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

Forage accumulation and nutritive value, canopy structure and grazing losses on Mulato II brachiariagrass under continuous and rotational stocking

Gabriel Baracat Pedroso

Dissertation presented to obtain the degree of Master in Science. Area: Animal Science and Pastures

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1. Altura de dossel 2. *Brachiaria* híbrida 3. Convert HD 364 4. Intensidade de desfolhação 5. Manejo do pastejo 6. Método de lotação 7. Severidad de desfolhação 8. *Urochloa* spp. I. Título

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"No man is an island entire of itself;
every man is a piece of the continent, a part of the main."

John Donne

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RESUMO

Acúmulo e valor nutritivo da forragem, estrutura do dossel e perdas em pastejo em capim Mulato II sob lotação contínua e intermitente

Apesar de estudos demonstrarem que métodos de lotação contínua e rotativa podem promover níveis de produtividade animal equivalentes, a lotação rotativa permanece comumente associada à ideia de intensificação de sistemas de produção. Além disso, estudos agronômicos de respostas de plantas forrageiras aos métodos de lotação são escassos. Os objetivos do presente trabalho foram explicar os efeitos de três métodos de lotação (lotação contínua – LC, lotação rotativa leniente – LRL e lotação rotativa severa – LRS) combinadas em arranjo fatorial com duas alturas médias de dossel (20 e 30 cm), sobre o acúmulo e valor nutritivo da forragem, estrutura de dossel e perdas de forragem por pastejo (PP) em pastos de capim Mulato II durante o verão agrostológico de 2016/2017 em Piracicaba, SP. O delineamento experimental foi em blocos completos cazualisados, com três repetições. Os métodos de lotação foram impostos por variações de 10% (lotação contínua mimetizada), 25% (lotação rotativa leniente) e 40% (lotação rotativa severa) em torno das duas alturas médias de dossel, aplicadas com o protocolo experimental do tipo "mob stocking". A concentração de fibra em detergente neutro da forragem (FDN), a proporção de colmos na massa de forragem (MF) e o índice de área foliar (IAF) do dossel sob lotação contínua e em pré-pastejo sob lotação rotativa foram afetados pela interação altura média de dossel × método de lotação. A digestibilidade *in vitro* da matéria orgânica (DIVMO) e a concentração de proteína bruta (PB) da forragem sob lotação contínua e em pré-pastejo sob lotação rotativa foram afetados por altura média de dossel e por método de lotação. As proporções de folhas e material morto na MF sob lotação contínua e em pré-pastejo sob lotação rotativa foram afetadas apenas por método de lotação. Acúmulo de forragem (8363 ± 1578 kg MS ha^{-1}) e PP (5305 ± 585 kg MS ha^{-1}) não diferiram entre os tratamentos. Para a altura média de dossel de 20 cm, LC promoveu a menor concentração de FDN da forragem (531g kg^{-1} MS), apesar de apresentar os menores valores de IAF (3,3) e a maior proporção de colmos na MF (30 %). Para a altura média de dossel de 30 cm, LC promoveu a menor concentração de FDN da forragem (535 g kg^{-1} MS), LRS apresentou o maior valor de IAF (8,9) e LRL apresentou a menor proporção de colmos na MF (31 %). Lotação contínua, apesar de apresentar a menor proporção de folhas (32 %) e a maior proporção de material morto (35 %) na MF, promoveu a maior DIVMO (609 g kg^{-1} MS) e a maior concentração de PB (150 g kg^{-1} MS) da forragem. Lotação rotativa severa, apesar de apresentar a menor proporção de material morto (24 %) e a maior proporção de folhas (46%) na MF, promoveu a menor DIVMO da forragem (549 g kg^{-1} MS). Lotação rotativa leniente apresentou proporções intermediárias de folhas (42 %) e material morto (29%) na MF, e não diferiu dos demais métodos de lotação quanto à DIVMO da forragem (574 g kg^{-1} MS). Em geral, conforme a altura média de dossel diminuiu, os valores de IAF (de 6,6 para 4,8), proporção de colmos na MF (de 33 para 28 %) e concentração de FDN da forragem (de 570 para 545 g kg^{-1} MS) diminuíram, enquanto DIVMO (de 554 para 600 g kg^{-1} MS) e concentração de PB (de 128 para 146 g kg^{-1} MS) da forragem aumentaram.

Palavras-chave: Altura de dossel; *Brachiaria* híbrida; Convert HD 364; Intensidade de desfolhação; Manejo do pastejo; Método de lotação; Severidade de desfolhação; *Urochloa* spp.

ABSTRACT

Forage accumulation and nutritive value, canopy structure and grazing losses on Mulato II brachiariagrass under continuous and rotational stocking

Regardless of studies demonstrating that continuous and rotational stocking can promote equivalent animal productivities, rotational stocking is still commonly associated with the idea of intensification of production systems. Moreover, studies evaluating agronomic responses of plants to stocking methods are scarce. The objectives of the present study were to explain the effects of three stocking methods (continuous stocking - CS, lenient rotational stocking - LRS, and severe rotational stocking - SRS), combined by factorial combinations with two mean canopy heights (20 and 30 cm), on forage accumulation (FA) and nutritive value, canopy structure, and grazing losses (GL) of Mulato II brachiariagrass during the 2016/2017 summer rainy season in Piracicaba, Brazil. The experimental design was a randomized complete block with three replications. Stocking methods were imposed by height variations around the two mean canopy heights: 10% (mimicked continuous stocking), 25% (lenient rotational stocking), and 40% (severe rotational stocking), applied using a mob stocking protocol. Forage neutral detergent fiber concentration (NDF), stem proportion in the forage mass (FM) and leaf area index (LAI) under continuous stocking and at pre-grazing under rotational stocking were affected by the mean canopy height × stocking method interaction. Forage in vitro digestible organic matter (IVDOM) and crude protein (CP) concentrations under continuous stocking and at pre-grazing under rotational stocking were affected by mean canopy height and stocking method. Leaf and dead material proportions in the FM under continuous stocking and at pre-grazing under rotational stocking were only affected by stocking method. Forage accumulation (8363 ± 1578 kg DM ha^{-1}) and GL (5305 ± 585 kg DM ha^{-1}) did not differ between treatments. For the 20-cm mean canopy height, CS, despite presenting the least LAI (3.3) and the greatest stem proportion in the FM (30%), promoted the least forage NDF concentration (531 g kg^{-1} DM). For the 30-cm mean canopy height, CS promoted the least forage NDF concentration (535 g kg^{-1} DM), SRS presented the greatest LAI (8.9), and LRS presented the least stem proportion in the FM (31%). Continuous stocking, despite presenting the least leaf proportion (32 %) and the greatest dead material proportion (35 %) in the FM, promoted the greatest forage IVDOM (609 g kg^{-1} DM) and CP (150 g kg^{-1} DM) concentrations. Severe rotational stocking, despite presenting the least dead material proportion (24 %) and the greatest leaf proportion (46%) in the FM, promoted the least forage IVDOM concentration (549 g kg^{-1} DM). Lenient rotational stocking, presented intermediate leaf (42 %) and dead material (29 %) proportions in the FM, and did not differ from the other stocking methods on forage IVDOM concentration (574 g kg^{-1} DM). In general, as mean canopy height decreased, LAI (from 6.6 to 4.8), dead material proportion in the FM (from 33 to 28 %) and forage NDF concentration (from 570 to 545 g kg^{-1} DM) declined, while forage IVDOM (from 554 to 600 g kg^{-1} DM) and CP (from 128 to 146 g kg^{-1} DM) concentrations increased.

Keywords: *Brachiaria* hybrid; Canopy height; Convert HD 364; Grazing intensity; Grazing management; Grazing severity; Stocking method; *Urochloa* spp.

1. INTRODUCTION

In 2017, agribusiness was responsible for approximately 20% of the Brazilian employed workforce (CEPA, 2017a) and for about 22% of the country's GDP (CEPEA, 2017c), of which approximately 31% was credited exclusively to the livestock industry (CEPEA, 2017b). The agribusiness share of the country's total exports was approximately 44% (CEPEA, 2017d). Brazilian beef exports increased 14% in 2017, contributing markedly to the increase of total agricultural exports (CEPEA, 2017d). Agribusiness boosted the Brazilian GDP growth and helped in controlling inflation (CEPEA, 2017c), which is especially important for the low-income segments of the population. In addition, it was responsible for the trade surplus in the country's international business relations, making up for the trade deficit in other sectors of the economy. Whereas the balance in other sectors was negative by almost US$ 15 billion, the positive balance generated by agribusiness was over US$ 81 billion, making agribusiness responsible for an extra US$ 66 billion of the Brazilian trade balance (CEPEA, 2017d). Despite this positive scenario, however, 2017 was a specially challenging year for the Brazilian livestock industry. It was marked by a low domestic demand, a residual effect of the Brazilian economic crisis, by low international prices, and by the negative implications of the polemic and controversial 'Weak Flesh' operation of the Brazilian Federal Police, which scrutinized and challenged the country's sanitary inspection system (CEPEA, 2017c), making the overall performance of the industry and the indices presented above even more remarkable.

As the backbone of the livestock industry, pastures support virtually the entire Brazilian beef production (Ferraz and Felício, 2010), which is a fortunate reality, because they represent the cheapest and most practical way of feeding cattle, resulting in low production costs (Dias Filho, 2014). This makes for profitable operations for producers and affordable products for consumers. Despite its importance, however, pasture and grazing management in Brazil are largely empirical, leading to low forage and animal productivity, inefficient production systems, and pasture degradation (Dias Filho, 2014).

The predominant forage species planted to Brazilian pastures is 'Marandu' palisadegrass [*Brachiaria brizantha* (Hochst. Ex A. Rich.) Stapf.] (Jank et al., 2014) and it has been argued that the diversification of species in planted pastures may reduce risks of deleterious effects such as those of pests and diseases. Mulato II brachiariagrass, a newly released highly productive B*rachiaria* hybrid, is an option for such species diversification. It presents high forage accumulation rates and nutritive value, but still lacks the understanding of optimum specific management guidelines (Argel et al., 2007; Silva et al., 2016a), which involves the definition of stocking methods and target canopy heights.

Rotational socking has commonly been associated with the intensification of production systems, although there are accounts to the fact that continuous stocking can result in equivalent plant and animal performances when grazing management warrants the maintenance of adequate canopy structures, which promote optimum forage productivity, harvest and nutritive value (Parsons et al., 1988a).

In many areas of the world such as the USA, Australia and European countries, the beef industry is based on feedlots, where forage harvest and feeding depend heavily upon labor, machinery, and fuel, with high levels of harvest efficiency of the forage. In Brazilian beef production systems, virtually all forage is grazed and production costs are less than those of confined systems (Dias Filho, 2011; Dias Filho, 2014), but control over forage waste is limited. Although forage losses are inevitable in grazing environments (Hodgson, 1990), appropriate grazing management can significantly increase grazing efficiency, if they can reduce losses by senescence and mechanical damage (Lemaire et al., 2009). Improving grazing management represents little or no increase in production costs, and if adequate canopy structure is warranted by management, positive results may include increased forage accumulation and nutritive value, pasture persistence, voluntary intake, animal performance, and more abundant ecossystem services (Hodgson, 1990; Silva and Pedreira, 1999; Silva et al., 2016a). In other words, enhanced grazing management has the potential to increase efficiency, sustainability and profitability of pasture-based livestock production systems. Defining grazing management strategies, however, depends on the establishment of specific management guidelines, such as target mean canopy heights, for the available forage species, and the clarification of yet unsolved questions, such as those regarding the comparison of stocking methods.

2. LITERATURE REVIEW

2.1. Perennial tropical grasses in the Brazilian livestock industry, the role of brachiariagrass, and cultivar development

Grasslands are among the world's largest ecossystems (61.2 M km²), covering approximately 25% of the earth's surface, and can provide numerous ecossystem services, as long as they are properly managed (Sollenberger et al., 2012). In Brazil, a country among the world's largest tropical countries, favorable environmental conditions for C4 tropical grasses are the foundation for the low feeding costs of the livestock industry. The country is the world's second (to the USA) greatest beef producer and fifth greatest milk producer (FAO, 2017). Accordingly, approximately 19% of the Brazilian land area is planted to perennial forage grasses (196 million ha) (IBGE, 2016), mainly *Brachiaria* (syn. *Urochloa*) species grazed under continuous stocking. In Brazil, approximately 97% of the 218 million head of cattle (IBGE 2016), the world's largest commercial cattle herd, complete their lifecycle exclusively on grazed pastures and the entire herd graze during at least one life stage, so that 100% of Brazilian cattle depend on pasture (ANUALPC, 2015).

Despite their importance, pasture management in Brazil is often empirical and lacks many of the scientific foundations that are commonly employed in row crop production. Not rarely, pastures are sown with forage varieties that are poorly adapted to the diverse environmental conditions found within the country, resulting in inefficient, unproductive and unsustainable production systems (Martha Jr. et al., 2012). Combining adapted forage varieties with appropriate grazing management has the potential to improve pasture productivity and persistence, and may also contribute to increase carbon sequestration (Silva et al., 2016b).

Brazilian cultivated pastures are predominantly planted to 'Marandu' palisadegrass, with the species occupying an estimated 50 million ha (Jank et al., 2014). Marandu is a highly productive brachiariagrass released in 1984 by Embrapa (the Brazilian Agricultural Research Corporation) due to its resistance to spittlebugs (e.g. *Zulia entreriana*, *Deois incompleta*, *Deois flavopicta* and *Aeneolamia selecta*) (Nunes et al., 1984). It is regarded to be the country's largest monoculture (Jank et al., 2014), and it has been argued that this might represent risks to the livestock industry. Marandu pastures have had their persistence and productivity impacted by decreased resistance to spittlebugs (Barbosa, 2006; Andrade and Valentim, 2007) and by a decline that has been named the "Marandu death syndrome", likely a result of the combined effects of poorly drained soils, pests (mainly spittlebugs), and diseases (*Rhizoctonia solani*, *Pythium* sp. and *Fusarium* sp.) (Caetano and Dias-Filho, 2008; Pequeno et al., 2015).

The release of new forage cultivars as alternatives for diversifying planted pastures has been a declared objective of agricultural research in Brazil and elsewhere in Latin America. The International Center for Tropical Agriculture (CIAT) released the hybrid Mulato brachiariagrass (*B. ruziziensis* × *B. brizantha*) in 2000. It has shown good persistence, rapid regrowth, great forage accumulation rates and nutritive value (Silveira et al., 2013). Seed production, however, is low (Argel et al., 2005) which has reportedly made for decreased interest in this genotype.

More recently, CIAT released a new hybrid brachiariagrass, Mulato II (*B. ruziziensis* × *B. decumbens* × *B. brizantha*) from three generations of hybridization between ruzigrass [*B. ruziziensis* R. Germ & Evrard (clone 44-6)] and signalgrass [*B decumbens* (Stapf) R. D. Webster (cv. Basilisk)]. The first generation was exposed to open pollination from lines of *B. brizantha*, including cv. Marandu (Argel et al., 2007). This genotype was subsequently identified as *Brachiaria* hybrid accession CIAT 36087 and released in 2005 as cv. Mulato II. It is adapted to a broad range of conditions, including acidic soils of low fertility and moderate soil moisture saturation, and has good productivity, nutritive value and resistance to spittlebugs (*Aeneolamia reducta, A. varia, Zulia carbonaria, Z. pubescens, Prosapia simulans, Mahanarva trifissa, Deois flavopicta, D. schach* and *Notozulia entrerriana*). It also has greater seed production than the Mulato I cultivar (Argel et al., 2007; Pequeno et al., 2015). In Brazil, Dow AgroSciences acquired the marketing rights and released Mulato II in 2009 as Convert HD 364®. It has been evaluated under continuous and rotational stocking, performing well when kept around canopy heights of 25 cm (Silva et al., 2016a; Silva et al., 2016b; Yasuoka et al., 2017).

Limited knowledge of optimal management guidelines for these newly released forage materials, however, limits their optimal use as defoliation management often derived from that of related materials, in this case, other brachiariagrasses. Although similarities may be found in some agronomic traits, genotype specificities will require the identification of management specificities. Research aimed at assessing different management options is, therefore, key to the successful adoption of such novel forages.

2.2. Grazing management: effects on grass canopy architecture and forage nutritive value

Leaves are often the main photosynthetic tissue and the most nutritive plant part. Pastures under grazing sustain two processes that "compete" for leaf tissue: plant growth and grazing (Parsons et al., 1988b). In such scenario, canopy structure is the link between responses of grazing animals and grazed plants, while grazing management is the practical tool to control it (Laca and Lemaire, 2000).

Management strategies that aim at maintaining adequate canopy structure can optimize plant growth and persistence, forage intake, forage nutritive value and animal performance. Canopy height has been proposed to be a good criterion for assessing and controlling canopy structure (Brougham, 1956).

Canopy structure, the distribution and arrangement of plant parts above the soil surface in crop stand is defined by a series of structural features. Among them, LAI, expressed as the ratio between leaf area and the soil surface area covered by those leaves (Watson, 1947), has been considered one of the most important. When moisture, temperature and mineral nutrients are not limiting, the potential productivity of forage crops is determined by the amount of incident radiation and the efficiency with which it is intercepted and used by the plant community (Cooper, 1970). The efficiency with which it is intercepted is affected by the LAI and its spatial distribution. The efficiency with which it is used is influenced by the photosynthetic activity of individual leaves, varying according to their physiological status, their position in the canopy profile, and the light intensity under which they were developed (Sheehy and Cooper, 1973).

Adaptations in structural features of community of plants can occur in response to defoliation regimes. For example, compensations in tiller population density commonly offset variations in LAI caused by changes in tiller size (Matthews et al., 1995; Sbrissia et al., 2003). Crop and pasture species are able to perform under various canopy structural arrangements resulting from different grazing managements. This phenomenon is called phenotypic plasticity (Bradshaw, 1965).

Along with the LAI, leaf angle, which defines how inclined leaves are in relation to the soil surface, determines the canopy's light extinction coefficient (k), which increases as leaves get more horizontal (Pedreira et al., 2001). In turn, the greater the k, the worse the light use by the canopy, for more upright leaves allow better light penetration through the canopy and its incidence over greater leaf area in more strata of the vegetation (Lemaire and Chapman, 1996).

Canopy bulk density (mass per unit of canopy volume) is an important determinant of animal voluntary intake, the main determinant of animal performance, which has a close correlation with the ease with which forage is apprehended (Hodgson, 1990). Forage intake is the product of grazing time and herbage intake rate, which is a function of biting rate and herbage mass per bite. If bite mass decreases, so does herbage intake rate, unless there is a compensatory increase in biting rate. If intake rate is compromised, there must be a compensatory increase in grazing time, or daily forage intake is depressed. Such compensatory behaviors usually indicate limiting canopy structural conditions. Herbage mass per bite, in turn, is mainly determined by canopy height, arrangement, and bulk density. As bulk density increases, so does intake per bite and rate of intake, because the herbage mass ingested for a given bite volume increases as bulk density does. For most forage canopies, bulk density increases from top to bottom and as canopies are kept shorter compared to taller canopies (Hodgson, 1990).

Plant-part composition, the proportion of each morphological component (i. e. leaves, stems and dead material) in the forage mass, along with canopy bulk density, also influences animal performance as they affect the ease of forage apprehension as well as nutritive value. Different plant-part components have different chemical compositions. Accordingly, animals are known to avoid forage with high proportions of stem and dead material. The taller the canopy, the greater the proportions of those components, the older the plant tissues and, therefore, the less the crude protein concentration and digestibility, and the greater the fiber concentration (Silva et al., 2016a).

Forage quality is defined by the combination of nutritive value - a function of chemical composition and digestibility - and voluntary intake (Mott and Moore, 1985). Voluntary intake is defined by selection, ease of apprehension, and the rate of feed passage through the digestive tract. As forage digestibility increases, so does the nutrient intake, as the rate at which feed passes through the tract also increases. Ultimately, forage quality is better expressed as animal performance (Sollenberger and Cherney, 1995). Through selection, grazing animals end up harvesting feed of better quality than that which is on offer (Hodgson, 1990). Due to their photosynthetic efficiency, C4 grasses inherently have less protein than C3 grasses. Defoliation management, therefore, can alter the quality of the diet harvested by the grazing animal.

Grazing management can also be an important provider of ecosystem services. When properly applied, it has the potential to help minimize pasture degradation. Degraded grasslands fail to provide appropriate feed for livestock and compromise the economic return of provisioning ecosystem services. Additionally, supporting and regulating ecosystem services may also be weakened because poor ground cover and depleted root mass lead to nutrient leaching, sediment runoff, soil erosion, reduced net primary production and depressed soil C inputs (Sollenberger et al., 2012).

2.3. Stocking methods as tools to achieve desired grazing systems outputs

Stocking methods are important descriptors of grazing management. They consist of techniques and procedures to manipulate animals in time and space, defining how they get access to a grazing management unit throughout the period when grazing is allowed (Allen, 2011). All stocking methods derive from continuous stocking, where animals have continued unbounded access to the entire grazing management unit, or from intermittent stocking, where there are alternate stocking and rest periods among portions of the grazing management unit (Allen, 2011).

Rotational stocking has commonly been associated with intensification of grazing systems, optimum grazing efficiency and maximum productivity levels. Brazilian ranchers, however, largely prefer continuous stocking and there are accounts to the fact that it can promote equivalent pasture and animal productivity to rotational stocking when compared under equal basis (Parsons and Penning, 1988; Parsons et al., 1988a). These equal bases are provided when the maintenance of adequate canopy structure, which are capable of promoting optimum forage productivity, harvest and nutritive value, is assured and adjustments, such as in stocking rates, are frequently done respecting forage accumulation rates (Parsons et al., 1988b).

Comparisons of plant responses under contrasting stocking methods are methodologically complex and thus scarce in the literature. Experimental results showing greater stocking rates as a response variable under rotational stocking may be explained by the greater efficiency in the use of the accumulated forage due to the greater stocking density associated with rotational stocking, where animals graze more uniformly across the grazing area. This is due to the fact that the period between visits to individual tillers or specific areas of the pasture are not only determined by the stocking rate but also by the rest period, which is imposed by the pasture manager (Barnes, 2008; Sollenberger et al., 2012).

The regrowth curve of a forage stand under rotational stocking can be divided in three parts: (i) exponentially increasing forage accumulation rate; (ii) constant linear maximum forage accumulation rate; (iii) declining forage accumulation rate (Brougham, 1956). Eventually, there will be the onset of competition for light among plants and rates of tissue senescence and stem elongation increase, depressing forage nutritive value. Regrowth must then be ceased before these processes are intensified. This coincides with the point where 95% of light is intercepted by the canopy, which is associated to a LAI called “critical”. The adoption of such management guideline optimizes leaf proportion in the forage mass, defoliation frequency, grazing efficiency, forage accumulation rates and digestibility (Brougham, 1956; Hodgson, 1990; Carnevalli et al., 2006; Pedreira et al., 2007; Silveira et al., 2013).

Likewise, the LAI remaining after grazing also impacts light interception (LI) and the amount of photosynthetic tissue available for regrowth, consequently determining the gross photosynthesis and the regrowth rate. This residual leaf area determines the extent to which plants rely on reserves to regrow and, in turn, plant persistence (Brougham, 1956). This means, the more severe the defoliation, the greater the dependence on reserves. As regrowth progresses, the development of new leaves increases the LAI, LI, and gross photosynthetic rates, to the point where surplus assimilates can be used to restore the consumed reserves (Lemaire and Chapman, 1996). Thus, not only the interruption of plant growth at the appropriate moment is important to guarantee the offer of good quality forage, but also maintaining adequate LAI after animals have grazed a specific pasture area, defined by grazing severity, is also crucial. Accordingly, in the long term, stubble height has greater influence on canopy leaf proportion than grazing frequency (Pedreira et al., 2017).

Under continuous stocking, if an optimal canopy height can be maintained constant, canopy structure can be kept in a steady state (Sollenberger et al., 2012). In this case, however, the LAI must be considerably lower than that associated with 95% LI, in order to promote optimum forage intake per ha, despite the fact that the greater LAI of pastures under more lenient grazing intensities promote greater levels of gross photosynthesis. This is not a direct function of photosynthetic rates, but mainly of herbage losses by senescence and the expenditure of photoassimilates with respiration and root growth, which do not lead to the accumulation of harvestable tissues. Canopies with greater LAI produce more tissues, due to greater gross photosynthetic rates, but also spend greater amounts of photoassimilates with respiration and root growth, because canopies under contrasting grazing intensities spend similar percentages of these compounds with such processes. This results in lesser forage ingestion, smaller proportions of photoassimilates being harvested and more forage being lost to senescence under more lenient grazing intensities than under more severe grazing, meaning less grazing efficiency (Parsons et al., 1983b). It is important to highlight that maintaining a steady canopy state under continuous stocking is only possible with variable stocking rates, which, in the short term, depends on varying the number of animals in the grazing unit. That, however, implies in a number of other challenges for the production system, which includes dealing with constant price fluctuations.

The harvested proportion of the accumulated forage is, therefore, the main difference between different grazing intensities and, consequently, despite lesser forage production, canopies under greater grazing intensities are associated with greater proportions of harvested forage. The great gross photosynthetic rates and forage production levels associated with canopies under lesser grazing intensities are not associated with high harvest efficiencies. Maximum consumption levels per ha, thereby, are achieved with LAI substantially lower than those required for optimum photosynthetic rates (Parsons et al., 1983a; Parsons et al., 1983b).

This shows the fundamental difference between forage production under rotational stocking, where canopies grow from a small post-graze LAI to a great pre-graze LAI, and forage production under continuous stocking, where canopies are kept a more or less stable LAI. Under rotational stocking, tissue production rate increases as the canopy gross photosynthetic rate increases. There is a delay before produced tissues begin to senesce and, under this condition, when harvesting happens at 95% LI, great gross photosynthetic rates coincide with great forage net accumulation rates and low rates of senescence. Thus, a great proportion of the accumulated herbage is likely to be harvested (Parsons et al., 1983b).

In contrast with the above, under continuous stocking, when a LAI is maintained close to a value capable of intercepting all incident light (95% of LI), gross photosynthesis and tissue production are both intense, but so is the rate of senescence. Here, greatest tissue production rates and greatest senescence rates happen simultaneously and keeping canopies at elevated LAI compromises forage harvesting, because a considerable proportion of what is produced is wasted by senescence. When canopies are kept at a smaller LAI than that associated with almost maximum LI, senescence rates are maintained at small levels and greater proportions of the produced forage can be harvested (Parsons et al., 1983b). Accordingly, under continuous stocking, the increase in grazing intensity, in spite of decreasing gross photosynthetic rates and forage production levels, increases grazing efficiency, so that maximum forage consumption per ha is achieved with a LAI maintained below the one related to maxim photosynthetic rates (Parsons et al., 1983b).

Under rotational stocking, though, maximum forage intake per ha is achieved when pre and post-grazing LAI result in a small average LAI during regrowth. This small average LAI correspond to the relative small LAI found to promote maximum forage intake per ha under continuous stocking. Therefore, forage accumulation under both stocking methods can be better correlated to an average canopy condition (Parsons et al., 1988a).

2.4. Grazing efficiency

Numerous definitions have been proposed for the efficiency with which herbage is used, or harvested in grazing environments. According to Hodgson (1979), grazing efficiency may be defined as: (i) consumed herbage expressed as a proportion of herbage accumulation over the same time interval, whether for a single defoliation or a series of defoliations; or (ii) as the herbage consumed at each defoliation expressed as a proportion of the herbage mass originally present. The first definition should be preferred because it avoids the difficulty of counting herbage residues more than once (Leaver, 1976; cited by Hodgson, 1979). The second, synonymous with degree of defoliation and better expressed as such, seems to underestimate grazing efficiency by systematically accounting the forage mass below the stubble height, not destined for grazing (Pedreira et al., 2005).

Hodgson (1979) also defined harvest efficiency in the case of clipping management, and utilization efficiency as the ratio of animal product to accumulated herbage, obtained as the product of grazing efficiency and gross conversion efficiency (ratio of animal product to herbage consumed). More recently, Hodgson (1990) defined herbage utilization efficiency as the partitioning between consumption and senescence.

Mazzanti and Lemaire (1994) defined herbage utilization efficiency as the ratio between herbage consumption and herbage growth. Lemaire and Chapman (1996) defined herbage use efficiency as the proportion of gross herbage production removed by grazing animals before entering the senescent state, which depends on the proportion of each leaf accumulated length that escapes defoliation and senesce. In both cases, grazing efficiency (Mazzanti and Lemaire, 1994), or herbage harvest efficiency (Lemaire and Chapman, 1996) are dependent on the defoliation interval of individual leaves and the leaf lifespan of the considered grass species, or, in other words, it is closely related to the ratio between defoliation frequency and leaf lifespan. Thus, a decrease in herbage growth rate and in stocking rate (assuming a variable stocking rate dictated by herbage growth), would have more negative effects over the grazing efficiency of short leaf lifespan species than over those with longer leaf lifespans.

Lemaire et al. (2009) defined harvesting process efficiency as the proportion of each leaf defoliated before senescence, or, as the proportion of herbage growth harvested before entering the senescent state. The same authors also defined grazing efficiency as the ratio between the quantity of leaf tissue removed by grazing and the quantity of leaf tissue produced during a given period of time when canopies are kept in steady state, or, as the removed leaf length as a proportion of the total leaf length accumulated over the leaf lifespan. Smart et al. (2010) defined grazing efficiency as the proportion that consumed forage represents of the total forage disappearance due to all other factors, and harvest efficiency as the proportion that consumed forage represents of the produced forage.

According to definitions regarding leaf senescence, grazing efficiency expresses the probability of leaves being harvested, which in turn depends on leaf longevity - because leaves that are more long-lived have less chances of escaping defoliation - as well as on grazing frequency and severity (Lemaire et al., 2009).

Excessively light grazing (large post-grazing forage mass), excessively long rest periods (large pre-grazing forage mass) and excessively light grazing intensity (large forage mass kept under continuous stocking) are related to greater forage waste due to senescence and mechanical damage. This is explained by the fact that competition between plants leads to increases in senescence rate and stem elongation, whereas animals do not consistently harvest forage associated with large proportions of these tissues (Parsons and Penning, 1988; Hodgson, 1990).

Under continuous stocking, the period between visits to an individual tiller depends on the stocking rate. As stocking rate increases, so do the chances of the time between visits to a tiller being shorter than its leaves' lifespan (Lemaire et al., 2009; Parsons and Penning, 1988). Under rotational stocking, the period between visits to a tiller is defined by stocking rate as well, but also depends on the rest period established by the manager, as stated above. Both rest period and stocking rate, however, regardless of stocking method, must be adjusted according to the forage growth rate (Lemaire et al., 2009), which then, indirectly, becomes a main determinant of grazing efficiency (Mazzanti and Lemaire, 1994; Silva et al., 2016a; Braga et al., 2007; Lemaire et al., 2009). According to these authors, when stocking rate is adjusted in order to maintain a certain canopy feature stable (e. g. height, forage mass, LAI), variations in growth rate lead to greater relative impacts on grazing efficiency, harvest rate and intake than on forage accumulation.

Conversely, grazing efficiency also affects stocking rate (Pedreira et al., 2005; Silveira et al., 2013) by determining the amount and nutritive value of the forage on offer (Braga et al., 2007). Such counter effect is due to the fact that pre-established grazing efficiency levels, partially determined by grazing severity, dictate which canopy strata may be explored and, consequently, the percentage of each plant-part component within the consumed forage mass. Generally, as grazing severity increases, feed conversion efficiency decreases because animals are forced to consume lower layers of the canopy composed by greater proportions of stem and dead material, components with less nutritive value (Parsons and Penning, 1988; Braga et al., 2007; Sollenberger et al., 2012). Thus, greater grazing efficiencies not necessarily represent greater productivities, so that appropriate efficiency levels should combine animal performances and stocking rates that maximize profitability.

Part of the accumulated tissues in pastures must be preserved to attend plants' physiological needs, such as photosynthesis for regrowth; part of that is lost by senescence and mechanical damage and, consequently, only part of it may be consumed (Hodgson, 1990). It is indisputable, then, that forage accumulation rates and nutritive value can only be associated with low cost livestock production systems if the grazing animals effectively harvest the accumulated forage. Therefore, increasing productivity levels not only depends on promoting better forage accumulation rates and nutritive value, but also on grazing strategies that minimize forage waste, optimizing its exploitation (Pedreira et al., 2005; Silveira et al., 2013).

3. HYPOTHESIS

The hypothesis of the present study was that there is no advantage in forage accumulation, nutritive value and grazing losses between stocking methods when grazing management strategies include the control of canopy height.

4. OBJECTIVE

The objectives of the present study were to describe and explain forage accumulation and nutritive value, canopy structure, and grazing losses of Mulato II brachiariagrass in response to continuous and rotational stocking methods, both based on the maintenance of similar mean canopy heights.

5. MATERIAL AND METHODS

5.1. Experimental period, site and conditions, and experimental site history

The experiment was carried out from 9 January to 5 April 2017 (87 days) on a Mulato II brachiariagrass pasture established in 2012, as described by Silva et al. (2016a), over a Kandiudalfic Eutrudox (Soil Survey Staff, 1990) in Piracicaba, SP, Brazil (22° 42’ 30” S, 47° 30’ 00” W, 580 m alt.) (Cervellini et al., 1973). Soil chemical analysis for the 0 – 20 cm layer were carried out on samples taken in May 2016 (Table 1). Weather data for the experimental period (Table 2) were obtained from a weather station located 2 km from the experimental site.

Table 1. Soil chemical characteristics.

pH	OM	P	K	Ca	Mg	H+Al	SB	CEC	V
($CaCl_2$)	g dm^{-3}	mg dm^{-3}	mmol$_c$ dm^{-3}						%
5.4	42	57	9.9	53	22	38	84.9	122.9	69

pH = 0.01 mole L^{-1} $CaCl_2$; P = Ion-exchange resin extraction method; OM = Organic matter; SB = Sum of bases; CEC = Cation exchange capacity; V% = Base saturation

Table 2. Monthly weather data for the experimental period and historic average weather data (1917 – 2017)

Weather variable	January	February	March	April
Max. Temperature (°C)	30.2	32.2	30.6	28.3
Min. Temperature (°C)	20.3	20.0	18.4	16.7
Mean Temperature (°C)	25.3	26.1	24.5	22.5
Rainfall (mm)	334	88	137	128
	Historic average (1917 - 2017)			
Mean Temperature (C°)	24.5	25.0	24.0	22.0
Rainfall (mm)	229	180	142	66

Previous grazing research was conducted on the same area during the summer rainy seasons of 2012/2013, 2013/2014 and 2014/2015 (Silva et al., 2016a; Silva et al., 2016b; Yasuoka et al., 2017). From May 2015 through September 2016, it was stocked with dairy cows (*Bos* spp.) weighing 450 kg on average. Starting in October 2016, experimental treatments were imposed for three months to condition the pastures, after an intense grazing for forage mass removal, a mechanical staging to 10 cm and the application of 50 kg ha^{-1} of N as NH_4NO_3.

5.2. Experimental design and treatments

The experimental design was a randomized complete block with three replications and six treatments composed by factorial combinations of two mean canopy heights (20 and 30 cm) and three mimicked stocking methods (continuous stocking with variable stocking rate - CS, lenient rotational stocking - LRS, and severe rotational stocking - SRS), totaling 18 experimental units (pastures) of 200 m^2. Stocking methods were imposed by height variations around the two mean canopy heights: 10% (mimicked continuous stocking), 25% (lenient rotational stocking), and 40% (severe rotational stocking), applied using a mob stocking protocol.

Canopy height was measured three times a week at 50 sites distributed in five equidistant transects in each pasture, using a measuring stick and a light polyethylene sheet (Figure 1). A group of dry Holstein cows and heifers (*Bos* spp.) was taken onto a pasture whenever the mean canopy height reached the treatment's upper limit, and taken off once it was brought down to its corresponding lower limit.

Before the begning of the experimental period, animals were weighted after 16 hours of liquid and solid fasting. Two groups of seven animals totaling 3100 ± 3.5 kg of body weight (BW) were then used in every stocking period to impose the same stocking density to all pastures.

A total of 187 kg ha^{-1} of N and K_2O were split applied simultaneously in all pastures as NH_4NO_3 and KCl in three equal doses of 62.4 kg ha^{-1} (01/09, 02/04 and 03/03, 2017).

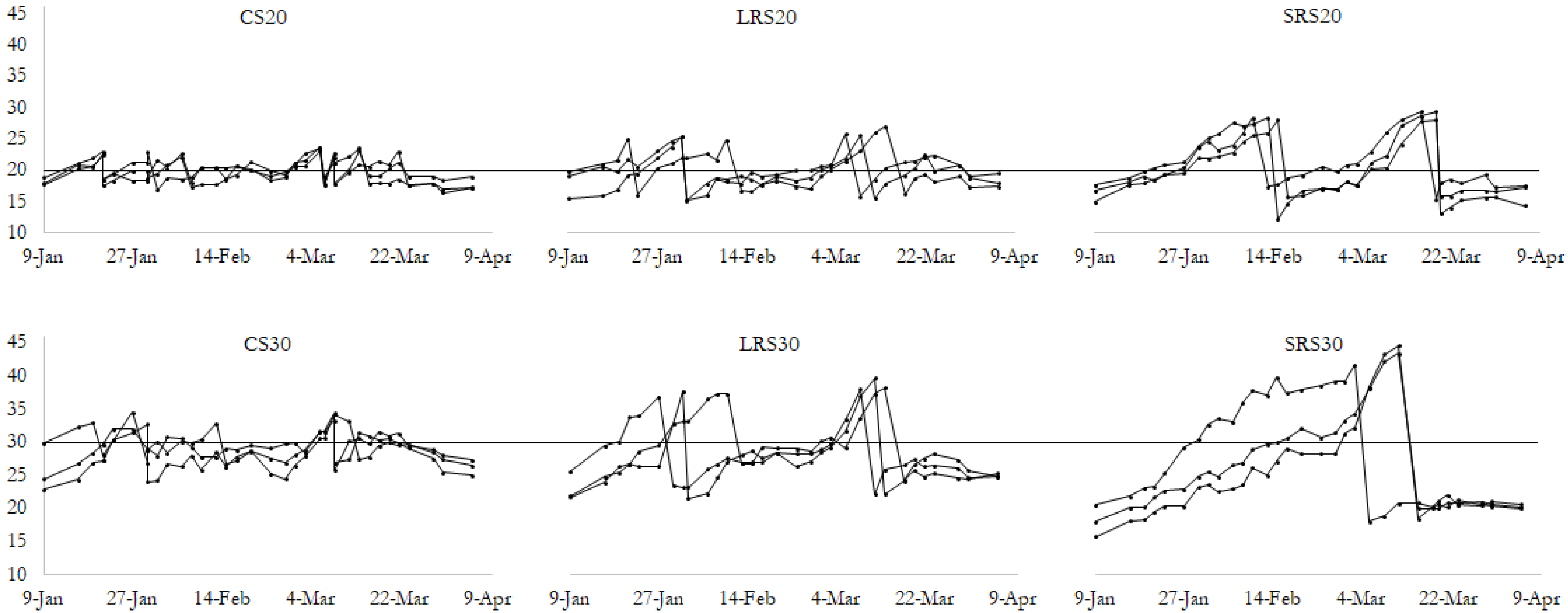

Figure 1. Mean canopy heights (cm) and measuring dates for individual pastures (replicate experimental units) under continuous stocking with mean canopy heights of 20 (CS20) and 30 cm (CS30), lenient rotational stocking with mean canopy heights of 20 (LRS20) and 30 cm (LRS30), and severe rotational stocking with mean canopy heights of 20 (SRS20) and 30 cm (SRS30).

5.3. Measurements

5.3.1. Forage mass, forage accumulation and forage accumulation rate

Forage mass (FM) was quantified for rotationally stocked pastures at pre- and post-grazing by sampling the vegetation at 2 cm above the soil surface inside two 0.25-m² quadrats allocated at sites where FM was considered to be representative of the pasture's average, by visual appraisal. Pastures under CS were sampled for FM every 21 days. Samples were weighed fresh, subsampled in about 250 g and dried in forced draft ovens at 60°C to constant weight.

Forage accumulation per cycle was calculated for rotationally stocked pastures as the difference between the pre-grazing FM of a cycle and the post-grazing FM of the previous cycle. For continuously stocked pastures, it was calculated as the difference between the mean FM inside two cylindrical exclosure cages (0.9 m in diameter) 21 days after they were anchored at sites where FM was considered to be representative of the pasture's average, by visual appraisal, and the FM at those sites on the first day of the cycle. Total seasonal forage accumulation (FA) was calculated as the sum across all cycles for each pasture.

Forage accumulation rate (FAR) was calculated by dividing FA by 21, for continuously stocked pastures, and by the observed rest period, for those under rotational stocking.

5.3.2. Forage allowance

For rotationally stocked pastures, forage allowance (FAL) was calculated as the relationship between the mean FM of each stocking period [(pre-grazing FM + post-grazing FM) / 2] and the stocking density. For continuously stocked pastures, it was calculated as the relationship between the mean pasture FM recorded every 21 days and the stocking density. An average FAL was then calculated considering every sampling date (Sollenberger et al., 2005).

5.3.3. Canopy bulk density

Canopy bulk density (CBD) was calculated by dividing the pre-grazing FM by the corresponding mean canopy height for rotationally stocked pastures, and by dividing the pasture FM recorded every 21 days by the corresponding mean canopy height for those under continuous stocking.

5.3.4. Light interception and leaf angle

Light interception (LI) and mean leaf angles (LA) were non-destructively characterized using a model LAI-2000 canopy analyzer (Li-Cor, Lincoln, Nebraska, USA) at 40 sites per pasture, at pre and post-grazing on rotationally stocked pastures and every 21 days on those under continuous stocking. One reference reading was taken above the canopy for every eight readings recorded at soil level.

5.3.5. Plant-part composition and leaf area index

Samples of FM for plant-part composition characterization were clipped at 2 cm above the soil surface inside two 0.25-m² quadrats allocated at sites where FM was considered to be representative of the pasture average, by visual appraisal, at pre and post-grazing on rotationally stocked pastures, and every 21 days on those under continuous stocking. Samples were weighed fresh, subsampled in about 250 g and manually separated into their morphological components: leaves, dead material (tissues with more than 50% of senescence) and stems (including pseudstems and leaf sheaths). The leaf area of approximately 30 leaves was measured using a model LI-3100 leaf area meter (Li-Cor, Lincoln, Nebraska, USA). All plant-part components were dried in forced draft ovens at 60°C to constant weight. The dry weight of each fraction was used to determine the relative proportion of leaf, stem and dead material in the FM. The relation of leaf area and leaf weight was used to obtain the specific leaf weight and to estimate the total leaf area of the sample, which in turn was used to calculate the LAI.

5.3.6. Grazing losses

For the quantification of grazing losses (GL), at the beginning of the experimental period, three 1.2-m² sites were permanently marked in every pasture with four wooden stakes firmly hammered to the soil, where FM was considered to be representative of the pasture average, by visual appraisal, from which all loose plant material (dead or green) was removed and discarded. Thereafter, all loose plant material (dead or green) was collected from these areas, at post-grazing on rotationally stocked pastures and every 21 days on those under continuous stocking. This material was dried in a forced draft oven at 60°C to constant weight, weighed, and considered as GL. Total seasonal GL were calculated as the sum of all GL recorded within the experimental period. As much as possible, the same sites were used for this purpose throughout the experimental period, but were replaced when fouled or otherwise made useless.

Figure 2. The permanently marked 1.2-m² sites from which grazing losses were collected, before (A) and after (B) the collection of grazing losses.

5.3.7. Nutritive value

Forage from the grazed portion of the canopy was characterized for nutritive value. Samples of approximately 500 g fresh weight were taken at pre-grazing from the canopy strata that would be grazed on rotationally stocked pastures, and by hand plucking during grazing periods on those under continuous stocking. These samples were taken to a forced draft oven, dried at 60°C to constant weight, and ground in a Wiley mill to pass a 1-mm screen. Nitrogen concentration was measured using a micro-Kjeldhal technique (Gallaher et al., 1975). Nitrogen concentration in the digestate was determined by semi-automated colorimetry (Hambleton, 1977). Forage crude protein (CP) concentration was calculated by multiplying the N concentration by 6.25. Forage neutral detergent fiber (NDF) concentration was quantified according to the A2000 Filter Bag Technique-Method 13 (Ankom Technology, Macedon, NY) (ANKOM Technology, 2014). Forage in vitro digestible organic matter (IVDOM) concentration was determined using the two-stage procedure of Tilley and Terry (1963) as modified by Moore and Mott (1974).

5.4. Data analysis

Data were analyzed using the MIXED procedure of SAS® (Statistical Analyses System) (Littel et al., 2006). Blocks were considered random effects. The covariance structure was chosen based on Akaike's Information Criterion (AIC) (Wolfinger, 1993). Means were estimated using LSMEANS and compared using PDIFF by Student test ($P<0.05$).

6. RESULTS

6.1. Forage mass under continuous stocking and at pre-grazing under rotational stocking

Forage mass under continuous stocking and at pre-grazing under rotational stocking was affected by the mean canopy height × stocking method interaction (P = 0.0002). For the 20-cm mean canopy height, FM was greatest under LRS and least under CS but did not differ between SRS and the other stocking methods. For the 30-cm mean canopy height, FM was greatest under SRS, least under CS and intermediate under LRS. Under all stocking methods, FM increased as mean canopy height increased (Table 3).

Table 3. Forage mass of Mulato II brachiariagrass under continuous stocking and at pre-grazing under rotational stocking as affected by mean canopy height and stocking method.

Canopy height	Stocking method †			SEM
	CS	LRS	SRS	
cm	- kg DM ha^{-1} - - - - - - - - - - - - - - - - -			
20	5800 b §	7130 a	6430 ab	172.8
30	7220 c	8170 b	10820 a	172.8
P ¶	0.0059	0.0299	<0.0001	
SEM	211.6	211.6	211.6	

† CS, continuous stocking; LRS, lenient rotational stocking; SRS, severe rotational stocking.
¶ $Pr > F$ for mean canopy height effect within stocking method.
§ Means within rows followed by the same letter are not different by t-test (α = 0.05).
SEM, standard error of the mean; DM, dry matter.

6.2. Canopy bulk density

Canopy bulk density (CBD) was affected by the mean canopy height × stocking method interaction (P = 0.0042). For the 20-cm mean canopy height, CBD was highest under CS, lowest under SRS and intermediate under LRS. For the 30-cm mean canopy height, CBD was less under LRS than under CS and SRS. Under SRS, CBD did not differ between mean canopy heights, but it increased as mean canopy height increased under CS and LRS (Table 4).

Table 4. Canopy bulk density of Mulato II brachiariagrass as affected by mean canopy height and stocking method.

Canopy height	Stocking method †			SEM
	CS	LRS	SRS	
cm	- kg DM ha^{-1} cm^{-1} - - - - - - - - - - - - - - - -			
20	348 a §	397 b	239 c	12.2
30	285 a	219 b	261 a	12.2
P ¶	0.0042	0.0010	0.2268	
SEM	12.2	12.2	12.2	

† CS, continuous stocking; LRS, lenient rotational stocking; SRS, severe rotational stocking.
¶ *Pr* > *F* for mean canopy height effect within stocking method.
§ Means within rows followed by the same letter are not different by t-test (α = 0.05).
SEM, standard error of the mean; DM, dry matter.

6.3. Forage allowance

Forage allowance (FAL) was affected by mean canopy height but not by stocking method (P = 0.3541) or by the mean canopy height × stocking method interaction (P = 0.2800). Forage allowance increased as mean canopy height increased (Table 5).

Table 5. Forage allowance of Mulato II brachiariagrass as affected by mean canopy height.

Canopy height	FAL
cm	kg DM kg^{-1} BW
20	1.8
30	2.3
P ¶	0.0012
SEM	0.08

¶ *Pr* > *F* for mean canopy height effect.
SEM, standard error of the mean; DM, dry matter; BW, body weight.

6.4. Forage accumulation, forage accumulation rate and grazing losses

Forage accumulation, FAR and GL were not affected by mean canopy height (P = 0.9250, P = 0.9273 and P = 0.2589, respectively), stocking method (P = 0.6833, P = 0.7153 and P = 0.0808, respectively), or by the mean canopy height × stocking method interaction (P = 0.8804, P = 0.8760 and P = 0.2090, respectively). Mean FA was 8363 ± 1578 kg DM ha^{-1}. Mean FAR was 97 kg ± 17.5 DM ha^{-1} d. Mean GL was 5305 ± 585 kg DM ha^{-1}.

6.5. Plant part composition under continuous stocking and at pre-grazing under rotational stocking

Leaf and dead material proportions in Mulato II brachiariagrass FM under continuous stocking and at pre-grazing under rotational stocking were affected by stocking method ($P <$ 0.0001 and $P = 0.0004$, respectively) but were not affected by mean canopy height ($P = 0.9295$ and $P = 0.0600$, respectively) and the mean canopy height × stocking method interaction ($P =$ 0.4287 and $P = 0.8891$, respectively). The proportions of both components in the FM were intermediate under LRS, but leaf proportion was greatest under SRS and least under CS, while, inversely, dead material proportion was greatest under CS and least under SRS (Table 6).

Table 6. Leaf and dead material proportions in Mulato II brachiariagrass forage mass under continuous stocking and at pre-grazing under rotational stocking as affected by stocking method.

Stocking method †	Leaf	Dead material
	- - - - - - - - - - - - - - - - - - - %	- - - - - - - - - - - - - - - - -
CS	32 c §	35 a
LRS	42 b	29 b
SRS	46 a	24 c
SEM	1.9	1.8

† CS, continuous stocking; LRS, lenient rotational stocking; SRS, severe rotational stocking.
§ Means within rows followed by the same letter are not different by t-test ($\alpha = 0.05$).
SEM, standard error of the mean.

Stem proportion in Mulato II brachiariagrass FM under continuous stocking and at pre-grazing under rotational stocking was affected by the mean canopy height × stocking method interaction ($P = 0.0318$). For the 20-cm mean canopy height, stem proportion in the FM was greater under CS than under LRS and SRS. For the 30-cm mean canopy height, stem proportion was less under LRS than under CS and SRS. Under all stocking methods, stem proportion increased as mean canopy height increased (Table 7).

Table 7. Stem proportion in Mulato II brachiariagrass forage mass under continuous stocking and at pre-grazing under rotational stocking as affected by mean canopy height and stocking method.

Canopy height	Stocking method †			SEM
	CS	LRS	SRS	
cm	- % -			
20	30 a §	27 b	27 b	0.3
30	35 a	31 b	34 a	0.3
P ¶	<0.0001	0.0005	<0.0001	
SEM	0.8	0.8	0.8	

† CS, continuous stocking; LRS, lenient rotational stocking; SRS, severe rotational stocking.
¶ *Pr* > *F* for mean canopy height effect within stocking method.
§ Means within rows followed by the same letter are not different by t-test (α = 0.05).
SEM, standard error of the mean.

6.6. Leaf area index under continuous stocking and at pre-grazing under rotational stocking

Leaf area index under continuous stocking and at pre-grazing under rotational stocking was affected by the mean canopy height × stocking method interaction (P = 0.0029). For the 20-cm mean canopy height, LAI was less under CS than under LRS and SRS. For the 30-cm canopy height, LAI was greatest under SRS, least under CS and intermediate under LRS. Under all stocking methods, LAI increased as mean canopy height increased (Table 8).

Table 8. Leaf area index of Mulato II brachiariagrass under continuous stocking and at pre-grazing under rotational stocking as affected by mean canopy height and stocking method.

Canopy height cm	Stocking method †			SEM
	CS	LRS	SRS	
20	3.3 b §	5.4 a	5.6 a	0.37
30	4.2 c	6.7 b	8.9 a	0.37
P ¶	0.0054	0.0101	<0.0001	
SEM	0.40	0.40	0.40	

† CS, continuous stocking; LRS, lenient rotational stocking; SRS, severe rotational stocking.
¶ *Pr* > *F* for mean canopy height effect within stocking method.
§ Means within rows followed by the same letter are not different by t-test (α = 0.05).
SEM, standard error of the mean.

6.7. Light interception under continuous stocking and at pre-grazing under rotational stocking

Light interception under continuous stocking and at pre-grazing under rotational stocking was affected by mean canopy height (Table 9) and by stocking method ($P < 0.0001$) (Table 10), but it was not affected by the mean canopy height × stocking method interaction ($P = 0.4038$). Light interception increased as mean canopy height increased (Table 9) and it was greatest under SRS, least under CS and intermediate under LRS (Table 10).

Table 9. Light interception by Mulato II brachiariagrass under continuous stocking and at pre-grazing under rotational stocking as affected by mean canopy height.

Canopy height	Light interception
cm	%
20	98.0
30	98.9
P [¶]	0.0006
SEM	0.17

[¶] *Pr* > *F* for mean canopy height effect.
SEM, standard error of the mean.

Table 10. Light interception by Mulato II brachiariagrass under continuous stocking and at pre-grazing under rotational stocking as affected by stocking method.

Stocking method [†]	Light interception
	%
CS	97.1 c [§]
LRS	98.8 b
SRS	99.4 a
SEM	0.19

[†] CS, continuous stocking; LRS, lenient rotational stocking; SRS, severe rotational stocking.
[§] Means within rows followed by the same letter are not different by t-test ($\alpha = 0.05$).
SEM, standard error of the mean.

6.8. Mean leaf angle under continuous stocking and at pre-grazing under rotational stocking

Mean leaf angle under continuous stocking and at pre-grazing under rotational stocking was affected by the mean canopy height × stocking method interaction ($P = 0.0097$). For the 20-cm mean canopy height, LA did not differ between the stocking methods. For the 30-cm canopy height, LA was less (more horizontal leaves) under SRS than under CS and LRS.

Under CS and LRS, LA did not differ between mean canopy heights, but it increased as mean canopy height increased under SRS (Table 11).

Table 11. Mean leaf angle of Mulato II brachiariagrass under continuous stocking and at pre-grazing under rotational stocking as affected by mean canopy height and stocking method.

Canopy height	Stocking method †			SEM
cm	CS	LRS	SRS	
20	43 a §	42 a	44 a	0.6
30	44 a	44 a	41 b	0.6
P ¶	0.1277	0.0646	0.0157	
SEM	0.8	0.8	0.8	

† CS, continuous stocking; LRS, lenient rotational stocking; SRS, severe rotational stocking.
¶ *Pr* > *F* for mean canopy height effect within stocking method.
§ Means within rows followed by the same letter are not different by t-test (α = 0.05).
SEM, standard error of the mean.

6.9. In vitro digestible organic matter and crude protein

Forage IVDOM and CP concentrations were affected by mean canopy height (*P* = 0.0038 and *P* = 0.0048, respectively) (Table 12) and by stocking method (*P* = 0.0036 and *P* = 0.0110, respectively) (Table 13), but they were not affected by the mean canopy height × stocking method interaction (*P* = 0.1744 and *P* = 0.1835, respectively). Both responses declined as mean canopy height increased (Table 12). Forage CP concentration was greater under CS than under LRS and SRS (Table 13). Forage IVDOM concentration was greatest under CS and least under SRS, but it did not differ between LRS and the other stocking methods (Table 13).

Table 12. Forage crude protein and IVDOM concentrations in Mulato II brachiariagrass as affected by mean canopy height.

Canopy height	Crude protein	IVDOM
cm	- - - - - - - - - - - - - - - - g kg^{-1} DM	- - - - - - - - - - - - - - - -
20	146	600
30	128	554
P ¶	0.0038	0.0048
SEM	4.4	107.0

¶ *Pr* > *F* for mean canopy height effect.
SEM, standard error of the mean; DM, dry matter.

Table 13. Forage crude protein and IVDOM concentrations in Mulato II brachiariagrass as affected by stocking method.

Stocking method †	Crude protein	IVDOM
	- - - - - - - - g kg^{-1} DM - - - - - - - -	
CS	150 a §	609 a
LRS	136 b	574 ab
SRS	124 b	549 b
SEM	5.0	12.5

† CS, continuous stocking; LRS, lenient rotational stocking; SRS, severe rotational stocking.
§ Means within rows followed by the same letter are not different by t-test (α = 0.05).
SEM, standard error of the mean; DM, dry matter.

6.10. Neutral detergent fiber

Forage NDF concentration was affected by the mean canopy height × stocking method interaction (P = 0.0036). For the 20-cm mean canopy height, forage NDF concentration was less under CS than under LRS and SRS. For the 30-cm mean canopy height, forage NDF concentration was greatest under SRS, least under CS and intermediate under LRS. Under CS, forage NDF concentration did not differ between mean canopy heights, but it increased as mean canopy height increased under LRS and SRS (Table 14).

Table 14. Forage neutral detergent fiber concentration in Mulato II brachiariagrass as affected by mean canopy height and stocking method.

Canopy height	Stocking method †			SEM
	CS	LRS	SRS	
cm	- - - - - - - - -	g kg^{-1} DM	- - - - - - - - -	
20	531 b §	553 a	552 a	5.2
30	535 c	579 b	597 a	5.2
P ¶	0.5638	0.0025	<0.0001	
SEM	6.4	6.4	6.4	

† CS, continuous stocking; LRS, lenient rotational stocking; SRS, severe rotational stocking.
¶ $Pr > F$ for mean canopy height effect within stocking method.
§ Means within rows followed by the same letter are not different by t-test (α = 0.05).
SEM, standard error of the mean; DM, dry matter.

6.11. Post-grazing forage mass and light interception

Post-grazing FM and LI were not affected by mean canopy height (P = 0.0740 and P = 0.0610, respectively), stocking method (P = 0.3049 and P = 0.0576, respectively), or by the mean canopy height × stocking method interaction (P = 0.8218 and P = 0.5118, respectively). Mean post-grazing FM was 4630 ± 588 kg DM ha^{-1}. Mean post-grazing LI was 88.2 ± 2.37 %.

6.12. Plant part composition and leaf area index at post-grazing under rotational stocking

Leaf proportion in Mulato II brachiariagrass FM and the LAI at post-grazing under rotational stocking were affected by stocking method but not by mean canopy height (P = 0.4909 and P = 0.5400, respectively) or by the mean canopy height × stocking method interaction (P = 0.9240 and P = 0.7728, respectively). Both responses were greater under LRS than under SRS (Table 15).

Table 15. Leaf proportion in the forage mass and leaf area index of Mulato II brachiariagrass at post-grazing under rotational stocking as affected by stocking method.

Stocking method †	Leaf	LAI
	%	
LRS	16	1.3
SRS	11	0.7
P ¶	0.0224	0.0014
SEM	1.4	0.13

† CS, continuous stocking; LRS, lenient rotational stocking; SRS, severe rotational stocking.
¶ $Pr > F$ for stocking method effect.
SEM, standard error of the mean.

Stem and dead material proportions in Mulato II brachiariagrass FM at post-grazing under rotational stocking were affected by mean canopy height but not by stocking method (P = 0.1668 and P = 0.4359, respectively) or by the mean canopy height × stocking method interaction (P = 0.2870 and P = 0.4348, respectively). Stem proportion in the FM increased and dead material proportion in the FM decreased as mean canopy height increased (Table 16).

Table 16. Stem and dead material proportions in Mulato II brachiariagrass forage mass at post-grazing under rotational stocking as affected by mean canopy height.

Canopy height	Stem	Dead material
cm	- - - - - - - - - - - - - - - - - %	- - - - - - - - - - - - - - - - -
20	35	51
30	41	46
P ¶	0.0211	0.0480
SEM	1.6	1.6

¶ *Pr* > *F* for mean canopy height effect.
SEM, standard error of the mean.

7. DISCUSSION

Total seasonal FA did not differ across treatments. This contrasts with the lesser FA observed by Silva et al. (2016a), who studied Mulato II brachiariagrass grazed at three mean canopy heights and contrasting nitrogen rates under continuous stocking, for Mulato II brachiariagrass managed at shorter height under continuous stocking, but is consistent with the results reported by Pequeno (2010) in a study with Xaraes palisadegrass [Brachiaria brizantha (Hochst ex A. Rich.) STAPF. cv. Xaraes] kept at canopy heights of 15, 30 and 45 cm under continuous stocking.

In addition to expressing the phenotypic plasticity of a species (Bradshaw, 1965) and its capacity to adapt to different defoliation regimes (Matthews et al., 1995), the fact that FA did not differ among treatments was probably due to the fact that responses that favored FA in one specific treatment seem to have been counterbalanced by other responses that contributed to increase in FA under another treatment. For example, the responses in LAI are assumed to have favored greater FA under SRS (Table 8). Post-grazing LAI probably favored greater regrowth vigor under LRS (Table 15). Frequent defoliations result in younger tissues in the canopy, which must have favored greater leaf photosynthetic capacity under CS. Despite statistically different, variations in LI (Tables 9 and 10) between treatments seem to have been too small to cause physiological differences that could lead to differences in total seasonal FA.

Forage accumulation rate did not differ across treatments. These results are in accordance with Silva et al. (2013), who studied Marandu palisadegrass under steady-state conditions and did not record differences in FAR in response to canopy heights (10, 20, 30, and 40 cm). It is known that canopies under rotational stocking undergo three distinct regrowth phases after defoliation, which differ in net FAR: (i) exponentially increasing FAR; (ii) constant linear maximum FAR; and (iii) declining FAR (Brougham, 1956). In other words, gross tissue production rate increases as the canopy LAI does, until LI reaches 95% (Parsons et al., 1983b). The recorded FARs in the present study, however, were actually averages of the different FARs that canopies experienced across regrowth periods. Under CS and variable stocking rate, on the other hand, canopies are kept in a steady state (Sollenberger et al., 2012), which implies in more constant FAR (Parsons et al., 1983a). It is also important to highlight that all canopies in this experiment exceeded the 95% LI, which, in general, is expected to depress FAR, due to senescence and stem elongation (Brougham, 1956; Parsons et al., 1983b).

Forage mass is often strongly related to canopy height and CBD, with taller canopies usually displaying greater FM (Sollenberger and Burns, 2001; Newman et al., 2002). In the present study, treatments with taller canopies (Figure 1) in general had greater FM (Table 3). This is in accordance with the findings of Silva et al. (2016a). For the 20-cm mean canopy height, SRS did not differ in FM from the other stocking methods (Table 3), despite its taller canopy. That is likely associated with the fact that CBD tends to decline as the canopy gets taller (Sollenberger and Burns, 2001; Newman et al., 2002), partially compensating for the increase in FM that results from increases in canopy height. In fact, for the 20-cm mean canopy height, SRS presented the lowest CBD (Table 4).

Canopy bulk density is normally greater in shorter canopies (Sollenberger and Burns, 2001; Newman et al., 2002), due to plant-part distribution throughout the canopy profile (Hodgson, 1990). Accordingly, treatments with shorter canopies (Figure 1) in general had greater CBD (Table 4) and Silva et al. (2016a) reported similar results. Despite having the tallest canopy height among treatments, however, SRS with 30-cm mean canopy height did not differ in CBD from SRS with 20-cm mean canopy height (Table 4). This may be explained by the fact that CBD declines as stem proportion increases in the FM. In fact, SRS with 30-cm mean canopy height had greater stem proportion than SRS with 20-cm mean canopy height (Table 7). In addition, the rate of the decrease in CBD in response to increases in canopy height seems to decline beyond a certain canopy height (Newman et al., 2002).

Leaves are the most efficient photosynthetic tissue and, in vegetative canopies, leaf production is often prioritized in terms of photosynthate allocation. When the canopy reaches 95% LI, however, leaves at the lower strata of the canopy become increasingly shaded by those in the upper portions. Two processes are then triggered and subsequently intensified: stem elongation, which exposes younger leaves to the incident light at the top of the canopy, and senescence of old tissues at the bottom of the canopy, as they become sinks of assimilates (Brougham, 1956). When those processes are intensified, the stem and dead material proportions in the FM are increased, whereas the relative proportion of leaves decrease (Hodgson, 1990; Carnevalli et al., 2006). It is, therefore, expected that taller canopies with greater FM will have greater LI levels and, consequently, have greater percentages of stems and dead material, and less leaf proportion in the FM (Sollenberger et al., 1988; Newman et al., 2002). In the present study, LI and stem proportion in the FM within stocking methods increased as mean canopy height increased (Tables 7, 9 and 10).

Canopy LI was above 95% at pregraze under all treatments (Tables 9 and 10) and, thus, senescence and stem elongation (not measured) likely occurred in all pastures. Treatments that resulted in the removal of a greater proportion of the pre-grazing canopy height during grazing (greater grazing severity, such as SRS), probably resulted in the harvest of a greater proportion of the accumulated stems and dead material. Conversely, there were greater stem and dead material proportions under CS, which, consequently, led to a decrease of the relative proportion of leaves (Tables 6 and 7).

Light interception is mainly determined by the LAI, but also by the LA. The smaller the LA, the more horizontal the leaves, the greater the k and the LI. Mean LA, in turn, is mainly determined by leaf length and weight, so that bigger leaves tend to be more horizontal (Pedreira et al., 2001). Leaf size varies in response to pseudo-stem length and shoot apex height, which are associated with canopy height. The SRS pastures with 30-cm mean canopy height, which presented the tallest canopy height across treatments (Figure 1), were the only ones that differed in LA (Table 11), which may also explain the fact that this management resulted in the greatest LI (Table 10), likely a consequence of long, heavy leaves, which were more horizontal.

The maximum LAI possible for a plant community is determined by the available incoming radiation (Briske, 1986). Until it reaches this maximum limit, LAI increases as canopy height and FM increase. As regrowth progresses after defoliation, the number of leaves per tiller increases until it also reaches a genetically established limit, although, even after such number is reached, LAI may still increase due to increases in leaf size. Younger leaves tend to be longer because they go through longer pseudo-stems than older leaves, which elongated when pseudo-stems were shorter. In this study LAI increased as canopy height increased (Table 8). That also explains the increase in LI (Tables 9 and 10).

Forage nutritive value is mainly determined by the plant-part composition and the age of the tissues in harvested components. Among plant-part components, leaves usually have the least NDF concentration and the greatest concentrations of CP and IVDOM. Grazing management strategies that favor greater leaf proportions in the FM are expected to result in greater forage CP and IVDOM and less NDF concentrations. Additionally, treatments based on taller canopies are expected to result in the opposite effect on these responses (Newman et al., 2002; Silva et al., 2016a). Crude protein and IVDOM concentrations decreased and NDF concentration in the FM increased as canopy height increased (Tables 12 and 13).

Opposite to the patterns of stems and dead material distribution in the canopy profile, the leaf proportion in the upper half of the canopy is approximately three times greater than in the lower half (Holderbaum et al., 1992). Those authors also showed that forage CP and IVDOM concentrations are approximately twice as big and 10 % greater, respectively, in the upper than in the lower half of the canopy. This suggests that decreasing grazing severity, for allowing the harvest of higher portions of the canopy, may result in less NDF and greater CP and IVDOM concentrations in the harvested forage, as it comes from the uper portions of the canopy. This may explain the fact that in the present study, CS had the least leaf proportion and the greatest stem and dead material proportions (Table 6 and 7), as well as the least concentrations of NDF (Table 12) and the greatest of CP and IDVOM across stocking methods (Table 14). One possible reason for that was the stocking methods' different grazing severities. Severe rotational stocking corresponded to grazing severities of approximately 60% (i. e. approximately 60% of the pre-grazing canopy height was removed during grazing); LRS corresponded to grazing severities of approximately 40%, and CS corresponded to grazing severities of approximately 20%. The CS resulted in more frequent defoliations, which naturally leads to younger tissues in the FM at the top of the canopy (Sollenberger et al., 2012). Pastures under steady canopy heights in the present study (i. e. CS), despite mimicking areas under continuous stocking, experienced stocking and rest periods due to the nature of the mob stocking protocol.

Post-grazing plant-part composition is a function of the pre-grazing canopy condition and grazing severity. The pre-grazing plant-part condition defines the composition of the lower layers of canopy. Grazing severity then defines which layers remain after defoliation. Treatments with taller pre-grazing heights are expected to have greater stem and dead material proportions, and less leaf proportion in the lower layers of the canopy. Lesser grazing intensities are expected to favor greater leaf proportion in the post-grazing FM, with less stem and dead material. This explains the greater leaf proportion in the FM measured at post-grazing under LRS, which explains the greater residual LAI as well (Table 15). The increase in stem proportion in the post-grazing FM as canopy heights increased (Table 16) is also based on this response. Consequently, due to the fact that leaf proportion did not vary and the stem proportion increased, the relative proportion of dead material in the post-grazing FM decreased as mean canopy height increased (Table 16).

Despite different post-grazing heights, post-grazing FM was not affected by canopy height or by stocking method. Forage mass is strongly related to canopy height and CBD. Canopy bulk density, therefore, must also have varied to balance variations in FM likely triggered by increases in canopy height. In fact, CBD tends to decline as canopy height increases (Sollenberger and Burns, 2001; Newman et al., 2002) and as stem proportion increases in the FM. This is consistent with the recorded post-grazing FM, considering that the stem proportion in the post-grazing FM increased as target mean canopy heights increased (Table 16). Variations in canopy height cause tiller population density to vary in response to variations in tiller size. This refers to the tiller size/density compensations that are found in plant stands, and that result in relatively stable LAI under a range of canopy heights (Matthews et al., 1995; Sbrissia and da Silva, 2008). Tiller size/density compensation mechanisms may be the reason why variations in defoliation regimes sometimes have little effect over the canopy LAI (Bircham and Hodgson, 1983) and it might have a similar effect over CBD.

Differently from the results recorded by Silva et al. (2016a), who found less forage losses on pasturess with shorter canopies under continuous stocking, total seasonal GL did not differ across treatments in the present study. Although the reasons for this are not clear, it may also have been the consequence of the combined effects of responses that ended up offsetting each other. For example, despite the fact that FAL did not differ among stocking methods, it increased as canopy heights increased (Table 5), which is expected to favor greater GL under treatments with taller mean canopy heights, due to greater senescence and trampling during grazing (Silva et al., 2016a). In addition, paddocks with taller mean canopy heights were more prone to lodging, which also may have increased GL. Forage allowance is a function of stocking density and FM. When stocking density is fixed, as in the present study, FAL depends only of FM. Accordingly, FAL increased as canopy heights increased. Responses in CBD (Table 4) are also expected to have contributed to greater GL under the treatments with taller mean canopy heights, especially under SRS. Less CBD allows for more selective grazing, so greater CBD of shorter canopies may limit the opportunity for leaf selection (Newman et al., 2002). On the other hand, the leaf proportion in the FM probably had the opposite effect, as it was greatest under SRS and smallest under CS (Table 6). Similarly, the greater stem proportion in the FM under CS and the treatments with shorter mean canopy heights (Table 7) probably contributed to greater GL under these treatments. Conversely, however, taller canopies resulting from more lenient grazing are also expected to result in more trampling damage of accumulated forage (Newman et al., 2002; Silva et al., 2016a). Greater grazing severities are known to promote greater grazing efficiencies, as they result in the harvest of greater proportions of the accumulated forage, by forcing animals to explore lower layers of the canopy (Braga et al., 2007). The treatments that included rotational stocking, especially SRS, must have been favored in this aspect, although forcing animals to explore lower layers of the canopy force them to graze canopy layers with greater stem and dead material proportions, perhaps resulting in greater trampling. Lastly, considering that the periods between samplings of GL were longer under rotational stocking, especially under SRS, part of the leaves that senesced during the rest periods may have decomposed before they could be collected and quantified, possibly underestimating the grazing losses recorded in those treatments.

It is important to highlight that the method used to assess GL in the present study differ from other studies, such as that of Silveira et al. (2013), where areas from where GL were collected were cleared of all loose plant material at pre-grazing and only what was found on the soil surface after the stocking periods was considered GL. In the present study, the sampling sites were not cleaned at pre-grazing under rotational stocking, in order to quantify loose plant material that was accumulated over the ground surface during stocking periods and rest periods as well. This strategy made the assessing methods for paddocks under rotational stocking more similar to the assessing methods applied for paddocks under continuous stocking, in which GL were evaluated every 21 days. Thus, both the plant material deposited over the soil surface due to mechanical damage and due to senescence during the rest periods were considered in the same pool and GL was considered to be plant material damaged during grazing plus litter deposition occurred during grazing and rest periods.

8. CONCLUSIONS

According to the results of the present study, there is no advantage in forage accumulation and grazing losses between continuous and rotational stocking methods for Mulato II brachiariagrass when grazing management strategies include the control of canopy height. Forage nutritive value, however, increases as mean canopy heights decrease and was greatest under continuous stocking. Ultimately, these results suggest that continuous stocking may result in best animal outputs on this grass, although full-scale grazing trials that can generate both pasture and animal performance and productivity data are needed to ascertain this.

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