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# Grazing management strategies for *Urochloa decumbens* (Stapf) R. Webster in a silvopastoral system under rotational stocking

Vitor D. Machado[1] | Dilermando M. da Fonseca[1] | Marina A. Lima[1] | Janaina A. Martuscello[2] | Domingos S. C. Paciullo[3] | Fernanda H. M. Chizzotti[1]

[1]Department of Animal Science, Universidade Federal de Viçosa, Viçosa, Brazil

[2]Department of Animal Science, Universidade Federal de São João del-Rei, Juiz de Fora, Brazil

[3]Embrapa Gado de Leite, Juiz de Fora, Brazil

**Correspondence**
Marina A. Lima, Department of Animal Science, Universidade Federal de Viçosa, Viçosa, Minas Gerais, Brazil.
Email: marinalima17@hotmail.com

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**Abstract**

Our objective was to compare herbage accumulation and nutritive value of *Urochloa decumbens* (Stapf) R. Webster managed under pre-grazing canopy light interception (LI) targets of 90%, 95% and 100% in silvopastoral system (SPS) and 95% in open pasture (OP; *U. decumbens* under full sunlight) to establish a pre-grazing target for SPS of ~43% shade. The evaluations were made during two rainy seasons and one dry season. The total herbage accumulation in SPS was lower than in OP at all LI targets and seasons. However, the difference in total herbage accumulation between SPS and OP was reduced when SPS was harvested at 95% LI, with reductions of 20% and 28% in both rainy seasons (12,191 × 15,324 kg DM/ha and 11,158 × 15,424 kg DM/ha respectively). Moreover, under 95% LI in SPS, crude protein concentration was 18% and 19% greater than that in OP in both rainy seasons (155 × 131 g/kg DM and 144 × 121 g/kg DM respectively), thus representing the optimal pre-grazing LI target for *U. decumbens* in SPS. In addition, a canopy height of 20 cm was necessary for 95% LI in OP and a height of 40 cm in SPS. Therefore, *U. decumbens* should be grazed at 40 cm canopy height, in SPS with ~43% shade to keep 95% LI as the target. However, this target will only be effective if the shade level is maintained, which will reduce height variation over time.

KEYWORDS

canopy height, herbage accumulation, light interception, nutritive value, shading

## 1 | INTRODUCTION

Brazil has the world's largest commercial cattle herd of 211 million head, and most of these animals (90%) are kept on tropical pastures, in a pastureland area of approximately 170 Mha (Abdalla Filho et al., 2019). The majority (99 Mha) of the cultivated pasture is planted to *Urochloa* spp. (Corrêa et al., 2020). *Urochloa decumbens* (Stapf) R. Webster originates in Africa. It is cultivated in Brazil because of its high resistance to acid soils and low fertility; its potential herbage accumulation makes it an excellent forage option for livestock production systems. However, it is estimated that 50%–70% of Brazilian pasturelands are in different stages of degradation (Dias-Filho, 2014), mainly as a result of inadequate establishment and management of pasture. In this context, the establishment of silvopastoral systems (SPS), associated with pasture recovery strategies, is a viable alternative to improve soil conservation, in addition to contributing to diversification and sustainability of production by farmers (Jose & Dollinger, 2019). Although research has been conducted to identify grazing management strategies that optimize pasture production, animal productivity and the sustainability of these systems (Baldissera et al., 2016; de Oliveira, de Oliveira, de Oliveira Macêdo, Andrade, & Edvan, 2019), grazing management recommendations for integrated systems remain scarce.

  

For temperate grasses cultivated under open pasture (OP; full sunlight), the growth of forage plants is related to the level of light interception by the canopy and its leaf area, with a constant rate of accumulation of dry matter when there is enough foliage to intercept practically all the incident light (Brougham, 1957; Parsons, Johnson, & Harvey, 1988). Studies have shown that the concept of critical leaf area index (LAI), a condition in which the canopy intercepts 95% of incident light, originally described and successfully applied to temperate-climate plants, is valid and can also be applied to tropical grasses (Carnevalli et al., 2006; Da Silva et al., 2009; Pedreira, Braga, & Portela, 2017). Under this condition, the herbage accumulation rate is at a maximum, with a greater proportion of leaf and lower proportions of stem and senescent forage, resulting in increased grazing efficiency (Carnevalli et al., 2006; Da Silva et al., 2009). Therefore, using the consistent relationship between 95% light interception (LI) and canopy height as a criterion for assessing OP defoliation is advantageous when compared to using grazing intervals based on chronological time (fixed rest periods; Pedreira, Valdson, Pedreira, & Sollenberger, 2017). In addition, simpler methods (other than for determining LI) are required for farmers to implement recommendations for grazing management (such as canopy height). However, observations of the morphophysiological changes in forage species subjected to shade emphasize the need for additional information on the effect of frequency and intensity of defoliation on pasture in SPS.

In this regard, the use of canopy height (based on LI) recommended for the management of different species and forage cultivars in OP under rotational stocking may not result in the most appropriate management for shaded pasture, considering the differences in the structural characteristics of the swards subjected to different light conditions (Geremia et al., 2018; Gomes et al., 2020).

Therefore, it is possible that regrowth is interrupted in SPS when the pasture has a canopy height greater than that observed under OP conditions (Baldissera et al., 2016; Geremia et al., 2018). Although the pattern of response to varying levels of shade has been documented extensively for several forage cultivars (Paciullo et al., 2017), little is known about grazing management in SPS. However, Geremia et al. (2018) indicated that the pre-grazing canopy height in shaded pastures is greater than that in OP and that the canopy height increases with increasing shade level. In this context, the definition of grazing management targets for SPS becomes even more complex, due to the great variability among systems since countless possibilities of spatial arrangements and species exist, with different levels of shade that vary over time because of the growth of the tree component. Therefore, studies evaluating different grazing frequencies based on LI may enable identification of grazing management strategies more suitable for SPS. In addition, the definition of the ideal harvest condition for every forage cultivar in SPS may permit more adequate and consistent comparisons between OP and SPS.

In the present study, we tested the hypothesis that the pre-grazing canopy height of *U. decumbens* in an SPS with an average shade of ~43% is higher than its recommended canopy height for OP based on 95% LI for rotational stocking, affecting herbage accumulation, nutritional value and organic reserves of the plants. Therefore, our objective was to compare herbage accumulation, nutritive value and organic reserves of *U. decumbens* managed under four pre-grazing canopy LI targets of 90%, 95% and 100% in an SPS and 95% in an OP during two rainy seasons and one dry season and thereby establish the pre-grazing canopy height target for rotational stocking in an SPS.

## 2 | MATERIALS AND METHODS

### 2.1 | Ethical approval

The procedures involving animals in the study were approved by the Animal Care and Use Committee of the Federal University of Viçosa, Brazil (protocol number 25/2014).

### 2.2 | Experimental site and pasture establishment

The experiment was carried out at the Forage and Pasture Teaching, Research and Extension Unit of the Federal University of Viçosa, in Viçosa, Minas Gerais, Brazil (20°46′S, 42°51′W; 689 m.a.s.l.; Figure 1) from October 2013 to April 2015. According to the Köppen climate classification, this region has a Cwa type (humid subtropical) climate, defined as a combination of dry winters (with temperatures below 18°C) and hot summers (with temperatures above 22°C). Weather data (Figure 2) for the experimental seasons were recorded at a station located 500 m from the experimental site. The tree component of the system consisted of *Eucalyptus urograndis* (*E. urophylla* × *E. grandis*), planted in 2010 in an east–west direction in single rows with an intra-row spacing of 4 m and an inter-row spacing of 10 m.

The soil type of the experimental site was classified as dystrophic Red-Yellow Latosol with clayey texture, according to the Brazilian soil classification system. Twenty single soil samples were collected at a depth of 0–20 cm using an auger and then mixed, and one representative sample (300 g) was analysed for chemical characteristics using the methods recommended by Embrapa (1997). The soil had the following chemical characteristics: pH (in water) = 4.8; $p$ = 2.1 mg/dm$^3$ (Mehlich-1); K = 49 mg/dm$^3$; Ca = 1.4 cmol$_c$/dm$^3$; Mg = 0.5 cmol$_c$/dm$^3$; Al = 0.6 cmol$_c$/dm$^3$; effective cation-exchange capacity = 2.6 cmol$_c$/dm$^3$; and base saturation = 24.9%. Soil correction was performed to increase the base saturation to 40%. For this, dolomitic limestone, with a composition of 30% CaO and 12% MgO and 82% total relative neutralizing power (TRNP), was distributed at 2.7 t/ha by broadcast application over the straw in the no-till system 90 days before planting the forage.

The forage component in the SPS and OP consisted of *U. decumbens* cv. Basilisk. The pastures were established in December 2012 and managed under rotational stocking until September 2013 prior to the start of data collection. At the time of forage


**FIGURE 1** Location map of the experimental site (indicated by a solid line) for the silvopastoral system (SPS) and open pasture (OP) at the Forage and Pasture Teaching, Research and Extension Unit of the Federal University of Viçosa, Minas Gerais (MG), Brazil [Colour figure can be viewed at wileyonlinelibrary.com]

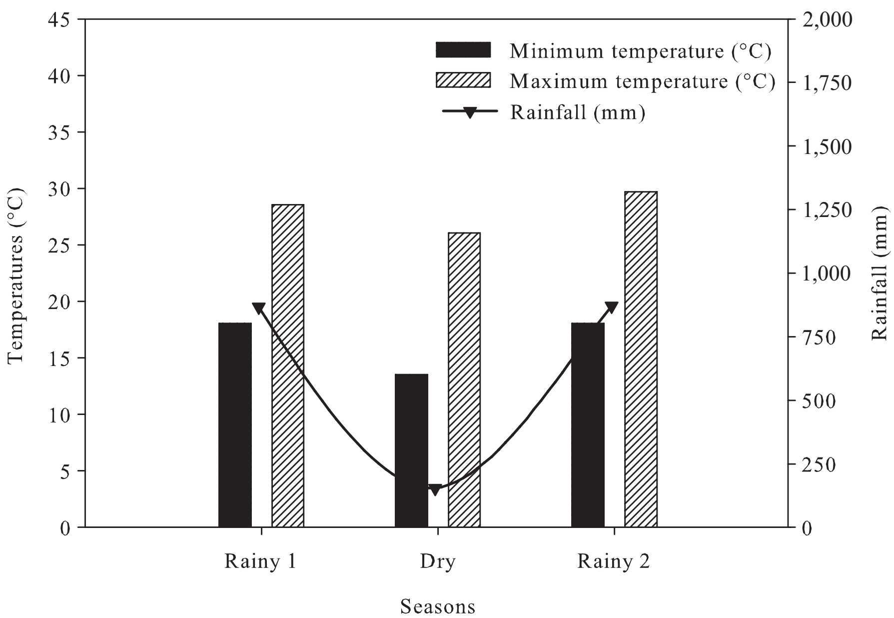


**FIGURE 2** Rainfall (mm) and minimum and maximum air temperatures (°C) during three seasons (rainy season 1, dry season and rainy season 2) at the experimental site

sowing, 200 kg/ha of 8–28–16 N–P–K formulation was applied. The seeding rate of *U. decumbens* was 8 kg/ha of pure live seeds on straw in the no-till system. For maintenance fertilization, 300 kg/ha of 20–5–20 formulation ($N_2$, $P_2O_5$ and $K_2O$), divided into six applications of 50 kg nitrogen/ha, was applied during the rainy seasons.

## 2.3 | Treatments and experimental design

Four treatments, corresponding to the three pre-grazing canopy LI targets in the SPS of 90%, 95% and 100% LI and 95% LI in OP (*U. decumbens* under full sunlight), were evaluated over three seasons—two rainy seasons and one dry season—defined as follows: rainy season 1 (from 1 October 2013 to 19 March 2014; 169 days), dry season (from 20 March 2014 to 21 September 2014; 185 days) and rainy season 2 (from 22 September 2014 to 5 April 2015; 195 days). We used a randomized block design (two blocks) with two replicates within a block ($n$ = 4), and season was considered a repeated measure. The experimental area of 0.32 ha was subdivided into 16 paddocks of approximately 200 $m^2$ (12 paddocks in the SPS and 4 paddocks in the OP) distributed in two blocks (Figure 1). Given the influence of the shade projected by the SPS tree canopy, a distance of ~30 m was kept between the SPS and OP paddocks.

## 2.4 | Tree measurements and shade percentage

Height and diameter at breast height (DBH) of 30% of the SPS trees were recorded during the rainy seasons. Height measurements were estimated using a digital clinometer, and the circumference of the tree was measured 1.30 m from the soil surface with a dendrometer tape to obtain DBH. The height of eucalyptus trees ranged from 22.3 to 28.4 m, and DBH ranged from 21.6 to 27.1 cm in the rainy seasons.

In rainy season 1, dry season and rainy season 2, the shade in SPS was 40.5%, 45.6% and 44.1% respectively. Shade was estimated once during each season, by taking measurements of photosynthetically active radiation every 30 min from 09:00 to 15:00 hr at 1 m above ground level using a ceptometer (Decagon LP-80 AccuPAR). Twenty-seven readings were taken per block below the canopy of trees, with nine readings intra-row, nine readings in the middle part of the inter-row and nine readings at an intermediate position between the row of trees and the centre of the inter-row. For each group of nine measurements taken within the SPS, two other measurements were taken under full light conditions, in order to calculate the percentage of shading.

## 2.5 | Grazing management

Light interception was monitored three times a week (at 2-day intervals) to ensure that targets were achieved with greater precision and accuracy. Canopy height was evaluated for each LI condition in the SPS and OP. Grazing was initiated when average LI in the four replicate paddocks reached the treatment target. All paddock replicates achieved the target LI very close in date, no more than two days apart. The post-grazing canopy height target was defined as 50% of the pre-grazing canopy height based on studies which suggested that a 40%–50% forage removal threshold could be used to maintain the instantaneous herbage intake rate at its maximum (Fonseca et al., 2012). Grazing was applied to simulate rotational stocking (mob stocking; Allen et al., 2011). In each paddock, five crossbred steers (Holstein × Zebu), with a mean body weight of 450 ± 10 kg, were used for defoliation after fasting for 12 hr. Grazing lasted 1–4 hr until a stubble height of 50% of the pre-grazing canopy height was attained. The number of grazing cycles (i.e. regrowth intervals) corresponded to the number of times the pasture was submitted to grazing. The rest period (days) was defined as the time required for the grazed pasture to reach 90%, 95% or 100% LI in the SPS or 95% LI in the OP.

## 2.6 | Light interception, canopy height, leaf area index and specific leaf area

Pre-grazing LI was measured from 05:30 to 07:30 hr using an LAI 2000 canopy analyzer (LI-COR), with one reading taken with the sensor levelled above the forage canopy and two readings taken at ground level. This sequence was performed at each paddock evaluation point. Nine points per experimental unit were used, totalling nine readings above the forage canopy, and 18 readings taken at soil level. For SPS, LI readings were taken in the 90%, 95% or 100% LI targets, with evaluation points divided into three strata and three points per stratum, from the trunks of the tree row (up to 2 m, between 2 and 4 m, and at the centre of the inter-row).

Canopy height was measured before and after grazing at 21 sites per paddock using a sward stick (Barthram, 1985). Height was measured from ground level to the insertion of the last fully expanded leaf, avoiding areas around gates, watering points and resting sites. In the OP, these measurements were taken at random in each paddock. In the SPS, seven measurements were made at distances of 2, 2–4 and 5 m from the trunks of trees in the tree row. Canopy height was also monitored during grazing to assure the established post-grazing target.

The leaf area index (LAI) was estimated from a subsample of the sample taken to determine tiller population density (TPD). For this, 100 segments, each 10-cm long, were cut from leaf blades, and the sum of the average width of all the segments was multiplied by 10 cm for estimating the leaf area of the subsample. The measured segments were oven-dried at 55°C for 72 hr and then weighed to estimate their specific leaf area (SLA; Alexandrino, Gomide, Cândido, & Gomide, 2005). LAI was estimated from SLA and leaf blade mass, as described by Radford (1967).

## 2.7 | Herbage mass, morphological composition, herbage accumulation and tiller traits

Pre- and post-grazing herbage mass was measured using metal frames 0.25-$m^2$ (0.5 × 0.5 m) in size, with two samples taken per paddock, once for each grazing cycle. The frames were positioned at points representative of the average canopy height, and the forage contained within the frame was harvested with a manual cutter at 5 cm from ground level. The harvested samples were weighed and divided into two subsamples: one (500 g) for herbage mass evaluation, expressed on a dry-matter (DM) basis, and the other (300 g) for characterization of morphological composition, including leaf blade, stem (stem + leaf sheaths, inflorescences) and dead material (senescent leaves and stems with 50% dry tissue by area). To obtain the DM concentration, both subsamples were oven-dried at 55°C for 72 hr and then weighed. The values for the morphological components were expressed as a proportion of the herbage mass.

Herbage accumulation per grazing cycle was calculated as the difference between the pre-grazing mass of the current cycle and the post-grazing herbage mass in the previous cycle. Total herbage accumulation was estimated as the sum of herbage accumulation of each grazing cycle over the season. Leaf blade accumulation was estimated using the same calculations used for total herbage accumulation, but the post- and pre-grazing leaf blade mass were used.

A metal frame 0.0625-$m^2$ (0.25 m × 0.25 m) in size was used to estimate TPD; two tiller samples were collected by placing the frame at points representative of the average canopy height of the pasture in each paddock. The tillers contained within the frame were removed at 5 cm from ground level, counted and weighed.

### 2.8 | Nutritive value

Before grazing, the herbage mass above stubble height (50% of the pre-grazing canopy height) was collected to determine the nutritive value of forage consumed by the animals. The sward was clipped at four sites per paddock using a 0.5-$m^2$ (1.0 m × 0.5 m) rectangular metal frame with an adjustable base.

The samples were oven-dried at 55°C for 72 hr, weighed and ground in a Wiley mill (TE-648, Tecnal) to pass through a 1-mm screen. The standard analytical procedures of the Institute of Science and Technology in Animal Science (INCT-CA; Detmann et al., 2012) were used to quantify DM concentration (dried overnight at 105°C; method INCT-CA no. G-003/1), ash (complete combustion in a muffle furnace at 600°C for 4 hr; method INCT-CA no. M-001/1), crude protein (CP; by multiplying the Kjeldahl nitrogen by 6.25; method INCT-CA no. N-001/1) and neutral detergent fibre corrected for ash and protein (NDFap; corrected for residual ash and protein; method INCT-CA no. F-002/1). In vitro dry-matter digestibility (IVDMD) was determined according to Tilley and Terry (1963).

### 2.9 | Organic reserves

Water-soluble carbohydrates were the only variable evaluated just in the second year, and these evaluations were carried out and compared across the four seasons of the year (autumn, winter, spring and summer). Thus, at the end of each season 2014/2015, two root samples and stem bases were evaluated for organic matter (OM) concentration using a 15-cm-diameter steel cylinder, which was centred on the tussock crown and then introduced to a depth of 20 cm from the soil surface. The samples were standardized to a 10-cm depth, and the shoot cut-off at a height of 5 cm from ground level (stem base). Shortly after collection, the samples were washed in sieves (10-mm mesh) to remove the soil, and the base of each stem was separated from the roots. Samples were oven-dried at 105°C for 1 hr and then at 55°C for 72 hr. The dried stem base samples and roots were ground in a Wiley mill to pass through a 1-mm screen and were used to determine the CP concentration (INCT-CA no. N-001/1). Water-soluble carbohydrates (WSC) were analysed using glucose (Sigma-Aldrich) to create a standard curve (Nelson, 1944).

### 2.10 | Statistical analysis

Data were analysed using the mixed models procedure of SAS® version 9.1 (SAS, 2002; SAS Institute). All data sets were tested before the overall global analysis for conformity with the assumptions of analysis of variance. The model included canopy LI target and seasons, and their interaction as fixed effects, whereas the block effect was random. Treatment means were estimated using "LSMEANS," and means comparisons were performed using Tukey's test at $p < 0.05$. Although the basic principle of independence between plots was initially questioned (Figure 1) under the experimental design implemented, different covariance matrices were tested under a repeated measures framework (Littell, Henry, & Ammerman, 1998). The variance components (VC) matrix was chosen based on the Akaike information criterion (AIC).

## 3 | RESULTS

### 3.1 | Number of grazing cycles and rest periods

During rainy season 1, a total of 6, 5, 4 and 7 grazing cycles and rest periods of 30, 37, 48 and 26 days were observed for the 90%, 95% and 100% LI targets in the SPS and for 95% LI OP respectively. The lowest number of grazing cycles occurred in the dry season, with averages of 2, 2 and 1 for 90%, 95% and 100% LI targets in the SPS, respectively, and 2 for OP. For this season, the rest periods were 97, 103, 149 and 80 days respectively. Rainy season 2 had 5, 4, 3 and 6 grazing cycles and rest periods of 37, 44, 64 and 33 days for the 90%, 95% and 100% LI targets in the SPS and 95% LI for OP respectively. Rest periods were longer in the SPS than in OP, even at the lowest 90% LI target.

### 3.2 | Light interception, canopy height, specific leaf area and leaf area index

Pre-grazing canopy height was affected by the canopy LI targets ($p < 0.01$) and differed from one another. For 90%, 95% and 100% LI targets in SPS and 95% LI in OP mean pre-grazing and post-grazing canopy heights were 30.4, 39.7, 49.8 and 19.7 cm and 14.4, 20.7, 27.5 and 10.5 cm respectively. The highest canopy height was observed in the target of 100% LI (49.8 cm), followed by 95% LI (39.7 cm), 90%

LI (30.4 cm) in SPS and the lowest canopy height was observed in the target of 95% LI in OP. Actual values for pre-grazing canopy LI (90.8, 95.5, 97.6 and 95.1%) were consistent during the experiment for the 90%, 95%, 100% and 95% LI targets respectively.

Canopy LI targets influenced SLA ($p < 0.01$; Figure 3a) and LAI ($p < 0.01$; Figure 3c); SLA was greater in the SPS than in OP. In addition, season also influenced SLA ($p < 0.01$; Figure 3b) and LAI ($p < 0.01$; Figure 3d); SLA was reduced in the dry season, with no differences between the two rainy seasons. However, LAI was greater in OP than under 90% LI in the SPS. There was no difference in LAI between 95% and 100% LI targets in the SPS; LAI was greater under these targets than under 90% LI and 95% OP. Rainy season 2 had an increased LAI compared to rainy season 1, while the dry season had the lowest value.

## 3.3 | Herbage mass, morphological composition, herbage accumulation and tiller traits

There were interactions between canopy LI target and season ($p < 0.01$) for herbage mass and the proportions of leaf blades, stems and dead material (Figure 4). Herbage mass in the SPS was greater in rainy season 2 than in other seasons, except for the 100% LI target, which exhibited greater mass in the dry season and rainy season 2 (Figure 4a). In OP, herbage mass was highest in rainy season 2 and lowest in the dry season. The canopy target of 100% LI allowed for accumulation of greater herbage mass.

Among the canopy LI targets, SPS with 90% LI and OP with 95% LI showed a greater proportion of leaf blades (Figure 4b). The lowest proportion of leaf blades was in the SPS with 100% LI, irrespective of the season. The proportion of stems was lower in the dry season compared to both rainy seasons; in the two rainy seasons, the stem proportions were similar (Figure 4c). In general, pasture in the SPS had a greater proportion of stems than that in OP, except in the 90% LI target—there was no difference between OP and 90% LI. In the dry season, the proportion of dead material increased relative to the other seasons (Figure 4d). In addition, the 100% LI target had the greatest proportion of dead material compared to the other canopy LI targets in the dry season. On the other hand, differences only existed in the proportion of dead material in rainy season 2 ($p < 0.01$), with greater values observed in OP than in the SPS.

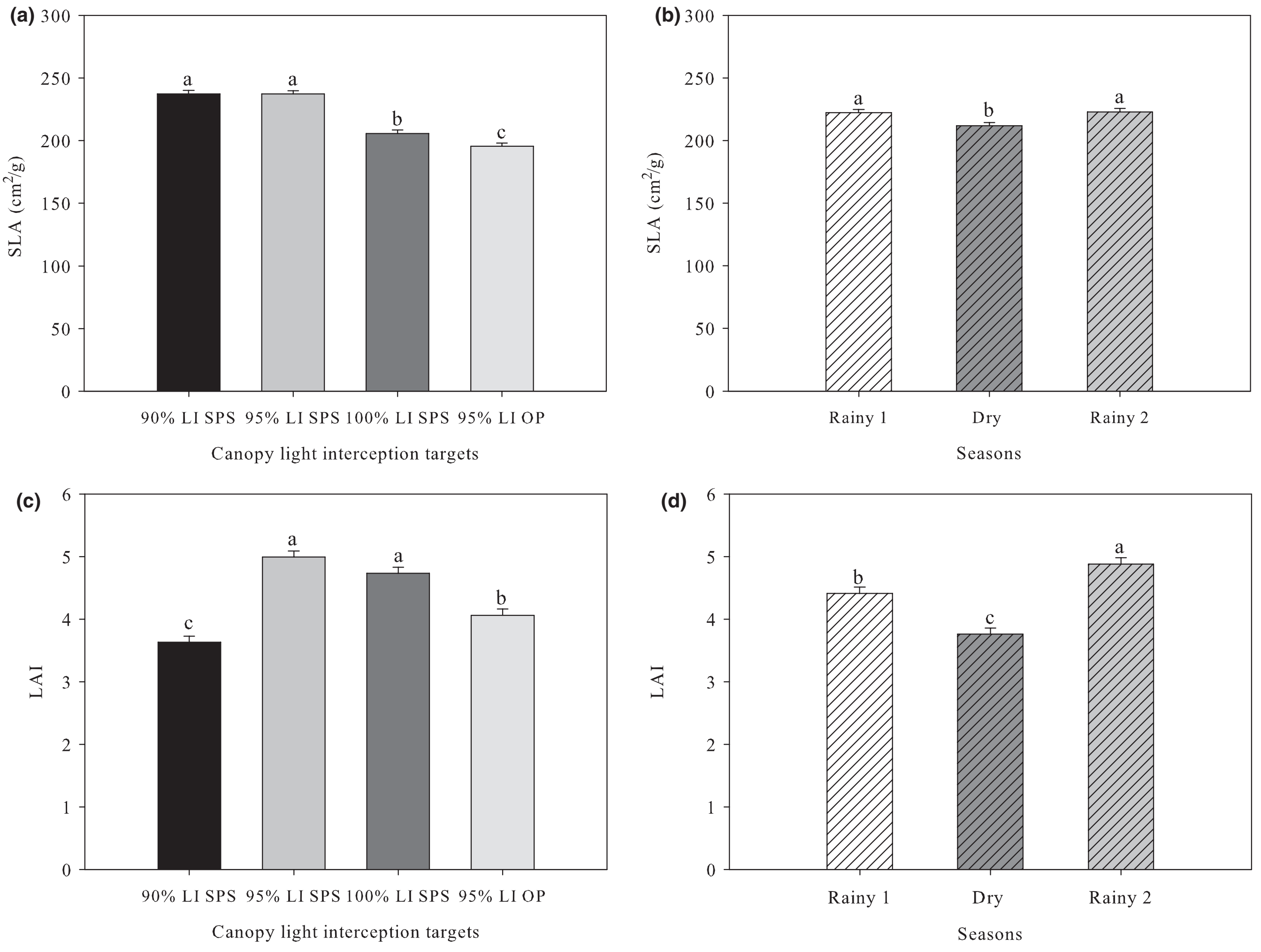


**FIGURE 3** Specific leaf area (SLA) and leaf area index (LAI) of *Urochloa decumbens* managed at 90%, 95% and 100% light interception (LI) in a silvopastoral system (SPS) and 95% LI in open pasture (OP) during rainy season 1, dry season and rainy season 2. Means indicated by different letters are different (Tukey's test; $p < 0.05$). Vertical bars indicate the standard errors of the means

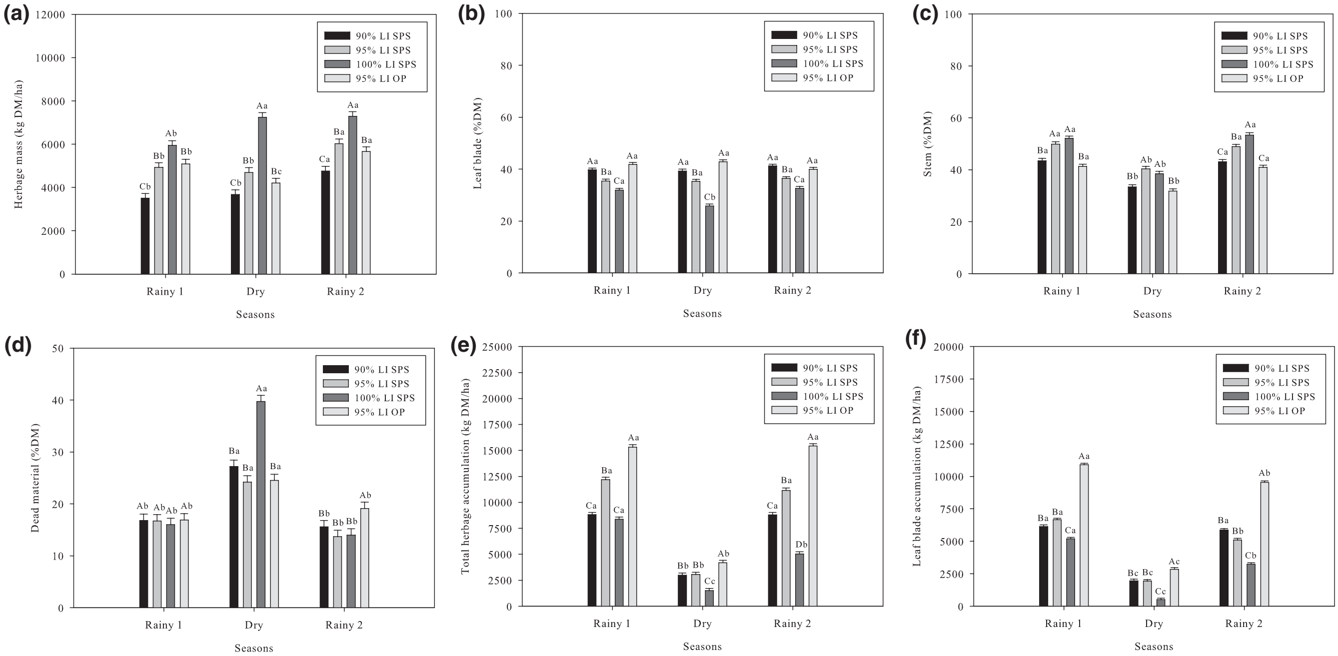


**FIGURE 4** Herbage mass and morphological composition of leaf blades, stems, and dead material, total herbage accumulation and leaf blade accumulation of *Urochloa decumbens* managed at 90%, 95% and 100% light interception (LI) in a silvopastoral system (SPS) and 95% LI in open pasture (OP) during rainy season 1, dry season and rainy season 2. Means followed by different letters, uppercase letters comparing the canopy LI targets in each season and lowercase letters comparing each canopy LI target in the seasons, are different (Tukey's test; $p < 0.05$). Vertical bars indicate the standard errors of the means

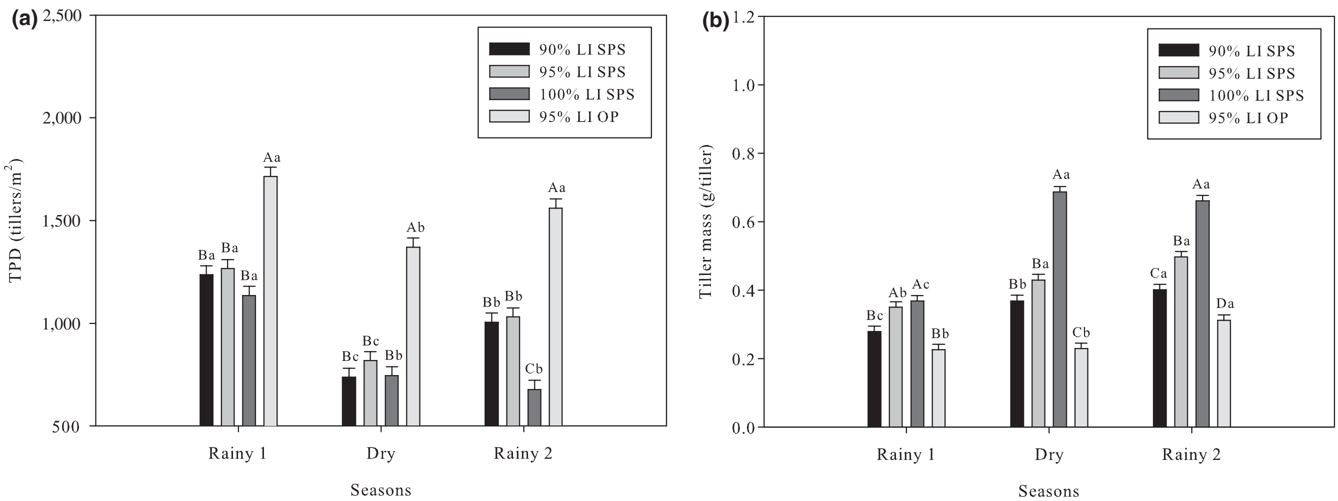


**FIGURE 5** Tiller population density (TPD) and tiller mass of *Urochloa decumbens* managed at 90%, 95% and 100% light interception (LI) in a silvopastoral system (SPS) and 95% LI in open pasture (OP) during rainy season 1, dry season and rainy season 2. Means followed by different letters, uppercase letters comparing the canopy LI targets in each season and lowercase letters comparing each canopy LI target in the seasons, are different (Tukey's test; $p < 0.05$). Vertical bars indicate the standard errors of the means

Total herbage accumulation and leaf blade accumulation were influenced by the interaction between canopy LI targets and seasons ($p < 0.01$; Figure 4e,f). The total herbage accumulation was lower in the SPS than in OP for all canopy LI targets and seasons. However, the reductions observed in SPS were less (20% and 28% respectively) compared to OP when the canopy was grazed at 95% LI in rainy season 1 and rainy season 2 (12,191 × 15,324 kg DM/ha and 11,158 × 15,424 kg DM/ha respectively). Leaf accumulation was the morphological component most adversely affected by shade, with a mean reduction of 39%, 32% and 46% in the SPS compared to OP for rainy season 1, dry season and rainy season 2 respectively (Figure 4f).

There was an interaction between canopy LI target and season for TPD ($p < 0.01$) and tiller mass ($p < 0.01$). A reduction in the tillering of plants cultivated in the SPS, compared to OP, was noted for all canopy LI targets and seasons (Figure 5a). TPD was lower in the dry season than in rainy season 1. At 90% and 95% LI targets, mean reductions of 27% and 34% were observed in rainy season 1 and rainy season 2, respectively, relative to OP. This reduction was even more pronounced (56%) in the 100% LI target in rainy season 2. Tiller mass was superior in the SPS than in OP, with greater values in the 95% and 100% LI targets in rainy season 2 (Figure 5b). In this season, the increase in tiller mass was 29%, 59% and 111% for the 90%, 95% and 100% LI targets, respectively, compared to OP.

### 3.4 | Nutritive value

There was an interaction between canopy LI target and season for CP concentration ($p < 0.01$; Figure 6a), with a reduction, especially in the SPS, in the dry season. Crude protein concentration was similar for SPS managed with 100% LI and 95% LI in OP and was lower when compared to the other targets in rainy season 1 and rainy season 2. Under 95% LI in SPS, CP concentration was 18 and 19% greater than that in OP in both rainy seasons (155 × 131 g/kg DM and 144 × 121 g/kg DM respectively). Neutral detergent fibre corrected for ash and protein concentration was influenced by the interaction ($p < 0.01$) between canopy LI target and season (Figure 6b). However, this difference was only seen in rainy season 1 when 100% LI allowed for an increase in the fibrous fraction. In vitro dry-matter digestibility was greater in OP than in the SPS (Figure 7a). In the SPS, the 90% LI target showed greater forage digestibility, followed by 95% LI and 100% LI. In vitro dry-matter digestibility was lower in the dry season ($p < 0.01$) than in rainy season 1 and rainy season 2 (Figure 7b). Mean IVDMD was 663 g/kg in the dry season and 693 g/kg in both rainy seasons.

### 3.5 | Organic reserves

The seasons did not influence CP concentration in the roots and stem base ($p > 0.05$); however, canopy LI targets had an influence, with greater concentrations in the SPS than in OP ($p < 0.01$; Figure 8). Water-soluble carbohydrate concentration in the stem base was not affected by canopy LI targets ($p > 0.05$). However, the interaction between canopy LI target and season had an effect on WSC in roots ($p < 0.01$; Figure 9). The concentration was greater in the winter, intermediate in the spring and autumn and lower in the summer. In addition, there was an increase in the percentage of WSC in roots with increased LI in the SPS. Silvopastoral system management with 95% LI allowed for a greater concentration than that achieved in OP in the autumn and winter, but WSC became similar in SPS and OP in the spring and summer. Management with the 90% LI target resulted in a lower WSC when compared to OP, except in the autumn. In addition, a greater WSC concentration was observed in the 100% LI target, except in the summer, when concentration was lowest in the 90% LI target.

## 4 | DISCUSSION

In general, the growth of *U. decumbens* was favoured during both rainy seasons, regardless of the LI targets, due to optimal climatic conditions (Figure 2); this was reflected in shorter rest periods and a greater number of grazing cycles. For the LI targets, pasture managed with greater LI had longer rest periods and fewer grazing cycles. Under favourable climatic conditions in which temperature and moisture do not restrict growth (Figure 2), light seemed to be the main limiting resource for herbage accumulation. Therefore, pasture in the SPS usually needs lower grazing frequency and decreased defoliation intensity than OP due to the time needed for

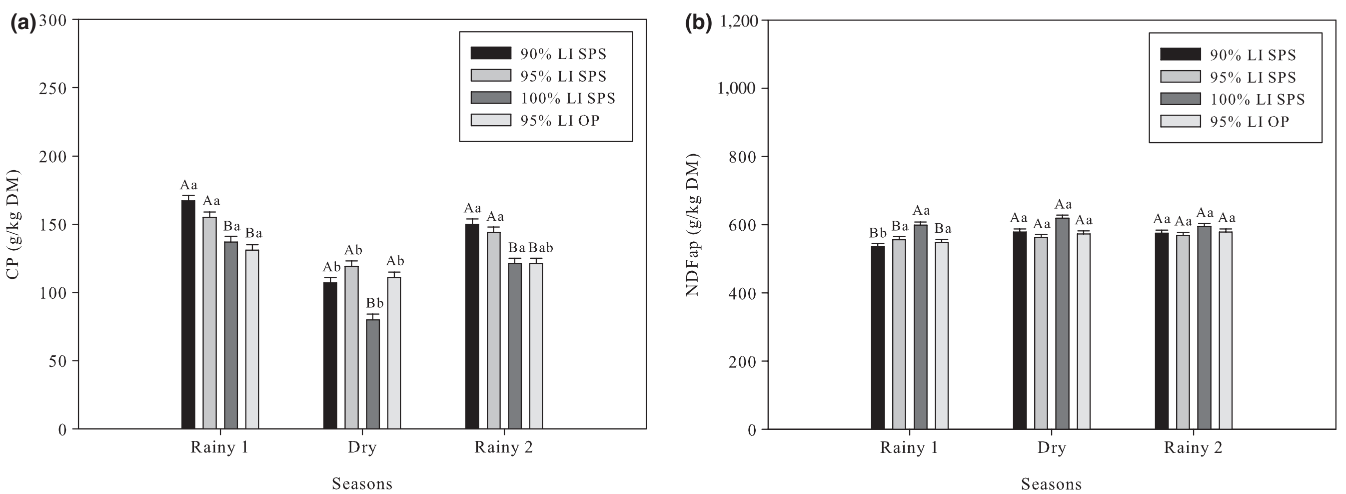


**FIGURE 6** Crude protein (CP) and neutral detergent fibre corrected for ash and protein (NDFap) concentration of *Urochloa decumbens* managed at 90%, 95% and 100% light interception (LI) in a silvopastoral system (SPS) and 95% LI in open pasture (OP) during rainy season 1, dry season and rainy season 2. Means followed by different letters, uppercase letters comparing the canopy LI targets in each season and lowercase letters comparing each canopy LI target in the seasons, are different (Tukey's test; $p < 0.05$). Vertical bars indicate the standard errors of the means

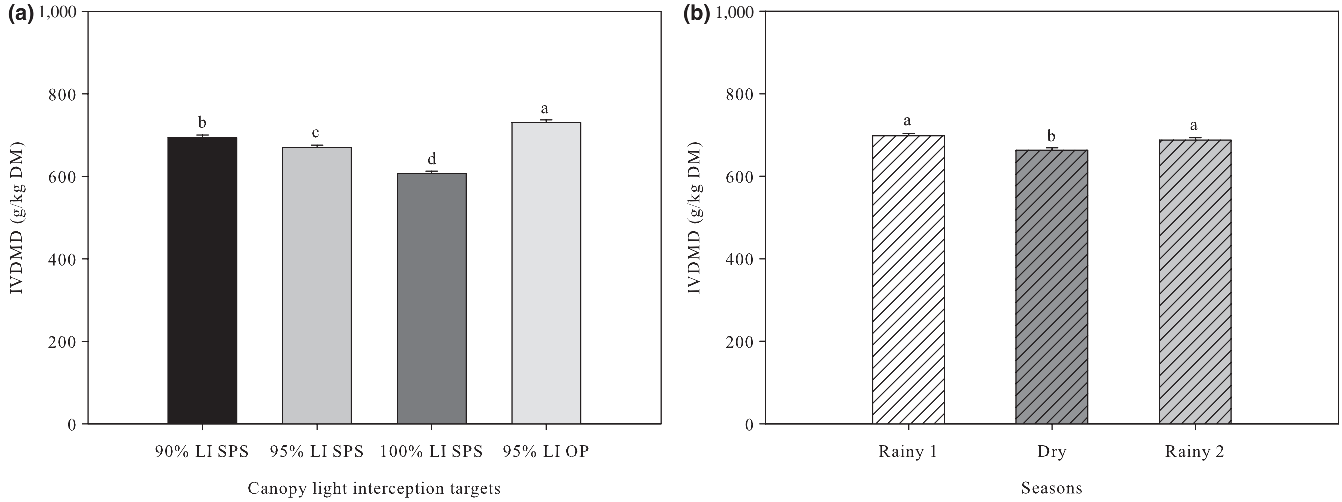


**FIGURE 7** In vitro dry-matter digestibility (IVDMD) concentration of *Urochloa decumbens* managed at 90%, 95% and 100% light interception (LI) in a silvopastoral system (SPS) and 95% LI in open pasture (OP) during rainy season 1, dry season and rainy season 2. Means indicated by different letters are significantly different (Tukey's test; $p < 0.05$). Vertical bars indicate the standard errors of the means

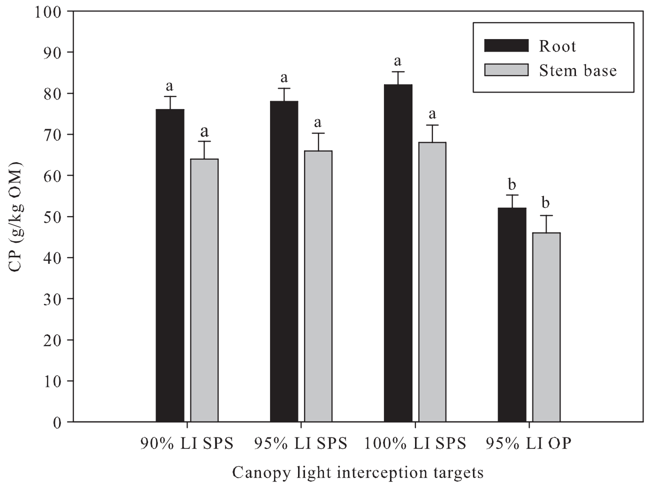


**FIGURE 8** Crude protein (CP) concentration in the roots and stem base of *Urochloa decumbens* managed at 90%, 95% and 100% light interception (LI) in a silvopastoral system (SPS) and 95% LI in open pasture (OP). Means indicated by different letters for root samples or stem bases are significantly different (Tukey's test; $p < 0.05$). Vertical bars indicate the standard errors of the means

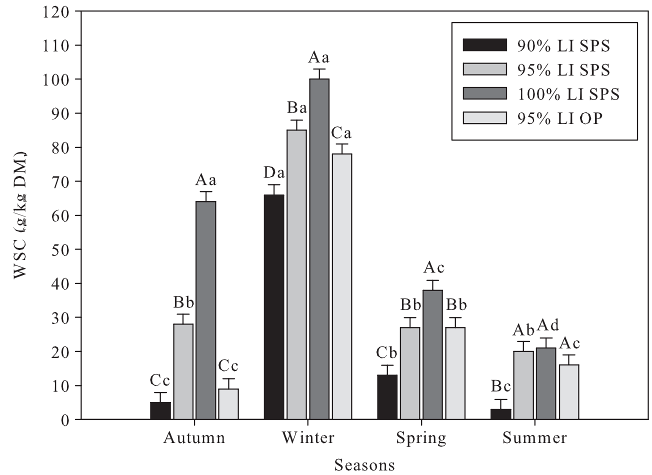


**FIGURE 9** Water-soluble carbohydrate (WSC) concentration in the roots of *Urochloa decumbens* managed at 90%, 95% and 100% light interception (LI) in a silvopastoral system (SPS) and 95% LI in open pasture (OP) in each season. Means followed by different letters, uppercase letters comparing the canopy LI targets in each season and lowercase letters comparing each canopy LI target in the seasons, are different (Tukey's test; $p < 0.05$). Vertical bars indicate the standard errors of the means

leaf regeneration when light is a limiting resource (Belesky, Burner, & Ruckle, 2011). On the other hand, in the dry season, minimum temperatures below 15°C and lower rainfall probably restricted herbage accumulation more than shade per se as grazing cycles were similar for 90% and 95% LI targets in the SPS and 95% LI in OP.

The tallest canopies in the SPS were associated with a low TPD (Figure 5), resulting in reduced capacity for canopy light interception. Thus, increased radiation interception in shaded pasture is conditioned by increases in leaf and stem elongation rates (Baldissera et al., 2016). Stem elongation is the result of a competitive light environment, wherein plants position leaves at the top of the sward, achieving greater heights leading to higher probability of LI, as demonstrated in the present study. Therefore, in the SPS, canopy height (40 cm) needed to be twice that in OP (20 cm) to intercept 95% of the light.

The greater SLA in the SPS than in OP (Figure 3) is consistent with previous observations (do Nascimento et al., 2019; Santos et al., 2016). Leaves become thinner under shade, presenting a larger leaf area per unit of leaf mass. In general, these changes increase the interception of incident light, thereby increasing the photosynthetic efficiency of the plant (Gomes et al., 2020). Furthermore, SLA was reduced in grass managed at 100% LI compared to 90% and 95% LI. Under OP conditions, reductions in SLA with the advancing regrowth period were also noted by Oliveira et al. (2000). The increase in SLA enabled grass managed at 95% LI in the SPS to obtain a higher

LAI in comparison to OP, despite the lower proportion of leaves (Figure 4b). However, the lack of increase in LAI under 100% LI indicated that maximum LAI was reached when the grass was managed at 95% LI. Leaf area index is determined by tiller population density, number of leaves per tiller and leaf size (leaf lamina area). Although the rest periods were longer for 100% LI, the leaf proportion (%) and accumulation (kg DM/ha) were greater for 95% LI, which may have resulted in no difference in LAI between these two canopy LI targets in the SPS. In addition, there was a marked decrease in tiller population density under 100% LI in rainy season 2 which also may have contributed to this result.

The lower LAI in the SPS managed at 90% LI, when compared to OP, was not accompanied by any change in biomass allocation to stems. Specific leaf area and LAI were lower in the dry season due to the reduction in rainfall and temperature observed in this period leading to a reduction in the growth of forage (Figure 3b,d).

Regarding the rainy seasons, there was a significant increase in herbage mass in rainy season 2, particularly in the SPS (Figure 4a). This indicates that plants modified their structure in response to grazing management, increasing overall mass through an increase in tiller mass (Figure 5b). However, the microclimate provided by the arboreal component in the SPS may have contributed to greater plant growth during the seasons. When managed at the 95% LI target, herbage mass was composed of a greater proportion of stems and a smaller proportion of leaf blades in the SPS compared to OP. On the other hand, management with the 90% LI target allowed a morphological composition equivalent to that in OP (Figure 4b,c,d). Pasture with a high proportion of stems have an undesirable structure for the grazing process, as well reduced nutritive value. Thus, the control of stem development has often been studied under full sunlight conditions (Carnevalli et al., 2006; Pedreira, Braga, & Portela, 2017), and altering the frequency of grazing based on LI has been established as an effective strategy for control of stem development. For the SPS, the highest grazing frequency (at 90% LI) was also effective in controlling canopy structure.

The interruption of regrowth at 95% LI is based on reaching the critical LAI, which would result in greater herbage accumulation with a higher proportion of leaves and a lower proportion of stems and dead material. As LAI increases and LI exceeds 95%, plants change their growth pattern to optimize light interception due to increased competition for light within the canopy and stem elongation and dead material accumulation (Carnevalli et al., 2006).

This pattern of response was not observed in the SPS when managed at 95% LI (i.e. 40-cm canopy height). Under this condition, pasture presented significant increases in the proportion of stems, indicating the possibility of reaching the critical LAI. Control of stem growth was achieved with 90% LI, at a canopy height of 30 cm. However, 95% LI had greater total herbage accumulation than 90%LI with no differences in leaf blade accumulation.

The proportion of dead material varied little with canopy light interception target; however, increases were observed in the dry season (Figure 4d). Management using higher LI (100%) is expected to show greater senescence (Carnevalli et al., 2006; Santana et al., 2017). Nonetheless, plant trampling during grazing contributes to increased forage senescence, especially in more frequently grazed canopies (lower LI), wherein damaged plant parts are included in dead material. Hence, the effect of maturity on senescence in taller pasture (higher LI) is likely to have been offset by the effect of more frequent grazing on shorter pasture. Moreover, there is evidence to suggest that shading delays plant maturation (Neel, Felton, Singh, Sexstone, & Belesky, 2016).

In general, herbage accumulation was satisfactory in *U. decumbens*, a species considered to be less productive, and is not much recommended for more intensive systems, such as rotational stocking. Paciullo et al. (2007) noted a 53% reduction in the dry mass of *U. decumbens* produced under intense shade (65%) and an 8% reduction under moderate shade (35%), when compared to OP under the same grazing management. However, in our study, the 95% LI (40 cm) lessened the negative effect of radiation reduction on the SPS. For this target, the difference in total herbage accumulation between the SPS and OP was 24% in rainy seasons, but was more pronounced (27%) in the dry season, indicating possible competition for water between the tree and pasture (Figure 4e) and an effect of low minimum temperature (Figure 2). The higher total herbage accumulation associated with 95% LI than with 90% LI was possibly due to the increase in stem yield, as shown by leaf blade accumulation (Figure 4f), for which no differences were observed between the two LI targets in the SPS. Therefore, there is evidence to suggest that an increase in stem height already occurs when the plant intercepts 95% light in the SPS with a high level of shade (40%–45%).

Tiller population density in the SPS was reduced by an average of 30% in the rainy season, at 90% and 95% LI (Figure 5a), compared to that in OP. The reduction in tillering is related to lower light availability, and there is an inverse relationship between shading level and tiller density (Paciullo et al., 2017). This reduction in TPD can be attributed to the allocation of photoassimilates to pre-existing tillers to the detriment of new tillers (Belesky et al., 2011). Lima et al. (2019a) detected a 20% reduction in the number of *U. decumbens* tillers when grown under 51% shade in the rainy season. However, in the 100% LI target in this study, there was a 50% decrease in tillering as a result of greater competition for light between tillers. Matthew, Lemaire, Hamilton, and Hernandez-Garay (1995) support the existence of a compensation mechanism between tiller mass and density, in which the reduction in TPD results in heavier tillers. In our study, this mechanism was apparent in the comparison of the 100% LI target to the other treatments. The canopy LI target of 90% resulted in lighter tillers, with no corresponding increase in TPD, compared to 95% LI. Such a result provides evidence to support the limitation in this compensation mechanism in the SPS. It is unlikely that management for very low sward height would favour tillering since the light restriction caused by the tree component in the SPS is the greatest modulator of the tillering process. Overall, tiller mass was greater in the SPS than in OP, which was a result of management for greater canopy height (Figure 5b). Moreover, as Pedreira, Mello, and Otani (2001) suggested, allocation of more assimilates to tiller growth (especially stems) to the detriment of new tiller development is a common mechanism in forage cultivars under light restriction.

The CP concentration was higher in pasture managed at 90% and 95% LI in the SPS, compared to OP, except at 100% LI (Figure 6a). The highest CP concentration in the SPS, compared to OP, was similar to the concentrations obtained in other studies (de Carvalho et al., 2019; Lima et al., 2019a; Santos, Guimarães Júnior, Vilela, Maciel, & França, 2018). There are several hypotheses for increased nitrogen concentration in shaded leaves. Wilson (1996) suggested that it is associated with the greater decomposition and mineralization of soil OM due to the higher humidity of the soil. Other explanations are an increase in chlorophyll concentration, delay in physiological maturity and accumulation of nitrates (Guenni, Romero, Guédez, de Guenni, & Pittermann, 2018; Neel et al., 2016). The need to maintain pasture at relatively earlier physiological stages may be attributed to the lack of variation in CP between 90% and 95% LI in the SPS.

Canopy LI targets did not have an effect on NDFap, except for the 100% LI target, which showed an increase in the fibrous fraction (Figure 6b) due to the most advanced stage of maturity and, consequently, a greater proportion of stem and a lower proportion of leaves in the herbage mass. However, results from the literature for $C_3$ and $C_4$ grasses are somewhat contradictory; in some studies, shade did not affect the neutral detergent fibre (NDF) concentration (de Carvalho et al., 2019; Geremia et al., 2018; Neel et al., 2016). While CP concentration usually increases with shading, fibrous fraction and digestibility do not present a defined pattern, and the results depend on forage species, shading level, seasons, stage of maturity and forage management (Lima et al., 2019a; Neel, Feldhake, & Belesky, 2008).

In vitro dry-matter digestibility was lower in the SPS than in OP (Figure 7a). As LI increased, which was accompanied by longer grazing intervals, IVDMD was lower than that estimated for 90% LI. Digestibility is reduced because of the thickening and lignification of cell walls as the regrowth period advances (Wilson, 1996). In the literature, there is no consensus on the effect of shade on IVDMD of forage, with increase (Paciullo et al., 2007), a decrease (Santos et al., 2018) and no impact (Limaet al., 2019a) noted. The differences observed in IVDMD between the SPS and OP were associated with the plant's morphological composition. A greater proportion of leaves and a lower proportion of stems in OP were reflected in greater forage digestibility, when compared to SPS managed with 95% LI. Another explanation may be associated with lower fibre digestibility since the two systems had similar in NDFap concentrations. Wilkinson and Beard (1975) reported that plants grown under shade develop vascular tissue mainly composed of lignin; this has been corroborated by later investigations that showed increased concentration of lignin in shaded forage than in their unshaded counterparts (Kyriazopoulos, Abraham, Parissi, Koukoura, & Nastis, 2013). It is noteworthy that decreased digestibility may lower forage consumption, due to the reduced passage rate (Mertens, 2010). However, changes in the microclimate in the SPS may generate more favourable conditions for thermal comfort of animals under tropical conditions and stimulate forage intake (Sousa et al., 2010). Regarding the seasons, IVDMD was lower in the dry season than in the two rainy seasons, probably due to the longer rest periods and consequently, most advanced stage of maturity and greater proportion of dead material in the herbage mass (Figure 7b). These changes no effected on IVDMD in the rainy seasons. Similar results were observed by Santos et al. (2018).

In general, an SPS managed at 90% or 95% LI targets would provide a diet of good nutritive value (similar to the forage produced under full sunlight conditions) with modest reductions in IVDMD and higher CP concentrations.

In addition, it is reasonable to assume that comparisons of the nutritive value of forage in managed SPS and OP with the same height or frequency of defoliation are inconsistent and provide little knowledge into the effects of shade on nutritive value.

The CP concentration in roots and stem bases was greater in the SPS than in OP (Figure 8); CP concentration was greater in the autumn and winter than in the spring and summer. The mechanism inducing higher CP concentrations in storage structures in the SPS is likely to be different from that in leaves since the magnitude and interaction with environmental factors occur in different ways in the different morphological structures.

The WSC concentration in roots was influenced by both canopy LI target and season (Figure 9). Under conditions of low accumulation rates, the turgor pressure causing cell expansion and formation of new tissues is reduced, allowing photoassimilates to be stored in storage structures. However, in seasons with increased temperature and precipitation, there is a decrease in WSC reserves, as energy demands are increased to support high accumulation in grass. Similar result was reported by Carvalho et al. (2001), where carbohydrate reserves were more consumed in the period most conducive to plant growth.

The canopy LI target of 90% resulted in a lower WSC concentration in roots, except in the autumn when the concentration in OP was similar to that found for this treatment (Figure 9). A close relationship existed between LAI and WSC concentration. The LAI of the 90% LI target was lower than that of OP (Figure 3), despite lower frequencies of defoliation and greater canopy height. In shaded environments, plants need more time to recover their reserves, as the low incidence of light decreases the photosynthetic rate and, consequently, the production of photoassimilates. Thus, there seems to be a greater interdependence between leaf area and WSC concentration in the SPS than in OP. This implies that the canopy height suitable for OP is not the same indicated for SPS. However, too low grazing frequencies will result in low herbage accumulation and nutritive value.

Our study showed that rotational stocking management of *U. decumbens* in an SPS at pre-grazing LI of 90% may threaten pasture persistence, as it compromises the accumulation of reserve carbohydrates in roots, while pre-grazing LI of 100% increases the proportion of stems and deteriorates the sward structure. On the other hand, 95% LI results in increased herbage accumulation compared to 90% and 100% LI. Moreover, in the 95% LI target, CP concentration was higher than in OP in the rainy seasons, with no difference in WSC concentration. Therefore, this grazing management strategy is indicated for *U. decumbens* in an SPS with an average shade of 43%. Furthermore, our data show that the pre-grazing canopy height of *U. decumbens* at 95% LI in the SPS is greater than the recommended height in OP, since it was necessary for the canopy height of the former (40 cm) to be twice as much as that of the latter (20 cm) to intercept 95% LI. However, under on-farm conditions, the use of canopy height targets in SPS will only be effective if the shade level is maintained, which will likely reduce height variation over time, thereby minimizing reductions in pasture and animal production while increasing wood quality. Accordingly, tree management (e.g. spatial arrangement, pruning and thinning) throughout the canopy growth cycle should be planned to provide moderate levels of shade and sustain pasture productivity over time (Lima et al., 2019b).

Finally, further research on pasture intake and animal productivity remains necessary to evaluate the implications for the grazier of these *U. decumbens* grazing management strategies in SPS.

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## CONFLICT OF INTEREST

There is no conflict of interest in this study.

## ORCID

*Marina A. Lima* https://orcid.org/0000-0001-8993-9775
*Fernanda H. M. Chizzotti* https://orcid.org/0000-0002-5903-8172

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