage using a LAI 2000 canopy analyzer (LI-COR, Lincoln, Nebraska, USA). Readings were taken from two sampling areas, in which one reading was taken above the canopy and five at ground level, following recommendation of Portela, Pedreira and Braga (2011) and Sousa *et al.* (2011). Canopy height was monitored during each regrowth cycle through 20 systematic readings along four transect lines, using a meter stick graduated in cm.

To determine the herbage mass (HM) and morphological composition during post- and pre-cutting stage, two samples were harvested at ground level using a 0.50 x 0.50 m (0.25 m^2) metallic frame. After cutting, samples were weighed and separated into two sub-samples: one for the determination of dry matter (DM) content and the other for manual dissection into the leaf (leaf laminae), stem (leaf sheath + stem) and dead material. The LAI of the pastures was then determined using the leaf samples drawn for the morphological composition. After the leaf blades were manually separated, they were passed through a leaf area meter LI-COR model LAI-3100 and then dried. Data collected from the leaf dry mass of the subsample and leaf area readings generated by the apparatus were used to calculate the relationship the relationship between the leaf area and leaf blade weight (specific leaf area, SLA in cm^2 g^{-1}) of the samples. Thus, LAI was determined by the ratio of the SLA of the samples and total leaf weight drawn from the corresponding sampling area.

The tiller population density (TPD, tiller m^{-2}) was determined during the pre-cutting stage by counting the number of basal and aerial tillers within two metallic frames (0.5 × 0.5 m). Tiller weight (TW, g $tiller^{-1}$) was accessed from 20 tillers randomly collected per paddock, which were dried in a forced-draught oven at 65 °C until a constant mass. All measurements, excepting LI and canopy height, which were made in each regrowth cycle, were evaluated during one regrowth cycle in each season of the year (monitored cycle).

Analysis of variance was performed using the Mixed Procedure (SAS®, version 9.2), and they were carried out separately for post- and pre-harvest stage, considering the liming doses, grazing severities, season of the year and their interactions as fixed factors and blocks as a random factor. The season of the year was considered a repeated measure. For all variables, the correction of the degrees of freedom was made by the Kenward and Roger (1997) method (DDFM = KR). When appropriate, means were calculated using the 'LSMEANS' command, comparisons were made using the 'PDIFF = ALL' option, and significant differences were declared when $P<0.05$.

RESULTS AND DISCUSSION

The post-cutting condition represents the initial stage of the leaf area recovering of the canopies. The average canopy heights of swards maintained under severe (R40%) and lenient (R60%) cuttings were, respectively, 14.4 and 19.4 ± 0.52 cm during late spring, 14.9 and 20.0 ± 1.08 cm during summer, and 14.9 and 20.0 ± 1.08 cm in the autumn. The residual HM, morphological composition and the remaining LAI in this stage are dependent upon the targets for management imposed, particularly the severity of cutting (SC), and affects how fast is the recovering of the surface leaf area (PEREIRA *et al.*, 2014). The post-cutting HM (kg DM ha^{-1}) varied with SC (P=0.0061), and higher values were recorded when lenient cuttings were adopted (3752.8 ± 142.39 and 4333.6 ± 134.56 kg DM ha^{-1}, respectively for R40% and R60%). In this stage, LAI varied with an interaction season x SC (P=0.0275). Differences between the SC were observed only in summer, with a higher LAI recorded in R60%. Swards under R40% were able to maintain similar LAI values between the seasons in the post-cutting stage (1.15 ± 0.182 in late spring, 0.87 ± 0.103 during summer, and 0.86 ± 0.142 in the autumn). However, when the R60% was adopted, a higher LAI was observed in the summer, which differed only from autumn (1.09 ± 0.182 during late spring, 1.34 ± 0.103 in the summer, and 0.82 ± 0.119 in the autumn).

In opposition to the results observed in other tropical grass species (SILVA; SBRISSIA; PEREIRA, 2015), the higher values of canopy height and HM during post-cutting stage in R60% were unable to generate differences in the LI, leaf (%L) and stem (%S) proportion compared to R40% in all seasons evaluated, as well as in LAI and proportion of dead material (%DMM) during late spring and autumn. These results indicate the plasticity of the forage species for the allocation of morphological components below the height of the residue, which is confirmed by the continued increase in LI of the post-cutting stage (Table 1) from late spring to autumn (P<0.0001 for the effect season on LI).

During post-cutting stage, HM and LAI varied with the limestone doses (P=0.0328 and P=0.0023, respectively). The higher HM was registered in C0.0, and higher LAI in C0.0 and C0.7 when compared to C1.0 (Table 1). Similarly, the %L in the post-cutting stage varied with the limestone doses (P=0.006), when higher values were observed in C0.0 e C0.7 (Table 2). The duration of regrowth was also affected by limestone doses (P=0.0428), and longer regrowth periods were registered in C1.0. The average duration of regrowth in C0.0, C0.7 and C1.0 corresponded to 32.8; 27.0 and 36.2 ± 2.40 days, respectively.

The %S (P=0.0009) and %DM (P<0.0001) were affected by season of the year. The higher %S and lower %DMM were observed during late spring and summer (Table 2). The %DMM was affected by an interaction season x SC (P=0.0201). Differences among SC were observed only during summer, in which higher values of %DMM were obtained in R40%.

Table 1 - Canopy light interception (LI, %), herbage mass (HM, kg MS ha^{-1}) and leaf area index (LAI) of post- and pre-cutting stages in *Brachiaria decumbens* cv. Basilisk. C0.0, C0.7 and C1.0 represent, respectively, swards lacking liming, application of limestone equivalent to 0.7 ton ha^{-1} and 1.0 ton ha^{-1}

Seasons/Limestone doses	LI	HM	LAI
		Post-cutting stage	
Late Spring	68.6 ± 1.39 C	4473.4 ± 355.57 A	1.11 ± 0.129 A
Summer	80.1 ± 0.70 B	3918.6 ± 107.40 A	1.11 ± 0.073 A
Autumn	88.5 ± 1.73 A	3737.7 ± 167.54 A	0.84 ± 0.093 A
C0.0	78.3 ± 1.32 A	4404.6 ± 157.88 A	1.19 ± 0.061 A
C0.7	81.2 ± 1.58 A	3898.0 ± 172.63 B	1.06 ± 0.073 A
C1.0	77.7 ± 1.32 A	3827.0 ± 157.88 B	0.80 ± 0.062 B
		Pre-cutting stage	
Late Spring	95.3 ± 0.17 A	4914.6 ± 284.28 A	3.36 ± 0.272 A
Summer	95.4 ± 0.09 A	5146.9 ± 328.26 A	2.84 ± 0.161 A
Autumn	95.2 ± 0.22 A	3378.2 ± 284.28 B	1.68 ± 0.114 B
C0.0	95.2 ± 0.13 A	4488.0 ± 284.28 A	2.72 ± 0.205 A
C0.7	95.1 ± 0.18 A	4496.4 ± 328.26 A	2.63 ± 0.199 A
C1.0	95.6 ± 0.13 A	4455.3 ± 284.28 A	2.54 ± 0.190 A

For each variable, means followed by the same uppercase letter in the columns are not statistically different from each other (P>0.05)

Table 2 - Canopy height during pre-cutting stage in *Brachiaria decumbens* cv. Basilisk. R40% and R60% represent severe and lenient cuttings, respectively. Uppercase letters are comparing severities of cutting within seasons; and lowercase letters are comparing seasons for each severity of cutting. Bars represent the standard error of the means

Seasons/Limestone doses	%L	%S	%DMM
		Post-cutting stage	
Late Spring	15.9 ± 1.22 A	49.9 ±1.60 A	34.2 ± 1.77 B
Summer	16.6 ± 1.41 A	48.9 ±1.12 A	32.7 ± 1.77 B
Autumn	18.4 ± 1.22 A	34.6 ± 2.53 B	48.3 ± 2.06 A
C0.0	19.0 ± 1.22 A	45.2 ± 1.53 A	35.7 ± 2.13 A
C0.7	18.3 ± 1.41 A	44.1 ± 2.05 A	36.9 ± 2.37 A
C1.0	13.5 ± 1.22 B	44.0 ± 1.53 A	42.5 ± 2.13 A
		Pre-cutting stage	
Late Spring	36.4 ± 1.68 A	40.7 ± 1.41 A	22.9 ± 2.74 B
Summer	34.9 ± 1.68 A	38.7 ± 1.41 A	26.4 ± 2.23 B
Autumn	35.5 ± 1.83 A	30.9 ± 1.54 B	33.3 ± 2.40 A
C0.0	35.3 ± 1.67 A	36.5 ± 1.41 AB	28.1 ± 2.49 AB
C0.7	37.5 ± 1.83 A	39.0 ± 1.54 A	23.2 ± 2.62 B
C1.0	33.9 ± 1.68 A	34.8 ± 1.41 B	31.3 ± 2.49 A

For each variable, means followed by the same uppercase letter in the columns are not statistically different from each other (P>0.05)

Swards subjected to severe cuttings were able to maintain a similar %DMM during late spring and summer, and values were higher during autumn (31.3 ± 2.51% during late spring, 36.5 ± 2.51% in summer, and 47.9 ± 3.26% during autumn). When R60% was adopted, lower %DMM was observed during summer, followed by late spring, but also higher values were registered during autumn (37.1 ± 2.51% during late spring, 28.8 ± 2.51% in summer, and 48.7 ± 2.51% during autumn). Restrictions for plant growth during autumn are commonly observed, due to the low precipitation in this season (Figure 1), contributing to higher %DMM observed in both SC. Summer (December to March) is the reproductive period of *Brachiaria decumbens* cv. Basilisk, and the highest %DMM is also due to the high tiller mortality associated with the post-flowering period (PEDREIRA; BRAGA; PORTELA, 2017). The longest duration of regrowth was observed in autumn in both SC (22.0 ± 1.78 days during late spring, 23.1 ± 1.19 days in summer, and 50.7 ± 5.19 days during autumn in R40%; 23.2 ± 1.78 days during late spring, 30.5 ± 1.19 days in summer, and 42.5 ± 5.19 days during autumn in R60%). The duration of regrowth was statistically different among SC only during summer, in which higher values were observed in R40% (P=0.025 for the interaction season x SC).

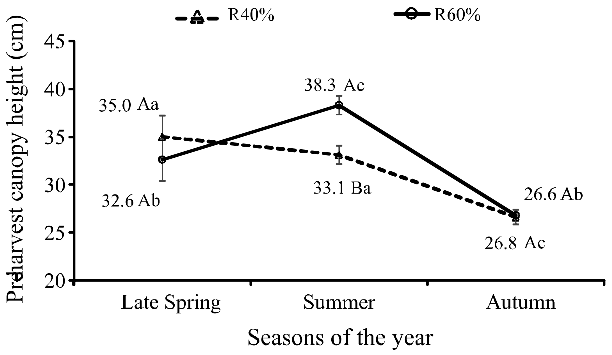
The characteristics of the canopy structure (canopy height, HM and LAI) in pre-cutting stage showed greater variations with the season than with the limestone doses applied. Therefore, and in opposition to the assumptions from the introduction, liming did not induce alterations in the sward structure. Canopy height during pre-cutting stage varied with an interaction season x SC (P=0.0044). For both SC, lower canopy height was registered during autumn. The canopy height in the pre-cutting stage was statistically different among SC only during summer, in which higher values were observed in R60%, and the limestone doses were found to exert no influence upon this trait (Figure 2).

Seasonal variations in canopy height observed in *B. decumbens* pastures at $LI_{0.95}$ were also recorded by Pedreira, Braga and Portela (2017), and were linked to the transition between the vegetative (late spring) and reproductive stage of this species (summer). These authors reported that severe cuttings performed at this time of the year can minimize the emergence of the reproductive stems, which is one reason for the lower pre-cutting heights registered in R40%, during the summer.

The HM during the pre-cutting stage was affected by season (P=0.0006), in which higher values were observed during late spring and summer (Table 1), and SC (P=0.0244), for which R60% resulted in higher values (4072.4 ± 256.61 and 4887.4 ± 232.11, respectively in R40% and R60%). The LAI at this stage also varied with season (P<0.0001), and higher values were observed during late spring, followed by summer, and lower values were observed in autumn (Table 1).

Limestone doses and SC affected the morphological composition in pre-cutting stage, particularly %L and %DMM. The %L varied with an interaction season x limestone doses x SC (P=0.0439), and it was observed

Figure 2 - Canopy height during pre-cutting stage in *Brachiaria decumbens* cv. Basilisk. R40% and R60% represent severe and lenient cuttings, respectively. Uppercase letters are comparing severities of cutting within seasons; and lowercase letters are comparing seasons for each severity of cutting. Bars represent the standard error of the means



that swards subjected to severe cuttings associated with C0.0 and C0.7 had higher %L during late spring, as well as in C0.0 during summer. For lenient cuttings (R60%), benefits for %L by using higher doses of limestone were registered only during late spring (Table 3).

The %S during pre-cutting stage varied with season (P<0.0001) and limestone doses (P=0.044), while %DMM varied with season (P=0.0006), limestone doses (P=0.0272) and with an interaction limestone doses x SC (P=0.0286). For the effect of season, higher %S and lower %DMM were observed during late spring and summer. The treatment C1.0 had higher %S and %DMM, although values were not statistically different from C0.0 (Table 2). Swards subjected to severe cuttings associated with C0.0 and C0.7 had lower %DMM (25.1 ± 3.01 and 17.5 ± 3.42, respectively) compared to C1.0 (33.4 ± 3.01 %). Limestone doses did not affect %DMM when lenient cuttings were adopted (31.1 ± 3.01 in C0.0, 28.8 ± 3.01 in C0.7 and 29.1 ± 3.01 in C1.0). Severities of cutting generated differences in %DMM only for the treatment C0.7, in which lower values were observed in R40%.

The adoption of severe cuttings showed positive impacts on morphological composition. Pedreira, Braga and Portela (2017) also pointed out that the severity of cutting had greater impact to leaf accumulation and traits related to sward structure than frequency of defoliation in *B. decumbens*. This response pattern differed from that described for some caespitose grass species, such as *Brachiaria brizantha* cultivars or species belonging to the *Panicum* genus (PEDREIRA; SILVA; ALONSO, 2015). The stubble of post-cutting stage defines the light penetration into the canopy during the initial phases of

Table 3 - Proportion of leaves (%) during pre-cutting stage in *Brachiaria decumbens* cv. Basilisk. C0.0, C0.7 and C1.0 represent, respectively, swards lacking liming, application of limestone equivalent to 0.7 ton ha^{-1} and 1.0 ton ha^{-1}. R40% and R60% represent severe and lenient cuttings, respectively

Cutting severities	Limestone doses		
	C0.0	C0.7	C1.0
	Late Spring		
R40%	41.5 ± 3.19 Aa	41.0 ± 3.19 Aa	33.2 ± 3.19 Aa
R60%	31.4 ± 3.19 Bb	31.2 ± 3.19 Bb	40.1 ± 3.19 Aa
	Summer		
R40%	41.5 ± 3.19 Aa	37.6 ± 3.19 Aa	34.0 ± 3.19 Aa
R60%	27.2 ± 3.19 Ba	35.5 ± 3.19 Aa	33.3 ± 3.19 Aa
	Autumn		
R40%	35.5 ± 3.19 Aa	44.8 ± 5.42 Aa	33.7 ± 3.19 Aa
R60%	34.9 ± 3.19 Aa	34.5 ± 3.19 Aa	29.4 ± 3.19 Aa

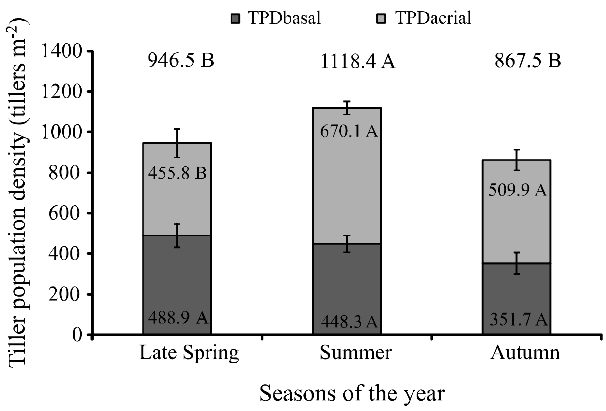
Means followed by the same uppercase letter in columns and lowercase letters in the rows are not statistically different (P>0.05)

regrowth, which, in turn, stimulates the axillary bud activation (PEREIRA *et al.*, 2014) and the increasing of the tiller population density. Thus, severe cuttings in swards of *B. decumbens* appear to favour the axillary bud outgrowth and the appearance of new tillers (PORTELA; PEDREIRA; BRAGA, 2011), contributing to higher %L and lower %DMM under conditions of frequent cuttings, typical of the $LI_{0.95}$ target.

Basal tiller population density (TPDbasal) during the pre-cutting stage was not affected by the treatments or interactions (P>0.05). The aerial (TPDaerial) and the total tiller population density (TPDtotal) during the pre-cutting stage varied with season (P=0.0016 and P=0.0013, respectively), and the highest values were observed during summer compared to late spring and autumn, which were statistically similar to each other (Figure 3). Limestone doses affected TPDtotal (P=0.0081), and higher values were registered in C0.0 and C0.7 compared with C1.0 (1005.4 ± 22.82; 1026.9 ± 31.32; 900.2 ± 22.82 tillers m^{-2}, respectively).

A clear seasonal effect on the canopy structure, morphological composition, population density and tiller weight was noted. The period between the beginning and end of spring is characterized by a strong renewal of the plant population (SILVA; SBRISSIA; PEREIRA, 2015). During this time, Portela, Pedreira and Braga (2011) suggested the adoption of severe grazing (10 cm) is a way of stimulating tiller appearance also ensuring the survival of the new plants, a condition that can be advantageous to forage accumulation during the overall growing season. The appearance of basal tillers during spring is important once they possess higher growth rates and longer lifespan

Figure 3 - Basal (TPDbasal), aerial (TPDaerial) and total tiller population density (means above bars) during pre-cutting stage in *Brachiaria decumbens* cv. Basilisk according to season of the year. Uppercase letters compare seasons. Bars represent the standard error of the means



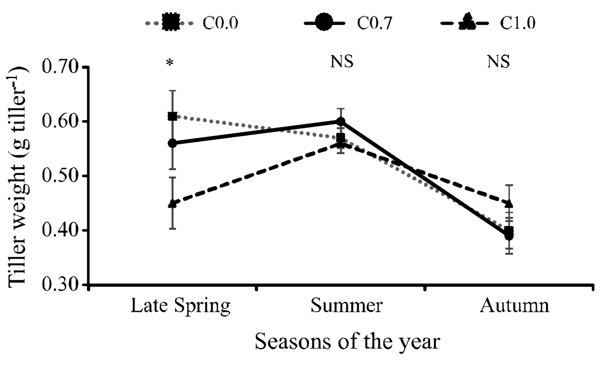
relatively to the aerial tillers (PEREIRA *et al.*, 2014). The basal tillers in this experiment corresponded to 52% of the population (Figure 3) during late spring, but decreased through the growing season, registering an average of 40% of the population in the summer and autumn.

Seasonal patterns of tillering (tiller birth and death) are widely related to the plant's perennation strategy: vegetative or reproductive (MATTHEW *et al.*, 2013). In species expressing the reproductive perennation strategy, population renewal occurs mainly during the post-flowering period, and the majority of the new tillers are produced at the base of the decapitated tillers that flowered. According to Bahmani *et al.* (2002), among the criteria that best describe the predominance of the reproductive perennation strategy are the high percentage of reproductive tillers, poor numbers of tillers that emerged in spring and remain vegetative in late summer, and a high proportion of vegetative tillers during autumn that arose from the activation and development of axillary buds of the reproductive tillers. In this experiment, the flowering period of *Brachiaria decumbens* was visible between December and February. During this period, canopy pre-cutting heights increased in swards subjected to lenient cuttings, and TPDaerial increased 47% compared to the late spring. The increasing of aerial tillers was responsible for a higher TPDtotal during summer, and the contribution of this tiller class to total population was maintained during autumn. These results allow to infer that *Brachiaria decumbens* expresses the reproductive perennation strategy.

The average tiller weight (TW, g tiller^{-1}) during the pre-cutting stage was affected by season ($P<0.0001$), but also varied with an interaction season x limestone doses ($P = 0.0135$). For a similar tiller population density, swards lacking liming expressed higher TW during late spring when compared to swards of the C1.0 treatment (Figure 4).

Siqueira *et al.* (1990) and Motta *et al.* (2017) highlighted that the association with arbuscular mycorrhizal fungi (AMF) plays an important role to increase the availability of nutrients, such as phosphorus, nitrogen, zinc and copper (CLARK; ZETO, 2000) when pastures of *Brachiaria decumbens* are stablished on acidic soils. They reported that liming exerted a negative influence on the spore production and fungal species population composition, limiting the efficacy of the association, which affects the potential growth of the plant. In addition, Soudzilovskaia *et al.* (2015) showed that the intensity of the AMF root colonization and infection is higher when the soil conditions were more acidic. The potential negative influence that liming has on the AMF root colonization in *Brachiaria decumbens* explains the lower TW and %L observed during late spring, and the lower TPDtotal in the pre-cutting stage for C1.0 treatment, compared to swards that did not receive limestone. However, such statements regarding the influence exerted by liming on the AMF require proper assessment under Brazilian soil conditions, in experiments particularly designed for this purpose.

Figure 4 - Average tiller weight (g tiller^{-1}) during the pre-cutting stage according to the interaction season x limestone doses in *Brachiaria decumbens* cv. Basilisk. C0.0, C0.7 and C1.0 represent, respectively, swards lacking liming, application of limestone equivalent to 0.7 ton ha^{-1} and 1.0 ton ha^{-1}. Bars represent the standard error of the means. ^{NS} non-significant ($P>0.05$)



The results reported here showed that the canopy height corresponding to the $LI_{0.95}$ target changed more significantly with the season than with the limestone doses applied. Thus, in production systems using low fertilization rates (conditions established in this experiment), the height at which the canopy reaches 95% LI is around 33 cm in late spring and summer and 27 cm in autumn. When these targets are adopted, severities of cutting ranging from 40 to 60% of the pre-cutting canopy height are within the limits of tolerance to grazing of the grass species, similarly to the results reported in the literature for other tropical grasses (SILVA; SBRISSIA; PEREIRA, 2015). For the species studied here, lenient cuttings result in higher HM and shorter regrowth period in summer, but severe cuttings maximized %L, particularly during late spring.

When the changes of the soil nutrients were analyzed, P levels increased probably as a result of the maintenance fertilization performed. However, a dramatic drop in the base saturation was noted as well as in the concentration of K, Ca and Mg when swards did not receive limestone (Table 4). According to Barcellos *et al*. (2011), liming is primarily crucial to supply Ca and Mg and sustain the growth rates in *B. decumbens*, and not necessarily as a corrective of the soil acidity or aluminum saturation.

The significance of liming in providing the essential nutrients is confirmed by the drop in the Ca concentration, even in those canopies that were supplied with the equivalent of 0.7 ton ha^{-1}. These results reflect the traditional lowering of soil fertility of pastures when liming is not applied regularly (GOULDING, 2016). If this state is followed by successive growth periods, it most often results in pasture degradation (DIAS-FILHO, 2014). From the findings of this experiment, the application of 0.7 ton ha^{-1} limestone yearly corresponds to the minimum dose suggested for *B. decumbens* to avoid a sharp decrease of base saturation and soil Ca concentration.

Table 4 - Chemical analysis of the soil at 0 to 20 cm depth in *Brachiaria decumbens* cv. Basilisk, at the end of the experimental period (May 2016). C0.0, C0.7 and C1.0 represent, respectively, swards lacking liming, application of limestone equivalent to 0.7 ton ha^{-1} and 1.0 ton ha^{-1}. Numbers in parentheses represent the increases or decreases compared to the values at the beginning of the experiment

Limestone doses	P	K	Ca	Mg	Base saturation
	mg dm^{-3}		mmol$_c$ dm^{-3}		%
C0.0	9.00 (+58.7%)	1.26 (-51.9%)	3.56 (-59.7%)	1.97 (-54.5%)	13.0 (-66.8%)
C0.7	9.50 (+29.6%)	2.27 (-8.1%)	10.19 (-19.6%)	6.02 (+9.5%)	36.2 (-21.3%)
C1.0	12.93 (+15.8%)	2.76 (19.0%)	16.22 (-16.1%)	12.97 (102.0%)	56.0 (+4.9%)

CONCLUSIONS

1. Increasing limestone doses does not improve herbage mass, leaf area index and leaf proportion in the pre-cutting stage;
2. Severe cutting, corresponding to 40% of the pre-cutting height, in the canopies lacking liming or when 0.7 ton ha^{-1} of limestone is applied, results in higher percentage of leaves and lesser quantity of dead material in the pre-cutting stage during the late spring and summer, although it produces a lower post-cutting herbage mass and results in longer regrowth periods during summer;
3. The *Brachiaria decumbens* cv. Basilisk demonstrated its ability to alter the shoot architecture throughout seasons. Hence, canopies reach $LI_{0.95}$ with lower pre-cutting heights during autumn;
4. The lack of liming causes a dramatic drop in base saturation and soil K, Ca and Mg concentration. The recommended minimum dose for the *B. decumbens* pastures is the application of 0.7 ton ha^{-1} of limestone yearly.

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