

**University of São Paulo
Luiz de Queiroz College of Agriculture**

**Grazing management and nitrogen effects on agronomic and nutritive
value responses of 'Zuri' guineagrass under rotational stocking**

Otávio Goulart de Almeida

Thesis presented to obtain the degree of Doctor in
Science. Area: Animal Science and Pastures

**Piracicaba
2022**

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of 'Zuri' guineagrass under rotational stocking**

versão revisada de acordo com a Resolução CoPGr 6018 de 2011

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*“Muitos homens vivem em seu próprio mundo e são bons.
Outros, porém, não resistindo às intensas vibrações de
energia de que são possuídos, saem de si e se tornam
inesquecíveis em suas ações e palavras”.*

(Autor desconhecido)

(...) *“E pela minha lei a gente é obrigado a ser feliz”* (...)

(Chico Buarque de Holanda, Sivuca)

(...) *“Vou mostrando como sou
E vou sendo como posso
Jogando meu corpo no mundo
Andando por todos os cantos
E pela lei natural dos encontros
Eu deixo e recebo um tanto
E passo aos olhos nus
Ou vestidos de lunetas
Passado, presente
Participo sendo o mistério do planeta.”* (...)

(Luiz Galvão, Moraes Moreira, interpretado por Novos Baianos)

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RESUMO

Efeitos do manejo do pastejo e nitrogênio sobre as respostas agronômicas e valor nutritivo do capim 'Zuri' sob lotação rotativa

A pecuária brasileira é baseada nas pastagens como a principal fonte de alimento para os bovinos, sendo as plantas forrageiras tropicais as mais utilizadas. O capim Zuri [*Megathyrsus maximus* (Jacq.) B.K. Simon & S.W.L. Jacobs (syn. *Panicum maximum* Jacq.)] foi lançado como uma nova opção para diversificação das pastagens. Além das principais vantagens dos capins dessa espécie que são altamente produtivos e responsivos a adubação nitrogenada, este apresenta resistência a cigarrinhas das pastagens [*Mahanarva fimbriolata* (Stål) e *M. liturata* (Le Peletier de Saint-Fargeau & Serville)], e a mancha foliar causada pelo fungo *Bipolaris maydis* (Y. Nisik e Miyake) Shoemaker. Os objetivos do presente estudo foram explicar as relações entre o acúmulo de forragem (AF), valor nutritivo, características estruturais do dossel, e eficiência de pastejo (EP) do capim Zuri submetido a lotação rotativa em resposta a alturas de dossel pré-pastejo e doses de nitrogênio. O experimento foi conduzido na ESALQ-USP em Piracicaba, Brasil, durante dois verões agrostológicos, utilizando o delineamento em blocos completos casualizados com tratamentos em arranjo fatorial 2×2 , combinando duas alturas de dossel em pré-pastejo [55 e 75 cm (A55 e A75, respectivamente)] e duas doses de N [150 e 300 kg N ha⁻¹ ano⁻¹ (N150 e N300, respectivamente)], com quatro repetições. A altura do resíduo foi aplicada como 50% da altura do dossel pré-pastejo. Independentemente da dose de N, a A75 alcançou 95% de interceptação de luz (IL). A combinação A55/N300 resultou em características estruturais (densidade populacional de perfilhos, área foliar específica, e ângulo da folhagem) que fizeram com que o dossel alcançasse 95% IL. A taxa de acúmulo de forragem (TAF) e o AF do capim Zuri aumentaram com o aumento da altura do dossel (160 vs. 190 kg MS ha⁻¹ dia⁻¹ e 18370 vs. 22120 kg MS ha⁻¹ ano⁻¹, para A55 e A75, respectivamente), e a EP foi 8% maior para A75, 85%. Na distribuição vertical dos componentes morfológicos, independente da altura pré-pastejo, a metade superior do dossel mostrou-se composta por apenas folhas e a metade inferior apresentou proporção de folhas progressivamente menor e as de colmo e material morto progressivamente maiores até o nível do solo. A proporção de folhas da metade superior do dossel contribuiu para que não houvesse diferença no valor nutritivo entre as alturas de manejo. A maior dose de N encurtou o período de descanso dos pastos e resultou em maior TAF e AF para N150 e N300 (145 vs. 200 kg MS ha⁻¹ dia⁻¹ e 16980 vs. 23500 kg MS ha⁻¹ ano⁻¹, respectivamente), e maior EP (84%). O valor nutritivo foi positivamente afetado pelo aumento da dose de N. A dose N300 resultou em maiores concentrações de proteína bruta e de digestibilidade *in vitro* da matéria orgânica (157 e 571 g kg⁻¹, respectivamente) comparada a N150. A A75 pode ser vantajosa devido às maiores TAF e AF e, conseqüentemente, maior EP, embora não tenha havido diferença no valor nutritivo entre as alturas. Maior taxa de adubação nitrogenada favoreceu as respostas agronômicas e de valor nutritivo.

Palavras-chave: Adubação, Altura do dossel, Doses de nitrogênio, Eficiência de pastejo, Estrutura do dossel, *Megathyrsus maximus*, Produção de forragem, Pastagem

ABSTRACT

Grazing management and nitrogen effects on agronomic and nutritive value responses of 'Zuri' guineagrass under rotational stocking

The Brazilian livestock farming is based on pastures as the main source of food for cattle, with tropical forage plants being the most widely used. 'Zuri' guineagrass [*Megathyrsus maximus* (Jacq.) B.K. Simon & S.W.L. Jacobs (syn. *Panicum maximum* Jacq.)] was released as a new option for pasture diversification. In addition to the features of guineagrass that include high productivity and responsiveness to nitrogen fertilization, Zuri is resistant to leafhopper [*Mahanarva fimbriolata* (Stål) and *M. liturata* (Le Peletier de Saint-Fargeau & Serville)] and leaf spot caused by the fungus *Bipolaris maydis* (Y. Nisik and Miyake) Shoemaker. The objectives of the present study were to explain the agronomic responses such as forage accumulation (FA), nutritive value, canopy structural characteristics, and grazing efficiency (GE) of Zuri guineagrass under rotational stocking, to pre-graze canopy heights and nitrogen fertilization rates. The experiment was carried out at USP-ESALQ in Piracicaba, Brazil, during two warm rainy seasons, using a randomized complete block design, with a 2×2 factorial arrangement of treatments, which corresponded to combinations of two pre-graze canopy heights [55 and 75 cm (H55 and H75, respectively)] and two N fertilization rates [150 and 300 kg N ha⁻¹ yr⁻¹ (N150 and N300, respectively)], with four replications. The stubble height was always 50% of the pre-graze canopy height. Regardless of N rate, H75 canopies achieved 95% light interception (LI). The H55/N300 combination resulted in structural features (tiller population density, specific leaf area, and foliage angle) that made the canopy achieve 95% LI. Forage accumulation rate (FAR) and FA increased with increased canopy height (160 vs. 190 kg DM ha⁻¹ d⁻¹ and 18370 vs. 22120 kg DM ha⁻¹ yr⁻¹, to H55 and H75, respectively), and the GE was 8% greater for H75, 85%. In the vertical distribution of plant-part components, regardless of pre-graze height, the upper half of the canopy was composed only of leaves and the lower half with progressively decreasing leaf proportion and increasing stem and dead material down to ground level. The leaf proportion in the upper half of the canopy contributed to the lack of a height effect on nutritive value. The increase in N rate shortened the rest period of and resulted in greater FAR and FA to N150 and N300 (145 vs. 200 kg DM ha⁻¹ d⁻¹ and 16980 vs. 23500 kg DM ha⁻¹ yr⁻¹, respectively), and greater GE (84%). The nutritive value was positively affected by the increase in N rate. The N300 rate resulted in greater concentrations of crude protein and in vitro digestible of organic matter, 157 and 571 g kg⁻¹, respectively, compared to N150. The H75 canopies were superior due to greater FAR, FA, and GE, although there was no height effect on nutritive value. Increased nitrogen fertilization favors the agronomic and nutritive value responses.

Keywords: Canopy height, Canopy structure, Fertilization, Forage production, Grazing efficiency, *Megathyrsus maximus*, Nitrogen rates, Pasture

1 INTRODUCTION

Grasslands are key to the Brazilian livestock industry, an activity that contributes notably to the national economy. Beef production in Brazil in 2020 was around 10.3 million metric tons, resulting in a R\$ 747 billion contribution to the Gross Domestic Product (GDP). This represents a 20.8% increase over 2019, when the contribution of beef cattle to the GDP was R\$ 618 billion. When all the economic activity is considered, beef production represented 10% of the GDP in 2020 (ABIEC, 2021). The Brazilian beef cattle herd is between largest or second largest in the world, competing in total production with the United States of America (Jank et al., 2014a).

According to Ferraz & Felício (2010), almost the entire Brazilian livestock industry is based on the use of pastures as the main source of feed, which is the least expensive way of beef production (Jank et al., 2014b). Despite the importance of pastures for ruminant production, pasture management in Brazil is often done empirically, resulting in less-than-optimal forage and animal productivity, and in production systems that are less efficient than they could be (Dias-Filho, 2016). If changes are to be brought about in this scenario, there must be a perspective of better use of these areas, with the adoption of efficient strategies that can provide increased animal productivity from pastures.

Guineagrass [*Megathyrsus maximus* (Jacq.) B.K. Simon & S.W.L. Jacobs (syn. *Panicum maximum* Jacq.)] is a forage species of major importance in Brazil and has been widely studied for many decades. It has its center of diversity in East Africa (Combes & Pernès, 1970) and the accidental introduction of ‘Colonião’ (“common”) guineagrass via slave-trading in the 19th century was positive to the Brazilian beef industry, due to its adaptation to our climate and soil conditions and high forage production (Jank, et al., 2014a). Systematic research on the germplasm collection of this species began in the 1980s, a result of expeditions carried out in Kenya and Tanzania in East Africa (Martuscello et al., 2020). Through an agreement with ORSTOM (*Institut Français de Recherche Scientifique pour le Développement en Coopération*), Embrapa (Empresa Brasileira de Pesquisa Agropecuária) received this collection and has been breeding this species for different traits, resulting in the release of several commercial cultivars such as ‘Tanzania’ in 1990, ‘Mombaça’ in 1993, ‘Massai’ in 2001, ‘Zuri’ in 2014, and the hybrids ‘Tamani’ and ‘Quenia’ in 2015 and 2017, respectively (Martuscello et al., 2020).

Zuri is one of the most recently released guineagrass cultivars, and its morphological and management characteristics are similar to those of Tanzania. Embrapa's guidance on the management of Zuri is that it should be managed under rotational stocking at a pre-graze

height of 70 to 75 cm with a post-graze height of 30 to 35 cm (Embrapa, 2014), controlling the elongation of stems and ensuring maintenance of the forage canopy structure (Barbosa et al., 2021). In addition, Zuri is resistant to pasture leafhoppers [*Mahanarva fimbriolata* (Stål) and *M. liturata* (Le Peletier de Saint-Fargeau & Serville)] and to the leaf spot disease caused by the fungus *Bipolaris maydis* (Y. Nisik and Miyake) Shoemaker, of high incidence in other guineagrass cultivars, mainly Tanzania (Muir & Jank, 2004). This fungus may cause lesions that result in dryness as well as premature leaf loss, resulting in reduced productivity in affected areas (Charchar et al., 2003). Despite being recently launched on the market, Zuri has become popular due to its productive potential (Barbosa et al., 2021). A study carried out with Tamani, Massai, and Zuri guineagrasses showed that Tamani and Zuri had greater nutritive value than Massai, which resulted in the greater performance of beef cattle (Maciel et al., 2018).

Rotational stocking is the most used stocking method for guineagrass use under grazing mainly due to its upright, tufted growth habit. Traditionally, rest periods between grazing have been established according to practical guidelines such as number of pasture subdivisions and days of rest. Despite its simplicity and practicality, this guideline does not take into consideration the varying rates of regrowth of the pasture during the growing season. As a result, the vegetation experiences a wide range of variation in characteristics such as canopy height, density, leaf area, etc. at each subsequent grazing event. This happens because the environment (mainly soil moisture, temperature, and irradiance) is not constant from one rest period to the next (Silva & Nascimento Júnior, 2007b).

In the 1950s, studies with perennial ryegrass (*Lolium perenne* L.) and white clover (*Trifolium repens* L.) described the sigmoid pattern of forage regrowth over time during defoliation intervals, following three phases (Brougham, 1955). The first phase represents an exponential increase in rate of growth (forage accumulation), followed by a linear phase where the maximum accumulation rate is constant until the canopy approaches full light interception, and a third phase, where there is a decrease in growth rate and an increase in tissue senescence. These phases represent the increase in forage mass associated with the increase in leaf area index (LAI) and light interception (LI). This would support the notion that it might be advantageous to interrupt regrowth when the canopy reached about 95% LI, because above this value (the critical LAI) there is the onset of competition for resources (mainly light) accentuating the senescence process (Brougham, 1956, 1957). In theory this would result in maximum green forage production over time, with maximum leaf proportion, also minimizing stem and dead material proportion in the accumulated forage.

Parsons et al. (1988) showed that the 95% LI level would be the canopy condition at which the average forage accumulation rate was maximized and where the balance between growth and senescence would provide the greatest net forage accumulation (growth minus senescence). Subsequent studies proposed that defoliation management might be optimized if it took into account the morphological and ecophysiological aspects of forages (Silva & Nascimento Júnior, 2007a; Silva & Pedreira, 1997), since the biological processes involved in regrowth dynamics are strongly impacted by soil moisture, temperature, light, mineral nutrients, and management. Several studies followed in the late 1990s and early 2000s, seeking to understand the plant-environment interactions as a foundation for pasture management planning (Silva & Nascimento Júnior, 2007a).

Considerable research has been conducted in the last 25 years with guineagrass evaluating canopy LI and/or an intended corresponding canopy height as management criterion of Tanzania (Barbosa et al., 2007, 2011; Difante, et al., 2009a; Difante, et al., 2009b; Lemos et al., 2014; Zanine et al., 2011), Mombaça (Carnevali et al., 2006, 2021; Carvalho et al., 2017; Euclides et al., 2016, 2018; Silva et al., 2009, 2020a, 2021), Massai (Gurgel et al., 2017), Aruana (Campos et al., 2021; Zanini et al., 2012); Tamani (Tesk et al., 2020), Quenia (Tesk et al., 2020), Aries (Campos et al., 2021), and Zuri (Barbosa et al., 2021). The general conclusions of those studies were that when grazing is initiated when the canopy intercepts 95% of incoming light, forage accumulation is mainly from leaves relative to stem and dead material, improving forage nutritive value, grazing efficiency, and animal performance.

Pioneering work carried out in Brazil using LI as a management criterion to stop pasture regrowth was with Mombaça. Carnevali et al. (2006) studied Mombaça managed at 95 and 100% LI and reported that it had a significant difference in canopy structure (height, forage mass, and plant-part composition). Despite the lesser forage mass in the 95% LI, the number of grazing cycles was greater, which resulted in similar forage production with the 100% LI. However, the plant-part composition of the forage accumulated from 100% LI was below 95% LI, being characterized by greater proportions of stem and dead material and a lesser proportion of leaf, which resulted in lesser nutritional value. In addition, the greater forage losses were recorded in the 100% LI, which was accompanied by lesser grazing efficiency.

Tanzania was evaluated in pre-graze with 90, 95, and 100% LI, in which these intercepts were correlated with heights of 60, 70, and 85 cm, respectively. The canopies managed at 90% LI resulted in more grazing cycles compared to the other treatments. Forage accumulation was greater for LI 95% compared to LI 90 and 100%, however, the accumulation of leaves was the same for 90 and 95% LI. However, when the canopies exceed

95% LI, there is a considerable increase in the accumulation of stems, showing the importance of defoliation frequency for this control (Barbosa et al., 2007). These works show that the 95% LI becomes the maximum limit to interrupt the regrowth of pastures, since after this moment there is an accumulation of morphological components that are not of interest at the plant level and at the level of animal intake.

In a study with kikuyugrass (*Pennisetum clandestinum* Hochst. Ex Chiov) managed at 10, 15, 20, and 25 cm in the pre-graze condition and with stubble height being 50% of the pre-graze canopy height, the taller canopy (25 cm) was found to be associated with 95% LI, making this the recommended moment for starting defoliation (Sbrissia et al., 2018). Between 15 and 25 cm of pre-graze height, however, there was similar forage accumulation (Sbrissia et al., 2018) and chemical composition of the harvested forage (Schmitt et al., 2019). The 10 cm pre-graze height resulted in pasture collapse over time. The conclusion was that kikuyugrass cannot be managed at a height of less than 15 cm at pre-graze, but there is not much difference between 15 and 25 cm (Sbrissia et al., 2018). In another study with 'Marandu' palisadegrass [*Urochloa brizantha* Hochst. ex A. Rich. Webster (syn. *Brachiaria brizanta* Hochst. ex A. Rich. Stapf.)], managed under rotational stocking at 16, 19, 22, and 25 pre-graze height with 50% defoliation, the 25 cm height was when the canopy intercepted 95% of light. Marandu palisadegrass canopies managed at pre-graze heights between 19 and 25 cm showed no difference in forage accumulation rate and achieved the same LI (Gomes, 2019). These two studies show that pre-graze height can vary across a range where there is no reduction in forage accumulation.

Research is continuously helping generate new technologies to improve grazing management. The study and evaluation of morphological and canopy structural responses in tropical forages can help understand and plan improved management strategies. Nitrogen plays an important role in plant growth rates (Duru & Ducrocq, 2000), favoring the increases in forage accumulation (Domiciano et al., 2020; Pontes et al., 2016; Silva et al., 2016; Yasuoka et al., 2017), and causing changes in plant-part composition (Pereira et al., 2015), LAI (Silva et al., 2016; Yasuoka et al., 2017), tiller population density (Paciullo et al., 2017; Silva et al., 2020b), and LI (Pontes et al., 2016). These factors contribute to the dynamics of forage accumulation, in addition to nutritive value (Paciullo et al., 2017; Silva et al., 2020), and grazing efficiency (Pereira et al., 2015; Silva et al., 2016).

However, the lack of this nutrient leads to reduced animal production on tropical pastures (Gurgel et al., 2020). Forage plants, especially those of *M. maximus* species, are very responsive to nitrogen fertilization (Paciullo et al., 2017), and respond as the N rate increases.

A study by Silva et al. (2020c) with Mombaça submitted to N rates of 150, 300, and 400 kg N ha⁻¹ year⁻¹ showed increases in forage accumulation and nutritive value as the N rate increases, which may contribute to increases in pasture stocking rate. Furthermore, for daily weight gain and gain per hectare, the values of 300 and 400 kg N ha⁻¹ year⁻¹ were similar, and greater than the rate of 150 kg N ha⁻¹ year⁻¹ (Silva et al., 2020c). Understanding that the forage accumulation process is associated with management strategies, canopy heights and N supply may contribute to more productive pastures with higher harvest efficiency.

1.1 Hypothesis

Canopies of Zuri guineagrass managed under rotational stocking below the height corresponding to the supposed critical leaf area index (75 cm), combined with nitrogen fertilization, do not differ in forage accumulation and nutritive value.

1.2 Objective

The general objective of this study was to explain the relationships between forage accumulation and nutritive value, structural characteristics, and grazing efficiency in Zuri guineagrass under rotational stocking, with grazing initiated at two canopy heights (55 and 75 cm) and two N rates imposed by nitrogen fertilization (150 and 300 kg N ha⁻¹ yr⁻¹).

References

- ABIEC. (2021). *A pecuária no Brasil*. Beef Report. <http://abiec.com.br/publicacoes/beef-report-2021/>
- Barbosa, P. L., Silva, V. J., Pedreira, C. G. S., Sbrissia, A. F., & Sollenberger, L. E. (2021). Herbage accumulation and tillering dynamics of 'Zuri' guineagrass under rotational stocking. *Crop Science*, 61(5), 3787–3798. <https://doi.org/10.1002/csc2.20536>
- Barbosa, R. A., Nascimento Júnior, D., Euclides, V. P. B., Silva, S. C., Zimmer, A. H., & Torres Júnior, R. A. A. (2007). Capim-tanzânia submetido a combinações entre intensidade e frequência de pastejo. *Pesquisa Agropecuária Brasileira*, 42(3), 329–340. <https://doi.org/10.1590/s0100-204x2007000300005>

- Barbosa, R. A., Nascimento Júnior, D., Vilela, H. H., Silva, S. C., Euclides, V. P. B., Sbrissia, A. F., & Sousa, B. M. L. (2011). Morphogenic and structural characteristics of guinea grass pastures submitted to three frequencies and two defoliation severities. *Revista Brasileira de Zootecnia*, 40(5), 947–954. <https://doi.org/10.1590/S1516-35982011000500002>
- Brougham, R. W. (1955). A study in rate of pasture growth. *Australian Journal of Agricultural Research*, 6(6), 804. <https://doi.org/10.1071/AR9550804>
- Brougham, R. W. (1956). Effect of intensity of defoliation on regrowth of pasture. *Australian Journal of Agricultural Research*, 7(5), 377–387. <https://doi.org/10.1071/AR9560377>
- Brougham, R. W. (1957). Interception of light by the foliage of pure and mixed stands of pasture plants. *Australian Journal of Agricultural Research*, 9(1), 39–52. <https://doi.org/10.1071/AR9580039>
- Campos, F. P., Sarmiento, P., Mattos, W. T., Gerdes, L., Carnevalli, R. A., & Lima, C. G. (2021). Management of Aries and Aruana Guinea grass cultivars under rotational stocking based on canopy light interception. *The Journal of Agricultural Science*, 1–19. <https://doi.org/10.1017/S0021859621000678>
- Carnevalli, R. A., Congio, G. F. S., Sbrissia, A. F., & Silva, S. C. (2021). Growth of *Megathyrsus maximus* cv. Mombaça as affected by grazing strategies and environmental seasonality. II. Dynamics of herbage accumulation. *Crop and Pasture Science*, 72(1), 66–74. <https://doi.org/10.1071/CP20199>
- Carnevalli, R. A., Silva, S. C., Bueno, A. A. O., Uebele, M. C., Bueno, F. O., Hodgson, J., Silva, G. N., & Morais, J. P. G. (2006). Herbage production and grazing losses in *Panicum maximum* cv. Mombaça under four grazing managements. *Tropical Grasslands*, 40(3), 165–176.
- Carvalho, A. L. S., Martuscello, J. A., Almeida, O. G., Braz, T. G. S., Cunha, D. N. F. V., & Jank, L. (2017). Production and quality of Mombaça grass forage under different residual heights. *Acta Scientiarum Animal Sciences*, 39(2), 143–148. <https://doi.org/10.4025/actascianimsci.v39i2.34599>
- Charchar, M. J. A.; Anjos, J. R. N.; Fernandes, F. D.; Fernandes, C. D. (2003). *Panicum maximum* cv. Tanzânia nova hospedeira de *Bipolaris maydis*. *Fitopatologia Brasileira*, 28, p. 385. Suplemento.
- Combes, D., & Pernès, J. (1970). Variations dans le nombres chromosomiques du *Panicum maximum* Jacq. en relation avec le mode de reproduction. *Comptes Rendues Académie Des Sciences*, 270, 782–785.
- Dias-Filho, M. B. (2016). Uso de pastagens para a produção de bovinos de corte no Brasil: Passado, presente e futuro. In *Embrapa Amazônia Oriental* (1st ed.). Embrapa Amazônia Oriental.

- Difante, G. S., Euclides, V. P. B., Nascimento Júnior, D., Silva, S. C., Torres Júnior, R. A. A., & Sarmento, D. O. L. (2009a). Ingestive behaviour, herbage intake and grazing efficiency of beef cattle steers on Tanzania guineagrass subjected to rotational stocking managements. *Revista Brasileira de Zootecnia*, 38(6), 1001–1008. <https://doi.org/10.1590/s1516-35982009000600005>
- Difante, G. S., Nascimento Júnior, D., Euclides, V. P. B., Silva, S. C., Barbosa, R. A., & Gonçalves, W. V. (2009b). Sward structure and nutritive value of tanzania guineagrass subjected to rotational stocking managements. *Revista Brasileira de Zootecnia*, 38(1), 9–19. <https://doi.org/10.1590/S1516-35982009000100002>
- Domiciano, L. F., Santos, M. L., Boote, K. J., Santos, P. M., Pereira, D. H., & Pedreira, B. C. (2020). Physiological responses and forage accumulation of Marandu palisadegrass and Mombaça guineagrass to nitrogen fertilizer in the Brazilian forage-based systems. *Grassland Science*, 67(2), 93–101. <https://doi.org/10.1111/grs.12291>
- Duru, M., & Ducrocq, H. (2000). Growth and senescence of the successive leaves on a cocksfoot tiller. Effect of nitrogen and cutting regime. *Annals of Botany*, 85(5), 645–653. <https://doi.org/10.1006/anbo.1999.1117>
- Embrapa. (2014). *BRS Zuri, produção e resistência para a pecuária*. <https://ainfo.cnptia.embrapa.br/digital/bitstream/item/123642/1/Folder-Zuri-Final-2014.pdf>
- Euclides, V. P. B., Carpejani, G. C., Montagner, D. B., Nascimento Júnior, D., Barbosa, R. A., & Difante, G. S. (2018). Maintaining post-grazing sward height of *Panicum maximum* (cv. Mombaça) at 50 cm led to higher animal performance compared with post-grazing height of 30 cm. *Grass and Forage Science*, 73(1), 174–182. <https://doi.org/10.1111/gfs.12292>
- Euclides, V. P. B., Lopes, F. C., Nascimento Júnior, D., Silva, S. C., Difante, G. S., & Barbosa, R. A. (2016). Steer performance on *Panicum maximum* (cv. Mombaça) pastures under two grazing intensities. *Animal Production Science*, 56(11), 1849–1856. <https://doi.org/10.1071/AN14721>
- Ferraz, J. B. S., & Felício, P. E. (2010). Production systems - An example from Brazil. *Meat Science*, 84(2), 238–243. <https://doi.org/10.1016/j.meatsci.2009.06.006>
- Gomes, C. M. (2019). *Oportunidade para flexibilização das metas pré-pastejo do manejo rotativo do capim-marandu* [Universidade de São Paulo]. <https://doi.org/10.11606/D.11.2019.tde-03092019-112655>
- Gurgel, A. L. C., Difante, G. S., Emerenciano Neto, J. V., Souza, J. S., Veras, E. L. L., Costa, A. B. G., Carvalho Netto, R. T., Fernandes, L. S., Cunha, J. C., & Roberto, F. F. S. (2017). Estrutura do pasto e desempenho de ovinos em capim-massai na época seca em resposta ao manejo do período das águas. *Boletim de Indústria Animal*, 74(2), 86–95. <https://doi.org/10.17523/bia.v74n2p86>
- Gurgel, A. L. C., Difante, G. S., Montagner, D. B., Araújo, A. R., Dias, A. M., Santana, J. C. S., Rodrigues, J. G., & Pereira, M. G. (2020). Nitrogen fertilisation in tropical pastures: what are the impacts of this practice? *Australian Journal of Crop Science*, 14(6), 978–984. <https://doi.org/10.21475/ajcs.20.14.06.p2357>

- Jank, L., Barrios, S. C., Valle, C. B., Simeão, R. M., & Alves, G. F. (2014a). The value of improved pastures to Brazilian beef production. *Crop and Pasture Science*, *65*(11), 1132–1137. <https://doi.org/10.1071/CP13319>
- Jank, L., Braz, T. G. S., & Martuscello, J. A. (2014b). Gramíneas de clima tropical. In R. S. Reis, T. F. Bernardes, & G. R. Siqueira, (Eds.), *Forragicultura: ciência, tecnologia e gestão dos recursos forrageiros* (1st ed., pp. 109–124). Gráfica Multiplex.
- Lemos, N. L. S., Ruggieri, A. C., Silva, V. C., Campos, A. F., Malheiros, E. B., & Teixeira, I. A. M. A. (2014). Tanzania grass structure grazed by goats managed with different residual leaf area index under intermittent stocking. *Bioscience Journal*, *30*(6), 1811–1818.
- Maciel, G. A., Braga, G. J., Guimarães Júnior, R., Ramos, A. K. B., Carvalho, M. A., Fernandes, F. D., Fonseca, C. E. L., & Jank, L. (2018). Seasonal liveweight gain of beef cattle on guineagrass pastures in the Brazilian Cerrados. *Agronomy Journal*, *110*(2), 480–487. <http://doi:10.2134/agronj2017.05.0262>
- Martuscello, J. A., Almeida, O. G., Jank, L., & Santos, M. F. (2020). Gestão do manejo de gramíneas da espécie *Panicum maximum*. In R. C. Rodrigues & J. O. Santos (Eds.), *IV Simpósio Maranhense de Produção de Ruminantes e Pastagens* (pp. 65–92). EDUFMA.
- Muir, J. P., & Jank, L. (2004). Guineagrass. In L. E. Moser, B. L. Burson, & L. E. Sollenberger (Eds.), *Warm-Season (C4) Grasses* (45th ed., Issue 45, pp. 589–621). ASA. <https://doi.org/10.2134/agronmonogr45.c17>
- Paciullo, D. S. C., Gomide, C. A. M., Castro, C. R. T., Maurício, R. M., Fernandes, P. B., & Morenz, M. J. F. (2017). Morphogenesis, biomass and nutritive value of *Panicum maximum* under different shade levels and fertilizer nitrogen rates. *Grass and Forage Science*, *72*(3), 590–600. <https://doi.org/10.1111/gfs.12264>
- Parsons, A. J., Johnson, I. R., & Harvey, A. (1988). Use of a model to optimize the interaction between frequency and severity of intermittent defoliation and to provide a fundamental comparison of the continuous and intermittent defoliation of grass. *Grass and Forage Science*, *43*(1), 49–59. <https://doi.org/10.1111/j.1365-2494.1988.tb02140.x>
- Pereira, L. E. T., Paiva, A. J., Guarda, V. D., Pereira, P. M., Caminha, F. O., & Silva, S. C. (2015). Herbage utilisation efficiency of continuously stocked marandu palisade grass subjected to nitrogen fertilisation. *Scientia Agricola*, *72*(2), 114–123. <https://doi.org/10.1590/0103-9016-2014-0013>
- Pontes, L. S., Baldissera, T. C., Giostri, A. F., Stafin, G., Santos, B. R. C., & Carvalho, P. C. F. (2016). Effects of nitrogen fertilization and cutting intensity on the agronomic performance of warm-season grasses. *Grass and Forage Science*, *72*(4), 663–675. <https://doi.org/10.1111/gfs.12267>
- Sbrissia, A. F., Duchini, P. G., Zanini, G. D., Santos, G. T., Padilha, D. A., & Schmitt, D. (2018). Defoliation strategies in pastures submitted to intermittent stocking method: Underlying mechanisms buffering forage accumulation over a range of grazing heights. *Crop Science*, *58*(2), 945–954. <https://doi.org/10.2135/cropsci2017.07.0447>

- Schmitt, D., Padilha, D. A., Dias, K. M., Santos, G. T., Rodolfo, G. R., Zanini, G. D., & Sbrissia, A. F. (2019). Chemical composition of two warm-season perennial grasses subjected to proportions of defoliation. *Grassland Science*, *65*(3), 171–178. <https://doi.org/10.1111/grs.12236>
- Silva, L. S., Silva, V. J., Yasuoka, J. I., Sollenberger, L. E., & Pedreira, C. G. S. (2020b). Tillering dynamics of ‘Mulato II’ brachiariagrass under continuous stocking. *Crop Science*, *60*(2), 1105–1112. <https://doi.org/10.1002/csc2.20008>
- Silva, R. O., Miotto, F. R. C., Neiva, J. N. M., Silva, L. F. F. M., Freitas, I. B., Araújo, V. L., & Restle, J. (2020c). Effects of increasing nitrogen levels in Mombasa grass on pasture characteristics, chemical composition, and beef cattle performance in the humid tropics of the Amazon. *Tropical Animal Health and Production*, *52*, 3293–3300. <https://doi.org/10.1007/s11250-020-02360-0>
- Silva, S. C., Bueno, A. A. O., Carnevalli, R. A., Silva, G. P., & Chiavegato, M. B. (2020a). Nutritive value and morphological characteristics of Mombaça grass managed with different rotational grazing strategies. *Journal of Agricultural Science*, *157*(7–8), 592–598. <https://doi.org/10.1017/S0021859620000052>
- Silva, S. C., Bueno, A. A. O., Carnevalli, R. A., Uebele, M. C., Bueno, F. O., Hodgson, J., Matthew, C., Arnold, G. C., & Morais, J. P. G. (2009). Sward structural characteristics and herbage accumulation of *Panicum maximum* cv. Mombaça subjected to rotational stocking managements. *Scientia Agricola*, *66*(1), 8–19. <https://doi.org/10.1590/s0103-90162009000100002>
- Silva, S. C., & Nascimento Júnior, D. (2007a). Avanços na pesquisa com plantas forrageiras tropicais em pastagens: características morfofisiológicas e manejo do pastejo. *Revista Brasileira de Zootecnia*, *36*(suppl), 122–138. <https://doi.org/10.1590/s1516-35982007001000014>
- Silva, S. C., & Nascimento Júnior, D. (2007b). Ecofisiologia da produção animal em pastagens e suas implicações sobre o desempenho e a produtividade de sistemas pastoris. In A. R. Evangelista, V. B. Tavares, L. T. Medeiros, & A. R. Valeriano (Eds.), *Simpósio de Forragicultura e Pastagens* (6th ed., pp. 1–39).
- Silva, S. C., & Pedreira, C. G. S. (1997). Princípios de ecologia aplicada ao manejo da pastagem. In V. Favoretto, L. R. A. Rodrigues, & T. J. D. Rodrigues (Eds.), *Simpósio sobre Ecossistema de Pastagens* (pp. 1–62).
- Silva, S. C., Uebele, M. C., Congio, G. F. S., Carnevalli, R. A., & Sbrissia, A. F. (2021). Growth of *Megathyrus maximus* cv. Mombaça as affected by grazing strategies and environmental seasonality. I. Tillering dynamics and population stability. *Crop and Pasture Science*, *72*(1), 55. <https://doi.org/10.1071/CP20198>
- Silva, V. J., Pedreira, C. G. S., Sollenberger, L. E., Silva, L. S., Yasuoka, J. I., & Almeida, I. C. L. (2016). Canopy height and nitrogen affect herbage accumulation, nutritive value, and grazing efficiency of ‘Mulato II’ brachiariagrass. *Crop Science*, *56*(4), 2054–2061. <https://doi.org/10.2135/cropsci2015.12.0764>

- Tesk, C. R. M., Cavalli, J., Pina, D. S., Pereira, D. H., Pedreira, C. G. S., Jank, L., Sollenberger, L. E., & Pedreira, B. C. (2020). Herbage responses of Tamani and Quênia guineagrasses to grazing intensity. *Agronomy Journal*, *112*(3), 2081–2091. <https://doi.org/10.1002/agj2.20189>
- Yasuoka, J. I., Pedreira, C. G. S., Silva, V. J., Alonso, M. P., Silva, L. S., & Gomes, F. J. (2017). Canopy height and N affect herbage accumulation and the relative contribution of leaf categories to photosynthesis of grazed brachiariagrass pastures. *Grass and Forage Science*, *73*(1), 183–192. <https://doi.org/10.1111/gfs.12302>
- Zanine, A. M., Nascimento Júnior, D., Santos, M. E. R., Pena, K. S., Silva, S. C., & Sbrissia, A. F. (2011). Características estruturais e acúmulo de forragem em capim-tanzânia sob pastejo rotativo. *Revista Brasileira de Zootecnia*, *40*(11), 2364–2373.
- Zanini, G. D., Santos, G. T., & Sbrissia, A. F. (2012). Frequencies and intensities of defoliation in Aruana guineagrass swards: Morphogenetic and structural characteristics. *Revista Brasileira de Zootecnia*, *41*(8), 1848–1857. <https://doi.org/10.1590/S1516-35982012000800007>

2 DEFOLIATION INTENSITY AND NITROGEN AFFECT CANOPY STRUCTURAL TRAITS OF GRAZED GUINEAGRASS UNDER ROTATIONAL STOCKING

Abstract

The use of canopy light interception (LI) as a guide for establishing the optimum rest period for forage grasses has been proposed as a powerful tool for a number of temperate and tropical pasture species. Several benefits have been reported when regrowth is interrupted at 95% canopy LI, both for animals and pastures. It has been proposed that LI can be associated with specific canopy heights, but the relation between LI and height can be erratic due to inherent canopy structural changes and by nitrogen (N) supply, among other factors. Our objective was to study canopy structural responses and forage accumulation rate of ‘Zuri’ guineagrass [*Megathyrsus maximus* (Jacq.) B.K. Simon & S.W.L. Jacobs (syn. *Panicum maximum* Jacq.)] when grazed was initiated at two canopy heights [55 and 75 cm (H55 and H75, respectively)] and two N fertilization rates [150 and 300 kg N ha⁻¹ yr⁻¹ (N150 and N300, respectively)]. Defoliation management was 50% of pre-graze canopy height. Regardless of N rate, pastures managed at H75 always reached 95% LI. Compared to the other treatments, the H55/N300 pastures underwent structural changes over time with greater leaf proportion, greater tiller population density, greater specific leaf area, and lesser mean foliage angle, which resulted in 95% LI. The H55/N150 pasture presented 91.8% LI. The total forage accumulation (FA) was greater for H75 with 22120 kg DM ha⁻¹ yr⁻¹, an increase of 20% in relation to H55 which presented a value of 18370 kg DM ha⁻¹ yr⁻¹. The FAR for H75 showed an increase of 19% compared to H55. The greater N rate (N300) resulted in greater FA and FAR by 38% compared to the lesser N rate (N150). Grazing interval was shorter (19 days) for H55, especially when associated with N300, and longer (28 days) in H75/N150 pastures. Although the short canopy height (H55) combined with the greater N rate (N300) reached 95% LI, it did not result in FA similar to H75. In view of this, pastures should be defoliated when they reach H75 due to greater FA and FAR. The increase between N rates favored FA and, consequently, FAR. Thus, the adequate combination of pre-graze canopy height and N rate may contribute to the intensification of grazing systems with Zuri guineagrass.

Keywords: Forage production; Fertilization; Leaf area index; Management flexibility; Plant-part composition.

2.1 Introduction

Tropical grasses have a key role in the Brazilian livestock industry, comprising large areas of pasture for beef and dairy production systems (Jank et al., 2014). Forages are the major source of nutrients for ruminants and represent a low cost feeding option compared to other sources. Guineagrass [*Megathyrsus maximus* (Jacq.) B.K. Simon & S.W.L. Jacobs (syn. *Panicum maximum* Jacq.)], of African origin, was introduced in Brazil around the 19th century and adapted very well to the local soil and climate conditions. More recently, this species was widely exploited in breeding programs, resulting in several cultivar releases. ‘Tanzania’, ‘Mombaça’, and ‘Massai’ guineagrasses were released in the 1990s and still

contribute to livestock production (Jank et al., 2010). Tanzania guineagrass became a popular grass due to its leaf mass and green mass (53 and 73% of forage mass, respectively) (Euclides et al., 1999), and great potential for forage accumulation favoring grazing animal production, especially when there are no soil fertility limitations during the warm/rainy season (Pedreira et al., 2005). However, due to problems such as susceptibility to the fungus *Bipolaris maydis* (Y. Nisik and Miyake) Shoemaker, which causes the leaf spot disease, decline in forage production and persistence has been recorded (Muir & Jank, 2004). 'Zuri' guineagrass was released in 2014 due to its great forage accumulation and nutritive value, in addition to its resistance to the *Bipolaris* fungus (Embrapa, 2014).

Zuri is similar to Tanzania guineagrass regarding canopy structure and productive potential, and defoliation recommendations are for grazing initiation at a canopy height of 70-75 cm under rotational stocking (Embrapa, 2014). During the regrowth after grazing, plants reach a point where the accumulation of leaves is maximum and that has been associated with the interception of 95% of the incoming radiation (95% LI) by the canopy. Above 95% LI there is stem elongation increases and this has been associated with intra-specific competition for light among plants, and an increase in the accumulation of dead material due to mutual shading (Silva et al., 2015).

The 95% LI concept has been proposed as a practical guideline to establish optimum rest period between grazing in pastures under rotational stocking, but the nature of the concept and its measurement are not practical as an everyday management tool as it requires the manager to have the necessary equipment, which is often expensive and complex to use. Associations between canopy height and LI (height being much simpler, quicker, and less expensive to measure) have been proposed for canopies of tropical forage species, and some have been reported in the literature (Carnevalli et al., 2006; Congio et al., 2018; Pedreira et al., 2007; Pedreira et al., 2017a).

The association between canopy height and LI is not always clear and constant across grasses and environments (Pontes et al., 2016) and is not uniform across pasture conditions, seasons, and stage of development, even within forage species and cultivars. This has been shown for 'Marandu' palisadegrass [*Urochloa brizantha* Hochst. ex A. Rich. Stapf. (syn. *Brachiaria brizantha* Hochst. ex A. Rich. Stapf.)] (Gomes, 2019) and kikuyugrass (*Pennisetum clandestinum* Hochst. Ex. Chiov.) (Sbrissia et al., 2018). This can happen due to changes that occur, for example, in tiller weight and population density, modifying light interception under different managements in a particular environment (Bircham & Hodgson, 1983; Matthew et al., 1995; Sbrissia & Silva, 2008), as well as other structural characteristics

of the canopy. In addition to these changes in the canopy structural characteristics, Braga et al. (2006) described that different forage allowances may result in 95% LI at different canopy heights, suggesting that the relationship between canopy height and LI may vary over time. Thus, to understand how the crop intercepts the light that reaches the canopy and find the ideal moment to grazing initiated, it is important to consider variables that make up its structure, and that can impact forage accumulation (FA) (Macedo et al., 2021).

In addition to being influenced by grazing management, FA is also affected by nitrogen supply (Pontes et al., 2016; Silva et al., 2016), enhancing the carrying capacity (Vasques et al., 2019) and increases in pasture stocking rate (Delevatti, et al., 2019). Tropical pastures often grow in low soil fertility lands (Hungria et al., 2016), and the low fertility levels and the lack of fertilizer amendments contribute to reduce the amount of forage produced (Dubeux Jr. et al., 2006). This has been associated with poor pasture persistence and productivity (Euclides et al., 2019). In tropical and subtropical pasture ecosystems, N is the most limiting nutrient for forage production (Gurgel et al., 2020; Silveira & Kohmann, 2020) and low N supply is regarded as one of the main causes of pasture degradation. Thus, to avoid this, the use of forage plants with high forage production and responsive to nitrogen fertilization has been strategies to promote increases in beef cattle production (Silva et al., 2020), and efficiency of use land (Domiciano et al., 2020).

Opportunities exist for making better use of the forage resource in tropical grassland areas with the adoption of better grazing management practices (e.g., controlling pre-graze canopy height combined with N input), but more information is needed on the patterns of forage accumulation rate and canopy structure of Zuri guineagrass for intensive forage-based livestock systems. Our objective was to assess the canopy structural characteristics and forage accumulation rate in Zuri guineagrass pastures under rotational stocking, in response to pre-graze canopy height and N fertilization rate.

2.2 Materials and Methods

2.2.1 Site description, experimental design, and treatments

The study was carried out at the Luiz de Queiroz College of Agriculture, University of São Paulo (USP-ESALQ), in Piracicaba, state of São Paulo, Brazil (22°42' S, 47°30' W, 580 m a.l.s.), during two consecutive warm rainy seasons, from 8 Jan. to 7 May 2019 (119 days – Year 1) and from 17 Jan. to 11 May 2020 (115 days – Year 2). The soil at the experimental site is a highly fertile Kandiuudalfic Eutrudox. Soil analysis run in Oct. 2018 revealed pH (0.01

mol L⁻¹ CaCl₂) = 5.1 and base saturation = 64%, so to increase pH, 1.5 Mg ha⁻¹ of lime was surface broadcast on 21 Oct. 2018. Soil samples were taken again on 17 Dec. 2019, and new analysis revealed the following fertility characteristics: pH (0.01 mol L⁻¹ CaCl₂) = 6.1; organic matter = 37 g cm⁻³; P (ion-exchange resin extraction method) = 26 mg dm⁻³; K = 5.3 mmolc dm⁻³; Ca = 43 mmolc dm⁻³; Mg = 22 mmolc dm⁻³; H + Al = 23.5 mmolc dm⁻³; sum of bases = 70.3 mmolc dm⁻³; cation exchange capacity = 93.8 mmolc dm⁻³; base saturation = 75%. The Köppen classification for the local climate is Cfa (subtropical with an oceanic climate, without a dry season and with hot summer), with the average temperature of the warmest month above 22 °C and the coolest month below 18 °C (Alvares et al., 2013). The weather data during the experimental period were obtained at a station located 2 km from the experimental site.

Table 1. Monthly weather data during two rainy seasons and the historical average in Piracicaba, São Paulo, Brazil.

Weather variable	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May
Year 1 (2018–2019)								
Max. temperature (°C)	29.0	29.4	32.2	33.4	30.2	30.1	30.1	27.9
Min. temperature (°C)	17.6	18.3	19.2	20.4	19.5	19.4	17.9	15.6
Rainfall (mm)	164	201	92	145	163	78	164	30
Year 2 (2019–2020)								
Max. temperature (°C)	33.6	30.6	30.6	31.0	29.1	30.3	28.9	26.5
Min. temperature (°C)	17.9	18.3	19.2	19.6	19.6	17.6	14.7	10.5
Rainfall (mm)	109	220	145	180	399	72	3	13
Historical average ^a								
Max. temperature (°C)	29.2	29.7	29.9	30.0	30.0	30.0	29.0	26.0
Min. temperature (°C)	15.9	16.9	18.4	19.1	19.0	18.0	16.0	12.0
Rainfall (mm)	110	135	198	229	180	141	66	55

^a Historical average weather data from 1917 to 2020 (103 Years).

The experiment was carried out on a Zuri guineagrass pasture area established in the summer in 2015/16. During the 2016/17 and 2017/18 growing seasons another experiment was conducted in the same area with treatments consisting of combinations between two grazing frequencies and two grazing intensities. In mid-September 2018, coming out of the dry season, all pastures were grazed to reduce the canopy height and stimulate regrowth, and on 19 Oct. 2018, the entire area was mowed to a 30 cm stubble height. On 21 Oct. 2018, 50 kg N ha⁻¹ was applied as NH₄NO₃.

The experimental design for the current study was a randomized complete block with four treatments in a factorial arrangement (2 × 2) and four replications, totaling 16

experimental units (pastures) of 160 m² each. The treatments were the combinations of two pre-graze canopy heights, 55 and 75 cm (H55 and H75, respectively) and two N fertilization rates, 150 and 300 kg ha⁻¹ yr⁻¹ (N150 and N300, respectively) applied as NH₄NO₃. To impose the defoliation management, pastures were mob-stocked to mimic a rotational stocking method (graze/rest). Non-lactating crossbred Holstein cows and heifers (*Bos* spp.) weighing 450 kg on average were used to impose defoliation. These animals were used as defoliating agents, so when the average canopy target (H55 or H75) was reached for a specific pasture a group of animals was taken to the pasture and grazed until the canopy height reached 50% of the pre-graze height (27.5 and 37.5 cm for H55 and H75, respectively). When they were not grazing, the animals remained in an area adjacent to the experiment or were fed hay or silage. The research was approved by the ESALQ Committee on Ethics for Animal Use (protocol number 2018.5.2289.11.0; n° CEAU 2018-36).

In all pastures, 250 kg K₂O ha⁻¹ yr⁻¹ were split-applied as KCl, together with the respective N fertilization for the treatment, always at post-graze. The amount of N fertilizer applied after each grazing was calculated based on the number of days in the previous rest period and assuming a total 90 days of growing conditions for the season, starting at the beginning of the experimental period. The canopy height was measured three times per week during the rest period, at 45 sites in each pasture, taking a view of the top of the canopy against a measuring stick. There was no data collection from Jun. to Dec. 2019, but the grazing treatments – not the N fertilization – were maintained during that period.

2.2.2 Response variables

2.2.2.1 Pre- and post-graze forage mass, total forage accumulation, and forage accumulation rate

Pre- (FM_{PRE}) and post-graze (FM_{POST}) forage mass (FM) was measured in each pasture by harvesting two quadrats (0.5 × 1.0 m) per pasture at sites where FM was representative of the average FM, by visual appraisal, at 10 cm from the soil level immediately prior to each grazing and immediately after each grazing. The forage accumulation during the rest period was calculated as the difference between FM_{PRE} and FM_{POST} of the previous grazing cycle. The total forage accumulation (FA) was calculated as the sum across all cycles for each pasture. The FAR was calculated by dividing forage accumulation by the number of days of the corresponding rest period.

2.2.2.2 Plant-part composition, leaf:stem ratio, leaf area index, and specific leaf area

The plant-part composition of FM_{PRE} and FM_{POST} was estimated from sub-samples (~250 g) taken from the FM samples before drying. The subsamples were separated into leaf, stem (pseudostem + leaf sheath) and dead material. A fraction of approximately 30 leaves were scanned in a model LI-3100 leaf area meter (Li-Cor, Lincoln, Nebraska, USA) to determine the leaf area. After determining the leaf area, the leaf, stem, and dead material fractions were dried in a forced-air oven at 55°C until constant weight and weighed. The leaf:stem ratio (L:S) was calculated by dividing leaf proportion by stem proportion. The specific leaf area (SLA) at pre-graze was calculated as the ratio between the leaf area to its respective dry weight, and subsequently used to calculate leaf area index (LAI).

2.2.2.3 Canopy light interception, mean foliage angle, and light extinction coefficient

The LI and mean foliage angle (MFA) were measured using a model LAI-2000 canopy analyzer (Li-Cor, Lincoln, Nebraska, USA) both at pre- and post-graze. Measurements were taken along transect lines within each pasture, with one reading above the canopy (reference reading) for every five readings at soil level, totaling 30 readings per pasture. Readings were always taken at times of predominantly diffuse radiation, with overcast sky and/or low solar elevation (Welles & Norman, 1991). The light extinction coefficient (k) at pre-graze was calculated using the equation proposed by Sheehy & Cooper (1973), $k = - [\log_e (I / I_0)] / LAI$, where I is irradiance reaching the base of canopy, i.e., irradiance below the foliage, I_0 is the irradiance that reaches top of canopy, and LAI is the leaf area index.

2.2.2.4 Tiller population density and average tiller weight

The tiller population density (TPD) was assessed at post-graze in every grazing cycle by counting all tillers contained within two quadrats (0.5 × 1.0 m) per pasture, at sites representing the average canopy condition, by visual assessment. The average tiller weight (ATW) was obtained pre-graze from harvesting 50 tillers representing the mean tiller size, by visual assessment. These tillers were clipped at soil level and dried in a forced-draft oven at 55°C until constant weight and weighed.

2.2.2.5 Grazing interval (rest period)

Grazing interval (GI) was measured as the sum of days elapsed from post- to the following pre-graze condition. The GI was evaluated in all grazing cycles during the experimental period.

2.3 Statistical Analysis

The data were analyzed using the PROC MIXED procedure of SAS[®], with a model including the effects of canopy height, N rate, and their interaction as fixed effects. Year and block (replication) were considered random effects (Littell et al., 2006). The covariance structure was chosen based on the Akaike's Information Criterion (AIC) (Wolfinger, 1993). Linear predictor and quantile-quantile plots of the residues were used to verify homogeneity of variance and error normality. Treatment means were calculated using LSMEANS and compared by the probability of difference (PDIF), with Student test ($P < .05$).

2.4 Results

2.4.1 Pre- and post-graze forage mass, total forage accumulation, and forage accumulation rate

The FM_{PRE}, FA, and FAR were affected by canopy height ($P < .0001$, $P = .0103$, and $P = .0085$, respectively) (Table 2) and N rate ($P = .0243$, $P < .0001$ and $P = .0002$, respectively) (Table 3). The FM_{POST} was affected by canopy height ($P < .0001$) (Table 2) but not by N rate ($P = .2887$, mean = 2852 kg DM ha⁻¹). The FM_{PRE}, FM_{POST}, FA, and FAR were greater for H75 than for H55. The FA and FAR were 20% and 19% greater for the H75 than for H55 (Table 2) and the FM_{PRE}, FA, and FAR for N300 were greater than for N150 (Table 3).

Table 2. Pre- (FM_{PRE}) and post-graze (FM_{POST}) forage mass, total forage accumulation (FA), and forage accumulation rate (FAR) of Zuri guineagrass as affected by pre-graze canopy height during two grazing seasons, 2019 and 2020, in Piracicaba, São Paulo, Brazil.

Canopy height	FM _{PRE}	FM _{POST}	FA	FAR
cm	----- kg DM ha ⁻¹ -----		kg DM ha ⁻¹ yr ⁻¹	kg DM ha ⁻¹ d ⁻¹
55	5830 b	2385 b	18370 b	160 b
75	8560 a	3320 a	22120 a	190 a
SEM ^a	395	215	4551.1	35

Means within columns followed by different letters differ by t-test ($P < .05$).

^a Standard error of the mean.

Table 3. Pre-graze forage mass (FM_{PRE}), total forage accumulation (FA), and forage accumulation rate (FAR) of Zuri guineagrass as affected by N rate during two grazing seasons, 2019 and 2020, in Piracicaba, São Paulo, Brazil.

N rate	FM_{PRE}	FA	FAR
$kg\ ha^{-1}\ yr^{-1}$	--- $kg\ DM\ ha^{-1}$ ---	-- $kg\ DM\ ha^{-1}\ yr^{-1}$ --	--- $kg\ DM\ ha^{-1}\ d^{-1}$ ---
150	6870 b	16980 b	145 b
300	7525 a	23500 a	200 a
SEM ^a	395	4551.1	35

Means within columns followed by different letters differ by t-test ($P < .05$).

^a Standard error of the mean.

2.4.2 Pre-graze plant-part composition, leaf:stem ratio, leaf area index, and average tiller weight

Pre-graze leaf and dead material proportions as well as LAI were affected by canopy height ($P = .0003$, $P = .0141$, and $P < .0001$, respectively) (Table 4) and N rate ($P = .0473$, $P = .0022$, and $P = .0005$, respectively) (Table 5). The stem proportion, L:S, and ATW were affected only by canopy height ($P < .0001$ for all responses) (Table 4). The H55 resulted in greater L:S but lesser LAI and ATW. Under H75, LAI, ATW, and stem and dead material proportion were greater, and leaf proportion was lesser than in H55 (Table 4). Under N300, leaf proportion and LAI were greater, but the dead material proportion was 21% greater for the N150 (Table 5). The stem proportion was not affected by N rate ($P = .3715$) on average 19%.

Table 4. Pre-graze leaf, stem, and dead material proportions, leaf:stem ratio (L:S), leaf area index (LAI), and average tiller weight (ATW) of Zuri guineagrass as affected by pre-graze canopy height during two grazing seasons, 2019 and 2020, in Piracicaba, São Paulo, Brazil.

Canopy height	Leaf	Stem	Dead	L:S	LAI	ATW
cm	----- % -----				$cm^2\ cm^{-2}$	$g\ tiller^{-1}$
55	68 a	16 b	15 b	4.1 a	5.5 b	1.7 b
75	61 b	21 a	17 a	2.8 b	6.8 a	2.5 a
SEM ^a	2	0.7	1	0.2	0.8	0.2

Means within columns followed by different letters differ by t-test ($P < .05$).

^a Standard error of the mean.

Table 5. Pre-graze leaf and dead material proportions, and leaf area index (LAI) of Zuri guineagrass as affected by N rate during two grazing seasons, 2019 and 2020, in Piracicaba, São Paulo, Brazil.

N rate	Leaf	Dead	LAI
kg ha ⁻¹ yr ⁻¹	----- % -----	-----	cm ² cm ⁻²
150	63 b	17 a	5.8 b
300	66 a	14 b	6.4 a
SEM ^a	2	1	0.8

Means within columns followed by different letters differ by t-test ($P < .05$).

^a SEM, standard error of the mean.

2.4.3 Pre-graze canopy light interception, mean foliage angle, light extinction coefficient, and specific leaf area

The pre-graze canopy LI, MFA, k, and SLA were affected by the canopy height \times N rate interaction ($P = .0003$, $P = .0112$, $P = .0053$, and $P = .0276$, respectively). The 95% LI was reached in the H75 treatments regardless of N rate, however, under the H55, this value was only reached with the greater N rate. The H55/N150 treatment resulted in the least LI value 91.8%. Under N150 there was no difference in the MFA H55 and H75, but for the N300 lesser MFA (more horizontal) was found for H55. Under H75 the k was greater for N150, but in H55 there was no difference, whereas for the N300 it was greater in H55. The SLA differed between N rates in H55, N300 resulting in 12% greater SLA than N150. For H75, however, there were no SLA differences between N rates (Table 6).

Table 6. Pre-graze canopy light interception (LI), mean foliage angle (MFA), light extinction coefficient (k), and specific leaf area (SLA) of Zuri guineagrass as affected by the canopy height \times N rate interaction during two grazing seasons, 2019 and 2020, in Piracicaba, São Paulo, Brazil.

Canopy height (cm)	N rate (kg ha ⁻¹ yr ⁻¹)		<i>P</i> -value ^a	SEM ^c
	150	300		
----- LI (%) -----				
55	91.8	94.6	<.0001	0.3
75	95.1	95.3	.5028	0.3
<i>P</i> -value ^b	<.0001	.0580		
SEM ^c	0.3	0.3		
----- MFA (°) -----				
55	47	45	.0057	0.5
75	47	48	.3303	0.5
<i>P</i> -value ^b	.8028	.0009		
SEM ^c	0.5	0.5		
----- k -----				
55	0.50	0.52	.5900	0.01
75	0.49	0.45	.0116	0.01
<i>P</i> -value ^b	.2482	.0002		
SEM ^c	0.01	0.01		
----- SLA (cm ² g ⁻¹) -----				
55	132	148	.0013	3.6
75	135	138	.3850	3.5
<i>P</i> -value ^b	.3626	.0229		
SEM ^c	3.6	3.5		

^a N rate effect within canopy height.

^b Canopy height effect within N rate.

^c Standard error of the mean.

2.4.4 Post-graze plant-part composition, leaf:stem ratio, leaf area index, tiller population density, and mean foliage angle

The post-graze leaf proportion, LAI, and MFA were affected only by canopy height ($P < .0001$, $P = .0288$, and $P = .0002$, respectively) (Table 7). The stem proportion, L:S, and TPD were affected by the canopy height ($P < .0001$ for all responses) and N rate ($P < .0001$, $P = .0013$, and $P = .0016$, respectively) (Tables 7 and 8, respectively). In H75, the stem proportion, LAI, and MFA were the greatest. However, the leaf proportion, L:S, and TPD were greatest in H55 (Table 7). The dead material proportion differed among by N rate ($P =$

.0001), where the N300 was 10% less. The stem proportion was 17% lesser accompanied by 18% greater L:S and 10% lesser TPD in the N150 (Table 8).

Table 7. Post-graze leaf and stem proportions, leaf:stem ratio (L:S), leaf area index (LAI), tiller population density (TPD), and mean foliage angle (MFA) of Zuri guineagrass as affected by canopy height during two grazing seasons, 2019 and 2020, in Piracicaba, São Paulo, Brazil.

Canopy height	Leaf	Stem	L:S	LAI	TPD	MFA
cm	----- % -----	----- % -----		cm ² cm ⁻²	tillers m ⁻²	°
55	44 a	19 b	2.3 a	1.3 b	557 a	59 b
75	37 b	25 a	1.4 b	1.4 a	474 b	62 a
SEM ^a	0.8	0.9	0.1	0.1	11	0.4

Means within columns followed by different letters differ by t-test ($P < .05$).

^a Standard error of the mean.

Table 8. Post-graze stem and dead material proportions, leaf:stem ratio (L:S), and tiller population density (TPD) of Zuri guineagrass as affected by N rate during two grazing seasons, 2019 and 2020, in Piracicaba, São Paulo, Brazil.

N rate	Stem	Dead	L:S	TPD
kg ha ⁻¹ yr ⁻¹	----- % -----	----- % -----		tillers m ⁻²
150	20 b	39 a	2.0 a	488 b
300	24 a	35 b	1.7 b	543 a
SEM ^a	0.9	0.9	0.1	11

Means within columns followed by different letters differ by t-test ($P < .05$).

^a Standard error of the mean.

The post-graze LI was not affected by canopy height, N rate, or by the canopy height \times N rate interaction ($P = .1599$, $P = .9288$, and $P = .8456$, respectively), with an average of 69%.

2.4.5 Grazing interval (rest period)

The GI was affected by canopy height \times N rate interaction ($P = .0059$). For both N rates, the GI was lesser in the H55 than in the H75. Regardless of the canopy height, however, the GI was shorter in the N300 than N150. The combination of H55 with N300 resulted in the shortest GI among treatments (Table 9).

Table 9. Grazing interval (GI) of Zuri guineagrass as affected by the canopy height \times N rate interaction during two grazing seasons, 2019 and 2020, in Piracicaba, São Paulo, Brazil.

Canopy height (cm)	N rate (kg ha ⁻¹ yr ⁻¹)		<i>P</i> -value ^a	SEM ^c
	150	300		
	----- GI (days) -----			
55	22	19	.0415	0.9
75	28	22	<.0001	1
<i>P</i> -value ^b	<.0001	.0067		
SEM ^c	1	0.9		

^a N rate effect within canopy height.

^b Canopy height effect within N rate.

^c Standard error of the mean.

2.5 Discussion

Pastures managed in H75 had greater FM_{PRE} and FM_{POST} by 47 and 39%, respectively, mainly due to stem contribution. The stem is an important plant-part component to support plant growth and whose participation in the FM increases with canopy height. Stem elongation in tropical grasses results in taller plants and decreased TPD (Yasuoka et al., 2021), and this is corroborated by the results of the present study. On the other hand, stem elongation, increases shading of older leaves near the base of canopy by younger leaves, increasing crop respiratory losses and intensifying tissue senescence (Parsons et al., 1988), as illustrated by the greater proportion of dead material in taller canopies of Zuri guineagrass (Table 4). Shorter canopies (H55) have a smaller proportion of stem and dead material in FM_{PRE}, together with greater proportion of leaves, which resulted in greater L:S. The leaves, besides being the component of LAI, have the greatest photosynthetic capacity of all plant parts (Lemaire & Chapman, 1996), playing a fundamental role from a productive point of view (Silva et al., 2015). The greater LAI was recorded for H75, which may have resulted in greater competition for light between tillers leading to a reduction in TPD (Silva et al., 2021), due to less light reaching the base of the canopy.

The N300 rate increased FM_{PRE} of Zuri guineagrass by 9% greater compared to N150, accompanied by greater proportion of leaf and greater LAI. Nitrogen fertilization accelerates leaf elongation (Paciullo et al., 2017), resulting in a greater proportion of leaves in the FM_{PRE}, as observed in pastures that received the greater N rate (Table 5). In ‘Mulato II’ brachiariagrass hybrid [*Urochloa ruziziensis* Germ. & Evrard \times *U. decumbens* Stapf \times *U. brizantha* Hochst. ex A. Rich. Stapf (syn. *Brachiaria ruziziensis* Germ. & Evrard \times *B.*

decumbens Stapf. × *B. brizantha* Hochst. ex A. Rich. Stapf.)] pastures receiving 50 and 250 kg N ha⁻¹ yr⁻¹, the proportion of leaves and LAI increased when fertilized with the greater rate (Silva et al., 2016). Thus, the greater proportion of leaves in the FM and LAI may be associated with greater C assimilation and, consequently, greater forage accumulation rate (Yasuoka et al., 2017).

The greater LAI accompanied by the greater FAR probably occurs for taller canopies, as recorded in the present study, with the FAR 19% greater in H75 pastures than in H55 (Table 2). The greater FAR resulted in greater FA for H75, going from 18370 to 22120 kg DM ha⁻¹ yr⁻¹ when the height increased from H55 to H75, respectively (Table 2). This is probably derived from the greater pre and post FMs, by the greater proportion of stem in the FM, and also by the greater average tiller weight for these canopies (Table 4), occurring throughout the regrowth period. The dynamics of regrowth after defoliation is divided into three phases, the first phase is little slow growth due to post-graze conditions (depends on the severity of defoliation and the quality of residual LAI), the second phase shows accelerated growth as the LAI increases, and a third phase where there is a decline in growth (Hodgson, 1990). Phase two is where the canopy normally reaches 95% LI with leaves being the main plant-part composition accumulated, and after that point there is still forage accumulation, but it will be comprised by greater proportions of stem and dead material (Pedreira et al., 2009). Congio et al. (2018) studying elephant grass (*Pennisetum purpureum* Schum. cv. Cameroon) showed that the maximum LI resulted in greater total forage accumulation compared to 95% LI, although it was characterized by 20% stem, while at the 95% LI, the proportion of stem accumulated was only 5%. It could be argued that keeping the canopy between the lower and the upper limits of the linear phase of the growth curve might favor seasonal forage accumulation with greater production of leaves over the other plant parts.

Under N300, the FAR and FA were 200 kg DM ha⁻¹ d⁻¹ and 23500 kg DM ha⁻¹ yr⁻¹, respectively, which was 38% greater than N150 for both variables (145 kg DM ha⁻¹ d⁻¹ and 16980 kg DM ha⁻¹ yr⁻¹, respectively). Nitrogen application to pastures increases the rate of leaf elongation, an important contributor to grass growth (Paciullo et al., 2017). Additionally, the greater N rate (N300) can increase the tiller population (Silva et al., 2020) which, together with the greater rate of leaf elongation (Paciullo et al., 2017), can favor FA (Silva et al., 2016) and, consequently, the carrying capacity of pastures (Vasques et al., 2019). Tanzania guineagrass harvested at 33 days and fertilized with 250 kg N ha⁻¹ had a FAR of 121 kg DM ha⁻¹ d⁻¹ during the rainy season (Pedreira et al., 2005). Domiciano et al. (2020) studied Mombaça guineagrass and reported FAR of 140 kg DM ha⁻¹ d⁻¹ in summer harvested every

28 days and fertilized with 50 kg N ha⁻¹ per cycle. Tesk et al. (2020) measured FAR of 102 and 92 kg DM ha⁻¹ d⁻¹, in ‘Tamani’ and ‘Quenia’ guineagrasses, respectively, grazed at 95% LI and fertilized with 190 kg N ha⁻¹. This suggests that Zuri guineagrass has the potential to produce more than Tanzania, Mombaça, Quenia, and Tamani, and is very responsive to nitrogen fertilization, but this is dependent on the climate and soil conditions of the site.

The association between canopy height and light interception has been validated for several grasses, and 95% LI is arguably a biologically sound indicator of the moment at which the forage stand should be harvested (Carnevali et al., 2021; Congio et al., 2018; Pedreira et al., 2007; Pedreira, et al., 2017a). However, there is a possibility that pastures achieve this same interception at a range of canopy heights (Pontes et al., 2016), through variations in canopy architecture due to N fertilization. A study with ‘Aruana’ guineagrass subjected to defoliation intensities of 50 and 70% relative to 95% LI and rates of 0 and 300 kg N ha⁻¹ yr⁻¹, revealed that N and harvest intensity caused reduction in canopy height for 95% LI. This can be attributed to a leafier canopy structure, in the 50% harvest and N300 application, which resulted in canopy height decrease for 95% LI that can reach 6.6 cm lower (Pontes et al., 2016).

In our study, canopy LI of Zuri guineagrass pastures managed at H55 and N300 was 95% (Table 6). Although the relationship between canopy height and LI has been established in the literature, it is important to consider other variables that make up the canopy structure, and how plant stands intercept light (Macedo et al., 2021). The combination of H55 and N300 resulted in foliage with a more horizontal orientation (lesser MFA and greater k). According to Sheehy & Cooper (1973) a canopy with more horizontal leaves increases light interception, i.e., the greater k results in a flatter distribution of leaf area (Yunusa et al., 1993). Another reason that made canopies under H55/N300 reach 95% LI is the greater SLA (Table 6). According to Nascimento et al. (2019) since plants alter leaf structure by decreasing thickness in order to increase width (photosynthetic tissues), which also helped to improve light interception with increased leaf surface.

In addition to the variables mentioned above, the TPD is an important component for restoring canopy leaf area after defoliation (Matthew et al., 2000), and its adjustment is dependent on the defoliation strategy imposed (Barbosa et al., 2021), directly affecting canopy LI (Macedo et al., 2021). This is due to the fact that crop stands can compensate for smaller tiller sizes by increasing TPD (Bircham & Hodgson, 1983; Matthew et al., 1995; Sbrissia et al., 2001) as registered in H55. Taller canopies (H75) have lesser TPD (Table 7) with bigger and heavier tillers (Table 4). This is known as tiller size/density compensation.

The lesser ATW in H55 pastures (Table 4) was probably a result of the compensation mechanism triggered by the increased TPD (Table 7). Pastures under H75 had smaller TPD but greater ATW, and this may be one of the reasons that also contributed to greatest FAR in these canopies. The TPD can be affected by nutrient availability (Silva et al., 2020; Silva et al., 2021), and impact pasture persistence (Lemaire and Chapman, 1996; Matthew et al., 2000; Silva et al., 2020). In the current study, N300 resulted in 11% greater TPD than N150. Nitrogen plays a key role in the activation of the meristematic region where new leaves are produced (Alderman et al., 2011), and is an important contribution to the tillering process (Williamson et al., 2012), and to the longevity and productivity of grass pastures (Gomide et al., 2019). This may have been one of the reasons for the greater TPD for N300 and, consequently, greater FAR and FA, as recorded in the present study.

At post-graze, both heights and N rates resulted in the same LI, although leaf proportion and L:S ratio were greater for the shorter stubble (H55), and LAI was greater for the taller stubble (H75). Regarding N rate, the lesser L:S was recorded at N300 due to greater proportion of stem (Table 8). The LAI after defoliation needs to be such (in quantity and quality) that it can support vigorous plant regrowth. Hodgson (1990) argued that defoliation intensity greater than 50% of initial canopy height can delay the regrowth, whereas more lax defoliation (stubble taller than 50% of initial canopy height) is likely to increase senescence losses. Thus, the stubble left after grazing may also define the demand for organic reserves used in regrowth (Pedreira et al., 2017b). Defoliation to 50% of the pre-graze canopy height may result in residual leaf area that can intercept enough light for photoassimilate synthesis, with no impact on FAR (Sbrissia et al., 2018). Despite the same relative defoliation intensity for the two pre-graze heights, the lesser GI for H55/N300 pastures likely resulted from the combination of shorter canopy and greater N rate, which decreased the time to achieve the pre-graze target condition (19 days), probably favored by the greater leaf proportion and greater L:S for H55, and the greatest TPD for the two factors, both for the shorter canopy height (H55) and for the greater N rate (N300). Pastures defoliated when they reached H75 fertilized with N150 resulted in longest GI (Table 9). Nitrogen is often seen as the most limiting factor for plant growth after water deficit (Lemaire et al., 2008), being considered an important agronomic input for grasslands (Silveira et al., 2015), thus, nitrogen fertilization favors a fast return to the pre-graze condition, shortening the rest period. Thus, the results obtained in the present study showed that pre-graze canopy heights and N fertilization rates impacted LAI, FM, FAR, and FA, as well as plant-part composition and structural characteristics of the canopy, causing differences in plant morphology and forage production.

2.6 Summary and Conclusions

Zuri guineagrass reached 95% LI when managed with H75 regardless of N rate. The combination H55/N300 favored leaf architecture arrangement through lesser MFA, greater k , and greater SLA, reaching 95% LI. Pastures managed at height H55 intercepted 91.8% of light and had FAR 16% lesser than H75. Canopy managed at the height of H75 resulted in greater FA (22120 kg DM ha⁻¹ yr⁻¹) compared to the height of H55, an increase of 20%. When Zuri guineagrass pastures were submitted with N300, LAI was increased rapidly resulting in reduced GI and, consequently, increased FA and FAR by 38% for both variables. At post-graze the H55 pastures showed greater proportion of leaf and greater L:S, while H75 greater LAI. Regardless of N rate, forage should be harvested at H75 due to greater FA and FAR, and the effect on N rate (N300) was also quite marked in increasing forage production (FA and FAR). The ideal combination of pre-graze canopy height and N rate supports the intensification of grazing systems based of Zuri guineagrass.

References

- Alderman, P. D., Boote, K. J., & Sollenberger, L. E. (2011). Regrowth dynamics of “tifton 85” bermudagrass as affected by nitrogen fertilization. *Crop Science*, *51*(4), 1716–1726. <https://doi.org/10.2135/cropsci2010.09.0515>
- Alvares, C. A., Stape, J. L., Sentelhas, P. C., Gonçalves, J. L. M., & Sparovek, G. (2013). Köppen’s climate classification map for Brazil. *Meteorologische Zeitschrift*, *22*(6), 711–728. <https://doi.org/10.1127/0941-2948/2013/0507>
- Barbosa, P. L., Silva, V. J., Pedreira, C. G. S., Sbrissia, A. F., & Sollenberger, L. E. (2021). Herbage accumulation and tillering dynamics of ‘Zuri’ guineagrass under rotational stocking. *Crop Science*, *61*(5), 3787–3798. <https://doi.org/10.1002/csc2.20536>
- Bircham, J. S., & Hodgson, J. (1983). The influence of sward condition on rates of herbage growth and senescence in mixed swards under continuous stocking management. *Grass and Forage Science*, *38*(4), 323–331. <https://doi.org/10.1111/j.1365-2494.1983.tb01656.x>
- Braga, G. J., Pedreira, C. G. S., Herling, V. R., Luz, P. H. C., & Lima, C. G. (2006). Sward structure and herbage yield of rotationally stocked pastures of “Marandu” palisadegrass [*Brachiaria brizantha* (A.Rich.) Stapf] as affected by herbage allowance. *Scientia Agricola*, *63*(2), 121–129. <https://doi.org/10.1590/s0103-90162006000200003>
- Carnevali, R. A., Congio, G. F. S., Sbrissia, A. F., & Silva, S. C. (2021). Growth of *Megathyrsus maximus* cv. Mombaça as affected by grazing strategies and environmental seasonality. II. Dynamics of herbage accumulation. *Crop and Pasture Science*, *72*(1), 66–74. <https://doi.org/10.1071/CP20199>

- Carnevali, R. A., Silva, S. C., Bueno, A. A. O., Uebele, M. C., Bueno, F. O., Hodgson, J., Silva, G. N., & Morais, J. P. G. (2006). Herbage production and grazing losses in *Panicum maximum* cv. Mombaça under four grazing managements. *Tropical Grasslands*, 40(3), 165–176.
- Congio, G. F. S., Batalha, C. D. A., Chiavegato, M. B., Berndt, A., Oliveira, P. P. A., Frighetto, R. T. S., Maxwell, T. M. R., Gregorini, P., & Silva, S. C. (2018). Strategic grazing management towards sustainable intensification at tropical pasture-based dairy systems. *Science of the Total Environment*, 636, 872–880. <https://doi.org/10.1016/j.scitotenv.2018.04.301>
- Delevatti, L. M., Cardoso, A. S., Barbero, R. P., Leite, R. G., Romanzini, E. P., Ruggieri, A. C., & Reis, R. A. Effect of nitrogen application rate on yield, forage quality, and animal performance in a tropical pasture. *Scientific Reports*, 9, 7596. <https://doi.org/10.1038/s41598-019-44138-x>
- Domiciano, L. F., Santos, M. L., Boote, K. J., Santos, P. M., Pereira, D. H., & Pedreira, B. C. (2020). Physiological responses and forage accumulation of Marandu palisadegrass and Mombaça guineagrass to nitrogen fertilizer in the Brazilian forage-based systems. *Grassland Science*, 67(2), 93–101. <https://doi.org/10.1111/grs.12291>
- Dubeux Jr., J. C. B., Santos, M. V. F., Lira, M. A., Santos, D. C., Farias, I., Lima, L. E., & Ferreira, R. L. C. (2006). Productivity of *Opuntia ficus-indica* (L.) Miller under different N and P fertilization and plant population in north-east Brazil. *Journal of Arid Environments*, 67(3), 357–372. <https://doi.org/10.1016/j.jaridenv.2006.02.015>
- Embrapa. (2014). *BRS Zuri, produção e resistência para a pecuária*. <https://ainfo.cnptia.embrapa.br/digital/bitstream/item/123642/1/Folder-Zuri-Final-2014.pdf>
- Euclides, V. P. B., Montagner, D. B., Macedo, M. C. M., Araújo, A. R., Difante, G. S., & Barbosa, R. A. (2019). Grazing intensity affects forage accumulation and persistence of Marandu palisadegrass in the Brazilian savannah. *Grass and Forage Science*, 74(3), 450–462. <https://doi.org/10.1111/gfs.12422>
- Euclides, V. P. B., Thiago, L. R. L. S., Macedo, M. C. M., & Oliveira, M. P. (1999). Consumo voluntário de forragem de três cultivares de *Panicum maximum* sob pastejo. *Revista Brasileira de Zootecnia*, 28(6), 1177–1185. <https://doi.org/10.1590/s1516-35981999000600002>
- Gomes, C. M. (2019). *Oportunidade para flexibilização das metas pré-pastejo do manejo rotativo do capim-marandu* [Universidade de São Paulo]. <https://doi.org/10.11606/D.11.2019.tde-03092019-112655>
- Gomide, C. A. M., Paciullo, D. S. C., Morenz, M. J. F., Costa, I. A., & Lanzoni, C. L. (2019). Productive and morphophysiological responses of *Panicum maximum* Jacq. cv. BRS Zuri to timing and doses of nitrogen application and defoliation intensity. *Grassland Science*, 65(2), 93–100. <https://doi.org/10.1111/grs.12226>

- Gurgel, A. L. C., Difante, G. S., Montagner, D. B., Araújo, A. R., Dias, A. M., Santana, J. C. S., Rodrigues, J. G., & Pereira, M. G. (2020). Nitrogen fertilisation in tropical pastures: what are the impacts of this practice? *Australian Journal of Crop Science*, *14*(6), 978–984. <https://doi.org/10.21475/ajcs.20.14.06.p2357>
- Hodgson, J. (1990). *Grazing Management: science into practice*. Longman Group UK Ltd.
- Hungria, M., Nogueira, M. A., & Araujo, R. S. (2016). Inoculation of *Brachiaria* spp. with the plant growth-promoting bacterium *Azospirillum brasilense*: An environment-friendly component in the reclamation of degraded pastures in the tropics. *Agriculture, Ecosystems and Environment*, *221*, 125–131. <https://doi.org/10.1016/j.agee.2016.01.024>
- Jank, L., Barrios, S. C., Valle, C. B., Simeão, R. M., & Alves, G. F. (2014). The value of improved pastures to Brazilian beef production. *Crop and Pasture Science*, *65*(11), 1132–1137. <https://doi.org/10.1071/CP13319>
- Jank, L., Martuscello, J. A., Euclides, V. P. B., Valle, C. B., & Resende, R. M. S. (2010). *Panicum maximum* Jacq. In D. M. Fonseca & J. A. Martuscello (Eds.), *Plantas Forrageiras* (1^o, pp. 166–196). Editora UFV.
- Lemaire, G., & Chapman, D. (1996). Tissue flows in grazed plant communities. In J. Hodgson & A. W. Illius (Eds.), *The Ecology and Management of Grazing Systems* (pp. 3–36). CAB International.
- Lemaire, G., Jeuffroy, M. H., & Gastal, F. (2008). Diagnosis tool for plant and crop N status in vegetative stage. Theory and practices for crop N management. *European Journal of Agronomy*, *28*(4), 614–624. <https://doi.org/10.1016/j.eja.2008.01.005>
- Littell, R. C., Milliken, G. A., Stroup, W. W., Wolfinger, R. D., & Schabenberger, O. (2006). *SAS for Mixed Models*. (2nd ed.). SAS Institute.
- Macedo, V. H. M., Cunha, A. M. Q., Cândido, E. P., Domingues, F. N., Silva, W. L., Lara, M. A. S., & Rêgo, A. C. (2021). Canopy structural variations affect the relationship between height and light interception in Guinea Grass. *Field Crops Research*, *271*, 1–10. <https://doi.org/10.1016/j.fcr.2021.108249>
- Matthew, C., Assuero, S. G., Black, C. K., & Hamilton, N. R. S. (2000). Tiller dynamics of grazing swards. In G. Lemaire, J. Hodgson, A. Moraes, P. C. F. Carvalho, & C. Nabinger (Eds.), *Grassland ecophysiology and grazing ecology* (pp. 127–150). CABI Publishing.
- Matthew, C., Lemaire, G., Hamilton, N. R. S., & Hernandez-Garay, A. (1995). A modified self-thinning equation to describe size/density relationships for defoliated swards. *Annals of Botany*, *76*(6), 579–587. <https://doi.org/10.1006/anbo.1995.1135>
- Muir, J. P., & Jank, L. (2004). Guineagrass. In L. E. Moser, B. L. Burson, & L. E. Sollenberger (Eds.), *Warm-Season (C4) Grasses* (45th ed., Issue 45, pp. 589–621). ASA. <https://doi.org/10.2134/agronmonogr45.c17>

- Nascimento, H. L. B., Pedreira, B. C., Sollenberger, L. E., Pereira, D. H., Magalhães, C. A. S., & Chizzotti, F. H. M. (2019). Physiological characteristics and forage accumulation of grazed Marandu palisade grass (*Brachiaria brizantha*) growing in monoculture and in silvopasture with *Eucalyptus urograndis*. *Crop and Pasture Science*, 70(4), 384–394. <https://doi.org/10.1071/CP18403>
- Paciullo, D. S. C., Gomide, C. A. M., Castro, C. R. T., Maurício, R. M., Fernandes, P. B., & Morenz, M. J. F. (2017). Morphogenesis, biomass and nutritive value of *Panicum maximum* under different shade levels and fertilizer nitrogen rates. *Grass and Forage Science*, 72(3), 590–600. <https://doi.org/10.1111/gfs.12264>
- Parsons, A. J., Johnson, I. R., & Harvey, A. (1988). Use of a model to optimize the interaction between frequency and severity of intermittent defoliation and to provide a fundamental comparison of the continuous and intermittent defoliation of grass. *Grass and Forage Science*, 43(1), 49–59. <https://doi.org/10.1111/j.1365-2494.1988.tb02140.x>
- Pedreira, B. C., Pedreira, C. G. S., & Silva, S. C. (2007). Estrutura do dossel e acúmulo de forragem de *Brachiaria brizantha* cultivar Xaraés em resposta a estratégias de pastejo. *Pesquisa Agropecuária Brasileira*, 42(2), 281–287. <https://doi.org/10.1590/s0100-204x2007000200018>
- Pedreira, B. C., Pedreira, C. G. S., & Silva, S. C. (2009). Acúmulo de forragem durante a rebrotação de capim-xaraés submetido a três estratégias de desfolhação. *Revista Brasileira de Zootecnia*, 38(4), 618–625. <https://doi.org/10.1590/S1516-3598200900040005>
- Pedreira, C. G. S., Braga, G. J., & Portela, J. N. (2017a). 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. *Crop and Pasture Science*, 68(1), 62–73. <https://doi.org/10.1071/CP16333>
- Pedreira, C. G. S., Rosseto, F. A. A., Silva, S. C., Nussio, L. G., Moreno, L. S. B., Lima, M. L. P., & Leme, P. R. (2005). Forage yield and grazing efficiency on rotationally stocked pastures of “Tanzania-1” guineagrass and “Guaçu” elephantgrass. *Scientia Agricola*, 62(5), 433–439. <https://doi.org/10.1590/s0103-90162005000500004>
- Pedreira, C. G. S., Silva, V. J., Pedreira, B. C., & Sollenberger, L. E. (2017b). Herbage accumulation and organic reserves of palisadegrass in response to grazing management based on canopy targets. *Crop Science*, 57(4), 2283–2293. <https://doi.org/10.2135/cropsci2016.11.0957>
- Pontes, L. S., Baldissera, T. C., Giostri, A. F., Stafin, G., Santos, B. R. C., & Carvalho, P. C. F. (2016). Effects of nitrogen fertilization and cutting intensity on the agronomic performance of warm-season grasses. *Grass and Forage Science*, 72(4), 663–675. <https://doi.org/10.1111/gfs.12267>
- Sbrissia, A. F., Duchini, P. G., Zanini, G. D., Santos, G. T., Padilha, D. A., & Schmitt, D. (2018). Defoliation strategies in pastures submitted to intermittent stocking method: Underlying mechanisms buffering forage accumulation over a range of grazing heights. *Crop Science*, 58(2), 945–954. <https://doi.org/10.2135/cropsci2017.07.0447>

- Sbrissia, A. F., & Silva, S. C. (2008). Compensação tamanho/densidade populacional de perfilhos em pastos de capim-marandu. *Revista Brasileira de Zootecnia*, 37(1), 35–47. <https://doi.org/10.1590/S1516-35982008000100005>
- Sbrissia, A. F., Silva, S. C., Carvalho, C. A. B., Carnevalli, R. A., Pinto, L. F. M., Fagundes, J. L., & Pedreira, C. G. S. (2001). Compensação tamanho/densidade populacional de perfilhos em pastagens de capim coastcross. *Scientia Agricola*, 58(4), 655–665. <https://doi.org/10.1590/S0103-90162001000400002>
- Sheehy, J. E., & Cooper, J. P. (1973). Light interception, photosynthetic activity, and crop growth rate in canopies of six temperate forage grasses. *The Journal of Applied Ecology*, 10(1), 239. <https://doi.org/10.2307/2404727>
- Silva, L. S., Silva, V. J., Yasuoka, J. I., Sollenberger, L. E., & Pedreira, C. G. S. (2020). Tillering dynamics of ‘Mulato II’ brachiariagrass under continuous stocking. *Crop Science*, 60(2), 1105–1112. <https://doi.org/10.1002/csc2.20008>
- Silva, R. O., Miotto, F. R. C., Neiva, J. N. M., Silva, L. F. F. M., Freitas, I. B., Araújo, V. L., & Restle, J. (2020c). Effects of increasing nitrogen levels in Mombasa grass on pasture characteristics, chemical composition, and beef cattle performance in the humid tropics of the Amazon. *Tropical Animal Health and Production*, 52, 3293–3300. <https://doi.org/10.1007/s11250-020-02360-0>
- Silva, S. C., Sbrissia, A. F., & Pereira, L. E. T. (2015). Ecophysiology of C4 Forage Grasses—Understanding Plant Growth for Optimising Their Use and Management. *Agriculture*, 5(3), 598–625. <https://doi.org/10.3390/agriculture5030598>
- Silva, S. C., Uebele, M. C., Congio, G. F. S., Carnevalli, R. A., & Sbrissia, A. F. (2021). Growth of *Megathyrus maximus* cv. Mombaça as affected by grazing strategies and environmental seasonality. I. Tillering dynamics and population stability. *Crop and Pasture Science*, 72(1), 55–65. <https://doi.org/10.1071/CP20198>
- Silva, V. J., Pedreira, C. G. S., Sollenberger, L. E., Silva, L. S., Yasuoka, J. I., & Almeida, I. C. L. (2016). Canopy height and nitrogen affect herbage accumulation, nutritive value, and grazing efficiency of ‘Mulato II’ brachiariagrass. *Crop Science*, 56(4), 2054–2061. <https://doi.org/10.2135/cropsci2015.12.0764>
- Silveira, M. L., Vendramini, J. M. B., Sellers, B., Monteiro, F. A., Artur, A. G., & Dupas, E. (2015). Bahiagrass response and N loss from selected N fertilizer sources. *Grass and Forage Science*, 70(1), 154–160. <https://doi.org/10.1111/gfs.12078>
- Silveira, M. L. & Kohmann, M. M. (2020). Maintaining soil fertility and health for sustainable pastures. In M. Roquette Júnior & G. E. Aiken (Eds.), *Management Strategies for Sustainable Cattle Production in Southern Pastures* (pp. 35–58). Academic Press. <https://doi.org/10.1016/B978-0-12-814474-9.00003-7>
- Tesk, C. R. M., Cavalli, J., Pina, D. S., Pereira, D. H., Pedreira, C. G. S., Jank, L., Sollenberger, L. E., & Pedreira, B. C. (2020). Herbage responses of Tamani and Quênia guineagrasses to grazing intensity. *Agronomy Journal*, 112(3), 2081–2091. <https://doi.org/10.1002/agj2.20189>

- Vasques, I. C. F., Souza, A. A., Morais, E. G., Benevenuto, P. A. N., Silva, L. C. M., Homem, B. G. C., Casagrande, D. R., & Silva, B. M. (2019). Improved management increases carrying capacity of Brazilian pastures. *Agriculture, Ecosystems and Environment*, 282(1), 30–39. <https://doi.org/10.1016/j.agee.2019.05.017>
- Welles, J. M., & Norman, J. M. (1991). Instrument for indirect measurement of canopy architecture. *Agronomy Journal*, 83(5), 818–825. <https://doi.org/10.2134/agronj1991.00021962008300050009x>
- Williamson, M. M., Wilson, G. W. T., & Hartnett, D. C. (2012). Controls on bud activation and tiller initiation in C₃ and C₄ tallgrass prairie grasses : the role of light and nitrogen. *Botany*, 90(12), 1221–1228. <https://doi.org/10.1139/b2012-091>
- Wolfinger, R. (1993). Covariance structure selection in general mixed models. *Communications in Statistics - Simulation and Computation*, 22(4), 1079–1106. <https://doi.org/10.1080/03610919308813143>
- Yasuoka, J. I., Pedreira, C. G. S., Holschuch, S. G., Almeida, O. G., & Pedroso, G. B. (2021). The enclosure cage technique revisited: Pasture responses under continuous stocking and their relationship with estimates of forage accumulation in grazing experiments. *Crop Science*, 61(2), 1488–1499. <https://doi.org/10.1002/csc2.20447>
- Yasuoka, J. I., Pedreira, C. G. S., Silva, V. J., Alonso, M. P., Silva, L. S., & Gomes, F. J. (2017). Canopy height and N affect herbage accumulation and the relative contribution of leaf categories to photosynthesis of grazed brachiariagrass pastures. *Grass and Forage Science*, 73(1), 183–192. <https://doi.org/10.1111/gfs.12302>
- Yunusa, I. A. M., Siddique, K. H. M., Belford, R. K., & Karimi, M. M. (1993). Effect of canopy structure on efficiency of radiation interception and use in spring wheat cultivars during the pre-anthesis period in a mediterranean-type environment. *Field Crops Research*, 35(2), 113–122. [https://doi.org/10.1016/0378-4290\(93\)90144-C](https://doi.org/10.1016/0378-4290(93)90144-C)

3 CANOPY HEIGHT AND N AFFECT FORAGE ACCUMULATION AND GRAZING EFFICIENCY OF ZURI GUINEAGRASS PASTURES UNDER ROTATIONAL STOCKING

Abstract

Grazing strategy and nitrogen fertilization may impact forage accumulation (FA), nutritive value, and grazing efficiency (GE). The objective of this study was to describe and explain the effects of pre-graze canopy heights [55 and 75 cm (H55 and H75, respectively)] and N fertilization rates [150 and 300 kg N ha⁻¹ yr⁻¹ (N150 and N300, respectively)] on FA, GE, grazing losses (GL), and forage nutritive value of 'Zuri' guineagrass [*Megathyrsus maximus* (Jacq.) B.K. Simon & S.W.L. Jacobs (syn. *Panicum maximum* Jacq.)]

under rotational stocking during two rainy seasons in Piracicaba, state of São Paulo, Brazil. The stubble height was 50% of the pre-graze canopy height. The FA was greatest at H75 (22120 kg DM ha⁻¹ yr⁻¹), which resulted in the greatest forage allowance (FAL) (3.7 kg DM kg⁻¹ BW), while at H55 the FA and FAL were 18370 kg DM ha⁻¹ yr⁻¹ and 2.6 kg DM kg⁻¹ BW, respectively. The H75 canopies resulted in greater GL, but GE was 8% greater compared to defoliated pastures at height H55. Regardless of pre-graze height, the upper half of the canopy (top of canopy) was composed only of leaves and the lower half is comprised mostly of stem and dead material. This upper half consisting only of leaves was which contributed to similarities in nutritive value of the forage harvested between the two heights, the crude protein concentration (CP) was 142 g kg⁻¹ and in vitro digestible of organic matter concentration (IVDOM) was 559 g kg⁻¹. The N300 increased FA by 38% compared with N150 and resulted in greater FAL and GE. Concentrations of CP and IVDOM in the forage on offer under N300 were 157 and 571 g kg⁻¹, respectively, greater than for the N150. Grazing of Zuri guineagrass should be initiated when canopy reaches a height H75.

Keywords: Fertilization; Forage production; Grazing losses; Management height; *Megathyrsus maximus*; Nutritive value.

3.1 Introduction

Brazil has one of the largest beef cattle herds in the world (about 187.5 million head), which is maintained on 165.2 million hectares of grazed pastures. Of this herd, about 84.3% of slaughtered animals are pasture-finished and 15.7% are confined (ABIEC, 2021), indicating the importance and representativeness of pastures for animal production in the country. Guineagrass is originally from East Africa (Jank et al., 2010), and is considered an important species for intensive grazing systems (Jank et al., 2008). Due to its medium to high soil fertility requirements (Jank et al., 2010), guineagrass is best suited for systems that include pasture fertilization, favoring high forage accumulation (FA) and nutritive value (Paciullo et al., 2017).

‘Tanzania’ guineagrass, one of the most important guineagrass cultivar in Brazil (Jank et al., 2008) has shown decline in FA and reduced pasture persistence, and this has been partially associated to its susceptibility to leaf spot disease caused by the fungus *Bipolaris maydis* (Y. Nisik and Miyake) Shoemaker (Muir & Jank, 2004). ‘Zuri’ guineagrass was released by Embrapa in 2014, and has similar growth habit to Tanzania, besides being tolerant to pasture leafhopper [*Mahanarva fimbriolata* (Stål) and *M. liturata* (Le Peletier de Saint-Fargeau & Serville)] and leaf spot (Embrapa, 2014). Studies comparing guineagrass cultivars indicate that Zuri may have greater FA than guineagrasses Tanzania, ‘Mombaça’ and ‘Massai’ (Hare, 2020; Oliveira et al., 2019).

According to Embrapa, Zuri guineagrass should be grazed under rotational stocking and defoliation should occur when the pasture canopy reaches 70 to 75 cm, leaving a stubble height of 30 to 35 cm (Embrapa, 2014), a similar management recommendation to that of Tanzania guineagrass (Barbosa et al., 2007). Pontes et al. (2016) evaluated ‘Aruana’ guineagrass using 95% canopy light interception (LI) as the criterion for initiating grazing and N rates of 0 and 300 kg N ha⁻¹ yr⁻¹. They reported that the 95% LI was achieved at canopy height 6.6 cm shorter when fertilized with 300 kg N ha⁻¹ yr⁻¹. Additionally, they reported a variation in 14 cm of pre-graze height over seasons, in which the 95% LI was reached in the fall at a height of 50 cm, in the spring at a height of 64 cm, and the summer at a height of 61 cm, variation that may be related from stem formation due to the plant maturity developmental stage. Thus, decreases in harvesting intensity and N fertilization rate are also powerful tools for managing and controlling canopy structure (e.g. by avoiding stem development) to optimize herbage intake by ruminants (Pontes et al., 2016).

When pastures are managed at shorter pre-graze canopy height, there is an increase in tiller population density, leaf proportion, and a reduction in the angle of the foliage resulting in more horizontal leaves (Chapter 2). Nitrogen fertilization is one of the nutrients responsible for accelerated plant growth (Lemaire et al., 2009), and may contribute to changes in pasture structural (Silva et al., 2020a) and morphological characteristics (Yasuoka et al., 2017), contributing to a leafier canopy and possibly reducing the canopy height at which the critical leaf area index (LAI) is reached (Pontes et al., 2016). Thus, the pre-graze height of defoliation may be reduced according to changes in canopy structural characteristics (Macedo et al., 2021; Pontes et al., 2016; Sbrissia et al., 2018).

After grazing, part of forage mass is left as stubble to meet physiological needs for the regrowth process. In addition, a portion of the pre-graze mass is lost due to trampling or fouled upon and will not be of any use during the following regrowth. This means that only a

fraction of the total pre-graze mass is consumed by the animals (Hodgson, 1990). Although losses are inherent to the process, having grazing management targets (e.g., canopy heights) may favor forage intake (Lemaire et al., 2009) due to its possible effects on canopy characteristics, including proportion of leaf and stem, and the vertical distribution of plant-part components. Specific grazing management targets may also contribute to reduce forage losses and improve grazing efficiency (Congio et al., 2018; Pedreira et al., 2005; Silveira et al., 2013). Management may also include and nitrogen fertilization rates, which may regulate growth process rates (e.g., FA) and forage nutritive value (Silva et al., 2016).

Considering the importance of pasture-based livestock systems, and that grazing management and N fertilization can impact productive performance and contribute to efficient grazing, our objective with this study was to describe and explain the FA, GE, grazing losses (GL), and nutritive value responses of Zuri guineagrass pastures managed at two pre-graze canopy heights (55 and 70 cm) and two N fertilization rates (150 and 300 kg N ha⁻¹ yr⁻¹) under rotational stocking.

3.2 Materials and Methods

3.2.1 Site description, experimental design, and treatments

The study was conducted at the Luiz de Queiroz College of Agriculture, University of São Paulo (USP-ESALQ), in Piracicaba, São Paulo state, Brazil (22°42' S, 47°30' W, and 580 m a.s.l.). The soil at the experimental site is a Kandiuudalfic Eutrudox. Chemical analysis for the 0-20 cm layer were done on samples taken on 11 Oct. 2018, with the following results: pH (0.01 mol L⁻¹ CaCl₂) = 5.1 and base saturation = 64%. To reduce soil acidity and increase pH, 1.5 Mg ha⁻¹ of lime was surface broadcast on 21 Oct. 2018. On 17 Dec. 2019 new soil samples were taken and analyzed, with the results: pH (0.01 mol L⁻¹ CaCl₂) = 6.1; organic matter = 37 g cm⁻³; P (ion-exchange resin extraction method) = 26 mg dm⁻³; K = 5.3 mmol_c dm⁻³; Ca = 43 mmol_c dm⁻³; Mg = 22 mmol_c dm⁻³; H + Al = 23.5 mmol_c dm⁻³; sum of bases = 70.3 mmol_c dm⁻³; cation exchange capacity = 93.8 mmol_c dm⁻³; base saturation = 75%. The climate at the experimental site is Cfa according to the Köppen classification (Alvares et al., 2013). Weather data for the experimental period were obtained from a station located 2 km from the experimental site (Table 1).

Table 1. Monthly weather data (maximum and minimum temperature and rainfall) during two rainy seasons and the historical average in Piracicaba, São Paulo, Brazil.

Weather variable	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May
	Year 1 (2018–2019)							
Max. temperature (°C)	29.0	29.4	32.2	33.4	30.2	30.1	30.1	27.9
Min. temperature (°C)	17.6	18.3	19.2	20.4	19.5	19.4	17.9	15.6
Rainfall (mm)	164	201	92	145	163	78	16	30
	Year 2 (2019–2020)							
Max. temperature (°C)	33.6	30.6	30.6	31.0	29.1	30.3	28.9	26.5
Min. temperature (°C)	17.9	18.3	19.2	19.6	19.6	17.6	14.7	10.5
Rainfall (mm)	109	220	145	180	399	72	3	13
	Historical average ^a							
Max. temperature (°C)	29.2	29.7	29.9	30.0	30.0	30.0	29.0	26.0
Min. temperature (°C)	15.9	16.9	18.4	19.1	19.0	18.0	16.0	12.0
Rainfall (mm)	110	135	198	229	180	141	66	55

^a Historical average weather data from 1917 to 2020 (103 Years).

The experiment was carried out on a pasture area of Zuri guineagrass established in the summer of 2015/16. During the 2016/17 and 2017/18 growing seasons the pastures were grazed as described by Barbosa et al. (2021). In mid-September 2018, the pasture was grazed down to reduce the canopy height and stimulate regrowth, and on 19 Oct. 2018 it was mechanically staged to a 30 cm stubble. On 21 Oct. 2018, 50 kg N ha⁻¹ was applied as NH₄NO₃ to stimulate growth. From Oct. to Dec. 2018, the treatments were imposed.

A randomized complete block design was used with a factorial 2 × 2 treatment arrangement, combining two pre-graze canopy heights [55 and 75 cm (H55 and H75, respectively)] and two N fertilization rates [150 and 300 kg ha⁻¹ yr⁻¹ (N150 and N300, respectively)], with four replications, totaling 16 experimental units (pastures) of 160 m² each. Pastures were mob-stocked to mimic a rotational stocking. The experiment was conducted during the warm rainy seasons of two years, from 8 Jan. to 7 May 2019 (Year 1 – 119 days), and from 17 Jan. to 11 May 2020 (Year 2 – 115 days). There was no data collection from Jun. to Dec. 2019, but all pastures were grazed according to their canopy height (pre- and post-graze) – but not the N fertilization.

The stubble height was applied as 50% of the pre-graze canopy height to provide a similar relative grazing intensity for all treatments, resulting in post-graze heights of 27.5 and 37.5 cm for H55 and H75, respectively. Non-lactating crossbred Holstein cows and heifers

(*Bos* spp.) weighing 450 kg on average were used to impose treatments. Throughout the experimental period, animals were grouped to make for similar total liveweight to graze individual pastures. The animals were weighed after 16 hours of water and feed fasting, and group of animals were formed. When they were not grazing the animals remained in an adjacent pasture area to the experiment, and, when necessary, provided hay and/or silage. The research was approved by the ESALQ Committee on Ethics in Animal Use (Protocol number 2018.5.2289.11.0, CEAU number 2018-36).

Nitrogen fertilization was split-applied according to the respective treatments as NH_4NO_3 , always post-graze. The amount of fertilizer applied at each post-graze event was calculated based on the number of days of the preceding rest period (grazing interval). The approximate duration of the grazing season was estimated at the beginning of each summer to be 90 days (best growing conditions at the location) and the total N amount was then divided by 90 for a daily N rate. The daily rate was then multiplied by the number of days of the preceding rest period. In all pastures, 250 kg de K_2O ha^{-1} yr^{-1} were split-applied in the form of KCl using the same procedure as for N fertilization. The average canopy height was measured of the leaf plane in the horizon viewed above the forage canopy against a graduated stick, at 45 sites in each pasture three times a week.

3.2.2 Response variables

3.2.2.1 Total forage accumulation

Pre- and post-graze forage mass (FM) were measured by harvesting the forage inside two quadrats (0.5×1.0 m) per pasture at representative average canopy condition (average FM), chosen by visual assessment, at 10 cm from the soil surface. The FA was calculated as the difference between the pre-graze FM of a grazing cycle and the post-graze FM of the previous grazing cycle. Total seasonal FA was calculated as the sum across all regrowth cycles for each pasture.

3.2.2.2 Grazing losses and grazing efficiency

To quantify GL in all grazing cycles, two representative sites of average canopy condition (0.5×1.5 m) were identified in each pasture using wooden stakes. At pre-graze, all plant material (living or dead) on the soil surface was manually collected and discarded. After the grazing event, all plant material (living or dead) lying on the soil surface, or physically damaged above and below post-graze height, or tramples or fouled upon (even if still green and attached to the plant immediately after grazing) was collected, taken in a forced-air oven

55°C to constant weight. The potentially consumable FM was estimated as difference between disappearance (pre-graze FM – post-graze FM) minus GL. Grazing efficiency was calculated as the potentially consumable FM as a proportion of FA at each grazing cycle (Hodgson, 1979).

3.2.2.3 Forage allowance and canopy bulk density

Forage allowance (FAL) was calculated as the ratio between average FM [(pre-graze FM + post-graze FM) × 0.5] to the stocking density for each grazing period (Sollenberger et al., 2005). The canopy bulk density (BD) was calculated by dividing the pre-graze FM by the corresponding average canopy height at each regrowth cycle.

3.2.2.4 Vertical distribution of plant-part components

The vertical distribution of plant-part components of the canopy was obtained using the inclined point quadrat (Wilson, 1959) at pre-graze. The inclined point quadrat was positioned at representative sites of average canopy height (visual assessment). The equipment rod was mounted at a 32.5° angle inclination between the point of penetration into the canopy profile plane and the ground level. The rod was introduced into the canopy, and its tip touched different components (leaf, stem, and dead material). Each component touched was identified and the height at which it occurred was recorded. This procedure was repeated until the tip of rod touch the soil surface (the reference height). In each pasture, a minimum of 100 hits were recorded (at least 800 hits per treatment).

3.2.2.5 Forage nutritive value

Samples for estimating the forage nutritive value were collected at various locations in at post-graze height and were composed from several sites in each pasture. These hand-plucked samples were dried in a forced-air oven at 55°C to constant weight, and ground in a Wiley mill to pass a 1-mm screen. Ground samples were analyzed for concentrations of crude protein (CP), neutral detergent fiber (NDF), and in vitro digestible of organic matter (IVDOM). For CP analyses the N concentration was determined using micro-Kjeldahl method and the concentration of CP calculated by multiplying the total N × 6.25 (ID 2001.11) (AOAC, 2011). Neutral detergent fiber concentration was determined using Tecnal TE-149 fiber analyzer (ID 2002.04) (AOAC, 2011). The IVDOM concentration was determined using the two-stage procedure of Tilley & Terry (1963) as modified by Moore & Mott (1974).

3.3 Statistical Analysis

Data were analyzed using PROC MIXED of SAS[®] (*Statistical Analyses System*), with a model including effects of canopy height, N rate and their interaction as a fixed effect. Year and block (replication) effects were considered as random (Littell et al., 2006). The covariance structure was chosen based on Akaike's Information Criterion (AIC) (Wolfinger, 1993). Linear predictor and quantile-quantile plots of the residues were used to verify homogeneity of variance and error normality. Treatment means were calculated using LSMEANS and compared by the probability of difference (PDIFF) by Student test ($P < .05$).

3.4 Results

3.4.1 Total forage accumulation

Forage accumulation was affected by canopy height and N rate ($P = .0103$ and $P < .0001$, respectively). Pastures grazed at H75 showed greater FA compared to H55 (22120 vs. 18370 kg DM ha⁻¹ yr⁻¹; SEM = 4551.1). The application of greater N fertilization rate (N300) contributed to an increase of 38% compared to the application of 150 kg N ha⁻¹ yr⁻¹ (23500 vs. 16980 kg DM ha⁻¹ yr⁻¹; SEM = 4551.1).

3.4.2 Grazing losses and grazing efficiency

Grazing losses were affected by the canopy height × N rate interaction ($P = .0312$) (Table 2). Pastures managed at pre-graze height of H75 showed greater GL regardless of N rate. When managed at pre-graze height of H55, the application of more N increased GL by 22% (Table 2). The GE was affected by canopy height and N rate ($P = .0005$ and $P = .0186$, respectively). Pastures grazed at H55 showed lesser GE than that at H75 (79 vs. 85% for H55 and H75, respectively) (SEM = 1.8). For N rate, GE was 80 and 84% (SEM = 1.8) for N150 and N300, respectively.

Table 2. Grazing losses (GL) of Zuri guineagrass in response by the canopy height \times N rate interaction during two rainy seasons, 2019 and 2020, in Piracicaba, São Paulo, Brazil.

Canopy height (cm)	N rate (kg ha ⁻¹ yr ⁻¹)		P-value ^a	SEM ^c
	150	300		
	----- GL (kg DM ha ⁻¹) -----			
55	383	470	.0087	26.1
75	666	660	.7932	26.1
P-value ^b	<.0001	<.0001		
SEM ^c	26.1	26.1		

^a N rate effect within canopy height.

^b Canopy height effect within N rate.

^c Standard error of the mean.

3.4.3 Forage allowance and canopy bulk density

Forage allowance was affected by canopy height and N rate ($P < .0001$ and $P = .0425$, respectively). The FAL was greater for H75 compared to H55 pre-graze height with values of 3.7 and 2.6 kg DM kg⁻¹ BW (SEM = 0.18), respectively. The lesser N rate resulted in a FAL of 2.9 kg DM kg⁻¹ BW compared to 3.2 kg DM kg⁻¹ BW (SEM = 0.18) when N300 was applied.

The BD was affected by the canopy height and N rate interaction ($P = .0421$) (Table 3). The BD was similar ($P > .05$) for H75 pre-graze height independently of N rate. For pastures grazed at H55, the greatest BD was observed at the N rate of N300. The greatest BD for the pasture that received N150 was for the H75 height management (Table 3).

Table 3. Canopy bulk density (BD) of Zuri guineagrass in response by the canopy height \times N rate interaction during two rainy seasons, 2019 and 2020, in Piracicaba, São Paulo, Brazil.

Canopy height (cm)	N rate (kg ha ⁻¹ yr ⁻¹)		P-value ^a	SEM ^c
	150	300		
	----- BD (kg DM ha ⁻¹ cm ⁻¹) -----			
55	98	115	.0065	4.9
75	112	113	.8640	4.9
P-value ^b	.0200	.6098		
SEM ^c	4.9	4.9		

^a N rate effect within canopy height.

^b Canopy height effect within N rate.

^c Standard error of the mean.

3.4.4 Vertical distribution of plant-part components

Regardless of height and N rate, the upper half of the canopy was comprised only by leaves, and the lower half mostly of stem and dead material. At both stubble heights (27.5 and 37.5 cm), canopies had a small leaf proportion, and greater stem and dead material proportion. In pastures receiving the greater N rate, regardless of pre-graze height, after leaves, the stem was first recorded by the point quadrat at a slightly higher stratum than in the lesser N rate (Figure 1).

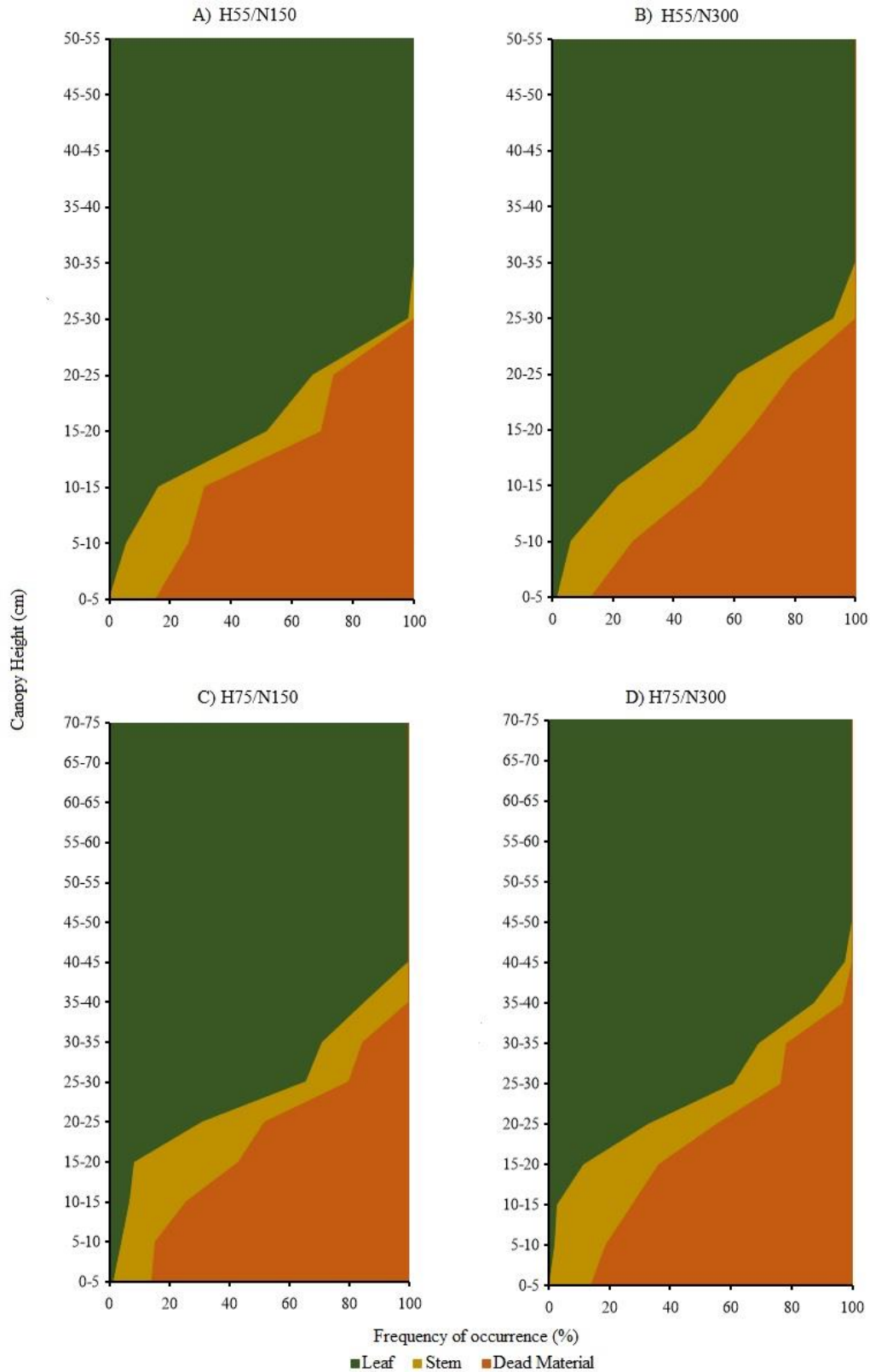


Figure 1. Vertical distribution of plant-part components of Zuri guineagrass subjected by canopy height and N rates during two rainy seasons in Piracicaba, São Paulo, Brazil. (A) H55/N150; (B) H55/N300; (C) H75/N150; and, (D) H75/N300.

3.4.5 Forage nutritive value

The concentration of CP and IVDOM was not affected by canopy height ($P > .05$), with average values of 142 (SEM = 14.1) and 559 g kg⁻¹ (SEM = 10.1), respectively, but was affected by the N rate ($P < .0001$ and $P = .0046$, respectively) (Table 4). The CP concentration was 22% greater under the N300 while the increase in IVDOM was 4% for N300 compared to N150 (Table 4). The NDF concentration was not affected by pre-graze canopy height, N rate, or their interaction ($P > .05$), with average of 669 g kg⁻¹ (SEM = 4.8).

Table 4. Crude protein (CP) and in vitro digestible organic matter (IVDOM) in Zuri guineagrass in response to N rates during two rainy seasons, 2019 and 2020, in Piracicaba, São Paulo, Brazil.

N rate	CP	IVDOM
kg ha ⁻¹ yr ⁻¹	g kg ⁻¹	
150	128 b	547 b
300	157 a	571 a
SEM ^a	14.1	10.1

Means within columns followed by different letters differ by t-test ($P < .05$).

^a Standard error of the mean.

3.5 Discussion

Pastures grazed at taller pre-graze height (H75) had greater FM and FA, but greater stem proportion. Despite the potential of stems to reduce forage nutritive value, the greater participation of stem in the FM may contribute to greater FA (Chapter 2) highlighting its importance as component of FA in tropical grasses (Lemaire et al., 2009). Longer regrowth is generally necessary to reach taller canopy height (H75), which may result in greater proportions of stem and dead material in the FM (Chapter 2). In the current study, however, the H75 pre-graze height resulted in 20% more FA than H55. The pre-graze height (H75) showed FA value close to the guineagrass cultivar, such as Mombaça with value of 22710 kg DM ha⁻¹ (Carnevalli et al., 2006) and, both pre-grazed height (H55 and H75) showed greater values of FA in relation to Tanzania with a value of 13530 kg DM ha⁻¹ (Barbosa et al., 2007), Quenia, and Tamani both with values close to 16810 kg DM ha⁻¹ (Tesk et al., 2020).

The adoption of pre-graze management canopy targets (e.g. height), besides favoring FA, may contribute to improve GE (Carnevalli et al., 2006; Silveira et al., 2013). In general, taller canopies may be associated with greater FM (Chapter 2), but also greater losses during grazing (Table 2). This trend has been recorded for other tropical grasses such as, Mombaça guineagrass (Carnevalli et al., 2006), ‘Mulato II’ hybrid brachiariagrass [*Urochloa brizantha*

(Hochst. ex A. Rich.) R. D. Webster \times *U. decumbens* (Stapf) R. D. Webster \times *U. ruziziensis* (R. Germ. & C. M. Evrard) Crins] (Silva et al., 2016), ‘Mulato’ hybrid brachiariagrass [*U. brizantha* (Hochst. ex A. Rich.) R. D. Webster \times *U. ruziziensis* (R. Germ. & C. M. Evrard) Crins] (Silveira et al., 2013), and elephantgrass (*Pennisetum purpureum* Schum. cv. Cameroon) (Congio et al., 2018). During grazing, only part of the accumulated forage is consumed by the animals (Palhano et al., 2006), and part is lost through grazing effects (e.g. leaf and tiller pulling, and trampling) and tissue aging (e.g. senescence and death), which affect GE. In the present study, despite greater GL under H75 (Table 2), the GE was 8% greater compared to H55 pre-graze height (85 vs. 79% for H75 and H55, respectively). The pre-graze height (H75) showed greater FM which resulted in greater FAR (Chapter 2), greater FA and, consequently, greater GE.

The GE for pastures grazed at H55 (79%) was similar to that reported for Mombaça guineagrass grazed when the canopy reached 95% LI (79%) (Carnevalli et al., 2006), and greater than values reported for other forage grasses (Silva et al., 2016; Silveira et al., 2013). The consumption of accumulated forage may be affected by canopy morphological and structural characteristics (Savian et al., 2020). Leaf is the first plant-part component to be consumed during grazing (Silva et al., 2020b) while stems and pseudostems may become a physical constraint to forage consumption (Benvenuti et al., 2009), especially in bunchgrasses like guineagrass. Barbosa et al. (2021) evaluating Zuri guineagrass managed at 95% LI or 70 cm canopy height, reported that the apical meristem was located at 5 cm height, indicating that even though it is an erect growing grass, it does not present exacerbated stem growth if well managed.

Pastures grazed at H75 had 42% greater FAL compared to H55, increasing as canopy height increased. Grazing changes the structure and architecture of the canopy (Fonseca et al., 2012), affecting the proportions of plant-part components in each canopy stratum throughout the profile. Taller pastures generally tend to have lesser BD (Sollenberger & Burns, 2001), and shorter pastures have greater BD, in which the lesser BD allows for more selective grazing, and may do not limit the opportunity for forage selection (Newman et al., 2002). In the present study, pastures grazed at H55 with N150 had the least BD compared to the other treatments (Table 3), this is likely due to lesser tiller population density and FM under the lesser N rate (Chapter 2).

Greater N rate increased FA by 38% and resulted in an increase of 10% in FAL. Although resulting in greater GL (Table 2), the greater N rate resulted in greater GE. A study with Mulato II hybrid brachiariagrass submitted to rates of 50 and 250 kg N ha⁻¹ yr⁻¹ showed

that the greater GL occurred when the grass grew most rapidly due to receiving of 250 kg N ha⁻¹ yr⁻¹, even so it presented the greater GE due to the relative increase in FA than in GL associated with the application of the greater N rate (Silva et al., 2016). This is probably due to the contribution of N to greater canopy photosynthesis by increasing leaf area index, LI (Yasuoka et al., 2017), and also in leaf size (Paciullo et al., 2017). The leaves, when detached from tillers and tillers that are uprooting by the grazing animals, along with senescent leaves, fall to the soil surface contributing to increase in GL, however, did not compromise GE in N300 (84%), due to the greatest contribution of AF by applying the highest dose of N.

The vertical distribution of plant-part components indicates that leaves are present along the entire canopy profile. The upper half of the canopy, however, is comprised entirely of leaves and the lower half is comprised mostly of stem and dead material, but also by a decreasing leaf participation until it reaches the base of the tussocks (Figure 1). When these canopies are defoliated, there is a decrease in proportion of leaves and an increase in proportions of stem and dead material (Euclides et al., 2016; Silveira et al., 2016), especially under greater grazing intensity. Setting defoliation at 50% of the pre-graze height results in the animal consuming mostly leaves (Figure 1). Silva et al. (2020b) evaluated nutritive value of upper and lower part of the plant of Mombaça guineagrass harvested at 95% LI, reported that the upper part generally shows a greater concentration of CP and IVDOM and lesser NDF compared to lower part, most likely due to the plant-part components existing along the canopy profile. Euclides et al. (2018) evaluated nutritive value of leaves in vertical canopy strata (20 cm) of Mombaça guineagrass and reported that leaf mass increases from the base of the clump toward top of the canopy, resulting in increased concentrations of CP and IVDOM and decreased concentration of NDF, and showing that as leaf mass increases the nutritive value of forage increases.

In the present study, regardless of pre-graze canopy height, the forage present at the upper stratum, was mostly leaves, which probably contributed to lack of difference between heights in nutritive value, with average CP, IVDOM, and NDF of 142, 559, and 669 g kg⁻¹, respectively. This result confirms the hypothesis that both heights (H55 and H75) offer the same forage nutritive value, due to the circumstance of offering only leaves in the grazing events. This is because the first and only component that was consumed by the animals during grazing was leaves (Figure 1). Schmitt et al. (2019) evaluating kikuyugrass (*Pennisetum clandestinum* Hochst. Ex Chiov) managed at 10, 15, 20, and 25 cm pre-graze canopy height associated with proportion of defoliation of 50% of initial height, showed that there is a range of heights at which kikuyugrass can be managed resulting in 95% LI (between 15 and 25 cm)

(Sbrissia et al., 2018). This same height range resulted in no difference in forage nutritive value, because the morphological composition found in this grazing stratum was similar (Schmitt et al., 2019).

Greater N rate contributed to increased concentrations of CP and IVDOM (Table 4) but did not affect NDF concentration. The CP concentration on Zuri guineagrass at N300 (157 g kg⁻¹) was greater than that found by Pontes et al. (2016) with Aruana guineagrass subjected to same fertilization (147 g kg⁻¹ CP). Studies with various forage plants that have evaluated N rates have shown results in which the nutritive value of the forage follows with increasing N rate (Moreno et al., 2021; Paciullo et al., 2017; Pontes et al., 2016; Silva et al., 2016). The increase in nutritive value and FA due to nitrogen fertilization may allow for greater stocking rate which can result in improve animal performance (Gurgel et al., 2020). Greater N input must be associated with other practices that allow for efficient use of the forage produced. This may include the use of canopy targets and adjustments in stocking rate. Zuri guineagrass can be considered a good option for producers in intensive systems, especially those who make use of moderate to high N fertilization.

3.6 Summary and Conclusion

Grazing Zuri guineagrass at H75 canopy height results in greater FA, FAL, and an increase of 8% in GE compared to H55, even presenting greater GL. The forage nutritive value (concentrations of CP, IVDOM, and NDF) was similar between two pre-graze heights, likely due to the large participation of leaves in grazable stratum in both cases. The upper half of the canopy of Zuri guineagrass was mainly leaves, regardless of canopy height and N rate. The greater N rate (N300) increased FA, FAL and GE, and contributed to greater CP and IVDOM. Reducing the pre-graze height of Zuri guineagrass to H55 results in lesser GL and did not result in greater forage nutritive value. It is suggested that Zuri guineagrass be harvested when it reaches the pre-graze height of H75, due to greater FA, FAL, and GE.

References

- ABIEC. (2021). *A pecuária no Brasil*. Beef Report. <http://abiec.com.br/publicacoes/beef-report-2021/>
- Alvares, C. A., Stape, J. L., Sentelhas, P. C., Gonçalves, J. L. M., & Sparovek, G. (2013). Köppen's climate classification map for Brazil. *Meteorologische Zeitschrift*, 22(6), 711–728. <https://doi.org/10.1127/0941-2948/2013/0507>

- AOAC. (2011). *Official methods of analysis of the AOAC* (18th ed.). Gaithersburg: AOAC International.
- Barbosa, P. L., Silva, V. J., Pedreira, C. G. S., Sbrissia, A. F., & Sollenberger, L. E. (2021). Herbage accumulation and tillering dynamics of 'Zuri' guineagrass under rotational stocking. *Crop Science*, *61*(5), 3787–3798. <https://doi.org/10.1002/csc2.20536>
- Barbosa, R. A., Nascimento Júnior, D., Euclides, V. P. B., Silva, S. C., Zimmer, A. H., & Torres Júnior, R. A. A. (2007). Capim-tanzânia submetido a combinações entre intensidade e frequência de pastejo. *Pesquisa Agropecuária Brasileira*, *42*(3), 329–340. <https://doi.org/10.1590/s0100-204x2007000300005>
- Benvenuti, M. A., Gordon, I. J., Poppi, D. P., Crowther, R., Spinks, W., & Moreno, F. C. (2009). The horizontal barrier effect of stems on the foraging behaviour of cattle grazing five tropical grasses. *Livestock Science*, *126*(1–3), 229–238. <https://doi.org/10.1016/j.livsci.2009.07.006>
- Carnevali, R. A., Silva, S. C., Bueno, A. A. O., Uebele, M. C., Bueno, F. O., Hodgson, J., Silva, G. N., & Morais, J. P. G. (2006). Herbage production and grazing losses in *Panicum maximum* cv. Mombaça under four grazing managements. *Tropical Grasslands*, *40*(3), 165–176.
- Congio, G. F. S., Batalha, C. D. A., Chiavegato, M. B., Berndt, A., Oliveira, P. P. A., Frighetto, R. T. S., Maxwell, T. M. R., Gregorini, P., & Silva, S. C. (2018). Strategic grazing management towards sustainable intensification at tropical pasture-based dairy systems. *Science of the Total Environment*, *636*, 872–880. <https://doi.org/10.1016/j.scitotenv.2018.04.301>
- Embrapa. (2014). *BRS Zuri, produção e resistência para a pecuária*. <https://ainfo.cnptia.embrapa.br/digital/bitstream/item/123642/1/Folder-Zuri-Final-2014.pdf>
- Euclides, V. P. B., Carpejani, G. C., Montagner, D. B., Nascimento Júnior, D., Barbosa, R. A., Difante, G. S. (2018). Maintaining post-grazing sward height of *Panicum maximum* (cv. Mombaça) at 50 cm led to higher animal performance compared with post-grazing height of 30 cm. *Grass and Forage Science*. *73*(1), 174–182. <https://doi.org/10.1111/gfs.12292>
- Euclides, V. P. B., Lopes, F. C., Nascimento Júnior, D., Silva, S. C., Difante, G. S., & Barbosa, R. A. (2016). Steer performance on *Panicum maximum* (cv. Mombaça) pastures under two grazing intensities. *Animal Production Science*, *56*(11), 1849–1856. <https://doi.org/10.1071/AN14721>

- Fonseca, L., Mezzalira, J. C., Bremm, C., Filho, R. S. A., Gonda, H. L., & Carvalho, P. C. F. (2012). Management targets for maximising the short-term herbage intake rate of cattle grazing in *Sorghum bicolor*. *Livestock Science*, *145*(1–3), 205–211. <https://doi.org/10.1016/j.livsci.2012.02.003>
- Gurgel, A. L. C., Difante, G. S., Montagner, D. B., Araújo, A. R., Dias, A. M., Santana, J. C. S., Rodrigues, J. G., & Pereira, M. G. (2020). Nitrogen fertilisation in tropical pastures: what are the impacts of this practice? *Australian Journal of Crop Science*, *14*(6), 978–984. <https://doi.org/10.21475/ajcs.20.14.06.p2357>
- Hare, M. D. (2020). Herbage yield and quality of *Megathyrsus* cultivars in Northeast Thailand. *Tropical Grasslands-Forrajes Tropicales*, *8*(3), 187–194. [https://doi.org/10.17138/TGFT\(8\)187-194](https://doi.org/10.17138/TGFT(8)187-194)
- Hodgson, J. (1979). Nomenclature and definitions in grazing studies. *Grass and Forage Science*, *34*(1), 11–17. <https://doi.org/10.1111/j.1365-2494.1979.tb01442.x>
- Hodgson, J. (1990). *Grazing Management: science into practice*. Longman Group UK Ltd.
- Jank, L., Martuscello, J. A., Euclides, V. P. B., Valle, C. B., & Resende, R. M. S. (2010). *Panicum maximum* Jacq. In D. M. Fonseca & J. A. Martuscello (Eds.), *Plantas Forrageiras* (1º, pp. 166–196). Editora UFV.
- Jank, L., Resende, R. M. S., Valle, C. B., Resende, M. D. V., Chiari, L., Cançado, L. J., & Simioni, C. (2008). Melhoramento genético de *Panicum maximum*. In R. M. S. Resende, C. B. Valle, & L. Jank (Eds.), *Melhoramento de Forrageiras Tropicais* (pp. 55–87).
- Lemaire, G., Silva, S. C., Agnusdei, M., Wade, M., & Hodgson, J. (2009). Interactions between leaf lifespan and defoliation frequency in temperate and tropical pastures: a review. *Grass and Forage Science*, *64*(4), 341–353. <https://doi.org/10.1111/j.1365-2494.2009.00707.x>
- Littell, R. C., Milliken, G. A., Stroup, W. W., Wolfinger, R. D., & Schabenberger, O. (2006). *SAS for Mixed Models* (2nd ed.). SAS Institute.
- Macedo, V. H. M., Cunha, A. M. Q., Cândido, E. P., Domingues, F. N., Silva, W. L., Lara, M. A. S., & Rêgo, A. C. (2021). Canopy structural variations affect the relationship between height and light interception in Guinea Grass. *Field Crops Research*, *271*(July), 1–10. <https://doi.org/10.1016/j.fcr.2021.108249>
- Moore, J. E., & Mott, G. O. (1974). Recovery of residual organic matter from in vitro digestion of forages. *Journal of Dairy Science*, *57*(10), 1258–1259. [https://doi.org/10.3168/jds.S0022-0302\(74\)85048-4](https://doi.org/10.3168/jds.S0022-0302(74)85048-4)

- Moreno, L. S. B., Boote, K. J., Sollenberger, L. E., Dubeux Jr., J. C. B., Kohmann, M. M., & Pequeno, D. N. L. (2021). Shade and nitrogen fertilization affect forage accumulation and nutritive value of C₄ grasses differing in growth habit. *Crop Science*, *62*(1), 512–523. <https://doi.org/10.1002/csc2.20617>
- Muir, J. P., & Jank, L. (2004). Guineagrass. In L. E. Moser, B. L. Burson, & L. E. Sollenberger (Eds.), *Warm-Season (C4) Grasses* (45th ed., Issue 45, pp. 589–621). ASA. <https://doi.org/10.2134/agronmonogr45.c17>
- Newman, Y. C., Sollenberger, L. E., Kunkle, W. E., & Chambliss, C. G. (2002). Canopy height and nitrogen supplementation effects on performance of heifers grazing limpograss. *Agronomy Journal*, *94*(6), 1375–1380. <https://doi.org/10.2134/agronj2002.1375>
- Oliveira, J. S., Emerenciano Neto, J. V., Difante, G. S., Lista, F. N., Santos, R. S., Bezerra, J. D. V., Bonfim, B. R. S., Milhomens, L. B. S., & Ribeiro, J. S. M. (2019). Structural and productive features of *Panicum* cultivars submitted to different rest periods in the irrigated semiarid region of Brazil. *Bioscience Journal*, *35*, 682–690. <https://doi.org/10.14393/BJ-v35n3a2019-36402>
- Paciullo, D. S. C., Gomide, C. A. M., Castro, C. R. T., Maurício, R. M., Fernandes, P. B., & Morenz, M. J. F. (2017). Morphogenesis, biomass and nutritive value of *Panicum maximum* under different shade levels and fertilizer nitrogen rates. *Grass and Forage Science*, *72*(3), 590–600. <https://doi.org/10.1111/gfs.12264>
- Palhano, A. L., Carvalho, P. C. F., Dittrich, J. R., Moraes, A., Silva, S. C., & Monteiro, A. L. G. (2006). Padrões de deslocamento e procura por forragem de novilhas leiteiras em pastagem de capim-mombaça. *Revista Brasileira de Zootecnia*, *35*(6), 2253–2259. <https://doi.org/10.1590/S1516-35982006000800008>
- Pedreira, C. G. S., Rosseto, F. A. A., Silva, S. C., Nussio, L. G., Moreno, L. S. B., Lima, M. L. P., & Leme, P. R. (2005). Forage yield and grazing efficiency on rotationally stocked pastures of “Tanzania-1” guineagrass and “Guaçu” elephantgrass. *Scientia Agricola*, *62*(5), 433–439. <https://doi.org/10.1590/s0103-90162005000500004>
- Pontes, L. S., Baldissera, T. C., Giostri, A. F., Stafin, G., Santos, B. R. C., & Carvalho, P. C. F. (2016). Effects of nitrogen fertilization and cutting intensity on the agronomic performance of warm-season grasses. *Grass and Forage Science*, *72*(4), 663–675. <https://doi.org/10.1111/gfs.12267>
- Savian, J. V., Schons, R. M. T., Mezzalira, J. C., Neto, A. B., Neto, G. F. S., Benvenuti, M. A., & Carvalho, P. C. F. (2020). A comparison of two rotational stocking strategies on the foraging behaviour and herbage intake by grazing sheep. *Animal*, *14*(12), 2503–2510. <https://doi.org/10.1017/S1751731120001251>

- Sbrissia, A. F., Duchini, P. G., Zanini, G. D., Santos, G. T., Padilha, D. A., & Schmitt, D. (2018). Defoliation strategies in pastures submitted to intermittent stocking method: Underlying mechanisms buffering forage accumulation over a range of grazing heights. *Crop Science*, *58*(2), 945–954. <https://doi.org/10.2135/cropsci2017.07.0447>
- Schmitt, D., Padilha, D. A., Dias, K. M., Santos, G. T., Rodolfo, G. R., Zanini, G. D., & Sbrissia, A. F. (2019). Chemical composition of two warm-season perennial grasses subjected to proportions of defoliation. *Grassland Science*, *65*(3), 171–178. <https://doi.org/10.1111/grs.12236>
- Silva, L. S., Silva, V. J., Yasuoka, J. I., Sollenberger, L. E., & Pedreira, C. G. S. (2020a). Tillering dynamics of ‘Mulato II’ brachiariagrass under continuous stocking. *Crop Science*, *60*(2), 1105–1112. <https://doi.org/10.1002/csc2.20008>
- Silva, S. C., Bueno, A. A. O., Carnevalli, R. A., Silva, G. P., & Chiavegato, M. B. (2020b). Nutritive value and morphological characteristics of Mombaça grass managed with different rotational grazing strategies. *Journal of Agricultural Science*, *157*(7–8), 592–598. <https://doi.org/10.1017/S0021859620000052>
- Silva, V. J., Pedreira, C. G. S., Sollenberger, L. E., Silva, L. S., Yasuoka, J. I., & Almeida, I. C. L. (2016). Canopy height and nitrogen affect herbage accumulation, nutritive value, and grazing efficiency of ‘Mulato II’ brachiariagrass. *Crop Science*, *56*(4), 2054–2061. <https://doi.org/10.2135/cropsci2015.12.0764>
- Silveira, M. C. T., Nascimento Júnior, D., Rodrigues, C. S., Pena, K. S., Souza, S. J., Barbero, L. M., Limão, V. A., Euclides, V. P. B., & Silva, S. C. (2016). Forage sward structure of Mulato grass (*Brachiaria* hybrid ssp.) subjected to rotational stocking strategies. *Australian Journal of Crop Science*, *10*(6), 864–873. <https://doi.org/10.21475/ajcs.2016.10.06.p7568>
- Silveira, M. C. T., Silva, S. C., Souza Júnior, S. J., Barbero, L. M., Rodrigues, C. S., Limão, V. A., Pena, K. S., & Nascimento Júnior, D. (2013). Herbage accumulation and grazing losses on Mulato grass subjected to strategies of rotational stocking management. *Scientia Agricola*, *70*(4), 242–249. <https://doi.org/10.1590/S0103-90162013000400004>
- Sollenberger, L. E., & Burns, J. C. (2001). Canopy characteristics, ingestive behaviour and herbage intake in cultivated tropical grasslands. *International Grassland Congress*, 321–327.
- Sollenberger, L. E., Moore, J. E., Allen, V. G., & Pedreira, C. G. S. (2005). Reporting forage allowance in grazing experiments. *Crop Science*, *45*(3), 896–900. <https://doi.org/10.2135/cropsci2004.0216>

- Tesk, C. R. M., Cavalli, J., Pina, D. S., Pereira, D. H., Pedreira, C. G. S., Jank, L., Sollenberger, L. E., & Pedreira, B. C. (2020). Herbage responses of Tamani and Quênia guineagrasses to grazing intensity. *Agronomy Journal*, *112*(3), 2081–2091. <https://doi.org/10.1002/agj2.20189>
- Tilley, J. M. A., & Terry, R. A. (1963). A two-stage technique for the in vitro digestion of forage crops. *Grass and Forage Science*, *18*(2), 104–111. <https://doi.org/10.1111/j.1365-2494.1963.tb00335.x>
- Wilson, J. W. (1959). Analysis of the spatial distribution of foliage by two-dimensional point quadrats. *New Phytologist*, *58*(1), 92–99. <https://doi.org/10.1111/j.1469-8137.1959.tb05340.x>
- Wolfinger, R. (1993). Covariance structure selection in general mixed models. *Communications in Statistics - Simulation and Computation*, *22*(4), 1079–1106. <https://doi.org/10.1080/03610919308813143>
- Yasuoka, J. I., Pedreira, C. G. S., Silva, V. J., Alonso, M. P., Silva, L. S., & Gomes, F. J. (2017). Canopy height and N affect herbage accumulation and the relative contribution of leaf categories to photosynthesis of grazed brachiariagrass pastures. *Grass and Forage Science*, *73*(1), 183–192. <https://doi.org/10.1111/gfs.12302>

4 FINAL CONSIDERATIONS

Although it has been recently released, Zuri guineagrass, is already considered a good forage option for intensive forage systems in Brazil due to its high forage accumulation (FA) (Barbosa et al., 2021), nutritive value (Braga et al., 2019), and responsiveness to nitrogen fertilization (Gomide et al., 2019). The objective of this study was to evaluate the agronomic performance of Zuri guineagrass under rotational stocking when grazed was initiated at two canopy heights [55 and 75 cm (H55 and H75, respectively)] and two N fertilization rates [150 and 300 kg N ha⁻¹ yr⁻¹ (N150 and N300, respectively)]. The results indicate that forage accumulation rate (FAR), FA, and grazing efficiency (GE) were influenced by canopy height and N rate, but nutritive value was affected only by N rate.

Pastures managed at H75 as recommended by Embrapa (Embrapa, 2014), regardless of N rate, reach 95% light interception (LI) due to the greater leaf area index (LAI) of these canopies. However, under H55 with N300, this same LI was achieved at pre-graze, most likely due to canopy structural characteristics (e.g., foliage angle, light extinction coefficient, specific leaf area, and tiller population density). The structural characteristics of the canopy can establish the relationship between height and LI (Macedo et al., 2021) and favored by nitrogen fertilization (Pontes et al., 2016).

When managed at H75 Zuri pastures showed greater FAR and FA, which were accompanied by greater forage allowance (FAL) followed by greater GE, even with greater grazing losses. Despite the lesser FA in canopies managed at H55 height, there was no indication of stand deterioration after two years. Nitrogen fertilization likely impacted stand vigor positively, maintaining tiller population density to keep the plant stand stable and productive.

The vertical distribution of plant-part components shows a similar pattern along the canopy profile for both canopy heights. For both heights the upper half of the canopy is composed predominantly of leaves, but leaf proportion decreases and stem and dead material proportion both increase until soil level. The upper half of the canopy was the proportion of forage removed by animals during grazing and this resulted in similar nutritive value of the forage on offer between heights, due to the animals having access only to the leaves during grazing.

Nitrogen fertilization impacted FA positively in Zuri guineagrass. Compared to 150 kg N ha⁻¹ yr⁻¹, the use of 300 kg N ha⁻¹ yr⁻¹ resulted in an increase in LAI which contributed to greater FAR and FAL resulted in greater GE. In addition, the N300 favored the forage nutritive value with greater values of crude protein and in vitro digestible of organic matter.

The greater FA favors greater pasture carrying capacity, contributing to animal output per hectare.

The results of this study indicate that Zuri guineagrass under rotational stocking should be managed at a pre-graze height of H75, due to the greater values of FAR, FA, FAL, and GE. Increasing nitrogen fertilization will increase pasture performance and improve both agronomic and nutritive value responses.

References

- Barbosa, P. L., Silva, V. J., Pedreira, C. G. S., Sbrissia, A. F., & Sollenberger, L. E. (2021). Herbage accumulation and tillering dynamics of ‘Zuri’ guineagrass under rotational stocking. *Crop Science*, *61*(5), 3787–3798. <https://doi.org/10.1002/csc2.20536>
- Braga, G. J., Maciel, G. A., Guimarães, R., Ramos, A. K. B., Carvalho, M. A., Fernandes, F. D., Fonseca, C. E. L., & Jank, L. (2019). Performance of young Nellore bulls on guineagrass pastures under rotational stocking in the Brazilian Cerrado. *Tropical Grasslands-Forrajes Tropicales*, *7*(3), 214–222. [https://doi.org/10.17138/TGFT\(7\)214-222](https://doi.org/10.17138/TGFT(7)214-222)
- Embrapa. (2014). *BRS Zuri, produção e resistência para a pecuária*. <https://ainfo.cnptia.embrapa.br/digital/bitstream/item/123642/1/Folder-Zuri-Final-2014.pdf>
- Gomide, C. A. M., Paciullo, D. S. C., Morenz, M. J. F., Costa, I. A., & Lanzoni, C. L. (2019). Productive and morphophysiological responses of *Panicum maximum* Jacq. cv. BRS Zuri to timing and doses of nitrogen application and defoliation intensity. *Grassland Science*, *65*(2), 93–100. <https://doi.org/10.1111/grs.12226>
- Macedo, V. H. M., Cunha, A. M. Q., Cândido, E. P., Domingues, F. N., Silva, W. L., Lara, M. A. S., & Rêgo, A. C. (2021). Canopy structural variations affect the relationship between height and light interception in Guinea Grass. *Field Crops Research*, *271*, 1–10. <https://doi.org/10.1016/j.fcr.2021.108249>
- Pontes, L. S., Baldissera, T. C., Giostri, A. F., Stafin, G., Santos, B. R. C., & Carvalho, P. C. F. (2016). Effects of nitrogen fertilization and cutting intensity on the agronomic performance of warm-season grasses. *Grass and Forage Science*, *72*(4), 663–675. <https://doi.org/10.1111/gfs.12267>