Herbage accumulation, plant-part composition and nutritive value on grazed signal grass (*Brachiaria decumbens*) pastures in response to stubble height and rest period based on canopy light interception

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Abstract. Signal grass (*Brachiaria decumbens* cv. Basilisk, syn. *Urochloa decumbens* Stapf R.D. Webster) has been widely grown in the Brazilian tropics over the last 40 years, but management recommendations have been largely empirical and not based on canopy targets. This study was designed to characterise and explain the impact of canopy-based grazing strategies on herbage accumulation, plant-part composition, and nutritive value of signal grass. Treatments were factorial combinations of two stubble heights, 5 cm (SH5) and 10 cm (SH10), and two grazing frequencies, grazing initiated when 95% (LI95) and 100% (LI100) of incoming light was intercepted by the canopy. Rest periods were imposed during summer and autumn of both experimental years. Leaf blade accumulation was greater for LI100 than LI95 (9.5 v. 8.8 t/ha) associated with increased stem accumulation (4.6 v. 3.5 t/ha for LI100 v. LI95). The SH10 pastures produced more stem than SH5 pastures (4.4 v. 3.6 t/ha), with no difference in leaf blade accumulation. In general, SH10 pastures had more residual leaf blade mass post-graze, whereas SH5 pastures combined with higher grazing frequency (SH5-LI95) became more prostrate over time, increasing leaf blade proportion in post-graze forage. Over time, stubble height had more influence than grazing frequency on leaf blade proportion at pre-graze, and SH5 pastures had leafer canopies than SH10 pastures. Digestibility was less under LI100, especially when associated with SH5 stubble (SH5-LI95) became more prostrate over time, increasing leaf blade proportion in post-graze forage. Over time, stubble height had more influence than grazing frequency on leaf blade proportion at pre-graze, and SH5 pastures had leafer canopies than SH10 pastures. Digestibility was less under LI100, especially when associated with SH5 stubble (SH5-LI95), regardless of season of the year. To provide optimal leaf blade yield and overall forage digestibility, particularly during warm, rainy seasons, defoliation of signal grass should include pre-graze height varying from 18 to 30 cm (95–100% of light interception) and mean stubble height close to 10 cm.

Additional keywords: leaf area index, canopy height, crude protein, digestibility, brachiariagrass.

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Introduction

Signal grass (*Brachiaria decumbens* cv. Basilisk, syn. *Urochloa decumbens* Stapf R. D. Webster) is a decumbent perennial grass (Loch 1977), considered one of the major tropical forage C<sub>4</sub> grasses introduced from Africa, and responsible for increasing the average stocking rate from 0.3 to 1 animal per ha over the last 40 years in Brazil (Valle et al. 2010). Despite being highly susceptible to spittlebug (*Deois* sp. and *Zulia* sp.), signal grass is still used in beef cattle operations, owing to its high tolerance to acid, infertile soils (Rao et al. 1996) and because it is well adapted to stockpiling management (Euclides et al. 2007). Signal grass is also widely used throughout Latin America (Pizarro et al. 1996) and Australia and Southeast Asia (Stur et al. 1996). Average daily gain of individual steers (~300 kg liveweight) on signal grass pastures has been reported at 0.55 kg (at 3.5 steers/ha) in the warm, rainy season and 0.26 kg (at 2.5 steers/ha) in the cool, dry season (Euclides et al. 2001) in central Brazil.

Research-based recommendations regarding defoliation strategies for signal grass have not been widely available until recently (Braga et al. 2009; Santos et al. 2010; Portela et al. 2011). Canopy targets for rotational stocking were first developed for fixed rest (regrowth) periods, but proved to be of limited use for fine-tuning defoliation practice, because the growth rate does not remain constant across, or even within, seasons. Based on time schedules, fixed rest periods do not allow flexible regrowth periods according to prevailing environmental conditions and may result, for example, in excessive forage losses and the accumulation of unfavourably large proportions of stems in the forage on offer. If the initiation of grazing dictated by time intervals is excessively delayed under conditions of rapid growth,
excessive accumulation of stem, known to be avoided by grazing animals (Benvenutti et al. 2008), can occur. At the same time, it is important to ensure sufficient leaf area after grazing for fast regrowth following defoliation. Forage growth rate is largely determined by leaf area, and when available light is limited by self-shading, plants respond by elongating their stems (Korte et al. 1982).

Research into tropical grasses has suggested that regrowth intervals based on a specific canopy condition instead of fixed periods may help to reduce forage losses due to senescence as well as stem elongation due to excessively delayed harvest. This canopy condition has been proposed as occurring when 95% of the incoming radiation is intercepted by the forage canopy (Carnevalli et al. 2006). Additionally, it has been proposed that a relationship between light interception (LI) and canopy height exists, height being a practical and inexpensive criterion for use by producers (Braga et al. 2006). The qualitative responses (e.g. nutritive value) of Brachiaria grasses under rotational stocking, using LI-based criteria, may also support forage production with improved nutritive value (Nave et al. 2009).

The objectives in this study were to quantify and discuss the herbage accumulation and relative plant-part composition (leaf blade, stem and dead material) of the forage on offer pre-graze, and nutritive value descriptors, in signal grass pastures managed under contrasting levels of variable-rest managements and stubble heights under rotational stocking.

Materials and methods

Site and treatments

The research was carried out at the APTA (Agência Paulista de Tecnologia dos Agronegócios) Experimental Station in Brota, state of São Paulo, Brazil (21°59'S, 47°26'W; 650 m a.s.l.). The climate at the site is a subtropical Cwa, according to the Köppen-Geiger classification (Peel et al. 2007). The experimental area was in a 25-year-old pasture of signal grass cv. Basilisk. The soil at the site is a typic Quartzipsamments (Entisol) (Soil Survey Staff 1999) with 9% clay, 33% sand, 57% coarse sand and 1% silt. Chemical analysis in the 0–20 cm layer showed 4.2 mg/dm³ of resin phosphorus (P), 10 mmol/dm³ of calcium, 5 mmol/dm³ of magnesium, 0.9 mmol/dm³ of potassium (K), 28 mmol/dm³ of H+Al, 17 g/dm³ of organic matter, 36% base saturation and 4.9 pH(CaCl₂). Rainfall data were obtained by the Department of Environment of the City of Brota, and the maximum and minimum monthly average temperatures for the periods 1991–2006 and 2007–2008 were recorded at a weather station 45 km from the experimental site (Table 1).

Treatments included four factorial combinations between two stubble-height and two defoliation-frequency treatments. Stubble heights applied were 5 cm (SH5) and 10 cm (SH10). Defoliation frequencies corresponded to the rest periods until the canopy reached 95% (LI95) or 100% (LI100) of light interception. A 2 × 2 arrangement of treatments was set in a completely randomised design with four replications. The experiment was run from January 2007 to August 2008.

Pasture management and measurements

In November 2006, after mowing the pasture to 5 cm height, dolomitic lime (1.5 t/ha) and P (44 kg/ha as single superphosphate) were surface-applied to increase the base saturation to 40% and P to >15 mg/dm² (resin P) in a single application. The experimental area was divided by electric fence into 16 experimental plots measuring 80 m² (10 m by 8 m) each. The experimental period began on 23 January 2007. Mob stocking was used to impose defoliation to the experimental units according to their respective treatments. Two crossbreed steers per plot (each 650 kg liveweight) were used for imposing defoliation, always after overnight fast for solids. Grazing events lasted from 15 min to 2 h, and steers were not allowed to lie down on the vegetation. Measurements of light interception were taken immediately before and immediately after grazing by using a model LAI-2000 canopy analyser (Li-COR, Lincoln, NE, USA) at 10 sites per paddock, with one reading above the canopy taken for every five readings at soil level. During regrowth, LI was measured twice per week, the frequency increasing to every other day as the target LI approached. Because the level of 100% cannot be reached in measurements with the LAI-2000, LI was considered to be 100% when the canopy intercepted 99% of the incoming light or when two consecutive readings >97% were obtained. All replicate plots under the same LI treatment level were grazed on the same day (i.e. target LI was averaged over the four replicates for the same LI treatment). This procedure was adopted throughout

| Table 1. Monthly rainfall and temperatures during experimental period (2007–08), and average monthly rainfall and temperatures from 1983 to 2006 |
|---------------------------------|----------|----------|----------|----------|----------|----------|----------|
|                                 | Rainfall (mm) | Av. 2007 | 2008 | Max. temp. (°C) | Av. 2007 | 2008 | Min. temp. (°C) | Av. 2007 | 2008 |
| January                         | 322       | 536      | 237   | 30.1             | 29.6   | 29.4 | 19.9             | 19.9     | 18.6 |
| February                        | 258       | 203      | 266   | 30.3             | 31.7   | 30.5 | 19.8             | 19.0     | 18.8 |
| March                           | 196       | 196      | 198   | 30.3             | 32.0   | 30.9 | 19.2             | 19.4     | 18.2 |
| April                           | 98        | 86       | 142   | 29.3             | 31.3   | 29.4 | 17.0             | 18.5     | 16.6 |
| May                             | 96        | 85       | 58    | 26.0             | 26.4   | 26.4 | 13.5             | 12.6     | 12.2 |
| June                            | 40        | 15       | 37    | 25.8             | 27.8   | 25.9 | 12.8             | 13.1     | 12.1 |
| July                            | 38        | 212      | 0     | 25.9             | 24.9   | 27.7 | 12.2             | 11.6     | 11.7 |
| August                          | 34        | 0        | 56    | 28.2             | 29.1   | 29.9 | 13.5             | 12.8     | 14.2 |
| September                       | 81        | 2        | –     | 29.0             | 32.6   | –   | 15.2             | 16.1     | –   |
| October                         | 122       | 51       | –     | 30.3             | 32.2   | –   | 17.2             | 17.1     | –   |
| November                        | 161       | 219      | –     | 30.1             | 30.9   | –   | 18.0             | 16.2     | –   |
| December                        | 270       | 241      | –     | 30.1             | 30.1   | –   | 19.2             | 18.1     | –   |
the experimental period. Canopy height was measured before and after grazing at 15 sites per paddock in a systematic way following a grid-like pattern inside the plot and using a light-transparent acetate sheet (21 cm by 30 cm by 0.02 cm) as a reference of the canopy surface.

Immediately before grazing, the forage above the stubble height was clipped at three sites per plot, inside a 0.25-m² quadrat. The post-graze herbage mass (HM) was measured by clipping the forage inside two square 0.25-m² quadrats at soil level per plot, at sites representative of the current canopy height. Pre- and post-graze HM sampling was done mostly on the same day, and previously sampled sites were avoided in current sampling. From the pre- and post-graze samples, subsamples (~0.3 kg) were taken and separated into green leaf blades, green stems (true stems plus leaf sheaths) and dead material. Dead material was visually defined as senescent leaves and stems with ≥50% area of yellow or dry tissue. All samples were dried in an air-forced oven at 55°C for 72 h. Pre-graze HM was the sum of the HM above the stubble height and the post-graze (at soil level) HM. Ammonium sulfate and potassium chloride were used to provide 200 kg/ha of nitrogen (N) and 168 kg/ha of K. Fertilisers were split-applied at post-graze (at soil level) HM. Ammonium sulfate and potassium chloride were used to provide 200 kg/ha of nitrogen (N) and 168 kg/ha of K. Fertilisers were split-applied at post-graze (at soil level) HM. Ammonium sulfate and potassium chloride were used to provide 200 kg/ha of nitrogen (N) and 168 kg/ha of K. Fertilisers were split-applied at post-graze (at soil level) HM.

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The nutritive value of leaf blade samples collected above the stubble was assessed in order to detect differences in nutritive value in the most quality-sensitive component of plant parts, which is also predominant in the grazed strata of the canopy. Samples of leaf blade and whole forage above the stubble height were ground in a Wiley mill to pass a 1-mm screen and taken to the laboratory for chemical analyses. Organic matter (OM) was determined by ashing samples at 600°C. The Dumas combustion method was used to determine N concentration by using an automatic N analyser (LECO FP-528; Wiles et al. 1998). The crude protein (CP) concentration was calculated as N × 6.25. Neutral detergent fibre (NDF) and acid detergent fibre (ADF) concentrations were determined by the sequential method of the Ankom Fibre Analyser (Ankom Technology Corp., Fairport, NY, USA), described by Holden (1999). Concentration of in vitro digestible OM (IVDOM) was determined using the Ankom Fibre Analyser protocol, as described by Holden (1999).

Calculations and statistical analyses

Because the grazing frequency based on LI resulted in variable rest-period lengths and thus precluded synchrony between the two levels of frequency, data were balanced by seasons to rationalise the statistical analysis and assess the effect of season on the response variables. Because defoliations were concentrated in summer and autumn, plant-part composition and leaf blade nutritive value were studied in both 2007 and 2008 covering the following seasons: summer 2007 (23 January to 20 March), autumn 2007 (21 March to 20 June), summer 2008 (21 December 2007 to 20 March 2008) and autumn 2008 (21 March to 20 June). Whole-forage nutritive value was assessed in summer and autumn 2008. In order to balance the datasets so that all treatments had the same number of observations for statistical analyses, the response variables were weighted for the different seasons. For example, if a season included 3 months with two grazing events, then the variables related to these grazing events were considered as a single mean. Inevitably, certain grazing cycles (i.e. regrowth intervals) fell in two different seasons, and for such events, the variable effect for each season was proportional to the regrowth interval in each period. The original mean HM and their plant-part components are shown to describe the fluctuations in pre- and post-graze forage mass over time and to allow for the identification of each grazing event. Total herbage accumulation (leaf blade, stem and dead) was evaluated in the entire experimental period (Jan.–Aug. 2008).

The balanced data were analysed by using the Mixed Models procedure of SAS (Littell et al. 2006) with a special parametric structure in the covariance matrix. The covariance matrix was selected by using the Akaike information criterion (Wolfgang and O’connel 1993). Data were analysed by year so that stubble height, grazing frequency, season and their interactions were considered fixed effects, and seasons were considered repeated-measures (Littell et al. 2006). Total herbage accumulation data (leaf blade, stem and dead) were analysed by considering fixed effects of stubble height, grazing frequency and their interactions. Treatment means were estimated by using LSMEANS and were compared by using the probability of the difference (PDIFF) adjusted for Tukey test, using a significance level of P = 0.05. Model adjustments between transformed canopy light interception and height were evaluated by using the REG procedure of SAS. Post-graze canopy height distribution was assessed through histograms, and their mean, skewness, kurtosis and mode parameters were calculated for each treatment.

Results

Rainfall and temperature

Rainfall recorded in 2007 exceeded the 24-year average of the location in January, and more so in July (Table 1). In 2008, rainfall during the experimental period (January–August) was near average. Maximum temperature in 2007 was at least 1°C greater than average, and minimum temperatures were close to the 24-year average in 2007 and were ~1°C less in 2008, except for August.

Canopy height and herbage mass

For the treatments SH5-LI95, SH10-LI95, SH5-LI100 and SH10-LI100, mean post-graze canopy heights were 8.4, 11.7, 8.7 and 12.1 cm, respectively. Canopy height distribution was positively skewed for all treatments, and had a flatter distribution for SH10 (1.9 and 1.2 kurtosis for SH10-LI95 and SH10-LI100, respectively) than SH5 pastures (3.9 and 3.7 kurtosis for SH5-LI95 and SH5-LI100, respectively) (Fig. 1), although all were considered leptokurtic. Means were greater than the most common values (mode), which were closer (at 5, 10, 6 and 10 cm for SH5-LI95, SH10-LI95, SH5-LI100 and SH10-LI100, respectively) to the post-graze targets of the experiment. Most of the area (>50%) was grazed between 4 and 8 cm for SH5 pastures and between 8 and 13 cm for SH10 pastures, regardless of grazing frequency (Fig. 1). Fluctuations for herbage mass components during the experimental period were obtained by linking the means in each rest period (Fig. 2). For example, from late December 2007 to January 2008, the stubble mass was markedly affected...
by grazing intensity (1110 vs. 1980 kg/ha for SH5 and SH10 stubble, respectively). In this period (reproductive phase of signal grass), the pre-graze stem mass was 1270 and 940 kg/ha for LI100 and LI95, respectively, and there were no major differences in stem mass between stubble height treatments (1080 vs. 1120 kg/ha for SH5 and SH10, respectively), and stem proportion was the same (36%) for all treatments. The leafiest pre-graze swards in that period were SH5-LI100 (1240 kg/ha of leaves, or 35% of total HM) and SH5-LI95 (1010 kg/ha of leaves, or 41% of total HM), whereas amount of dead material was higher for SH10-LI95 (1060 kg/ha, or 39% of HM) and SH10-LI100 (1590 kg/ha, or 43% of HM). Mean pre-graze herbage mass was affected by grazing managements and averaged 1990, 2720, 2550 and 3530 kg/ha for SH5-LI95, SH10-LI95, SH5-LI100 and SH10-LI100, respectively. At post-graze, HM was 740, 1670, 930 and 1830 kg/ha for SH5-LI95, SH10-LI95, SH5-LI100 and SH10-LI100, respectively. In the first 6 months of the experiment (Jan.–June 2007), there was an increase in dead material for all treatments, but this was more pronounced for SH10-LI100. From that point onwards, dead proportion stabilised, regardless of treatment, but more variation in dead mass between pre and post-graze occurred for SH5-LI100.

**Defoliation events and length of rest periods**

For the SH5-LI95, SH10-LI95, SH5-LI100 and SH10-LI100 treatments, the number of grazing events was 10, 13, 7 and 9, respectively (Fig. 2). The last defoliation of the experimental period was made on 29 August 2008, simultaneously for all treatments, and was not considered a valid grazing event because pastures did not reach their respective pre-graze targets (95% or 100%). During the 584 days of the experimental period, the average rest periods were 53, 42, 73 and 58 days for SH5-LI95, SH10-LI95, SH5-LI100 and SH10-LI100 treatments, respectively. In summer 2007, rest periods were shortened to 39, 33, 44 and 42 days, whereas in the summer 2008 they were 32, 27, 45 and 38 days.

**Herbage accumulation**

There were effects of grazing frequency and stubble height on total herbage accumulation ($P<0.05$), and these effects were greater for pastures under the LI100 frequency and the SH10 stubble (Table 2). Leaf blade accumulation was affected by grazing frequency ($P<0.05$), and LI100 pastures produced an additional 0.7 t/ha of green leaf blade compared with LI95, regardless of stubble height. Similar to leaf blade, stem accumulation was affected by grazing frequency ($P<0.05$), increasing 1.1 t/ha from LI95 to LI100, whereas for stubble height, there was an increase ($P<0.05$) of 0.8 t/ha in stem from SH5 to SH10. There was a grazing frequency x stubble height interaction effect on dead material accumulation ($P<0.05$), with greater values for LI100 pastures, and even greater when associated with SH10.

**Plant-part components**

Proportions of plant components were affected by the season x grazing frequency x stubble height interaction ($P<0.05$) both post- and pre-graze. In summer 2007, SH10 pastures had a greater leaf blade proportion post-graze than SH5 pastures, whereas in autumn 2007, SH5-LI95 was similar to SH10-LI95, where leaf blade proportion was close to 15% (Table 3). In 2008, LI95 pastures presented a greater leaf blade proportion post-graze than LI100 pastures. Post-graze dead material proportions increased during the course of the experiment and peaked in autumn 2008, when stem proportions were small. In 2007, the lower pre-graze leaf blade proportion of SH10 pastures was restricted to LI100 pastures. When plotted against the taller stubble (SH10) had a smaller pre-graze leaf blade proportion (32%), whereas in pastures grazed to the shorter stubble (SH5),

**Fig. 1.** Post-graze canopy height frequency distribution for (a) SH5-LI95, (b) SH10-LI95, (c) SH5-LI100, and (d) SH10-LI100 treatments in Brotas, SP, Brazil. SH5, SH10: Stubble height 5 and 10 cm; LI95, LI100: grazing frequency grazing initiated at 95% and 100% canopy light interception.
leaf blade was 46% of the pre-graze mass, regardless of grazing frequency. Differences between LI levels were found in summer 2007, with greater leaf blade proportion for LI95 than LI100 in the SH10 stubble. In the second summer (2008), however, leaf blade proportion was higher for LI95 than LI100 at the SH5 level. The pre-graze stem proportion in the first summer (2007) for the SH10-LI100 treatment was higher than that of SH5-LI100. In general, stem proportion started to decline in autumn 2007, with higher values found for SH5-LI95 than for SH5-LI100. In summer and autumn 2008, SH10 pastures had greater stem proportion than SH5 pastures, regardless of grazing frequency.

Leaf area index

Post-graze leaf area index (LAI) was affected by a season × grazing frequency × stubble height interaction (P < 0.05, Table 3). SH10 pastures had greater LAI than SH5 pastures, regardless of season. Post-graze LAI of LI95 pastures was less than of LI100 in summer 2007. In autumn 2007, however, post-graze LAI was greater for LI100 than LI95 only in SH10 pastures. In 2008, the opposite occurred, with LI95 resulting in a 2–3-fold increase in post-graze LAI from autumn 2007 onward. Pre-graze LAI was affected by a season × grazing frequency × stubble height interaction (P < 0.05, Table 4). In summer and autumn 2007, pre-graze LAI was greater in SH10 pastures and for LI100 frequency than SH5 and LI95, respectively. By contrast, there was an advantage of SH5 over SH10 stubble in summer 2008, whereas in autumn 2008, the highest pre-graze values of LAI were found for SH5-LI95 and SH10-LI100 pastures.

Nutritive value

Concentrations of IVDOM, CP, NDF and ADF in leaves were affected by a season × grazing frequency × stubble height interaction (P < 0.05). Leaf blade IVDOM was greater in forage from pastures grazed to SH10 than from those grazed to SH5, regardless of grazing frequency (Table 5). For all seasons in both years, SH5-LI100 resulted in lower IVDOM concentration than SH5-LI95 (means 490 vs. 587 g/kg, respectively). At the SH10 stubble height, an effect of frequency on IVDOM was found only in autumn 2007, with greater values for LI95. The leaf blade CP concentration in summer 2007 was greater for SH10 (mean 142 g/kg) than SH5 (mean 121 g/kg). The opposite occurred in summer 2008, because of higher CP concentration in SH5 (mean 149 g/kg) than SH10 (mean 133 g/kg). In the first summer, CP was always greater for the LI100 frequency, whereas in the second summer, an effect of frequency was only found for SH5 stubble, with greater values for SH5-LI95. The SH5-LI95 treatment resulted in lower NDF concentration in leaves during summer 2007.
(P<0.05) compared with the SH5-LI100 and SH10-LI95 treatments (Table 5). In autumn (2007 and 2008), SH10-LI95 resulted in lower leaf blade NDF concentration than SH10-LI100. In this season, leaf blade NDF was lower at LI100 frequency on pastures grazed to SH5 than SH10, in contrast with summer 2008. Leaf blade ADF concentrations were lower for SH5-LI95 in summer 2007 than the other treatments. In the second autumn, ADF concentration was lower in LI95 than in LI100, regardless of stubble height.

For the whole-forage IVDOM and CP concentrations, a season × grazing frequency × stubble height interaction was found (P<0.05) (Table 6). The mean IVDOM for the SH5-LI100 treatment was the lowest compared with the other three treatments, whereas the effect of grazing frequency varied with

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(P<0.05) compared with the SH5-LI100 and SH10-LI95 treatments (Table 5). In autumn (2007 and 2008), SH10-LI95 resulted in lower leaf blade NDF concentration than SH10-LI100. In this season, leaf blade NDF was lower at LI100 frequency on pastures grazed to SH5 than SH10, in contrast with summer 2008. Leaf blade ADF concentrations were lower for SH5-LI95 in summer 2007 than the other treatments. In the second autumn, ADF concentration was lower in LI95 than in LI100, regardless of stubble height.

For the whole-forage IVDOM and CP concentrations, a season × grazing frequency × stubble height interaction was found (P<0.05) (Table 6). The mean IVDOM for the SH5-LI100 treatment was the lowest compared with the other three treatments, whereas the effect of grazing frequency varied with
season, the highest values registered for LI95 in autumn 2008. An effect of stubble height on IVDOM, regardless of frequency, was found only in autumn 2008, with greater values for SH10 pastures. In summer 2008, the SH5 stubble had mean forage CP concentration of 140 g/kg, compared 118 g/kg for the SH10 stubble. The LI95 frequency resulted in mean CP of 140 g/kg, compared with 118 g/kg for LI100. In autumn 2008, forage from pastures managed at LI95 had greater CP concentration (mean 142 g/kg) than forage from pastures managed at LI100 (mean 113 g/kg). Both NDF and ADF concentrations in whole-forage samples were affected by a season × grazing frequency × stubble height interaction ($P < 0.05$) (Table 6). There was no effect of grazing frequency on NDF or ADF concentration. The ADF concentration at LI100 was affected by stubble height in the autumn 2008, with greater values for SH10 pastures.

### Light interception v. canopy height

Considering all measurements ($n = 1338$), an exponential relationship was found between LI and canopy height (Fig. 3a). For the three season-based equations in summer + autumn (2007 and 2008), and winter 2008 (Fig. 3b), the slope of the models decreased from the first summer to the last winter, whereas the intercept decreased only in winter 2008. This means that for the same LI level, canopy height decreased as the experiment progressed, as seen from the predicted height values at 95%. The intermediate winter and spring seasons of 2007 were not plotted, in order to simplify visualisation. For the four treatment-based equations in the first summer (Fig. 3c), the highest $R^2$ in 2007 was 0.88 for SH5-LI100 and the lowest was 0.73 for SH5-LI95. In summer 2008, however, the fit for the linear
model was poor, especially for SH10-LI95 ($R^2 = 0.12$) and SH5-LI95 ($R^2 = 0.44$) pastures (Fig. 3d).

**Discussion**

The greater number of grazing events (13) on SH10-LI95 pastures was a consequence of the combination of greater grazing frequency (shorter rest periods) based on 95% light interception (LI95) and lower grazing intensity (SH10), which decreased the time to achieve the pre-graze target condition, resulting in 30 days of rest in summer. Mean rest periods at LI95 and LI100 during the rainy season have been reported, respectively, at 22 and 32 days for Xaraés palisadegrass (Brachiaria brizantha Hochst. ex A. Rich. Stapf.) (Pedreira et al. 2007), 32 and 44 days for Tanzania-1 guineagrass (Panicum maximum Jacq.) (Barbosa et al. 2007), and 25 and 34 for Mombaça guineagrass (Panicum maximum Jacq.) (Carnevali et al. 2006). In addition to specific plant architecture, differences among studies are a consequence of environmental conditions such as soil fertility, N fertilisation, season of the year and local climate, showing the importance of a flexible grazing criterion based on plant growth rather than fixed time intervals, especially for high-yielding forages and high-input intensive grazing systems. In the studies mentioned above, rest period differences between LI95 and LI100 were ~10 days in summer, consistent with those obtained in the present study (33 v. 43 days).

The skewed distribution (asymmetrical, skewness >1) of post-graze canopy height was a consequence of the development of tall and short patches in the pasture, which are infrequently and frequently grazed, respectively. The right long tail-height distribution (Fig. 1), according to Gibb and Ridout (1986), prevents the description of canopy height as a single mean. Castillo et al. (2009) reported a skewed height distribution for tropical pastures (Paspalum sp. and Axonopus sp.) in the post-graze canopy, regardless of stocking rate. In the present study, canopy height distributions were peaked (kurtosis >0), but SH10 pastures were flatter than SH5, probably because of the lower grazing intensity. Although the height means (8.6 and 11.9 cm, respectively) were greater than the initial 5 and 10 cm post-graze target heights proposed, the denomination was preserved because of the proximity to the mode value.

There was a marked difference in the pattern of ‘disappearance’ of the plant-part components, likely influenced
by animal preference and selection during grazing, and according to plant-part position in the canopy profile (Fig. 2). The upper portion of the canopy, where leaf blade proportion is higher, was grazed almost completely, particularly in the SH5-LI100 treatment (Fig. 2c). Compared with leaf blade mass, pre- and post-graze variations in stem and dead material mass were not so evident, except for SH5-LI100, apparently an indicator of greater forage harvested. As grazing intensity increased (shorter stubble), there was a corresponding increase in the apparent forage harvested (difference between pre- and post-graze HM of the same defoliation relative to pre-graze HM) from 30% and 49% (SH10-LI95 and SH10-LI100, respectively) to 65% (SH5-LI95 and SH5-LI100). Although stem mass for the SH10-LI100 treatment was greater (Fig. 2d), none of the grazing strategies resulted in increasingly uncontrolled and rejected amounts of stems as the grazing season progressed. The presence of stems in the HM is usually associated with lignified tissue, low grazing efficiency and lodging (Braga et al. 2006; Rueda et al. 2016). In addition, elongation of tropical grasses can open the canopy, resulting in taller plants and lower canopy bulk density, potentially hindering forage intake (Palhano et al. 2005). In contrast to the results for stems, the amount of dead material appeared to increase in the first 6 months, particularly for the SH10 stubble.

Mean herbage accumulation of 16.5 t/ha is comparable to results obtained by Hare et al. (2009) (12 t/ha.year) and Ng (1972) (16 t/ha.year), evaluating signal grass in clipping trials in Southeast Asia. Herbage accumulation was close to the 16 t/ha for signal grass observed in mixed legume–grass pastures in Cape York Peninsula, Australia (Winter 1976), supporting the high yield potential of signal grass in a broad range of humid tropical environments. Working with Tanzania-1 guineagrass, Barbosa et al. (2007) measured a decline in leaf blade accumulation in pastures harvested at LI100 compared with LI95 (7390 v. 9310 kg/ha.year), whereas in the present study, there was an increase in leaf blade accumulation for signal grass managed at LI100 compared with LI95 (Table 2), similar to reported in Xaraés palisadegrass pastures (Pedreira et al. 2009). The increase of 0.7 t/ha in leaf blade accumulation, however, was associated with an increase of 1.1 t/ha of stem and 0.9–1.5 t/ha of dead material. Greater stem and dead accumulation were also recorded for SH10 than SH5 pastures, with no effects on leaf blade accumulation. In perennial ryegrass (Lolium perenne L.) pastures, leaf blade yield was not responsive to a broad range of stubble heights above 3.5 cm (Tuñón et al. 2014). Even with small post-graze LAI, SH5 pastures accumulated the same amount of leaves as SH10 pastures with 2–3 times more residual leaf area. Carnevalli et al. (2006) showed that more frequent and closer (shorter stubble) grazing resulted in greater forage accumulation of Mombaça guineagrass because of flowering inhibition in late summer. In the present study, however, the lower grazing intensity (SH10) seemed sufficient to control signal grass flowering and maximise leaf blade accumulation.

Shorter stubble height (SH5) resulted in small post-graze leaf blade proportion (13%) and low post-graze LAI (0.17) at the beginning of the experiment (summer 2007) (Table 3). Over time, however, SH5 pastures associated with shorter rest periods (LI95) had their stubble leaf proportion and LAI increase in the second summer compared with LI100, although LAI remained lower than in SH10-LI95 pastures. The SH5-LI95 pastures probably adapted to the grazing regime and maximised leaf area after grazing by reducing leaf sheath length and maintaining additional leaf tissue below the severe grazing height, as has been observed in closely grazed perennial ryegrass pastures (Tuñón et al. 2014). Conversely, the SH5-LI100 treatment was the combination where residual leaf blade mass was the lowest. This is especially important because residual leaf area ensures faster regrowth by intercepting light immediately after grazing, allowing more rapid replenishment of carbohydrate reserves in plant-part components such as roots and stems (Donaghy and Fulkerson, 1998). In continuously stocked Marandu palisadegrass pastures kept at 10 cm canopy height, a large soluble-N and non-structural carbohydrate pool was measured in shoots, but regrowth was still limited because of the reduced leaf area (Da Silva et al. 2015).

Defoliating the canopy when it intercepts 95% of the incident light (LI95) is expected to result in a higher leaf blade proportion in the harvested HM (Barbosa et al. 2007). In summer, when there were virtually no environmental limitations to growth, the use of LI95 management resulted in higher leaf blade proportion at pre-graze, but this response depended on stubble height and year, with greater values only for the SH10 level in the first summer (2007), and only for the SH5 level in the second summer (2008). Over time, stubble height had a greater impact on leaf blade proportion at pre-graze than frequency, so that SH5 pastures resulted in leafier canopies than SH10 pastures (Table 4). It was also expected that LI100 would result in forage with more stem, but differences from LI95 were minimal and varied across seasons, not differing among treatments in summer, when grass growth is greatest and signal grass enters its reproductive phase. The stubble height effect was more pronounced than the frequency effect on pre-graze stem proportion as well as leaf blade proportion, so that SH10 pastures had more stem pre-graze than SH5 pastures, similar to the results for dead material proportion. According to Korte et al. (1982), close grazing is more important than light interception management to avoid reproductive development in perennial ryegrass pastures, owing to animals being forced to eat growing stems. Leafy pastures are known to favour animal performance (Euclides et al. 2010), because higher leaf blade proportions, of greater nutritive value than stem, can maximise forage intake rate by grazing animals (Benvenuti et al. 2008). Anjos et al. (2016) evaluated Marandu palisade grass pastures and found 48% leaf blade in pre-graze HM in pastures managed with 95% of light interception, consistent with the 48% found in the present study for LI95 pastures associated with the SH5 stubble. Pre-graze stem proportion (28%) was also comparable to the results of Anjos et al. (2016) for LI95 pastures (33%), but in this case, not affected by stubble height.

Whole-forage and leaf blade digestibilities were lower for the SH5-LI100 combination over the four seasons studied (Tables 5 and 6). Except for the SH5-LI100 treatment, mean forage IVDOM concentration during summer 2008 (587 g/kg) was only a little greater than that reported by Paciullo et al. (2009) for signal grass pastures in December (570 g/kg). In Xaraés palisadegrass pastures under defoliation frequencies determined by 95% and 100% during the summer, Nave et al. (2009) reported CP concentrations of 138 and 122 g/kg, respectively, and IVDOM concentrations of 693 and
680 g/kg, respectively. In the second year of the present study, combinations including the more frequent defoliation (LI95) resulted in greater mean forage digestibility (14%) than LI100, although in summer, the SH10-LI100 treatment was similar to SH10-LI95. A negative effect of increased grazing intensity on nutritive value was expected because of more dead material and stems from lower canopy strata, although the adaptation of the canopy to a specific grazing management may modify this assumption. For example, concentrations of CP and IVDOM in the tall, tufted Tanzania-I guineagrass were the same when managed at 25 and 50 cm at rotational stocking (Difante et al. 2009). In the present study, however, a lower IVDOM concentration was associated with SH5 stubble, a condition intensified when combined with the LI100 grazing frequency level.

Considering the high cost of light meters, the application of light interception to grazing management becomes unfeasible to the producer. One possible alternative to apply the concept would be to establish associations between canopy LI and height, provided the correlations between LI (and the associated LAI) and canopy height are high (King et al. 1986). Fitting the models, however, can be problematic due to LI being expressed as ‘per cent’ data with distributions other than normal. Coêlho et al. (2014) evaluated correlations between canopy LI and height and did not find high r values for many tropical grasses including signal grass (r = 0.44), although regression models were not tested. Wallau et al. (2016) found a poor linear fit (R² = 0.32) between canopy LI (maximum of 95%) and height for five breeding lines of limopgrass (Hemarthria altissima) (Poir.) Stapf & C.E. Hubb.). A fit for non-linear model was proposed for Mombaça guineagrass pastures by using the exponential model, resulting in 0.58 as the best R² fit (Pereira et al. 2012). To allow for easier interpretation, data from the present study were linearised by using a loge transformation (Braga et al. 2006). The model fit, however, was low (R² = 0.48) and it was not possible to restrict sward height to a sufficiently narrow range of values that would allow for establishing a specific, unequivocal value of canopy height, because 95% LI could be found all across the 14–22 cm height range (Fig. 3a). Going into autumn, with the increase in dead proportion in the herbage mass, this fraction may have had a significant role in the canopy light interception, where the model intercept diminished in winter 2008 (Fig. 2b), as discussed for Marandu palisadegrass by Braga et al. (2006). Considering only summer, there was no similarity between predicted values for 2007 and 2008, and this can be a consequence of changes in canopy architecture (Fig. 2c and d). Linear models resulted in poor fit for the SH10-LI95 treatment (R² = 0.12) in summer 2008, and a little better for the SH5-LI95 pastures (0.44). The more frequent the grazing the greater the tendency of the plants to become more prostrate, a likely explanation for the poor SH10-LI95 fit. According to our results, it is unlikely that a single ‘generic’ value of canopy height can be established for a specific light interception value of signal grass under grazing, at least in the range of LI and stubble heights tested in the present study.

Grazing management using pre-graze LI and stubble heights resulted in variations in signal grass morphology, as well as in forage nutritive value and accumulation. Despite the different rest periods between LI95 and LI100, differences in plant-part composition did not vary uniformly between the two LI levels, suggesting a high phenotypic plasticity of signal grass, as illustrated by the LI v. canopy height regression. Post-graze leaf blade proportion and LAI were greater for the SH10 stubble than the SH5 stubble, especially when associated with LI95 frequency, but with no impact on leaf blade yield. In fact, the leaf blade yield was greater when LI was close to 100% (LI100 pastures), although there was a simultaneous increase in stem yield, suggesting that stem elongation is triggered when the canopy approaches complete light interception. Although more productive, pastures in the LI100 treatment produced forage with lower concentrations of IVDOM and CP, particularly when combined with the shorter post-graze stubble (SH5). In addition to these changes in plant-part composition, grasses can adapt to grazing through a tillering response. Portela et al. (2011) reported basal tiller density of 1421 and 1306 tillers/m² for LI95 and LI100 grazing frequency, respectively, and 1439 and 1288 tillers/m² for SH5 and SH10 stubble, respectively, in this same field trial. This result reinforces the signal grass plasticity facing the grazing strategies imposed, even though the tiller density was not as contrasting among stubble height levels as were HM and LAI.

As a versatile grass used in many soil and climate conditions in Brazil, signal grass is more flexible than most tropical forages species. As demonstrated in the present study, the phenotypic plasticity of signal grass allows for a broad range of stubble heights and/or frequencies, with apparently no detrimental effects on pasture performance, particularly in well-fertilised pastures. To ensure high leaf blade yield and good forage nutritive value, however, particularly during the warm, rainy season, defoliation of signal grass under grazing can include pre-graze canopy heights varying from 18 to 30 cm (roughly equivalent to 95–100%). At the lower end of this range (~18 cm), greater nutritive value would be warranted, whereas at the upper limit (~30 cm), leaf blade accumulation would be maximised. Although no deleterious effect of the SH5 stubble on signal grass pastures was observed in the present study when associated with frequent defoliations (SH5-LI95 treatment)—in contrast with the poor nutritive value of SH5-LI100 pastures—a post-graze stubble closer to 10 cm would result in more nutritious forage on-offer. Further evaluations of signal grass under grazing should include measurements of animal performance and forage intake in order to evaluate the practical consequences of these grazing strategies to the producer.

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