

## Research Paper

# Canopy responses of signal grass cv. Basilisk pastures subjected to three fertilization regimes at two stubble heights

## *Respuestas del dosel en pastos de Urochloa decumbens cv. Basilisk sujetos a tres regímenes de fertilización y alturas de residuo*

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### Abstract

The impacts of fertilization regimes and stubble heights in signal grass cv. Basilisk pastures were evaluated during late spring and summer in Brazil. Liming and N, P and K fertilization were applied to generate gradients in soil fertility to maintain soil base saturations around 35%, 50% and 65%, increase soil P concentration and the proportion of K in soil cation exchange capacity, combined with two stubble heights of 10 and 15 cm. Herbage accumulation was not affected by fertilization regimes and stubble height reaching 10 t/ha of dry matter during the growing season. Cutting at 10 cm maximizes the leaf mass and leaf area index and decreases dead material mass without the need of high soil base saturation and NPK fertilization rates to sustain plant growth. However, this stubble height required longer regrowth periods to attain 95% of light interception ( $LI_{95\%}$ ). A stubble height of 15 cm is preferred when short regrowth periods are required. The canopy height at the point of  $LI_{95\%}$  does not change with fertilization regimes, but the  $LI_{95\%}$  is reached at different canopy heights in late spring and summer in signal grass pastures. The adoption of a moderate fertilization regime is recommended as a strategy to obtain an equitable forage distribution between late spring and summer.

**Keywords:** Canopy light interception, soil fertility, tropical pastures.

### Resumen

Se evaluaron los impactos de los regímenes de fertilización y la altura del rastrojo en pasturas de *Urochloa decumbens* cv. Basilisk a fines de la primavera y el verano en Brasil. Se aplicó encalado y fertilización con N, P y K para generar gradientes de fertilidad del suelo para mantener las saturaciones de base alrededor del 35%, 50% y 65%, aumentar la concentración de P del suelo y la proporción de K en la capacidad de intercambio catiónico, combinado con dos alturas de rastrojo (10 y 15 cm). La producción de forraje no se vio afectada por los regímenes de fertilización y la altura del rastrojo, alcanzando las 10 t/ha de materia seca durante el ciclo vegetativo. Cortes a 10 cm maximizan la biomasa foliar y el índice de área foliar y disminuye la cantidad de material muerto sin necesidad de tener una alta saturación de bases en el suelo y altas tasas de fertilización NPK para mantener el crecimiento de la planta. Sin embargo, esta altura de rastrojo requirió períodos de rebrote más prolongados para alcanzar el 95% de intercepción de luz ( $IL_{95\%}$ ). Se prefiere una altura de rastrojo de 15 cm cuando se usan períodos cortos de rebrote. La altura del dosel en el punto de  $IL_{95\%}$  no cambia con los regímenes de fertilización, pero en estas pasturas, el  $IL_{95\%}$  se alcanza a diferentes alturas del dosel en cortes a fines de la primavera y en el verano. Se recomienda la adopción de un régimen de fertilización moderado como estrategia para obtener una distribución equitativa del forraje entre finales de primavera y verano.

**Palabras clave:** Fertilidad del suelo, intercepción de luz del dosel, pastos tropicales.

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## Introduction

*Urochloa decumbens* (Stapf) R.D. Webster (syn. *Brachiaria decumbens* Stapf) cv. Basilisk, known as signal grass, is a tropical perennial grass that originated in East Africa (Uganda, Kenya, Tanzania, Rwanda, Burundi and Zaire), and is widely cultivated in tropical and subtropical pastures in Brazil ([Pereira et al. 2018b](#)), Colombia, Venezuela ([Guenni et al. 2008](#)), Tanzania, Thailand ([Gobius et al. 2001](#)), tropical Australia, South Pacific and Asia ([Stur et al. 1996](#)). The wide adoption can be attributed to its adaptation to low phosphorus soils ([Rao et al. 1996](#)), high aluminum saturation ([Werner et al. 1997](#)), drought tolerance under moderate soil water stress ([Guenni et al. 2002](#)) and persistence under low soil fertility ([Stur et al. 1996](#)) and severe grazing ([Valle et al. 2000](#)). However, its tolerance to low fertility soils, which has allowed it to spread over a diversity of ecosystems, has led to mismanagement and use of fertilization rates below the minimum requirement to sustain optimum growth rates ([Pereira et al. 2018b](#)). This has contributed to the large expanses of degraded grasslands in Brazilian ecosystems ([Valle et al. 2000](#)).

The management of pastures under rotational stocking should be based on criteria such as forage mass or canopy height and tolerance to grazing ([Da Silva et al. 2015](#)). Research on tropical perennial grasses has shown that to maximize leaf accumulation and avoid stem elongation during the vegetative growth ([Pedreira et al. 2007](#)), the grazing time should be defined to minimize light competition within the plant canopy during regrowth. Defoliation frequency has been based on the proportion of photosynthetically active solar radiation being intercepted by the canopy. The point of 95% of light interception ( $LI_{95\%}$ ) by the canopy is considered the optimum moment for grazing in tropical perennial grasses ([Portela et al. 2011](#); [Da Silva et al. 2015](#)). Canopy light interception at the point of  $LI_{95\%}$  has shown good correlations with canopy height in signal grass ( $r=0.83$  ([Coelho et al. 2020](#)),  $r=0.44$  to  $0.77$  ([Pedreira et al. 2017](#))), and canopy height has been used as a management tool to identify the ideal pre-grazing condition. Defoliation frequency is variable between seasons and regrowth cycles during the growth season and depends on the time required for the canopy to reach the height corresponding to  $LI_{95\%}$ .

Severities of defoliation from 40% to 60% can be adopted without any negative impacts on herbage accumulation or pasture persistence ([Nascimento Júnior et al. 2010](#)). Management criteria for most tropical perennial

grasses are being implemented based on these principles but adequate pre- and post-grazing stubble heights for management of signal grass pastures are still not clearly defined ([Braga et al. 2009](#); [Pedreira et al. 2017](#)). Portela et al. (2011) observed that signal grass pastures grazed down to 5 cm progressively lose their ability to replenish the tiller population. The combination of high frequency of defoliation, by using  $LI_{95\%}$ , and 5 cm stubble height, corresponding to approximately 70% of removal of the pre-grazing height, was excessive for this grass, leading the pastures to show initial signs of degradation.

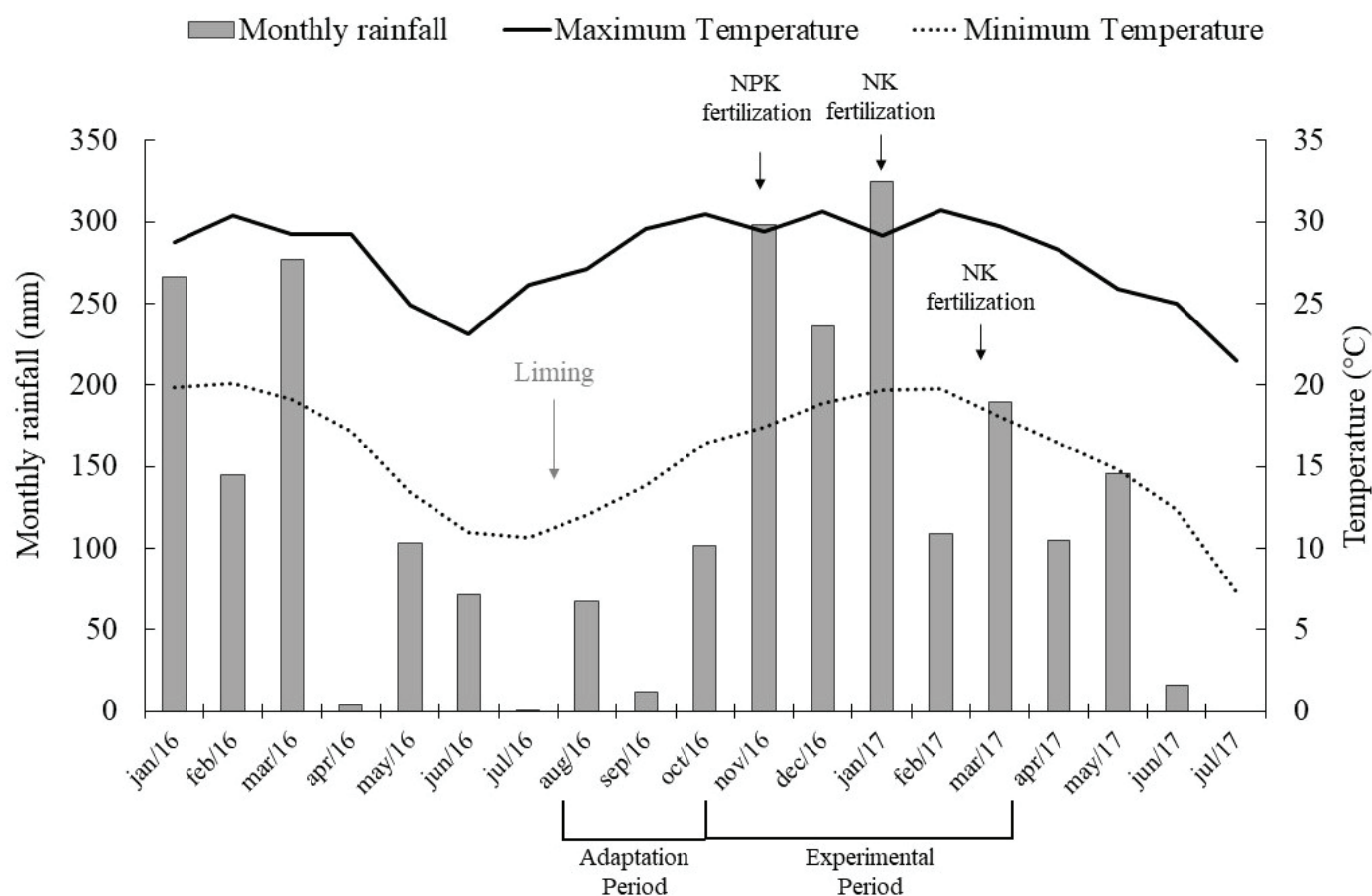
Adequate fertilization rates are required to sustain high growth rates, ensure persistence in the long-term and avoid pasture degradation ([Gimenes et al. 2011](#)). Since most of Brazil's tropical soils are weathered with low nutrient availability (especially P), medium to high acidity ( $H^+$  and  $Al^{3+}$ ) and low organic matter content ([Francisco 2016](#)), the low frequency of nutrient reposition through liming and fertilization can be detrimental to the sustainability of pasture-based livestock systems ([Werner et al. 1997](#); [Pereira et al. 2018b](#)), particularly when severe grazing is adopted ([Venter et al. 2020](#)). Benefits from liming and fertilization on herbage accumulation and nutritive value can be obtained only when pre- and post-grazing regimes are effectively implemented ([Gimenes et al. 2011](#)). The objectives of this study were to identify the canopy height at the point of  $LI_{95\%}$  and the possible combinations between the fertilization regime and stubble heights that optimize herbage accumulation in signal grass pastures.

## Materials and Methods

### *Location and experimental design*

The experiment was carried out at the Faculty of Animal Science and Food Engineering (FZEA), University of São Paulo, Pirassununga, SP, Brazil (21°57'31" S, 47°27'07", 620 m a.s.l.). The experimental area had a moderate slope and the soil was classified as Rhodic Hapludox ([Soil Survey Staff, 2015](#)) or dystrophic Red Latosol ([Santos et al. 2013](#)). The preparation of the experimental area for the present experiment started in July 2016 with canopy parameters monitored from October 2016 up to the end of the growth season in March 2017. The climate in the region is sub-tropical with dry winters ([Alvares et al. 2013](#)) with conditions during the experiment presented in Figure 1.

Pastures of signal grass cv Basilisk were established in 2012 in an experimental area comprising 18 plots of 80



**Figure 1.** Monthly rainfall (mm) and mean maximum and minimum temperatures (°C) of the experimental period for the region of Pirassununga, SP, Brazil, from January 2016 to July 2017.

m<sup>2</sup> (10 m x 8 m) each and left under free growth without a defined management procedure or fertilization until November 2014. During the 2015/2016 growth season, the pastures were subjected to a previous experiment based on rotational stocking, from which the post-grazing targets used in the present experiment were defined. During that period, three liming rates were applied (see details in [Pereira et al. 2018b](#)), where six plots received no liming, six plots received 0.7 t/ha limestone and six plots received 1 t/ha limestone. In that period, the annual maintenance fertilization was equivalent to 106.5 kg N/ha (as urea); 52.5 kg P/ha (as superphosphate); and 35 kg K/ha (using potassium chloride). The present experiment followed using the treatments of factorial combinations of three fertilization regimes (Fert) and two stubble heights (10 cm and 15 cm) in a randomized complete block design with three replications.

Soil samples were collected from a 0-20 cm soil depth in April 2016, and the results of analysis were used to define the amount of limestone needed to increase the soil base saturation (BS) to 35%, 50% and 65%, following the recommendations specified by Raji et al.

(1997) for the state of São Paulo, Brazil:

$$\text{Amount of limestone (t/ha)} = [\text{CEC} * (\text{BS2} - \text{BS1})] / (\text{RTNP} * 10),$$

where:

CEC is soil cation exchange capacity

BS2 is after liming

BS1 is actual BS determined before liming

RTNP is the limestone Relative Total Neutralizing Power (%).

The experiment started in July 2016, when plots were mowed down to 5 cm height. Dolomitic limestone (85% RTNP) was manually applied onto the soil surface without incorporation in August 2016. Soil samples from a 0-20 cm soil depth were collected again in October 2016, and the results were used to define the potassium and phosphorus fertilization rates. The first application of fertilizers was performed in November 2016. The three fertilization regimes were defined to generate different soil fertility conditions (Table 1) and consisted in the addition of limestone to increase soil base saturation (BS, %) and N, P and K fertilization. Fert1 can be considered the treatment of lower soil fertility, Fert2

the treatment of intermediary soil fertility and Fert3 the treatment of higher soil fertility. First applications corresponded to 1.3 kg K/ha, 1.7 kg P/ha and 0.35 kg N/ha in Fert1; 70.4 kg K/ha, 18.3 kg P/ha and 3.9 kg N/ha in Fert2; and 141.6 kg K/ha, 31.7 kg P/ha and 6.7 kg N/ha in Fert3. The remaining N and K fertilization was split in three applications: in late November 2016 (late spring) with the 16.0 kg K/ha and 19.65 kg N/ha in Fert1; 24.0 kg K/ha and 26.1 kg N/ha in Fert2; and 32.0 kg K/ha and 33.3 kg N/ha in Fert3; in January 2017 (early summer) and in early March 2017 (late summer) using 16.0 kg K/ha and 20.0 kg N/ha in Fert1; 24.0 kg K/ha and 30.0 kg N/ha in Fert2; and 32.0 kg K/ha and 40.0 kg N/ha in Fert3.

The fertilizers used as a source of N, P and K were, respectively, protected urea (trade name FH Nitro Mais®, 44.6% N, 0.15% Cu and 0.4% B), monoammonium phosphate (MAP, 11% N and 52% P) and potassium chloride (KCl, 58% K). All fertilizers were manually applied onto the soil surface without incorporation at the post-harvest stage. In August 2017, a new set of soil samples was collected from a 0–20 cm soil depth to determine the remaining soil nutrient concentration.

### Measurements

The defoliation frequency was determined as the time when the canopies intercepted 95% of the incoming photosynthetically active radiation ( $LI_{95\%}$ ). Readings were taken weekly throughout the regrowth period with one reading above the canopy and five readings at ground level using a LAI 2000 canopy analyzer (LI-COR, Lincoln, Nebraska, USA), following the recommendations specified by Portela et al. (2011). Canopy height was monitored weekly during each regrowth cycle through 20 systematic readings along four transect lines, using a light polyethylene sheet and a graduated measuring stick. Once plots reached the

pre-cutting criteria, all pre-harvest measurements were taken before pastures were cut down to the respective stubble heights using a gasoline grass trimmer.

For the determination of total forage mass (FM) and morphological composition at the post- and pre-harvest stages, two samples were collected at ground level using pruning shears from a 0.50 x 0.50 m (0.25 m<sup>2</sup>) quadrat. At each regrowth cycle, the previously sampled areas were excluded from the subsequent cutting procedures. Samples were weighed and separated into two subsamples. One was used for the determination of the dry matter (DM) content, and the other was hand-separated into leaf (leaf laminae), stem (leaf sheath + stem) and dead material components. After the leaf laminae were manually separated, they were weighed, passed through a leaf area meter, model LAI-3100 (LI-COR, Lincoln, Nebraska, USA), and then dried. The subsample data on leaf dry mass and the leaf area readings were used to calculate the specific leaf area (SLA in cm<sup>2</sup>/g) of the samples. The LAI was determined by the relationship between SLA of the samples and the total leaf weight of the corresponding sampling area

$$LAI = [FM (g/m^2) \times LP (\%)] \times SLA (cm^2/g),$$

where

FM = total forage mass

LP = leaf proportion in the total forage mass, obtained from the subsample

SLA = the specific leaf area

Morphological components were dried to constant weight in a forced-air oven at 65°C and the data were used to calculate the total forage mass in kg DM/ha.

Daily forage accumulation rates (kg DM/ha/day) were estimated from two regrowth cycles in each season, determined from the difference between pre- and post-harvest forage mass and the length of the regrowth period. In order to estimate the total forage accumulation of each season, the average daily forage accumulation

**Table 1.** Targets of the soil chemical attributes (0–20 cm soil depth) for each fertilization regime and total amount of NPK fertilizers applied.

Soil parameters	Fert1	Fert2	Fert3
		Targets	
Soil base saturation (%)	35	50	65
Proportion of K in the CEC <sup>1</sup>	3	4	5
Level of P in the soil (mg/dm <sup>3</sup> )	9	12	15
N fertilization rates (kg N/ha/year)	60	90	120
		Total amount applied	
K (kg/ha) <sup>2</sup>	49.3	142.4	237.6
P (kg/ha) <sup>3</sup>	1.7	18.3	31.7
N fertilization rates (kg/ha N/yr) <sup>3,4</sup>	60	90	120

<sup>1</sup>CEC represents the cation exchange capacity; <sup>2</sup> Source was potassium chloride (KCl, 58% of K); <sup>3</sup> Source was monoammonium phosphate (MAP, 11% N and 52% of P); <sup>4</sup> Source was protected urea (under the trade name FH Nitro Mais®, 44.6% N, 0.15% Cu and 0.4% B).



rates were multiplied by the length of the season. The late spring season was 54 days and included all regrowth cycles from 28 October to 21 December. The summer season was 93 days and included all regrowth cycles from 22 December to 25 March. The total herbage accumulation of the experimental period (147 days) was then determined by the sum of the herbage accumulation of the late spring and summer seasons.

Soil samples for analysis of chemical parameters were taken in October 2016 and August 2017 from five sampling points per plot (0 to 20 cm soil depth), which were homogenized to obtain a composite sample. Soil analyses were carried out according to the methods described by Claessen et al. (1997). Soil pH was determined in calcium chloride ( $\text{CaCl}_2$ ); soil P, K, Ca and Mg were extracted using the ion-exchange resin procedure; the calcium phosphate turbidimetric method was used to determine S soil concentration and soil organic matter was determined by using the colorimetric method (Yeomans and Bremner 1988).

#### *Statistical analysis*

Analysis of variance was carried out using the MIXED procedure in the software SAS®, version 9.3 for Windows®. For all variables, the covariance matrices were selected using the Bayesian Information Criterion (BIC) and blocks were considered a fixed factor. The analyses of canopy height, light interception, forage mass, proportions and mass of leaves, stems and dead material, and LAI were carried out separately for the post- and the pre-harvest stages, considering the fertilization regimes, stubble heights, season of the year and its interactions. The season of the year was considered a repeated measurement. Stubble height and their interactions, as well as blocks, were considered as fixed effects. For all variables, correction for degrees of freedom was applied according to the Kenward and Roger (1997) method (DDFM=KR). When appropriate, means were calculated using the least square means (LSMEANS), comparisons were made using the Student's t-test, and significant differences were declared when  $P < 0.05$ . The equations to fit the relationship among canopy light interception (LI) and canopy height (CH) were obtained with non-linear regression models and the Gauss-Newton algorithm, using the MINITAB®18 software.

## **Results**

### *Soil parameters*

The fertilization regimes defined for the experiment created gradients in soil nutrient concentration and effectively generated differences ( $P < 0.05$ ) in the soil parameters (Table 2). There were no significant effects of stubble height or significant interactions between fertilization regimes and stubble height ( $P > 0.05$ ) for the soil parameters.

### *Canopy parameters*

The stubble heights had average values of  $10.4 \pm 0.17$  cm and  $14.4 \pm 0.17$  cm in the late spring period and  $11.1 \pm 0.17$  cm and  $15.3 \pm 0.17$  cm in summer. Despite the differences between the stubble heights, the post-harvest leaf area index (LAI) was not affected by the treatments or interactions ( $P > 0.05$ ). The post-harvest forage mass (FM) was affected by the stubble height ( $P = 0.0348$ ) and season of the year ( $P = 0.0062$ ); and the highest forage mass was observed at 15 cm during late spring (Table 3).

There was an effect of season ( $P = 0.0346$ ) on the post-harvest leaf mass (LM). The remaining LM corresponded to 27.7% of the post-harvest forage mass in late spring and 18.5% in summer. The post-harvest stem mass (SM) was affected by stubble height ( $P = 0.0437$ ) and season of the year ( $P = 0.0084$ ), higher values being observed at 15 cm stubble height in summer. The proportion of stems in the post-harvest forage mass corresponded to 39.9% during late spring and 40.2% in summer. Dead material mass (DMM) at the post-harvest stage was affected only by season of the year ( $P = 0.0001$ ), with higher values observed in summer, corresponding to 41.3% of the FM compared with late spring, for which the proportion was 32.4%.

The LAI at the pre-harvest stage was affected by the stubble height ( $P = 0.0205$ ), season of the year ( $P = 0.0375$ ) and also varied with the interaction between fertilization regimes x stubble heights x season of the year ( $P = 0.0463$ ). A higher LAI at the pre-harvest was observed only in the late spring when Fert3 was combined with the stubble height of 10 cm (Figure 2), whereas there were no significant differences between the fertilization regimes in late spring or summer with 15 cm stubble height.

**Table 2.** Soil chemical attributes (0–20 cm soil depth) for each fertilization regime at the beginning (October/2016) and at the end (August/2017) of the experimental period.

Soil parameters	Fert1				Fert2				Fert3			
	2016	s.e.m.	2017	s.e.m.	2016	s.e.m.	2017	s.e.m.	2016	s.e.m.	2017	s.e.m.
pH (CaCl <sub>2</sub> )	4.4 b	0.044	4.7 c	0.057	4.5 b	0.044	5.1 b	0.057	4.9 a	0.044	5.6 a	0.057
Ca (mmolc/dm <sup>3</sup> )	11.8 b	1.09	14.8 b	1.97	14.8 b	1.09	20.0 b	1.97	19.7 a	1.09	35.8 a	1.97
Mg (mmolc/dm <sup>3</sup> )	4.2 b	0.31	5.3 b	0.25	4.8 b	0.31	5.2 b	0.25	6.0 a	0.31	7.5 a	0.25
P (mg/dm <sup>3</sup> )	8.8 c	0.41	12.3 b	0.59	10.2 b	0.41	11.8 b	0.59	11.8 a	0.41	14.9 a	0.59
K (mmolc/dm <sup>3</sup> )	0.63 a	0.022	2.00 c	0.111	0.55 b	0.022	2.50 b	0.111	0.55 b	0.022	3.40 a	0.111
S (mmolc/dm <sup>3</sup> )	7.0 b	1.59	11.4 a	0.55	14.8 a	1.59	7.7 c	0.55	15.0 a	1.59	9.7 b	0.55
O.M. (g/kg)	14.8 a	1.47	21.8 a	0.55	15.8 a	1.68	21.9 a	0.55	15.4	1.68	22.6 a	0.55
H+Al (mmolc/dm <sup>3</sup> )	45.5 a	1.64	30.7 a	0.97	43.8 a	1.64	28.4 a	0.97	41.0 a	1.64	24.1 b	0.97
CEC (mmolc/dm <sup>3</sup> )	62.2 a	1.59	52.8 b	1.86	64.2 a	1.59	56.0 b	1.86	67.5 a	1.59	70.9 a	1.86
BS%	<sup>1</sup> 12.9 c	1.69	41.7 c	1.78	<sup>1</sup> 36.4 b	1.69	49.3 b	1.78	<sup>1</sup> 55.8 a	1.69	65.3 a	1.78
%K on the CEC	1.0 a	0.03	3.7 b	0.25	0.9 b	0.03	4.4 ab	0.25	0.8 b	0.03	4.8 a	0.25

Ca, Mg, P and K were determined by ion exchange resin method; the calcium phosphate turbidimetric method was used to determine S soil concentration; O.M. represents soil organic matter; BS represents soil base saturation; CEC is the cation exchange capacity. Fert1, Fert2 and Fert3 represent the different fertilization regimes. <sup>1</sup>Soil base saturation determined in April/2016 before liming. For each sampling year, lowercase letters compare fertilization regimes, and means followed by the same letter do not differ from each other (Student's t-test,  $P>0.05$ ). s.e.m. represents the standard error of the means.

**Table 3.** Leaf area index (LAI), forage mass (FM), leaf mass (LM), stem mass (SM) and dead material mass (DMM) (kg DM/ha) at the post and pre-harvest in signal grass cv. Basilisk pastures subjected to fertilization regimes (Fert1, Fert2 and Fert3) and stubble heights (10 cm and 15 cm) between late spring and summer.

Harvest	LAI		FM		LM		SM		DMM	
	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre
Fertilization regimes										
Fert1	0.88 a	2.43 a	2,758 a	4,578 a	694 a	1,769 a	1,067 a	1,772 a	997 a	1,037 a
Fert2	0.88 a	2.45 a	3,059 a	4,774 a	662 a	1,792 a	1,246 a	1,853 a	1,150 a	1,129 a
Fert3	0.66 a	2.51 a	2,568 a	4,586 a	542 a	1,900 a	1,046 a	1,873 a	979 a	812 b
s.e.m.	±0.070	±0.104	±142.2	±149.4	±48.0	±73.0	±62.6	±73.4	±69.8	±65.7
Stubble heights										
10 cm	0.75 a	2.63 a	2,595 b	4,699 a	579 a	1,934 a	1,037 b	1,907 a	978 a	858 b
15 cm	0.86 a	2.30 b	2,995 a	4,593 a	687 a	1,707 b	1,203 a	1,759 a	1,106 a	1,127 a
s.e.m.	±0.057	±0.085	±116.1	±122.0	±39.2	±59.6	±51.1	±60.0	±57.0	±53.6
Season of the year										
Late spring	0.88 a	2.32 b	2,523 b	4,317 b	699 a	1,809 a	1,007 b	1,624 b	817 b	883 b
Summer	0.73 a	2.61 a	3,067 a	4,975 a	567 b	1,832 a	1,234 a	2,041 a	1,266 a	1,102 a
s.e.m.	±0.057	±0.085	±116.1	±122.0	±39.2	±59.6	±51.1	±60.0	±57.0	±53.6

Means followed by the same lowercase letters in the columns do not differ from each other (Student's t-test,  $P>0.05$ ); s.e.m. represents the standard error of the mean.

The pre-harvest FM and SM varied only with the season of the year ( $P=0.0024$  and  $P=0.0004$ , respectively) and the highest values were observed in summer (Table 3). Stems represented 37.6% and 41.0% of the pre-harvest forage mass in the late spring and in summer, respectively. Leaves corresponded to 41.9% and 36.8% of the pre-harvest forage mass in the late spring and in summer, respectively. However, the pre-harvest LM was affected only by stubble heights ( $P=0.0224$ ), where defoliation at 10 cm resulted in higher LM compared to 15 cm. The DMM at pre-harvest was affected by the fertilization regimes, stubble heights

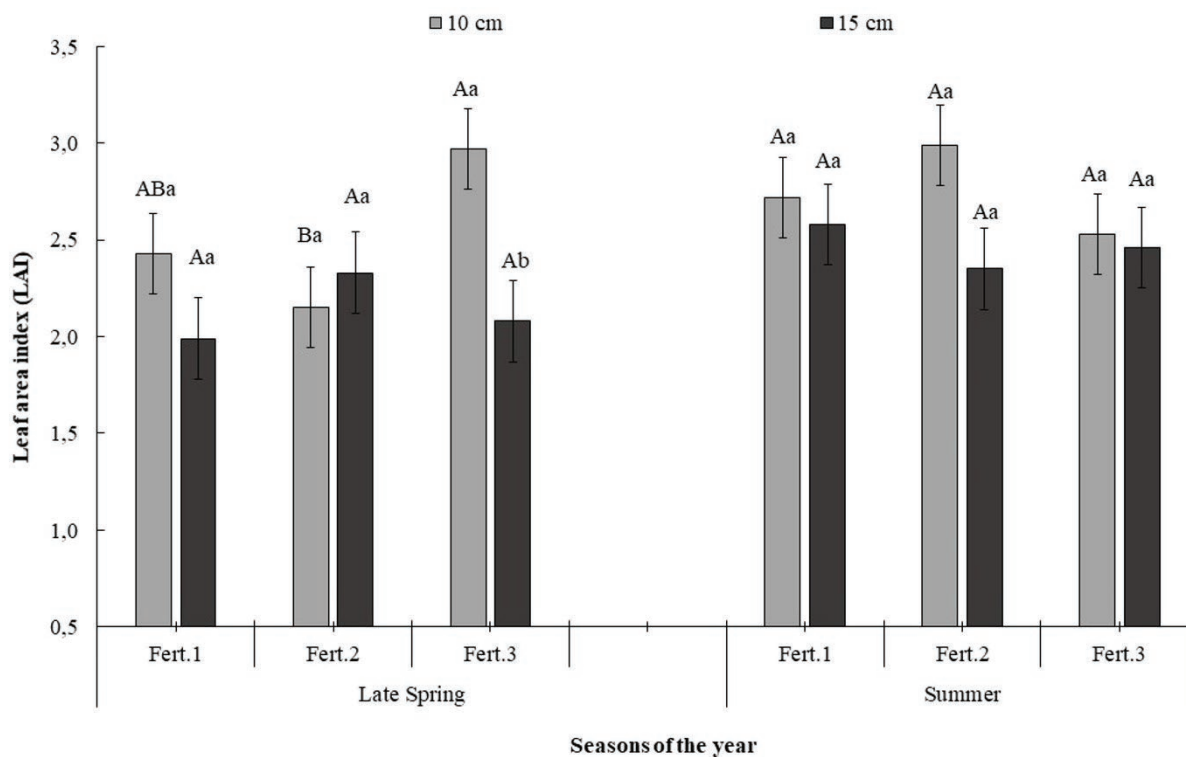
and season of the year ( $P=0.0181$ ;  $P=0.0053$  and  $P=0.0136$ , respectively). The lowest DMM was observed in Fert3 at 10 cm stubble height. Despite a higher DMM in summer, the proportion of this component in the total forage mass was similar in both seasons, corresponding to 20.5% and 22.2% in the late spring and summer respectively.

The length of the regrowth period to canopy height at  $LI_{95\%}$  varied with the stubble heights ( $P=0.0106$ ) (Table 4), where longer regrowth periods were observed at 10 cm ( $30 \pm 1.4$  days) compared with 15 cm ( $24 \pm 1.4$  days) and season of the year ( $P<0.0001$ ).

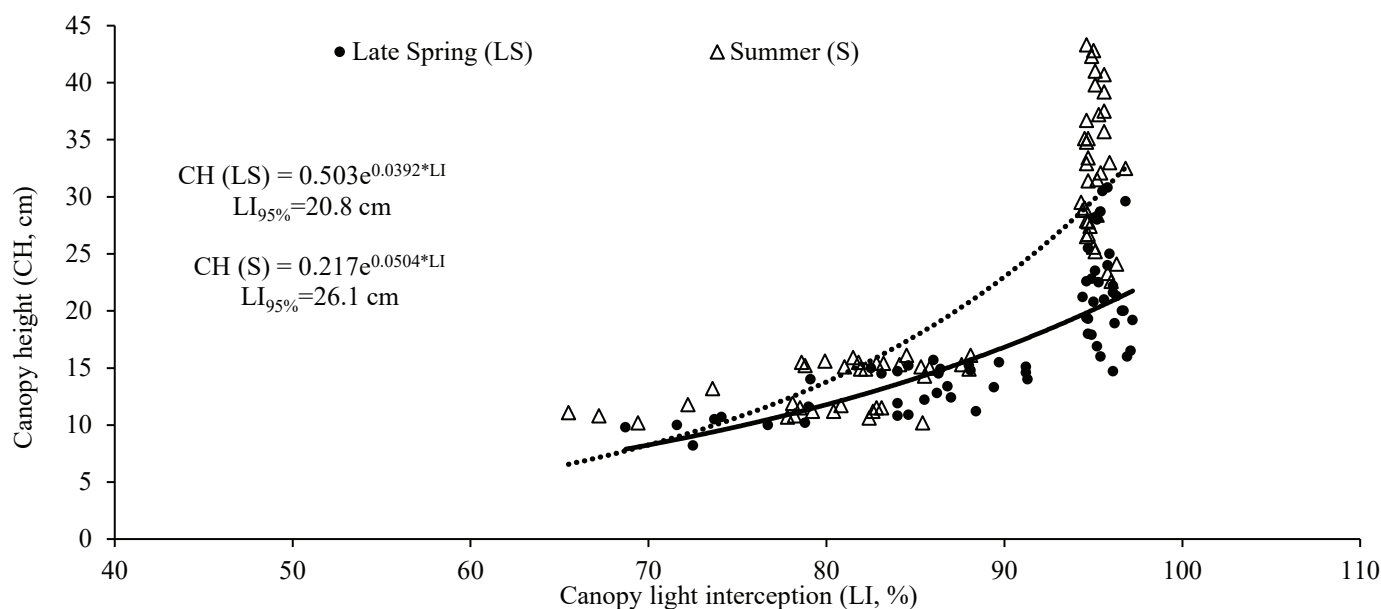
There were no effects of the treatments or significant interactions ( $P>0.05$ ) on seasonal herbage accumulation (SHC) or total herbage accumulation (THA).

The canopy height at  $LI_{95\%}$  did not change with the

combinations of fertilization regimes and stubble heights but varied between late spring and summer indicating adjustments in canopy height should be implemented between seasons of the year (Figure 3).



**Figure 2.** Leaf area index (LAI) at pre-harvest according to the interaction between fertilization regimes (Fert1, Fert2 and Fert3) x stubble heights (10 and 15 cm) x season of the year. For each season of the year, uppercase letters compare fertilization regimes within stubble heights, whereas lowercase letters compare stubble heights within fertilization regimes. Means followed by the same letters do not differ from each other (Student's t-test  $P>0.05$ ).



**Figure 3.** Relationship between canopy height (CH, cm) and canopy light interception (%LI) for the seasons of late spring (LS) and summer (S) in signal grass cv. Basilisk pastures.

**Table 4.** Length of the regrowth period (days to  $LI_{95\%}$ ) and total herbage accumulation (kg DM/ha) during late spring and summer in signal grass cv. Basilisk pastures subjected to fertilization regimes (Fert1, Fert2 and Fert3).

	Late spring	Summer
Length of the regrowth period	$22 \pm 0.5$ B	$32 \pm 1.8$ A
Herbage accumulation		
Fert1	$3,710 \pm 905$ a	$5,826 \pm 905$ a
Fert2	$4,970 \pm 905$ a	$5,806 \pm 905$ a
Fert3	$4,504 \pm 905$ a	$5,568 \pm 905$ a

Uppercase letters are comparing seasons and lowercase letters area comparing fertilization regimes. Means followed by the same letters do not differ from each other (Student's t-test  $P > 0.05$ ).

## Discussion

### Soil fertility

Signal grass is well adapted to low-fertility acidic soils (Raij et al. 1997) and despite its low nutrient requirement, fertilization regimes should replenish the nutrients exported by grazing animals. The soil base saturation (BS) considered adequate for signal grass is around 40% (Primavesi et al. 2008), which was reached at the end of the experimental period in all fertilization regimes (Table 2). However, this parameter should not be interpreted alone because Ca and Mg concentrations may also affect pasture growth. Liming is also required to provide Ca and Mg as nutrients (Barcelos et al. 2011). Primavesi et al. (2008) pointed out that while signal grass pastures can sustain their growth patterns in conditions of high soil acidity and low soil base saturation, the species is not able to sustain long term persistency when soil Ca concentration is low. Soil Ca concentration below  $16.0 \text{ mmolc/dm}^3$  is considered low within the ranges established for the species (Sobral et al. 2015) and only Fert1 was unable to provide a soil Ca concentration above this value. However, in the present experiment, the soil Ca and Mg concentration observed in Fert1 were not considered limiting factors for signal grass growth.

The soil K concentration was very low at the beginning of the experimental period but increased for all fertilization regimes. An unexpected increase was registered in Fert1, where soil K concentration reached  $2.0 \pm 0.1 \text{ mmolc/dm}^3$  and corresponded to 3.8% of the cation exchange capacity at the end of the experimental period, even considering the much lower K fertilization applied. This suggests that some K applied in Fert2 and Fert3 may have been lost by leaching. Santos et al. (2010) pointed out that for intensive pasture utilization, fertilization should be planned initially

to maintain K to at least 3% of the soil cation exchange capacity, but an ideal proportion is reached at 5%. The proportion of K in the cation exchange capacity registered in the present experiment was maintained within this range.

Soil P concentration also increased for all fertilization regimes throughout the experimental period. Raij et al. (1997), Santos et al. (2010) and Werner et al. (1997) described that for perennial crops P fertilization should be applied to maintain a range of  $13.0$  to  $30.0 \text{ mg/dm}^3$ , but Primavesi et al. (2008) recommended a minimum soil P concentration of  $15.0 \text{ mg/dm}^3$  for signal grass, particularly when high nitrogen fertilization rates are applied. In the present experiment, values registered at the end of the experimental period were below the minimum soil P concentration recommended by Primavesi et al. (2008) but it was not restricting the above ground biomass accumulation of signal grass pastures.

The soil organic matter is important for sustainable agroecosystem management due to its contribution to fertility, structure and biological functioning of soils (Fonte et al. 2012). Soil organic matter increased for all fertilization regimes from the beginning to the end of the experimental period, regardless of stubble heights. Management practices associated with adequate fertilization rates are important drivers of leaf and tiller turnover and may also affect root biomass (Silva et al. 2019). According to Apolinário et al. (2014), fertilizers increase N concentration in leaf litter, increasing signal grass litter decomposition rates compared with unfertilized pastures. Silva et al. (2019) showed that 71% of the root biomass of signal grass pastures decompose over a period of 512 days, providing nutrients during mineralization, but also affecting the grassland carbon cycle. Fine root biomass is more dynamic because of their short lifespan and fast turnover, providing an important source of nutrients to soil microbes and plants. Management practices and fertilization applied in the present experiment contributed to soil organic matter probably through leaf litter decomposition and fine root turnover.

The results showed that soil fertility was not restricting signal grass growth and did not affect canopy traits at both post- and pre-harvest (except for the pre-harvest LAI in late spring and dead material mass) or total herbage accumulation. Rao et al. (1996) reported that some of the mechanisms of *Urochloa* species to adapt to low-fertility acid soils include their ability to maintain root growth at the expense of shoot growth (an adaptive mechanism related to changes in carbon partitioning), their low internal P requirements, and hosting vesicular-arbuscular



mycorrhizae. The morphological and physiological traits of signal grass commonly described in the literature, such as its ability to adjust growth rates and longer tissue lifespan, are predominantly resource conservation strategies, which also contribute to maximizing nutrient-use efficiency and to reducing nutrient losses ([Louw-Gaume et al. 2010](#)). The absence of response to fertilizer in the present experiment may be because the levels used met the minimal requirements for signal grass.

It is worth noting that those responses should not be interpreted as an indication that periodic liming and fertilization are not necessary. Pereira et al. (2018b) showed that when signal grass pastures do not receive lime, even though the soil nutrients are considered adequate to meet their requirements, the extraction and exportation in the tissues harvested are intense. Decreases of approximately 51.9% for K, 59.7% for Ca, 54.5% for Mg, and 66.8% soil base saturation were measured from the beginning to end of the growth season in signal grass pastures that had not received lime. This suggests that due to the reduced availability of soil nutrients after one growth season, the negative impacts of lime absence and low fertilization rates on pasture growth would be observed in the following years.

### *Canopy parameters*

The severity of defoliation is an important management decision because it affects the remaining morphological composition and the LAI, components of the sward structure responsible for canopy recovery during early regrowth ([Rodrigues et al. 2014](#); [Pedreira et al. 2017](#)). However, in the present experiment, the residual leaf mass and the leaf area index remained statistically similar between the two levels of defoliation adopted (Table 3), indicating a high level of shoot morphological plasticity of the species as previously pointed out by Pedreira et al. (2017) and Pereira et al. (2018a).

For most tropical perennial grasses, severe defoliation (removal of more than 60% of the pre-harvest canopy height) results in low residual LAI and forage mass. The limited leaf surface to capture sunlight during initial regrowth results in longer regrowth periods for plant recovery in comparison to lenient defoliation ([Da Silva et al. 2015](#)). Longer regrowth periods were observed in plots mown to 10 cm. The stubble heights affected the morphological composition with defoliation at 10 cm favoring the maintenance of a greater leaf mass. Portela et al. (2011) observed that grazing down to 10 cm in signal grass allowed high tiller appearance and survival rates

which represented a fast population renewal, contributing to a younger tiller population profile. Young tillers have higher leaf appearance and elongation rates compared to mature and old tillers ([Paiva et al. 2012](#)), thus favoring leaf tissue growth.

The literature has reported that severity of defoliation has a minor impact on herbage accumulation and persistence when stubble heights are within the limits of tolerance to defoliation in tropical perennial grasses ([Da Silva et al. 2015](#); [Antunes et al. 2022](#)). These limits are equivalent to a removal ranging from 40% to 60% of the pre-harvest height during the vegetative growth stage and apply to various morphological types in tropical grasses ([Nascimento Júnior et al. 2010](#); [Euclides et al. 2018](#)). This range also allows maximum intake by grazing animals and sustained nutritional value ([Guzatti et al. 2017](#)). In the present experiment, the defoliation at 10 cm and 15 cm corresponded to a removal of, respectively, 50% and 37% of the canopy height during the vegetative growth stage at late spring, but 65% and 53% of the canopy height in summer, when pastures are stimulated to enter into the reproductive stage.

The 10 cm stubble height during summer, a more severe defoliation than those traditionally recommended for other tropical perennial grasses, did not affect the total herbage accumulation. Pedreira et al. (2017) observed that the severity of defoliation affected leaf proportion in the pre-grazing forage mass in this species, regardless of the defoliation frequency adopted ( $LI_{95\%}$  or maximum canopy light interception -  $LI_{100\%}$ ). The above authors observed a proportion of leaves corresponding to 32% of the pre-grazing forage mass when stubble height was 10 cm, but that proportion increased to 46% when the pastures were grazed down to 5 cm. In the present experiment, 41.1% of the pre-harvest forage mass was composed of leaves when the stubble height was 10 cm, and decreased to 37% when the post-harvest target was 15 cm (Table 3). This indicates that when the  $LI_{95\%}$  criterion is adopted to define the defoliation frequency in signal grass pastures, the 10 cm stubble height affects the morphological composition at pre-harvest, increasing the proportion of leaves without negative impacts on herbage accumulation.

In the present experiment, the total herbage accumulation during the growing season reached 10,000 kg DM/ha. This compares with an annual forage production of signal grass in Thailand between 9,000 and 13,000 kg DM/ha ([Hare et al. 2009](#)), from which 77% is concentrated in the wet season. Fagundes et al. (2005) found that 70% of the forage production of signal grass is during late spring and summer. The findings of the present study show

fertilization regimes affected the seasonal distribution of the forage produced between late spring and summer and highlight the importance of providing adequate fertilization during the growing season. This suggests that a moderate fertilizer regime could be adopted to improve herbage accumulation during the late spring period.

Transition from the vegetative to the reproductive growth stage is characterized by intense changes in morphological composition and canopy structure, particularly due to stem elongation and elevation of the apical meristems for inflorescence emergence ([Fagundes et al. 2005](#); [Pedreira et al. 2017](#)). These processes are predominantly observed during summer ([Pereira et al. 2018a](#)) when higher pre-harvest forage mass was associated with high stems and dead material mass and a higher pre-harvest canopy height was reached at the  $LI_{95\%}$  point (Figure 3). The moment when canopies reach  $LI_{95\%}$  has been considered the ideal point to interrupt regrowth in tropical perennial grasses because the growth pattern beyond that point is characterized by excessive stem and dead material accumulation due to light competition and low proportion of leaves in the forage mass due to tiller mortality ([Portela et al. 2011](#); [Euclides et al. 2018](#)). Light interception is not an easily measurable criterion because it requires expensive equipment, normally unaffordable to farmers ([Pedreira et al. 2017](#)) and canopy height has been used as a field criterion to define the condition of tropical grasses because of the consistent and positive association with the  $LI_{95\%}$  point ([Pedreira et al. 2007](#); [Portela et al. 2011](#)).

Pereira et al. (2018a) showed that even using  $LI_{95\%}$  to determine the correct point for grazing signal grass, during the reproductive stage (predominantly during summer for the species in the region of the present experiment), stem elongation and leaf senescence rates increased, and leaf elongation rates decreased faster from the 15th day of regrowth and that pattern occurred regardless of the level of defoliation imposed. During summer, the defoliation frequency could be associated with a light interception level lower than  $LI_{95\%}$  allowing use of a more frequent defoliation regime and stimulating tillering. However, the impacts of this grazing strategy on tiller renewal, population density, and morphological composition still need further evaluation.

## Conclusion

Different fertilization regimes (liming plus NPK fertilizers) did not increase herbage accumulation of signal grass during the growing season. Use of a moderate fertilization regime is recommended as a strategy

to improve the distribution of the forage produced. Defoliation at 10 cm stubble height maximizes leaf mass and leaf area index and decreases dead material mass, without the need of higher soil base saturation and NPK fertilization rates to sustain plant growth, but requires longer regrowth periods to attain the  $LI_{95\%}$  criterion. A stubble height of 15 cm may be used when short regrowth periods are required.

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