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SYLMARA DE MELO LUZ

PRODUTIVIDADE, QUALIDADE E NUTRIÇÃO NITROGENADA DE *Urochloa brizantha* EM PASTAGENS SOB LOTAÇÃO CONTÍNUA EM SISTEMAS DE INTEGRAÇÃO LAVOURA-PECUÁRIA-FLORESTA

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Tese apresentada à Universidade Federal Rural da Amazônia, como parte das exigências do Curso de Doutorado em Agronomia: área de concentração Nutrição e Fertilidade do Solo, para obtenção do título de Doutor.
Orientador: Prof. Dr. Mário Lopes da Silva Junior
Co-orientador: Pesquisador Dr. Alysson Roberto Baizi e Silva
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RESUMO

A estação e o pastejo podem alterar as respostas das pastagens, mesmo em sistemas inovadores e sustentáveis de integração lavoura-pecuária-floresta (ILPF). O objetivo deste trabalho foi avaliar a dinâmica e determinar a biomassa e o status de N de pastagens de *Urochloa brizanta* cv. Piatã pastejadas por búfalos sob lotação contínua em sistema de pastagem aberta (PA), ILPF com mogno africano (*Khaya ivorensis*) (ILPF-M) e sistema ICLF com teca (Tectona grandis) (ILPF-T), ao longo do tempo e das estações seca e chuvosa. A massa e a proteína bruta da forragem, bem como a concentração e o acúmulo de N nas folhas e caules foram avaliados a cada 28 dias em um período de 252 dias. O ganho de peso diário e a taxa de lotação dos búfalos foram avaliados em cinco ocasiões neste período. A massa de forragem foi menor nos sistemas ILPF do que no sistema PA na estação seca. Em contraste, o sistema ILPF-T forneceu forragem com o maior teor de proteína bruta nesta estação. Na estação chuvosa, não houve diferença entre os sistemas. A massa de forragem declinou em todos os sistemas ao longo do tempo na estação seca e chuvosa devido ao pastejo. O teor de proteína bruta também diminuiu em cada estação, mas foi maior na estação chuvosa do que na estação seca. Tanto o ganho de peso diário quanto a taxa de lotação dos búfalos também foram maiores na estação chuvosa. A estação altera a produtividade e a qualidade da forragem, bem como o desempenho animal, enquanto o pastejo determina a dinâmica da pastagem nos sistemas ILPF. A biomassa foliar chegou a valores muito baixos (228 a 295 kg ha^{-1}) no mês mais seco (novembro) da estação seca. No entanto, a matéria seca foliar e do caule aumentou na estação chuvosa, estimulada pela alta precipitação. O status de N da folha revelou que o pasto estava com deficiência de N no sistema PA. Nos sistemas ILPF, por outro lado, o status de N era suficiente. Em relação ao sistema PA, os sistemas ILPF-M e ILPF-T diminuíram a biomassa da folha e do colmo da gramínea, mas em compensação melhoraram a nutrição nitrogenada da planta no primeiro ano de exploração das pastagens com o início do pastejo na estação seca.

Palavras-chave: *Brachiaria*, búfalo. Proteína bruta. Relação folha/colmo. Sistema agrossilvipastoril

ABSTRACT

Season and grazing may change pasture responses even in innovative, sustainable crop-livestock-forest (ICLF) systems. The objective of this work was to evaluate the dynamics and determine biomass and N status of *Urochloa brizanta* cv. Piatã pastures grazed by buffaloes under continuous stocking in open pasture system (OP), ICLF with African mahogany (*Khaya ivorensis*) (ICLF-M) and ICLF system with teak (*Tectona grandis*) (ICLF-T) over time across the dry and rainy seasons. Mass and crude protein of forage, as well N concentration and accumulation in leaves and stems were evaluated every 28 days over a 252-days period. Daily weight gain and stocking rate of buffaloes were evaluated in five occasions within of this period. Forage mass was lower in the ICLF systems than in the OP system in the dry season. In contrast, ICLF-T system delivered forage with the highest crude protein content in this season. In the rainy season, no difference between systems was observed. Forage mass declined in all systems over time across the dry and rainy season due to grazing. Crude protein contents also declined within each season, but the contents were higher in the rainy season than in the dry season. Both daily weight gain and stocking rate of buffaloes also were higher in the rainy season. The season changes the productivity and quality of forage as well as the animal performance while the grazing determinates the pasture dynamics in ICLF systems. Leaf biomass arrived to very low values (228–295 kg ha^{-1}) in the driest month (November) of the dry season. However, leaf and stem dry matter increased in the rainy season stimulated by the high rainfall. Leaf N status revealed that the grass was with N deficiency in the OP system. In the ICLF systems, on the other hand, N status was sufficient. In relation to the OP system, ICLF-M and ICLF-T systems decreased leaf and stem biomass of the grass but in compensation improved plant N nutrition in the first year of pasture exploration with beginning of grazing in the dry season.

Keywords: Agrosilvopastoral sytems. *Brachiaria.* Buffalo. Crude protein. Leaf/stem ratio

SUMÁRIO

1. CONTEXTUALIZAÇÃO

O Brasil é o maior produtor de carne bovina do mundo, seguido da Índia, EUA e China. O Estado do Pará possui a quarta maior área de pastagem do país, com quase 98 milhões de hectares e com mais de 20 milhões de cabeças (ABIEC, 2019). A produção pecuária no Brasil é desenvolvida principalmente a pasto, pois é a forma mais prática e econômica de prover alimento para esses animais (FERRAZ e FELÍCIO, 2010; DIAS-FILHO, 2011), sendo que a região Norte é hoje considerada a principal fronteira agrícola para a atividade pecuária no país, e o Pará é um protótipo desta realidade (DIAS-FILHO, 2016). Assim, com as projeções de aumentos nas taxas anuais de crescimento do mercado de carne e leite, pode-se afirmar que a região amazônica irá contribuir para suprir essa demanda de mercado

Entretanto, estima-se que 70% das áreas de pastagem no país estejam em algum estágio de degradação (DIAS-FILHO, 2014). Um pasto é considerado degradado quando há um decréscimo da capacidade suporte e os fatores mais importantes relatados para esta degradação incluem o inadequado manejo animal e a falta de reposição de nutrientes (DIAS-FILHO, 2014; SANTOS et al., 2016).

Neste contexto, o uso de tecnologias capazes de restaurar a capacidade produtiva do pasto é essencial para alcançar sustentabilidade e aumentar a eficiência da pecuária no país (SANTOS et al, 2018). Uma das estratégias de produção que podem reverter esta degradação é o uso se sistemas integrados lavoura-pecuária-floresta (ILPF) (DIAS-FILHO, 2011).

Sistemas ILPF combinam produção de lavoura, pecuária e espécies florestais na mesma área, simultaneamente ou de forma de forma alternada (BALBINO et al., 2011). Esses sistemas estão atraindo o interesse de pesquisadores, técnicos e agricultores por causa dos benefícios econômicos e ambientais que proporcionam. Os sistemas ILPF são considerados uma atividade econômica de baixo risco e um empreendimento economicamente viável para todos os seus componentes (culturas, animais e árvores) devido ao sinergismo que há entre eles (MÜLLER et al., 2011; OLIVEIRA JUNIOR et al., 2016). Além disso, a diminuição na emissão de gases de efeito estufa é um benefício potencial para a produção animal em sistemas integrados, como observado por Figueiredo et al. (2017). Também são capazes de melhorar a qualidade física do solo (MOREIRA et al., 2018), o que é essencial para sustentar a produção agrícola ao longo do tempo. Para a pastagem, vantagens específicas desses sistemas também foram encontradas. A economia de água em pastagens pode ser alcançada pela menor frequência de busca de água por animais em pastejo, devido a um melhor conforto térmico proporcionado pela sombra da árvore (KARVATTE JR. et al., 2016; GIRO et al., 2019). Finalmente, uma contribuição para o ciclo do nitrogênio (N) pela presença de árvores no sistema foi confirmada nos últimos anos (XAVIER et al., 2014).

Devido a essas e outras vantagens econômicas e benefícios ambientais, os sistemas ILPF têm sido adotados em larga escala no Brasil, abrangendo uma área de 11 milhões de hectares (ICLF Network, 2019).

Apesar desses muitos benefícios, os sistemas ICLF precisam ser mais estudados para identificar possíveis fatores desfavoráveis relacionados ao desempenho dos componentes do sistema (ALVES et al., 2017).

O sombreamento de árvores pode diminuir a fotossíntese e o crescimento de plantas forrageiras tropicais (DIAS-FILHO, 2000; DIAS-FILHO, 2002; GUENNI et al., 2008) e consequentemente influenciar tanto a produtividade quanto a qualidade da forragem em pastos sob pastejo contínuo em sistemas ILPF.

Em um estudo realizado no centro-oeste, avaliando disponibilidade de matéria seca de capim-piatã em dois sistemas silvipastoris e em monocultivo (controle), foi observado que o monocultivo teve maior massa de matéria seca quando comparado com os outros sistemas (OLIVEIRA et al., 2014). Segundo estes autores, esta redução da massa de forragem nos sistemas ILPF pode ser associada com a competição direta com as árvores por água, radiação solar e nutrientes. No mesmo estudo, com relação ao valor nutritivo, foi observado que os teores de proteína bruta na folha e no colmo foram maiores na sombra do que no sol.

Em geral, tem sido encontrado menor massa de forragem em sistemas integrados quando comparados com sistemas de pasto aberto, no entanto esta diferença pode depender da estação. LIMA et al. (2019) reportaram 36% menos massa de forragem de *Urochloa decumbens* cv. Balilisk num sistema silvipastotil com árvores leguminosas em relação ao pasto aberto, na estação chuvosa (verão). Na estação seca (outono), contudo, a massa de forragem foi similar entre os sistemas. A proteína bruta foi maior no sistema silvipastoril em ambas as estações.

Estes resultados contrastam com aqueles encontrados por SANTOS et al. (2018), os quais relataram que a massa de forragem de *U. brizantha* vc. Piatã em dois sistemas silvipastoris com *Eucalyptus* foi pelo menos 27% menor do que em pasto aberto em ambas as estações, chuvosa e seca; mas não houve diferença para proteína bruta da forragem em ambas as estações. Tais descobertas conflitantes podem ser por causa da interação complexa entre sistemas e condições climáticas em cada estação. Assim sendo, a influência da estação é uma questão a ser estudada em sistemas ILPF.

Embora estudos tenham demonstrado o efeito do sombreamento sobre a produção de massa da forragem, esses efeitos sobre folhas e colmos separadamente, entretanto, ainda têm sido pouco explorados. No trabalho de LIMA et al. (2019), por exemplo, a matéria seca do colmo da *Urochloa decumbens* cv. Basilisk foi 33% menor em um sistema silvipastoril em comparação com um sistema de pastagem aberta (PA) (pastagem convencional sem árvores). Este efeito foi sazonal, uma vez que ocorreu na estação chuvosa (verão), mas não na estação seca (outono). Além disso, não houve diferença entre os sistemas para a matéria seca da folha.

Em estudos utilizando sombreamento artificial, a matéria seca de folhas e colmos foi individualmente diminuída em gramíneas tropicais sombreadas (GUENNI et al., 2008; GÓMEZ et al., 2012). A diminuição da biomassa foliar pelo sombreamento das árvores é particularmente preocupante nas pastagens onde o crescimento das gramíneas é limitado por outro fator adverso (por exemplo, seca). Neste caso, a matéria seca da folha residual poderia ser tão baixa que restringiria a recuperação das plantas desfolhadas. O limite inferior para a biomassa residual de folhas para rebrota das plantas é pouco conhecido. Para *Pennisetum purpureum*, foi determinado entre 2000 e 2500 kg ha^{-1} (VEIGA et al., 1985), enquanto 829 kg ha^{-1} parece ter sido a biomassa residual das folhas para a máxima oferta de forragem de *U. brizantha* cv. Marandu no trabalho realizado por REZENDE et al. (2008). Estes valores foram obtidos para pastejo rotacionado, sendo que para pastejo de lotação contínua estes valores desconhecidos. Portanto, é necessário avaliar se o sombreamento das árvores poderia reduzir a matéria seca das folhas a níveis provavelmente limitantes para o novo crescimento das plantas desfolhadas, por meio do pastejo de animais em pastagens sob lotação contínua em sistemas ILPF.

A avaliação das mudanças nas pastagens dentro de cada estação e no decorrer das estações seca e chuvosa tem sido negligenciada, apesar da utilidade deste tipo de estudo na detecção de tendências de curto prazo para a massa e qualidade da forragem, relacionada ao tempo de pastejo e interagindo com as condições climáticas prevalecentes.

Uma análise da dinâmica do pasto dentro de cada estação e no decorrer das estações seca e chuvosa, pode, por exemplo, revelar que o pastejo é o fator determinante para diminuir tanto o suprimento quanto a qualidade da forragem em pastagens ao longo do tempo, mesmo que as condições não sejam limitantes ao crescimento das plantas. Também pode indicar antecipadamente se a intensidade do pastejo em um período específico está levando a pastagem para a degradação. Assim, os resultados dessa análise podem ajudar a desenvolver estratégias de manejo efetivas e simples que garantam a perenidade das plantas forrageiras e a sustentabilidade das pastagens.

Outro aspecto que tem sido negligenciado no sistema ILPF é a avaliação do status de N da planta forrageira. Estudos mostraram que a concentração de proteína bruta na forragem de gramíneas *Urochloa* aumenta nos sistemas silvipastoris devido ao sombreamento das árvores em relação aos sistemas PA (SANTOS et al., 2018; LIMA et al.. 2019). Mecanismos que regem esse aumento não são bem compreendidos. No entanto, o efeito da concentração de N pela diminuição da matéria seca (JARRELL e BEVERLY, 1981) devido ao sombreamento parece estar presente. Como a proteína bruta está diretamente relacionada ao N, a concentração de N na planta deve aumentar nos sistemas ILPF.

O diagnóstico nutricional em plantas forrageiras baseia-se na concentração de nutrientes nos tecidos vegetais. Para a gramínea tropical, o N deve ser determinado em folhas verdes que simulem as que são pastejadas por animais, e a interpretação da concentração de N pode ser realizada por uma faixa crítica de N (WERNER et al., 1997).

A importância deste diagnóstico é indiscutível, pois pode indicar a deficiência de N e, em seguida, a necessidade de adubação nitrogenada para melhorar o crescimento da planta. O diagnóstico da nutrição também pode indicar alguma interrupção no ciclo do N. Isso é absolutamente relevante porque uma ciclagem de N deficiente pode levar ao declínio das pastagens e, consequentemente, à insustentabilidade do sistema pastoril.

As hipóteses deste estudo são: a) que eventuais diferenças na produtividade e qualidade da forragem entre os sistemas ILPF e PA podem depender da estação. Além disso, acredita-se que o pastejo determine a dinâmica das pastagens independentemente do sistema e da estação; b) em relação ao sistema PA, os sistemas ILPF diminuem a matéria seca de folhas e caules enquanto melhoram a nutrição de N em pastagens. O objetivo deste trabalho foi avaliar a dinâmica e determinar a biomassa de folhas e colmos, bem como o status de N de *Urochloa brizanta* cv. Piatã, sob pastejo de lotação contínua, em sistema de pasto aberto (PA), sistema ILPF com mogno africano (ILPF-M) e sistema ILPF com teca (ILPF -T) ao longo do tempo nas estações seca e chuvosa.

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2. Dynamics of Urochloa brizantha pastures grazed under continuous stocking in integrated crop-livestock-forest systems[1]

Short title: Pasture dynamics in integrated systems

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Abstract

Season and grazing may change pasture responses even in innovative, sustainable crop-livestock-forest (ICLF) systems. The objective of this work was to evaluate the dynamics of *Urochloa brizanta* cv. Piatã pastures grazed by buffaloes under continuous stocking in open pasture system (OP), ICLF with African mahogany (*Khaya ivorensis*) (ICLF-M) and ICLF system with teak (*Tectona grandis*) (ICLF-T) over time across the dry and rainy seasons. Mass and crude protein of forage were evaluated every 28 days over a 252-days period. Daily weight gain and stocking rate of buffaloes were evaluated in five occasions within of this period. Forage mass was lower in the ICLF systems than in the OP system in the dry season. In contrast, ICLF-T system delivered forage with the highest crude protein content in this season. In the rainy season, no difference between systems was observed. Forage mass declined in all systems over time across the dry and rainy season due to grazing. Crude protein contents also declined within each season, but the contents were higher in the rainy season than in the dry season. Both daily weight gain and stocking rate of buffaloes also were higher in the rainy season. The season changes the productivity and quality of forage as well as the animal performance while the grazing determinates the pasture dynamics in ICLF systems.

KEYWORDS

agrosilvopastoral system, *Brachiaria*, buffalo, crude protein, tropical pasture

1 | INTRODUCTION

Integrated crop-livestock-forest (ICLF) systems combine sustainable production of crops, grazing animals and forest species in a same area simultaneously or over time (Balbino et al., 2011). By combining different economic activities, ICLF systems have been found to be a low risk, economically viable enterprise (Muller et al., 2011; Oliveira Junior et al., 2016). For livestock, these systems can provide thermal comfort for grazing animals by decreasing the air temperature due to presence of trees, resulting in better animal welfare (Karvatte Jr. et al., 2016). Furthermore, decrease in greenhouse gas emission (GHG) is a potential benefit of integrated systems for animal production, as found by Figueiredo et al. (2017), who estimated carbon (C) footprint for beef cattle at –28.1 kg CO_2eq per kg body weight in an ICLF system with eucalyptus, value expressively lower than those in managed pasture (of 7.6 kg CO_2eq per kg BW) and degraded pasture (18.5 kg CO_2eq per kg BW). Due to these and other economic advantages and environmental benefits, ICLF systems have been adopted at large scale in Brazil, covering an area of at least 11 million ha (ICLF Network, 2019).

However, shade of trees can consecutively decrease photosynthesis and growth of tropical forage plants (Dias-Filho, 2000; Dias-Filho, 2002; Guenni, Seiter, & Figueroa, 2008; Gómez, Guenni, &

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Guenni, 2012) and consequently influence both productivity and quality of forage in pasture under continuous grazing in ICLF systems. Studies conducted in the tropics have shown lower forage mass in integrated systems compared with open pasture (OP) systems, but this difference can depend on the season. Lima et al. (2019) found 36% less forage mass of *Urochloa decumbens* cv. Basilisk in a silvopastoral system with legume trees in relation to the OP system in the rainy season (summer). In the dry season (autumn), however, the forage mass was similar between the systems. For crude protein content, it was higher in silvopastoral system in both seasons. These results contrast with those of Santos, Guimarães Júnior, Vilela, Maciel, and França (2018), according to which the forage mass of *U. brizantha* cv. Piatã in two silvopastoral systems with eucalyptus was at least 27% lower than that in the OP system in both the rainy and dry seasons, but no difference was observed for the crude protein contents in forage between the systems. Such conflicting findings may be due to a complex interaction between systems and weather conditions in each season. Therefore, influence of season is a matter to be studied in ICLF systems.

Evaluation of changes in grazed pastures within each and across of the dry and rainy seasons has been neglected despite the usefulness of this study type in detecting short-term trends for both mass and quality of forage related to grazing time interacting with prevailing weather conditions. This analysis of dynamics can for example reveal that grazing is the determining factor for decreasing both supply and quality of forage in a pasture over time even when whether conditions are not limiting to plant growth. It can also indicate in advance if grazing intensity in a specific time is leading a pasture to degradation. Thus, the results of this analysis can help to develop effective/simple management strategies that guarantee perenniality of forage plants and sustainability of pasture. Analysis of pasture dynamics has not been applied to ICLF systems.

We hypothesized that eventual differences in productivity and quality of forage between ICLF and OP systems can depend on the season. Moreover, grazing is believed to determine the pasture dynamics regardless of system and season. The objective of this work was to evaluate the dynamics of *Urochloa brizanta* cv. Piatã pastures grazed by buffaloes under continuous stocking in open pasture system (OP), ICLF with African mahogany (ICLF-M) and ICLF system with teak (ICLF-T) over time across the dry and rainy seasons.

2 | MATERIALS AND METHODS

2.1 | Study area

The field study was conducted in an Embrapa Amazônia Oriental’s experimental station (01°01’33.4”S, 47°53’58.3”W, elevation 40 m) located in the Terra Alta municipality, state of Pará, Brazil. This municipality is situated in the Amazon biome and it can be considered a typical local from the humid

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tropics. The regional climate is Am (tropical monsoon) by the Köppen's classification. Mean annual precipitation ranges from 2300 to 2800 mm, with a mean annual temperature of 26°C (Moraes, Costa, Costa, & Costa, 2005). Rainfall and temperature during the study period are presented in Figure 1. The data used in this figure are from the Castanhal municipality (Inmet, 2018), since Terra Alta does not have available climatic records. As these municipalities are adjacent to each other, their climatic patterns can be considered similar, making suitable the use of the rainfall and temperature data from neighboring municipality for the study area. The soil in this area is an *Argissolo Amarelo Distrófico textura arenosa/média* (Gama, Rodrigues, & Cardoso Junior, 2000) by the Brazilian Soil Classification System (Embrapa, 2018), corresponding to either Ultisol in Soil Taxonomy (Soil Survey Staff, 2014) or Acrisol in the FAO legend (IUSS Working Group WRB, 2014), and it was being occupied with a degraded pasture of *Urochloa humidicola* (Rendle) Morrone & Zuloaga [syn. *Brachiaria humidicola* (Rendle) Schweick.] for a number of years previously to the beginning this study. This soil had the following characteristics in the layer of 0-20-cm depth before the installation of the study: pH in water (1:2.5 soil:water ratio) 5.4, OM (organic matter by the Walkley-Black method) = 17.76 g/kg, Mehlich-1 P = 1 mg/dm^3, exchangeable K = 0.07 cmol$_c$/dm^3, exchangeable Ca = 0.7 cmol$_c$/dm^3, exchangeable Mg = 0.4 cmol$_c$/dm^3, exchangeable Al = 0.5 cmol$_c$/dm^3, H+Al (potential acidity) = 3.3 cmol$_c$/dm^3, CEC (cation exchange capacity) at pH 7 = 4.5 cmol$_c$/dm^3, V (base saturation) = 26 %, m (aluminum saturation) = 30 %, sand = 779 g/kg, silt = 86 g/kg, and clay = 135 g/kg. Chemical analyses and calculations for evaluation of soil fertility followed procedures described in Silva, Eira, Barreto, Pérez, and Silva (1998), and particle-size analysis was performed by the pipette method with previous soil sample dispersion with 1 *M* NaOH according to Embrapa (1997).

2.2 | Production systems

Two integrated crop-livestock-forest (ICLF) systems were installed in the study area in February 2009. A system was implanted with African mahogany (*Khaya ivorensis* A. Chev.) (ICLF-M) and the other with teak (*Tectona grandis* L. f.) (ICLF-T) as forest components since these species produce high-quality woods (Wiemann, 2010). Initially, 1.5 t/ha of limestone was applied to the soil surface following a conventional soil tillage. Then three forest species strips spacing 50 m to each other were established in the area of each system. In the ICLF-M system, three rows of African mahogany with trees spacing 5 × 5 m were planted in each strip, while four rows of teak with trees spacing 3 × 3 m were planted in each strip in the ICLF-T system. For both forest species, fertilization consisted of 100 g P_2O_5 (reactive phosphate rock) per hole at planting, 25 g N (urea) and 25 g K_2O (potassium chloride) per plant in March 2009 and also 20 g N and 20 g K_2O (20-0-20) per plant in April 2009.

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In both ICLF systems, maize (*Zea mays* L. cv. BRS 1030) was cultivated in the areas between tree strips in 2009, 2010, 2011, 2012 and 2013. Soil tillage was conventional in the first year, as cited above, and no-tillage system was adopted in the subsequent years. Fertilization in each year was carried out to supply 33 kg N/ha, 92 kg P_2O_5/ha and 66 kg K_2O/ha (10-28-20) at sowing, and 40 kg N/ha and 40 kg K_2O/ha (20-0-20) at top-dressing. Cowpea [*Vigna unguiculata* (L.) Walp cv. BRS Guariba] was only sown in the first year after harvest of maize as a second crop. No fertilizer was applied for cowpea.

In 2013, a pasture of *Urochloa brizantha* (Hochst. ex A. Rich.) R. Webster cv. BRS Piatã [syn. *Brachiaria brizantha* (Hochst. ex A. Rich.) Stapf cv. BRS Piatã] was established in the areas between the tree strips in both ICLF systems. Grass seeds were distributed together with the fertilizer applied at top-dressing for maize. In 2015, an open pasture (OP) of the same grass was also established in an area contiguous to the areas with ICLF systems in order to serve as a reference of conventional pasture system (i.e., only pastoral system, not integrated to other production systems). At the establishment of this pasture, 70 kg N/ha (urea), 110 kg P_2O_5/ha (triple superphosphate) and 60 kg K_2O/ha (potassium chloride) were applied.

In 2017, the areas between tree strips for each ICLF system were divided into four subareas. Similarly, OP system area was also divided into four subareas. Thus, the three production systems (OP, ICLF-M and ICLF-T) were replicated four times. A schematic representation for field allocation of the production systems is showed in Figure 2. Divisions of the areas were done using electric fences, and mineral salt trough and water trough were shared every two subareas. Each subarea was considered as a paddock of approximately 0.6 ha. The ICLF-M and ICLF-T systems had trees with average height of 14.24 and 12.72 m and average diameter at breast height of 23.78 and 19.61 cm, respectively.

All pastures were mown and then fertilized in May 2017. For fertilization, 50 kg N/ha (urea), 50 kg P_2O_5/ha (single superphosphate) and 50 kg K_2O/ha (potassium chloride) were applied. No fertilizer was subsequently applied to the pastures until the end of this study. In July 2017, pastures were again mown at a height of 35 cm for standardizing the sward canopy height.

Pastures were grazed from July 2017 to April 2018 (252 days) by buffaloes (*Bubalus bubalis* L.) under continuous stocking with variable stocking rate. Two tester steers at age of 18 months and each one weighting 332 kg [standard error of the mean = 14 kg, *n* = 24] were put into each paddock. However, only one animal was maintained until October 2017 in the ICLF-M system's paddocks in order to stimulate the plant growth in sward patches with a very low canopy. Additional buffaloes (regulator animals) were occasionally put into and take from the paddocks (i.e., put-and-take stocking) as an attempt to maintain the canopy height by about 35 cm. All animals received both mineral salt and water freely.

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2.3 | Pasture measurements

Ten points in the pasture in each paddock were selected randomly every 28 days over the 252-days grazing period from July 2017 to April 2018. In each point, canopy height was measured using a graduated ruler in cm, and plants in an area of 0.25 m^2 (0.50 × 0.50 m) were cut at the soil level. Plant samples collected in each paddock were bulked, and three subsamples were taken. Subsamples were then oven-dried at 65°C until constant weight. The weighted plant material was used to estimate the forage mass. Crude protein in forage was calculated by multiplying the total nitrogen (TN) content by 6.25, with TN determined by the Kjeldahl method (AOAC, 1990).

2.4 | Animal measurements

Buffaloes were weighed to each pasture evaluation with exception of the times 56, 112, 140 and 196 days after the beginning of grazing (DABG) due to operational reasons. Weightings of animals were performed after fasting water and food for 16 h (overnight). Daily weight gain was calculated as a difference in weight of tester animals between two successive weightings divided by number of days of grazing. Weights of tester animals in each evaluation time were used to calculate the stocking rate given in animal unit (450 kg body weight) per ha.

2.5 | Statistical analyses

Pasture and animal data were analyzed using a randomized complete block design with four replicates, each one allocated in a paddock. Replicates were considered as blocks in order to capturing possible variability among paddocks. Effects of production systems were tested using an analysis of variance (ANOVA) performed for each variable in each evaluation time. Additional ANOVA was run for production systems within each season (dry and rainy). When *F* test showed significance means were compared according to the least significant difference (LSD). Dynamics of pasture over the grazing period (i.e., 252 days) was analyzed using an ANOVA followed by a polynomial regression analysis. Regressions were selected based on scatter pattern, significance of model and its coefficients, and highest coefficient of determination (R^2). For all ANOVAs and regression analyses homogeneity of variance and normality were checked by the Bartlett's test and Shapiro-Wilk's test, respectively. Overall effects between seasons were evaluated by the Student's *t*-test after checking homogeneity of variance by the *F* test and normality by the Shapiro-Wilk's test. When there was heterocedasticity but data were normal Welch's *t*-test was adopted, while Wilcoxon's rank sum test was applied to non-normal data. Correlations were processed between selected variables. Pearson's correlation test (*r* coefficient) was used for normal data, and non-normal data were analyzed using the Spearman's

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correlation test (ρ coefficient). Standard errors of means (SEMs) and standard deviations (SDs) were calculated. All analyses were performed at *P* < 0.05 using the R software (R Core Team, 2018).

3 | RESULTS

3.1 | Canopy height

Measured canopy height differed between production systems at eight of the 10 evaluation times (Table 1). Canopy in the OP system was generally highest than those in the ICLF systems over the grazing period. Similarly, canopy height was greater in the OP system than in the ICLF systems as a mean of system within each season (dry and rainy) (Figure 3a, b). However, no difference was observed for canopy height between seasons (41.9 cm for dry season and 41.0 cm for rainy season, SEM = 1.2 cm, Wilcoxon's test, *P* = 0.465, *n* = 60).

3.2 | Mass and crude protein of forage

There was difference in forage mass between production systems but only for three of the first four evaluation times (Table 2). In general, OP had greater forage mass compared with the ICLFs systems. This result was also found for means of systems within the dry season (Figure 4a). For rainy season, no difference was observed (Figure 4b). As an overall effect of season, forage mass in the dry season (4497 kg/ha) was higher than that in the rainy season (3035 kg/ha) (SEM = 110 kg/ha, Welch's *t*-test, *P* < 0.001, *n* = 60).

Crude protein content in forage in the ICLF-T system was higher than those in the OP and ICLF-M systems at 84 DABG (Table 3) and for the dry season (Figure 5a). But within the rainy season, no difference was observed between systems (Figure 5b). There was a significant overall effect (*t* test, *P* < 0.001) of season. Crude protein content was lower in the dry season (42.32 g/kg) than in the rainy season (67.61 g/kg) (SE = 1.5 g/kg, *n* = 60).

The dynamics of pasture also was evaluated and it refers to evolution of both forage mass and crude protein in forage over the full grazing period across the dry and rainy seasons. The analyses were separated by production system since the data dispersion patterns were somewhat different between the systems.

There was a significant effect (*P* < 0.001) of evaluation time on forage mass for each production system. Considering the 252-dak2ys period, forage mass decreased with the grazing time in all systems (Figure 6). Decrease for the OP system was progressive in the dry season but with a tendency of stabilizing in the rainy season (Figure 6a). A quadratic regression model was used to represent the data pattern over the grazing period for this system. For the ICLFs systems, one unique regression equation was not sufficient to modeling the dynamics of pasture due to erratic data distribution (Figure 6b, c). Therefore, two equations were required for each integrated system. In the ICLF-M system, an increase in the forage mass occurred up to 84 DABG (Figure 6b). For this increase a linear regression equation was adjusted. In the following period (84-252 DABG), the forage mass declined abruptly in the dry season but it also had a tendency of stabilizing in the rainy season (Figure 6b) as in the OP system. A quadratic regression was used for this period. In the ICLF-T system, a relatively moderate decrease expressed by a quadratic regression occurred for the most of the grazing period (0-196 DABG), but in the final period (196-252 DABG) there was a sudden and intense decrease, which was represented by a linear regression (Figure 6c).

Crude protein in forage also varied significantly ($P < 0.001$) over the full grazing period for all systems. As there was considerable variation in crude protein between dry and rainy seasons, one unique regression equation was not appropriated to represent the dynamics of this variable over time for each system. For the OP system, two linear regressions were adjusted, one for 0-112 DABG and other for 140-252 DABG. Both regressions show decrease in crude protein for the two seasons (Figure 7a). Decreases were also observed for the ICLF-M system, with a quadratic regression adjusted for the dry season and a linear regression for the rainy season (Figure 7b). In the ICLF-T system, no variation was detected up to 112 DABG, but a curvilinear decrease represented by a quadratic regression occurred in the period of 140-252 DABG (Figure 7c). Regardless of the system, these results indicate a strong discontinuity in the nutritive value of forage, as indicated by the crude protein, from the dry season to the rainy season.

3.3 | Weight gain and stocking rate

Daily weight gain of buffaloes did not vary between production systems in each of the times in which it was evaluated (Table 4). However, the weight gain was higher (Wilcoxon's test, $P < 0.001$) in the rainy season (1.165 kg/animal/day, SD = 0.334 kg/animal/day, $n = 36$) than in the dry season (0.788 kg/animal/day, SD = 0.203 kg/animal/day, $n = 24$).

Similarly, stocking rate was not influenced by any system (Table 5), but it was higher (*t*-test, $P < 0.001$) in the rainy season (4.051 AU/ha, SD = 0.458 AU/ha, $n = 36$) than in the dry season (2.955 UA/ha, SD = 0.304 AU/ha, $n = 24$).

3.4 | Correlations

Canopy height and forage mass in the OP and ICLF-M systems were poorly correlated (OP: $\rho = 0.3397$, $P = 0.032$, $n = 40$; ICLF-M: $\rho = 0.4025$, $P = 0.010$, $n = 40$) and in the ICLF-T system moderately correlated ($\rho = 0.5445$, $P < 0.001$, $n = 40$), with all correlations tested by the Spearman's method (ρ coefficient).

Figure 8 shows that the decrease in forage mass was associated with the increase in stocking rate of buffaloes in pastures of all systems. In turn, stocking rate was positively correlated with the daily weight gain of animals for each system (Figure 9).

4 | DISCUSSION

4.1 | Effects of production systems on pastures

The higher sward canopy in the OP system in relation to the ICLF-M and ICLF-T systems (Table 1 and Figure 3) was the inverse of the result expected. Our expectation was a higher canopy in the ICLF systems due to the effect of shading caused by trees, as found by Baldissera et al. (2016) for *U. brizantha* cv. Marandu in ICLF system with *Eucalyptus*. In fact, height growth is a typical response of genus *Urochloa* grasses to shading (Eriksen & Whitney, 1981; Gobbi et al., 2009), and this response seems be related to a greater stem elongation in shaded plants (Castro, Garcia, Carvalho, & Couto, 1999; Paciullo et al., 2011). An explanation for this unexpected result may be in the canopy architecture. Leaves and stems were visually more erect in plants in the OP system than in the ICLF systems. Thus, grasses more vertically oriented in the OP system could be a primary reason for the highest canopy. The causes for this vertical orientation were not determined, but direct sunlight incidence on plants should be involved.

The greater forage mass in the OP system compared with ICLF systems (Table 2 and Figure 4a) was probably a consequence of a low (re)growth of plants in these integrated systems due to shading imposed by trees. Similar results were obtained by Santos, Guimarães Júnior, Vilela, Maciel, and França (2018) for the same grass used in this study (i.e., Piatã grass) in silvopastoral systems with *Eucalyptus urograndis* as tree species. Lima et al. (2019) have also found lower forage mass of other *Urochloa* species (*U. decumbens*) in a long-term silvopastoral system with three tree species (*Acacia mangium*, *Eucalyptus grandis* and *Mimosa artemisiana*) as compared with a OP.

Severe decrease in growth of genus *Urochloa* grasses has been found under shading conditions (Castro, Garcia, Carvalho, & Couto, 1999; Dias-Filho, 2000; Guenni, Seiter, & Figueroa, 2008; Gómez, Guenni, & Guenni, 2012). The mechanisms that account for this decreased growth are not fully understood. However, decline in net photosynthesis rate (Dias-Filho, 2002) accompanied by less tillering and reduced relative growth rate (Dias-Filho, 2000) resulting in lower shoot dry matter (Guenni, Seiter, & Figueroa, 2008; Gómez, Guenni, & Guenni, 2012) have been observed in shaded *U. brizantha*. In addition, this species submitted to shading has shown lower total nonstructural carbohydrate (TNC) content in stem base due to negative impact on photosynthesis derived of decrease in incident light (Castro, Garcia, Carvalho, & Couto, 1999). As a consequence, regrowth of shaded *U. brizantha* can be affected negatively, since TNC is potentially important in recovery of forage plants defoliated by cut or

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grazing animals, especially when a considerable proportion of leaves are removed (Pedreira, Sollenberger, & Mislevy, 2000).

All these negative effects associated with shading may have occurred in the ICLF systems tested in the present study. Although the degree of shading was not determined as it did in the work of Lima et al. (2019), who have measured photosynthetically active radiation (PAR), shade due to trees in these systems covered by about one-third of paddock area. This relatively extensive shade cover may then have inhibited grass growth such that the forage mass in the whole paddock was decreased as we found. However, less forage mass in the ICLF systems occurred only in some evaluation times and only in the dry season (Table 2 and Figure 4a), which suggests a seasonal fluctuation for the effect of shading on forage mass.

Shading also seems to have been the cause of the highest crude protein content in forage in the ICLF-T system for both 84 DABG (Table 3) and the dry season (Figure 5a). Increase in crude protein in *Urochloa*-grass pastures shaded by trees at silvopastoral systems have been found in other studies (Paciullo et al., 2007; Faria, Morenz, Paciullo, Lopes, & Gomide, 2018; Lima et al. 2019). Several factors have been pointed out to explain this phenomenon (Lima et al. 2019). However, the "concentration effect" of N in forage is believed to have been the prevailing factor in this work, since the crude protein, which is proportional to N, was negatively correlated with the forage mass for the dry season (ρ = -0.5874, P = 0.049, n = 12).

As the expression itself suggests, "concentration effect" refers to an increase in concentration of a nutrient (e.g., N) in plant tissue when the uptake rate of this nutrient does not decrease in the same proportion as the growth rate does due to some limiting factor to plant growth (Jarrell & Beverly, 1981). Similarly, the rate of N uptake of plants in the ICLF-T system should not have been decreased at the same intensity as the growth of plants should due to shading, resulting in concentrated N in grass tissues and, consequently, more crude protein in forage.

The greater crude protein content found in forage of the ICLF-T can be considered an advantage for nutrition of animals grazing in this system. This is especially important because the increase occurred in the dry season, when the forage nutritive value, particularly in terms of crude protein, is generally low as compared with that in the rainy season. The less crude protein content in forage in the ICLF-M system than in the ICLF-T system is likely a consequence of apparent difference in shading between the tree species. African mahogany canopy was visually less dense than that of teak, resulting in a shade less uniform for the former in relation to the last. As a result of this less uniformity, more light reached the sward canopy in the ICLF-M system, thus limiting the concentration effect of N and consequently the accumulation of crude protein in forage. This greater crude protein content in forage in the ICLF-T system in relation to the ICLF-M system indicates that the effect of ICLF system on crude protein could be dependent on tree species.

4.2 | Dynamics of pastures

Decrease in forage mass with the time of grazing under continuous stocking across the dry and rainy seasons in all production systems tested in this work (Figure 6) shows an imbalance between removal of forage by animals and regrowth of defoliated plants. This type of pasture dynamics analysis has been a little explored in research on pastures. Therefore, no direct comparison with previous results is apparently possible. However, the basic process that led the plants to decrease their mass is not difficult to understand. Defoliation decreased the foliar area and less photosynthesis was carried out by the plants that then were slowly recovering due to limitation in energy resulting from the lower photoassimilate production. Concomitantly to this slow recovery, grazing animals continued to remove forage from the sward such that the net mass accumulation was lower than that before the grazing.

Forage mass in the OP system decreased more intensely with the grazing time during the dry season (0-140 DABG) than during the rainy season (140-252 DABG) (Figure 6a). This indicates that the low rainfall in the dry season (Figure 1) contributed to a more negative forage mass balance over the full grazing period. On the other hand, the trend for the mass to stabilize in the rainy season suggests that the highest rainfall (Figure 1) in this period decreased the forage negative balance by stimulating the sward growth. Thus, the defoliation rate was relatively better synchronized with the recovery rate of defoliated plants when the water was not a limiting factor. Synchrony in rates of these processes even in grazing under continuous stocking is possible since a situation that favors the equilibrium between forage removal and plant regrowth is created (Lemaire & Chapman, 1996). It seems that the rainy season created this equilibrium situation in the present work.

The pasture dynamics patterns in the ICLF systems were somewhat different of that in the OP system by distinct reasons. In the ICLF-M system, the linear increase in forage mass up to 84 DABG (Figure 6b) was due to the less number of animals in the paddock (see Materials and Methods). However, the forage mass in the following period had a decrease pattern similar to that of the OP system (Figure 6b). Reversely, in the ICLF-T the decrease pattern was similar to that of the OP system in the first period (0-196 DABG) but different in the second, where there was a sharp drop in forage mass (Figure 6c) probably due to a higher forage intake by grazing animals. This higher intake is consistent with highest daily weight gain of buffaloes in evaluations done within this second period (Table 4).

These detailed pasture dynamics patterns indicate a decrease in forage mass with the grazing time even in ICLF systems. If the attenuation of this decrease is a goal to be achieved, then strategies

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that stimulate the regrowth of defoliated plants should be adopted. Specific studies on modeling of defoliated plant regrowth (Parsons, Schwinning, & Carrère, 2001) can help to select better strategies to maintain the grazed sward productivity relatively stable over time. Until the results of these studies are available, lowering the animal stocking rate could be a simple way to attenuate a large decrease in forage mass.

Pasture dynamics also was evaluated in this work by crude protein. The dynamics pattern for this forage attribute was clearly related with the season. The greater crude protein content in the rainy season relatively to the dry season (Figure 7) is probably related to a greater available N concentration in soil. The increase in N availability may have occurred due to a stimulus to organic N mineralization triggered by an increase in soil moisture caused by the highest rainfall (Figure 1). This relationship is plausible since studies have shown that the net N mineralization rate increases with increasing the soil water content (Myers, Campbell, & Weier, 1980; De Neve & Hofman, 2002; Guntiñas, Leirós, Trasar-Cepeda, & Gil-Sotres, 2012) and that mineralized N is correlated with N uptake by plants (Yagi, Ferreira, Cruz, & Barbosa, 2009). Thus, as the unique source of N to the grass was the soil-derived N, then rainfall-stimulated N mineralization is believed to be the factor that led to the greater crude protein in forage in the rainy season.

The changes in crude protein content in forage within each season may also be related with soil N mineralization. The decline of crude protein over the grazing period within the dry season for the OP and ICLF-M systems (Figure 7a, b) could be the effect of a low soil N mineralization rate. In this season, rainfall was successively reduced with time (Figure 1). Consequently, the moisture soil also was reduced accordingly. As a result, the N mineralization was decreased, and minus N was available to plants, which then accumulated a less amount of crude protein in forage. Interestingly, the crude protein content did not decline in the ICLF-T system (Figure 7c), probably by maintaining the soil moist for longer as compared to the other systems. In the rainy season, the decline in crude protein with time (Figure 7) could not be due to a decrease in soil moisture because the rainfall was abundant (Figure 1). However, heavy rainfall may have waterlogged the soil progressively over this period with consequent decrease in N mineralization. High water contents in soils are able of decreasing the net N mineralization (Myers, Campbell, & Weier, 1980). Moreover, decrease in mineralized-N plant uptake due to a more intense $N–NO_3^-$ leaching could not be ignored as another factor that decreased the crude protein content in forage over the rainy season.

From point of view of animal nutrition, the crude protein contents in forage of all systems over the dry season (Figure 7) were below 50 g/kg, which is the minimum dietary protein level required for buffaloes (Sinclair, 1975) that is generally adopted. For cattle, as the minimum crude protein requirement is estimated to be 71.3 g/kg (Lazzarini et al., 2009), no forage met this standard level in

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the dry season. On the other hand, the crude protein contents over the rainy season (Figure 7) were always sufficient for buffalos and occasionally sufficient for cattle.

4.3 | Animal performance

No difference in daily weight gain for buffaloes observed between OP and ICLF systems (Table 4) was also found by Santos, Guimarães Júnior, Vilela, Maciel, and França (2018) for Nellore heifers grazing a pasture with the same grass used in the present study (Piatã grass) under continuous stocking in silvopastoral systems with eucalyptus. Similar result for crossbred (Holstein x Gyr) dairy heifer grazing *U. decumbens* pasture under continuous stocking in a silvopastoral with tree legume was also verified by Lima et al. (2019). Thus, animal weight gain in an integrated production system can be as good as that in a conventional pasture.

The greater daily weight gain in the rainy season compared with the dry season was likely due to higher crude protein contents in forage (Figure 7). This would also explain the highest stocking rate in the rainy season.

4.4 | Pasture and animal interrelationship

The relatively low correlations between canopy height and forage mass for all systems across the dry and rainy season indicate that the height would be a bad predictor of the mass. For good predictions, frequent calibrations separated by season could improve the predictive capacity of canopy height as suggested by Silva and Cunha (2003) for continuous stocking and Braga et al. (2009) for rotational stocking. In ICLF systems, specific and exhaustive calibrations may be needed, since forage mass can be influenced by shading of trees.

The negative correlation between forage mass and stocking rate of buffaloes (Figure 8) is an indicative that forage mass was greatly decreased over time as an effect of grazing animals. By modeling Parsons, Schwinning, and Carrère (2001) have simulated similar relationships using growth functions. In addition, the stocking rate positively correlated with daily weight gain of buffaloes (Figure 9) suggests that the decrease in forage mass over the grazing time was accompanied by the progressive increase in weight of grazing animals. The decrease in forage mass concomitantly with the increase in both stocking rate and daily weight gain is a clear demonstration of the conversion of plant into meat.

5 | CONCLUSION

ICLF systems may be less productive in forage than the OP system in the dry season. However, they can deliver forage with the highest crude protein content in this season depending on the tree species.

In the rainy season, all these differences tend to be eliminated. Regardless of system, the forage mass declines over time across the dry and rainy seasons as an effect of the grazing under continuous stocking. Crude protein in forage may also decline, but within each season. Despite this decline, the crude protein content is higher in the rainy season than in the dry season. High-quality forage can then lead to greater daily weight gain and stocking rate of buffaloes in the rainy season regardless of system. The season changes the productivity and quality of forage as well as the animal performance while the grazing determinates the pasture dynamics in ICLF systems.

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CONFLICT OF INTEREST

Authors declare no conflict of interest.

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TABLE 1 Measured canopy height of *Urochloa brizanta* cv. Piatã grazed by buffaloes under continuous stocking in open pasture system (OP), integrated crop-livestock-forest system with African mahogany (ICLF-M) and ICLF system with teak (ICLF-T) over the grazing time across the dry (Jul-Nov 2017) and rainy (Dec 2017-Apr 2018) seasons

	Measured canopy height (cm)									
	Days after the beginning of grazing									
System	**0** **(Jul 2017)**	**28**	**56**	**84**	**112** **(Nov 2017)**	**140** **(Dec 2017)**	**168**	**196**	**224**	**252** **(Apr 2018)**
OP	69.0 a	51.0 a	49.0 a	41.3 a	41.8 a	40.0 a	68.3 a	41.0	36.5 a	35.8
ICLF-M	46.0 b	39.5 b	37.0 b	37.8 a	31.8 b	32.5 b	61.5 b	36.3	30.5 b	32.0
ICLF-T	48.3 b	37.8 b	37.0 b	30.0 b	31.8 b	32.0 b	65.5 ab	39.5	31.0 b	32.5
SEM	9.7	4.3	4.5	4.2	3.1	2.4	1.8	1.8	2.7	2.1
P-value	0.011	0.002	0.023	0.029	0.005	0.010	0.025	0.092	0.013	0.327

Means followed by different letters within a column are different according to LSD ($P < 0.05$). Means that are not followed by letters indicate *F* test from ANOVA not significant ($P > 0.05$). SEM: standard error of the mean. *P*-value: probability for the *F* test from ANOVA.

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TABLE 2 Forage mass of *Urochloa brizanta* cv. Piatã grazed by buffaloes under continuous stocking in open pasture system (OP), integrated crop-livestock-forest system with African mahogany (ICLF-M) and ICLF system with teak (ICLF-T) over the grazing time across the dry (Jul-Nov 2017) and rainy (Dec 2017-Apr 2018) seasons

	Forage mass (kg/ha)									
	Days after the beginning of grazing									
System	**0** (Jul 2017)	**28**	**56**	**84**	**112** (Nov 2017)	**140** (Dec 2017)	**168**	**196**	**224**	**252** (Apr 2018)
OP	6754 a	5837 a	5252	5250 a	4334	3594	3014	3733	2760	3243
ICLF-M	3416 c	3820 b	4202	4648 a	3140	2706	2737	2935	2370	2902
ICLF-T	4930 b	4621 b	4007	3524 b	3723	3292	3496	3902	2412	2431
SEM	777	511	521	561	462	305	261	336	229	250
P-value	<0.001	0.013	0.223	0.009	0.217	0.103	0.088	0.058	0.253	0.118

Means followed by different letters within a column are different according to LSD ($P < 0.05$). Means that are not followed by letters indicate *F* test from ANOVA not significant ($P > 0.05$). SEM: standard error of the mean. *P*-value: probability for the *F* test from ANOVA.

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TABLE 3 Crude protein in forage of *Urochloa brizanta* cv. Piatã grazed by buffaloes under continuous stocking in open pasture system (OP), integrated crop-livestock-forest system with African mahogany (ICLF-M) and ICLF system with teak (ICLF-T) over the grazing time across the dry (Jul-Nov 2017) and rainy (Dec 2017-Apr 2018) seasons

	Crude protein (g/kg)									
	Days after the beginning of grazing									
System	**0** (Jul 2017)	**28**	**56**	**84**	**112** (Nov 2017)	**140** (Dec 2017)	**168**	**196**	**224**	**252** (Apr 2018)
OP	46.95	41.29	41.77	29.26 b	34.87	69.01	75.77	66.74	54.67	65.03
ICLF-M	49.01	43.06	43.58	30.32 b	41.52	82.13	77.02	62.76	55.99	66.19
ICLF-T	50.43	49.44	43.77	45.87 a	43.67	90.18	78.66	66.80	60.15	71.60
SEM	1.91	3.78	2.28	4.99	3.27	6.13	3.30	2.89	1.92	2.26
P-value	0.344	0.267	0.830	0.024	0.179	0.058	0.843	0.626	0.092	0.153

Means followed by different letters within a column are different according to LSD ($P < 0.05$). Means that are not followed by letters indicate *F* test from ANOVA not significant ($P > 0.05$). SEM: standard error of the mean. *P*-value: probability for the *F* test from ANOVA.

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TABLE 4 Daily weight gain of buffaloes grazing *Urochloa brizanta* cv. Piatã under continuous stocking in open pasture system (OP), integrated crop-livestock-forest system with African mahogany (ICLF-M) and ICLF system with teak (ICLF-T) over the grazing time across the dry (Jul-Nov 2017) and rainy (Dec 2017-Apr 2018) seasons

	Daily weight gain (kg/animal/day)				
	Days after the beginning of grazing				
System	**28** **(Ago 2017)**	**84** **(Out 2017)**	**168** **(Jan 2017)**	**224** **(Mar 2017)**	**252** **(Apr 2018)**
OP	0.706	0.775	0.854	1.419	1.179
ICLF-M	0.673	0.823	0.780	1.408	1.219
ICLF-T	0.704	1.046	0.695	1.533	1.402
SEM	0.063	0.113	0.054	0.101	0.095
P-value	0.852	0.248	0.083	0.740	0.293

Means within a column do not differ to each other due to the *F* test from ANOVA not significant (*P* > 0.05). SEM: standard error of the mean. *P*-value: probability for the *F* test from ANOVA.

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TABLE 5 Stocking rate of buffaloes grazing *Urochloa brizanta* cv. Piatã under continuous stocking in open pasture system (OP), integrated crop-livestock-forest system with African mahogany (ICLF-M) and ICLF system with teak (ICLF-T) over the grazing time across the dry (Jul-Nov 2017) and rainy (Dec 2017-Apr 2018) seasons

	Stocking rate (AU/ha)				
	Days after the beginning of grazing				
System	**28** **(Ago 2017)**	**84** **(Out 2017)**	**168** **(Jan 2017)**	**224** **(Mar 2017)**	**252** **(Apr 2018)**
OP	2.968	3.305	3.775	4.368	4.608
ICLF-M	2.678	3.028	3.450	4.025	4.268
ICLF-T	2.650	3.100	3.475	4.100	4.379
SEM	0.116	0.125	0.142	0.146	0.151
P-value	0.165	0.410	0.305	0.343	0.411

Means within a column do not differ to each other due to the *F* test from ANOVA not significant (*P* > 0.05). SEM: standard error of the mean. *P*-value: probability for the *F* test from ANOVA.

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FIGURE 1 Rainfall distribution and mean minimum and maximum temperatures over the study period

FIGURE 2 Schematic representation for the production systems in the field. OP: open pasture system. ICLF-M: integrated crop-livestock-forest system with African mahogany. ICLF-T: integrated crop-livestock-forest system with teak

FIGURE 3 Measured canopy height of *Urochloa brizanta* cv. Piatã grazed by buffaloes under continuous stocking in open pasture system (OP), integrated crop-livestock-forest system with African mahogany (ICLF-M) and ICLF system with teak (ICLF-T) within the dry season (Jul-Nov 2017) (a) and the rainy season (Dec 2017-Apr 2018) (b). *P*-value: probability for the *F* test from ANOVA. Different letters on the bars within each season indicate difference between means according to LSD ($P < 0.05$). Lines on the bars represent standard error of the mean

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FIGURE 6 Dynamics of forage mass for *Urochloa brizanta* cv. Piatã grazed by buffaloes under continuous stocking in open pasture system (OP) (a), integrated crop-livestock-forest system with African mahogany (ICLF-M) (b) and ICLF system with teak (ICLF-T) (c) over the grazing time across the dry (Jul-Nov 2017) and rainy (Dec 2017-Apr 2018) seasons. ● $\hat{y} = 6767.7300 - 28.9909^{***}x + 0.0565^{**}x^2$ | $R^2 = 0.9394$ | $0 \leq x \leq 252$. ■ $\hat{y} = 3409.9750 + 14.5571^{**}x$ | $R^2 = 0.9990$ | $0 \leq x \leq 78$. ■ $\hat{y} = 8229.4700 -$

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58.7631***x + 0.1500***x^2 | R^2 = 0.8227 | 79 ≤ x ≤ 252. ▲ ŷ = 5043.9580 - 23.8463***x + 0.0896**x^2 | R^2 = 0.9307 | 0 ≤ x ≤ 192. ▲ ŷ = 8797.8330 - 26.2634***x | R^2 = 0.7402| 193 ≤ x ≤ 252. ** *P* < 0.01. *** *P* < 0.001

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FIGURE 8 Relationship between forage mass and stocking rate for *Urochloa brizanta* cv. Piatã grazed by buffaloes under continuous stocking in open pasture system (OP) (a), integrated crop-livestock-forest system with African mahogany (ICLF-M) (b) and ICLF system with teak (ICLF-T) (c) over a 252-days grazing period across the dry (Jul-Nov 2017) and rainy seasons (Dec 2017-Apr 2018). AU: animal unit (450 kg body weight). ρ: Spearman's correlation coefficient. *r*: Pearson's correlation coeficient. *P*: probability for the correlation test. *n*: number of observations

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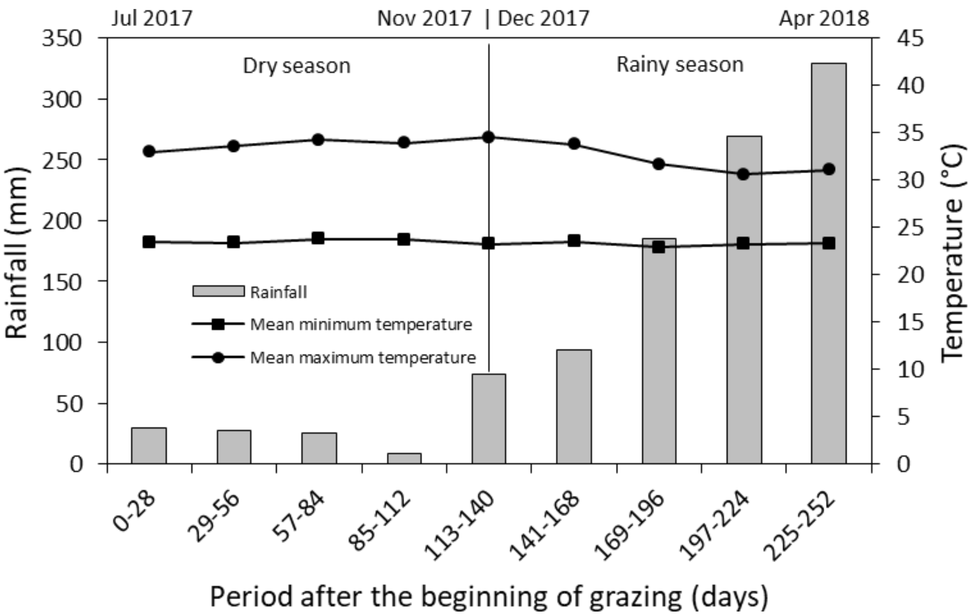

FIGURE 1 Rainfall distribution and mean minimum and maximum temperatures over the study period

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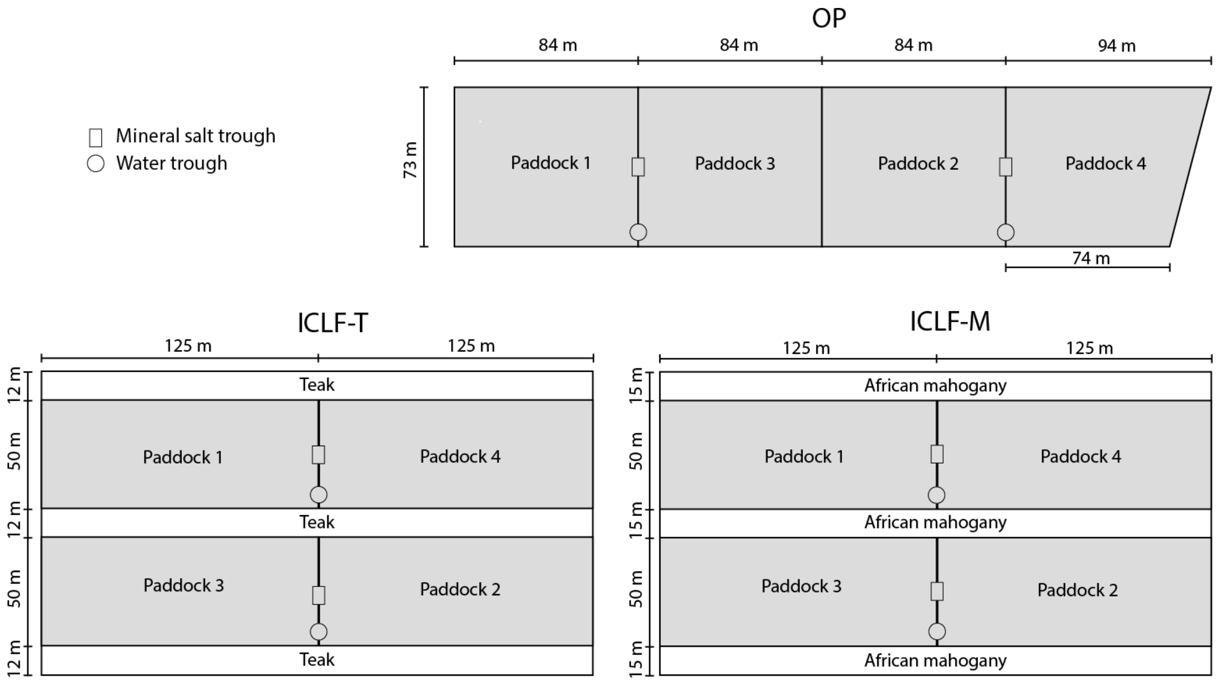

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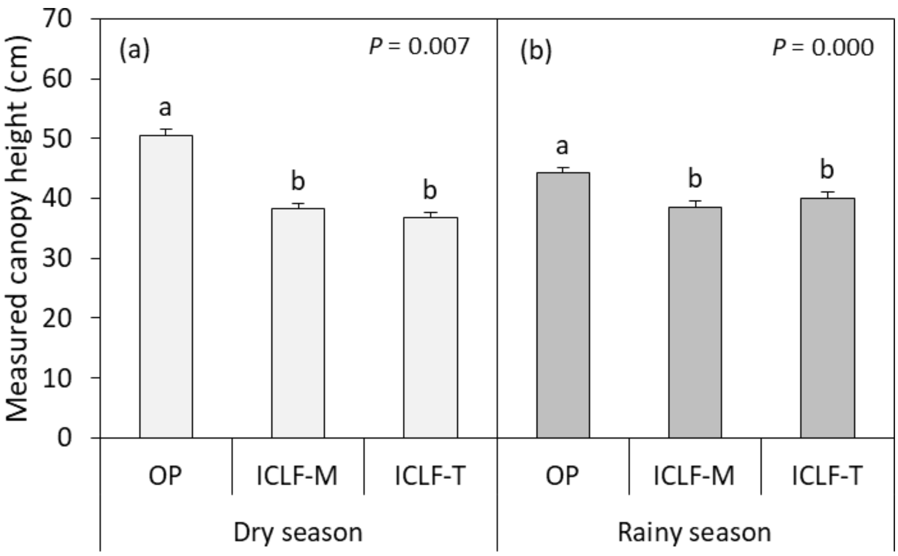

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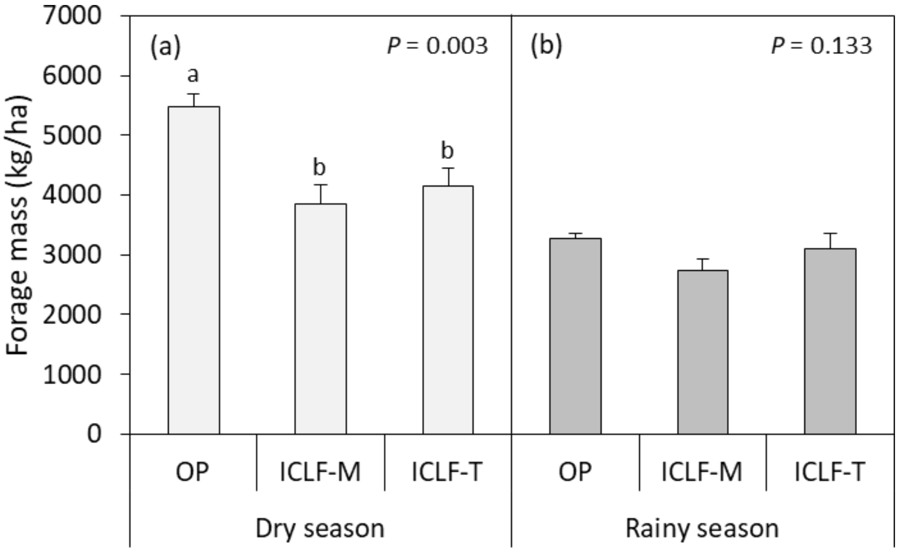

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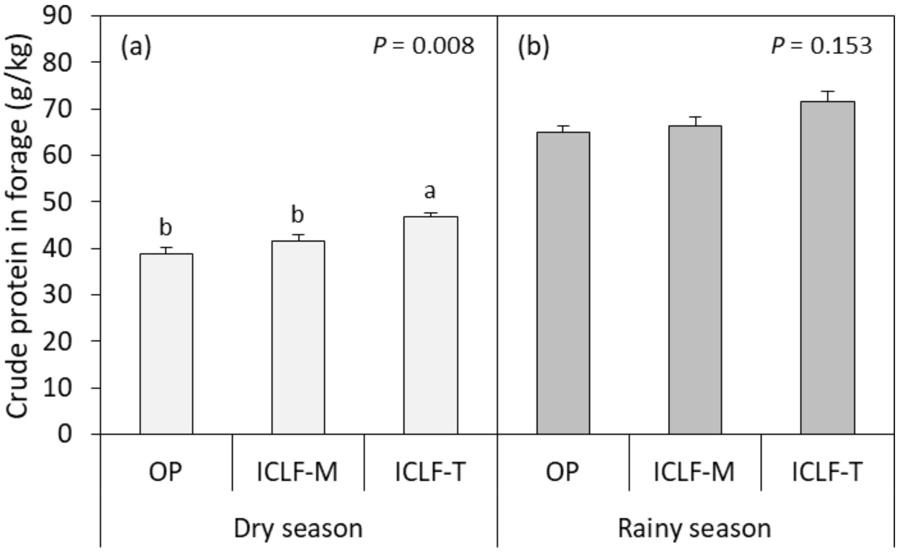

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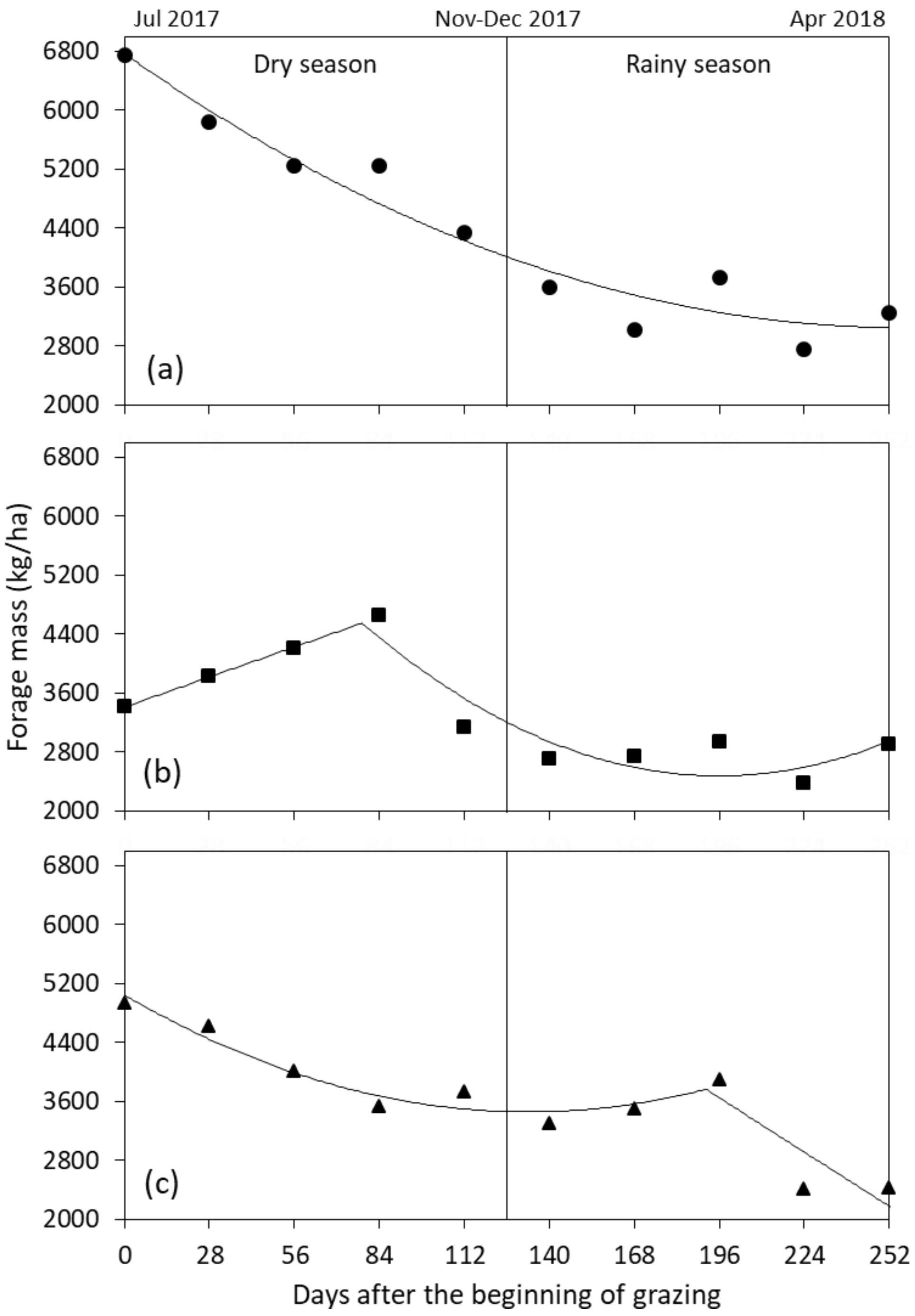

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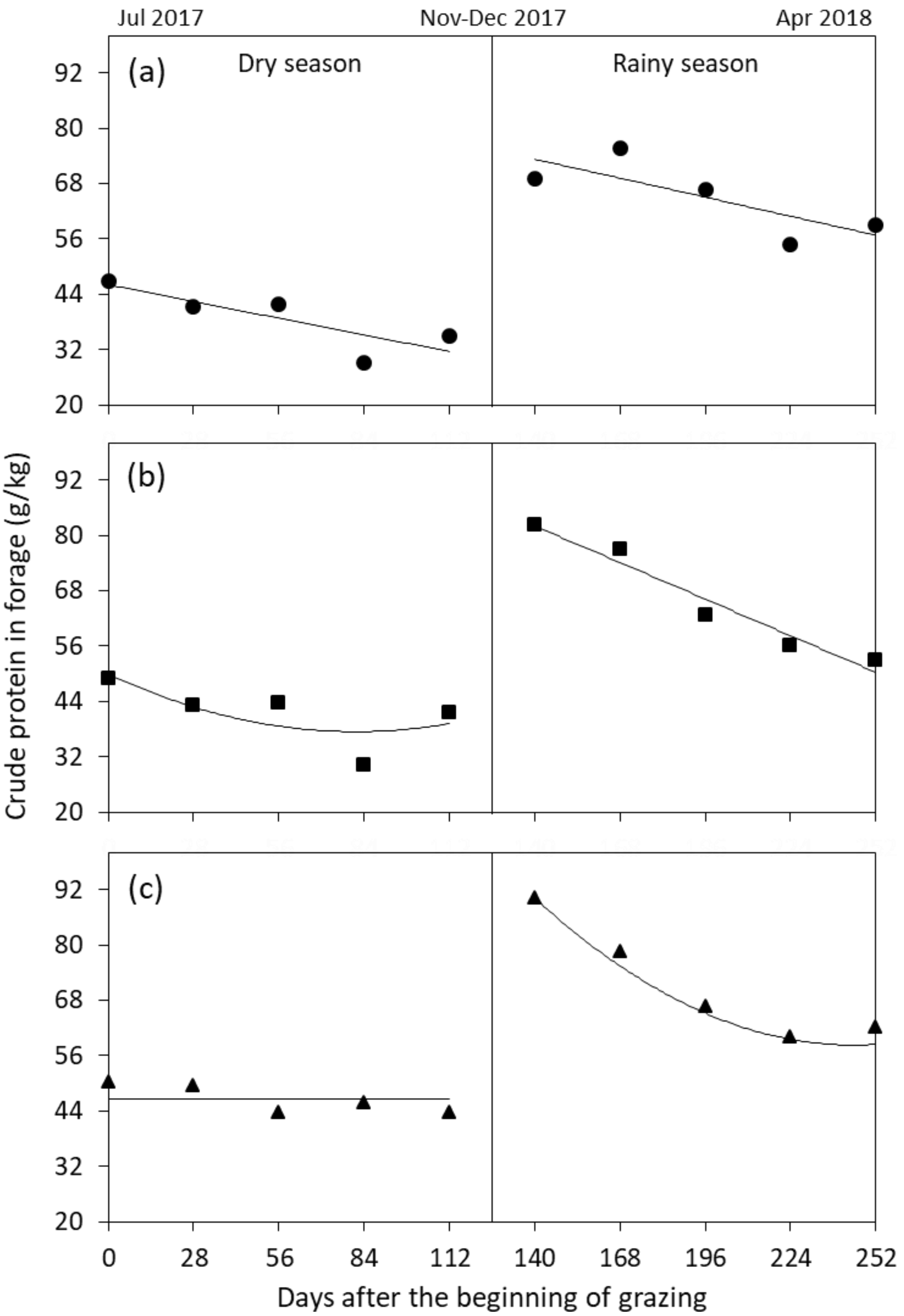

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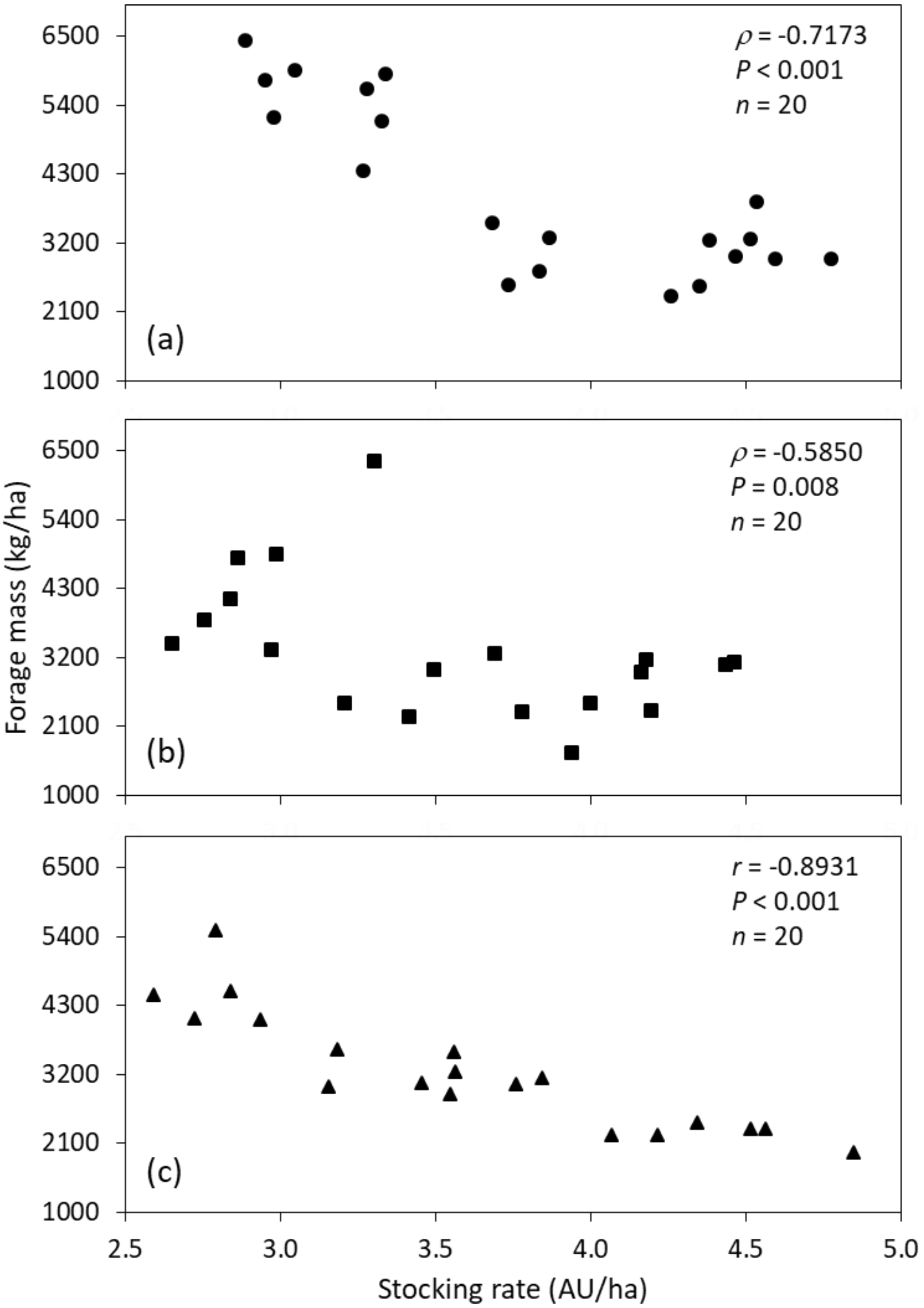

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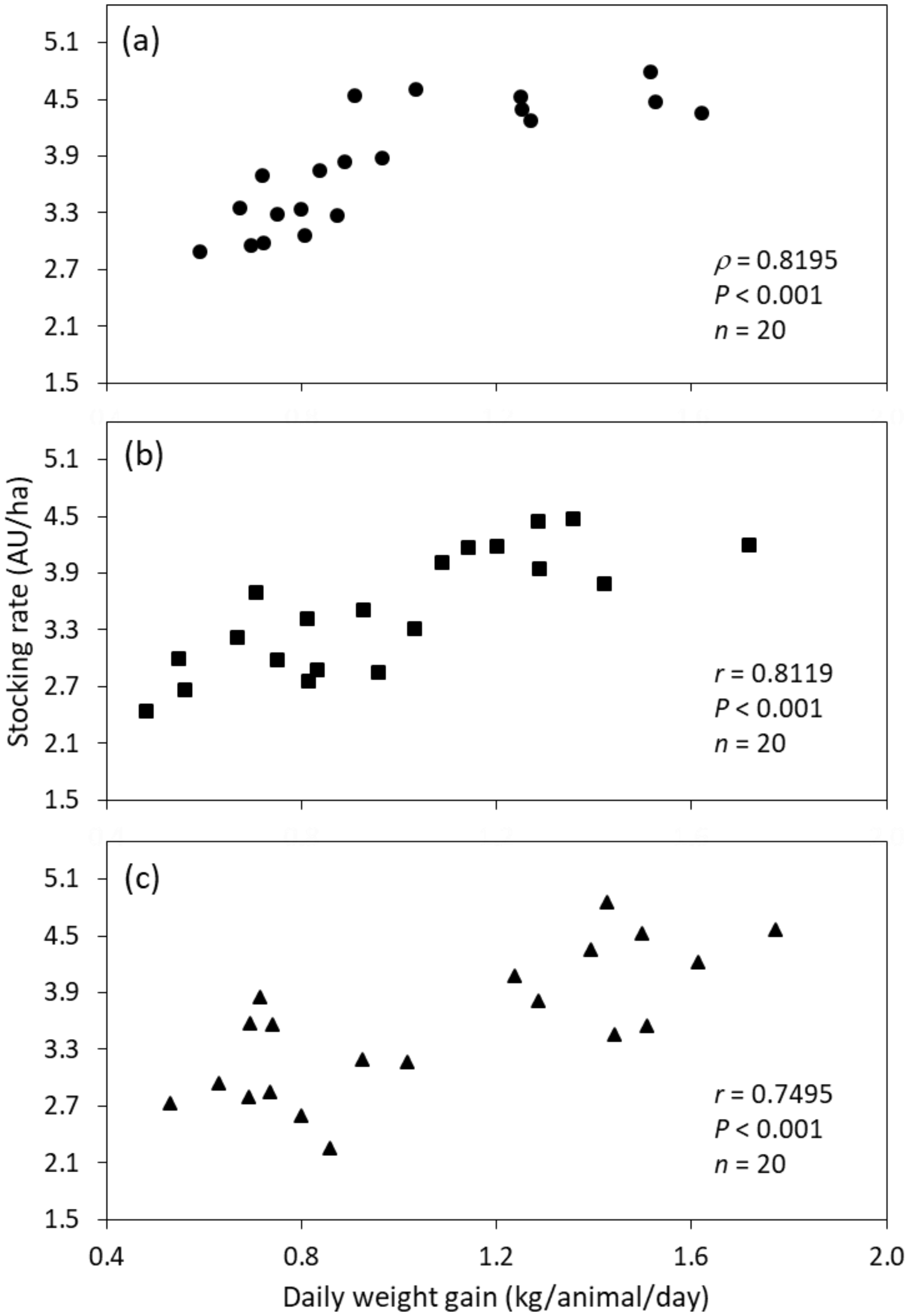

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3. Biomassa and nitrogen in *Urochloa brizantha* grazed under continuous stocking in integrated crop-livestock-forest systems[2]

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[2] Este capítulo segue as normas da revista Nutrient Cycling in Agroecosystems

Abstract Biomass and nitrogen (N) nutrition of forage plants in grazed pastures may be altered in reason of changes in the micro-environment caused by trees within integrated crop-livestock-forest (ICLF) systems. The objective this work was to determine biomass and N status of *Urochloa brizantha* cv. BRS Piatã grazed under continuous stocking in (i) open pasture (OP) system, (ii) ICLF system with African mahogany trees (*Khaya ivorensis*) (ICLF-T) and (iii) ICLF system with teak trees (*Tectona grandis*) (ICLF-T). Dry matter and N concentration and accumulation in leaves and stems of the grass were determined every 28 days during a 252-days grazing period across the dry and rainy season. In the dry season, leaf biomass and stem biomass in the ICLF systems were at least 28 and 31% lower than those in the OP system, respectively. Leaf biomass arrived to very low values (228–295 kg ha^{-1}) in the driest month (November) of the dry season. However, leaf and stem dry matter increased in the rainy season stimulated by the high rainfall. Leaf N status revealed that the grass was with N deficiency in the OP system. In the ICLF systems, on the other hand, N status was sufficient. In relation to the OP system, ICLF-M and ICLF-T systems decreased leaf and stem biomass of the grass but in compensation improved plant N nutrition in the first year of pasture exploration with beginning of grazing in the dry season.

Keywords Agrosilvopastoral system · *Brachiaria* · Leaf/stem ratio · Nitrogen nutrition · Tropical pasture

Introduction

Integrated crop-livestock-forest (ICLF) systems are attracting the interest of researchers, technicians and farmers because of the economic and environmental benefits they provide. ICLF systems are considered to be a low risk economic activity and an economically viable enterprise for all their components (crops, animals and trees) due to the synergism between

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them (Müller et al. 2011; Oliveira Junior et al. 2016). In addition, they are able to improve the physical soil quality (Moreira et al. 2018), which is essential for sustaining crop production over time. For pasture, particular advantages of these systems have been found as well. Water saving on pastures can be achieved by lower water search frequency by grazing animals due to a better thermal comfort provided by the tree shade (Karvatte Jr. et al. 2016; Giro et al., 2019). Moreover, decrease in greenhouse gas emission (GHG) from pasture is another possibility in ICLF systems (Carvalho et al. 2017). Overall GHG reduction included grazing animals has also been demonstrated (Figueiredo et al. 2017). Finally, a contribution to nitrogen (N) cycling by the presence of trees in the system has been confirmed in recent years (Xavier et al. 2014).

Despite these many benefits, ICLF systems need to be further studied to identify possible unfavorable factors related to performance of system components (Alves et al. 2017). One of these factors has been reported to be the depressive effect of tree shading on forage plant growth and therefore on pasture forage accumulation. Studies combining pastures with trees, i.e., silvopastoral systems, have shown a large decrease (above 25%) in forage mass of tropical grasses by influence of tree shading (Santos et al. 2018; Lima et al. 2019). However, evaluation of this effect on leaves and stems separately has still been little explored. In the Lima et al. (2019)'s work for example, stem dry matter of *Urochloa decumbens* cv. Basilisk was 33% lower in a silvopastoral system as compared with an open pasture (OP) system (conventional pasture without trees). This effect was seasonal, since it occurred in the rainy season (summer) but not in the dry season (autumn). In addition, there was no difference between systems for leaf biomass.

In studies using artificial shading, leaf and stem dry matter has individually been decreased in shaded tropical grasses (Guenni et al. 2008; Gómez et al. 2012). Decrease in leaf biomass by shading of trees is particularly worrisome in grazed pasture where the grass growth is limited by another adverse factor (e.g., drought). In this case, residual leaf dry mater could

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be as low that it would restrict the recovery of defoliated plants. The lower limit for residual leaf biomass for suitable plant regrowth is little known. For *Pennisetum purpureum*, it has been determined to be between 2000 and 2500 kg ha^{-1} (Veiga et al. 1985), while 829 kg ha^{-1} seems to have been the residual leaf biomass for maximum forage allowance of *U. brizantha* cv. Marandu in the work conducted by Rezende et al. (2008). These values were obtained for rotational stocking grazing, being values unknown for continuous grazing. Therefore, it is needed to assess if tree shading could decrease leaf dry matter to likely limiting levels for regrowth of defoliated plants by grazing animals in pastures under continuous stocking in ICLF systems.

Another aspect that has been neglected in ICLF system is the assessment of forage plant N status. Studies have shown that crude protein concentration in forage of *Urochloa* grasses increases in silvopastoral systems due to tree shading in relation to OP systems (Santos et al. 2018; Lima et al. 2019). Mechanisms governing this increase are not well understood. However, N concentration effect by decreasing dry matter (Jarrell and Beverly 1981) due to shading seems to be present. Since crude protein is directly related to N, plant N concentration is supposed to increase in ICLF systems.

Nutritional diagnosis in forage plants is based on nutrient concentration in plant tissues. For tropical grass, N should be determined in green leaves that simulate the ones grazed by animals, and interpretation of N concentration could be carried out by a critical N range (Werner et al. 1997). Importance of this diagnosis is undisputed. It can indicate N deficiency and then need for N fertilization to improve the plant regrowth. Nutrition N diagnosis can also point to some disruption in the N cycle. This is absolutely relevant because deficient N cycling can lead to pasture decline and consequently to unsustainability of pastoral system.

We hypothesized that, in relation to the OP system, ICLF systems decrease leaf and stem dry matter while improve N nutrition of grass in grazed pastures. The objective this work

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was to determine leaf and stem biomass and N status of *Urochloa brizantha* cv. BRS Piatã grazed under continuous stocking in (i) open pasture (OP) system, (ii) ICLF system with African mahogany trees (ICLF-M) and (iii) ICLF system with teak trees (ICLF-T).

Materials and methods

Study site

This field study was conducted in the Embrapa Amazônia Oriental's experimental station (01°01'33.4"S, 47°53'58.3"W, elevation 40 m) located in the Terra Alta municipality, state of Pará, Brazil. The climate in this region is Am (tropical monsoon) by the Köppen's classification (Alvares et al. 2013), with a mean annual precipitation of 2550 mm and a mean annual temperature of 26°C (Moraes et al. 2005). Rainfall and temperature over the present study are presented in Fig. 1. The data used in this figure are from the Castanhal municipality (Inmet 2018), because climatic records are not available for Terra Alta. The use of the rainfall and temperature data from neighboring municipality is considered to be suitable for the study site since Terra Alta and Castanhal are adjacent to each one and therefore they have similar climatic patterns. The soil in this site is an *Argissolo Amarelo Distrófico textura arenosa/média* (Gama et al. 2000) by the Brazilian Soil Classification System (Embrapa 2018), corresponding to either Ultisol in Soil Taxonomy (Soil Survey Staff 2014) or Acrisol in the FAO legend (IUSS Working Group WRB 2015), and it was under a degraded pasture of *Urochloa humidicola* (Rendle) Morrone & Zuloaga [syn. *Brachiaria humidicola* (Rendle) Schweick.]. The characteristics of this soil at the 0-20-cm depth before the installation of the production systems were: pH (H_2O) (1:2.5 soil:water ratio) 5.4, OM (organic matter | Walkley-Black) = 17.76 g kg^{-1}, P (Mehlich-1) = 1 mg dm^{-3}, K^+ = 0.07 $\text{cmol}_c\ \text{dm}^{-3}$, Ca^{2+} = 0.7 $\text{cmol}_c\ \text{dm}^{-3}$, Mg^{2+} = 0.4 $\text{cmol}_c\ \text{dm}^{-3}$, Al^{3+} = 0.5 $\text{cmol}_c\ \text{dm}^{-3}$, H+Al (potential acidity) = 3.3 $\text{cmol}_c\ \text{dm}^{-3}$, CEC (cation exchange

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capacity) at pH 7 = 4.5 $\text{cmol}_c\ \text{dm}^{-3}$, base saturation = 26%, aluminum saturation = 30%, sand = 779 g kg^{-1}, silt = 86 g kg^{-1}, and clay = 135 g kg^{-1}. Chemical analyses followed procedures described in Silva et al. (1998), and particle-size analysis was performed by the pipette method with previous soil sample dispersion with 1 M NaOH according to Embrapa (1997).

The production systems

Three production systems were installed in the study area: (i) open pasture (OP) system, (ii) integrated crop-livestock-forest (ICLF) system with African mahogany (*Khaya ivorensis* A. Chev.) (ICLF-M), and (iii) ICLF system with teak (*Tectona grandis* L. f.) (ICLF-T). African mahogany and teak were selected as forest species for the ICLF systems because they produce high-quality woods (Wiemann 2010). In all systems the forage species used for establishment of pasture was *Urochloa brizantha* (Hochst. ex A. Rich.) R. Webster cv. BRS Piatã [syn. *Brachiaria brizantha* (Hochst. ex A. Rich.) Stapf cv. BRS Piatã]. Piatã grass was chosen due to its high performance for animal production in tropical pastures (Euclides et al. 2009; Nantes et al. 2013).

The ICLF systems were implanted in February 2009 after the application of 1.5 t ha^{-1} limestone on the soil surface followed by conventional soil tillage. Then three forest species strips spacing 50 m to each other were established for each system. In the ICLF-M system, three rows of African mahogany with trees spacing 5 × 5 m were planted in each strip, while four rows of teak with trees spacing 3 × 3 m were planted in each strip in the ICLF-T system. For both forest species, fertilization consisted of 100 g P_2O_5 (reactive phosphate rock) per hole at planting, 25 g N (urea) and 25 g K_2O (potassium chloride) per plant in March 2009, and 20 g N and 20 g K_2O (20-0-20) per plant in April 2009.

Maize (*Zea mays* L. cv. BRS 1030) was annually cultivated from 2009 to 2013 in the areas between tree strips of both ICLF systems. Conventional soil tillage was used in the first

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year, as cited above, and no-tillage system was adopted in the posterior years. Fertilization for the maize crop in each year consisted of 33 kg N ha^{-1}, 92 kg P_2O_5 ha^{-1} and 66 kg K_2O ha^{-1} (10-28-20) at sowing, and 40 kg N ha^{-1} and 40 kg K_2O ha^{-1} (20-0-20) at top-dressing. Cowpea [*Vigna unguiculata* (L.) Walp cv. BRS Guariba] was sown only in the first year as a second crop after the harvest of the summer maize. No fertilization was carried out for cowpea.

Piatã grass pastures were established in 2013 in the areas between the tree strips in both ICLF systems. Grass seeds were distributed together with the fertilizer applied at top-dressing for maize. In 2015, this same forage species was sown in an area adjacent to the areas with ICLF systems in order to be the OP system (i.e., only pastoral system, without trees and previous crops cultivation). Fertilization at the establishment of this pasture consisted of, in kg ha^{-1}, 70 N (urea), 110 P_2O_5 (triple superphosphate), and 60 K_2O (potassium chloride).

In 2017, the area of each system was divided into four paddocks using electric fences. Each paddock was considered one replicate. Thus, four replications for each system were established. A representation of the three production systems (OP, ICLF-M and ICLF-T) replicated in the field is showed in Fig. 2. As the available area was small, it is not possible to allocate one replicate of each system in a same block due to the risk of trees to shade the OP system. Area of each paddock was approximately 0.6 ha, and one mineral salt trough and one water trough were shared every two paddocks.

All pastures were mown in May 2017 followed by fertilization with 50 kg N ha^{-1} (urea), 50 kg P_2O_5 ha^{-1} (single superphosphate) and 50 kg K_2O ha^{-1} (potassium chloride). No fertilizer was posteriorly applied to the pastures until the end of this study. In July 2017, pastures were again mown at a 35-cm height in order to standardize sward canopy height.

Pastures in all systems were grazed from July 2017 to April 2018 (252 days) by buffaloes (*Bubalus bubalis* L.) under continuous stocking with variable stocking rate. Two tester steers at age of 18 months and each one weighting 332 kg [standard error of the mean

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(SE) = 14 kg, n = 24] were put into each paddock. In the ICLF-M system's paddocks, however, only one animal was maintained until October 2017 to stimulate the plant growth in sward patches with a low canopy height. Additional buffaloes (regulator animals) were occasionally put into and take from the paddocks (i.e., put-and-take stocking) aiming to maintain the mean canopy height of approximately 35 cm. All animals received freely both mineral salt and water.

Height and diameter at breast height of African mahogany and teak were by about 14.2 m and 23.8 cm and 12.7 m and 19.6 cm, respectively.

Determination of dry matter and nitrogen in leaves and stems

Plants were cut at the soil level in an area of 0.25 m^2 (0.50 × 0.50 m) in 10 random points in each paddock every 28 days over the 252-days grazing period. Plant samples collected in each paddock to each evaluation time were bulked, and three subsamples were taken. Subsamples were separated into leaves (leaf blades) and stems (included sheath) and then these fractions were oven-dried at 65°C until constant weight for determination of dry matter. In addition, sum of leaves + stems dry matter was calculated. Nitrogen (N) concentration in each plant fraction was determined by the Kjeldahl method (AOAC, 1990). N concentration in leaves + stems was calculated as a weighted mean by the biomass of each fraction. N accumulated in leaves and stems and leaves + stems was calculated by multiplying N concentration by dry matter divided per 1000. Both fractions consisted of green tissues, since dead material was removed.

Statistical analyses

Data were analyzed using a randomized complete block design with four replicates, each one allocated in a paddock. Replicates were considered blocks in order to separate the variability among paddocks, and each block consisted of one paddock of each system in corresponding position (Fig. 2). An analysis of variance (ANOVA) was performed for each variable in each

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evaluation time. Additional ANOVA was performed for each variable in each season using means of all evaluation times within the season. When *F* test from ANOVA showed significance, means were separated by the Fisher's least significant difference (LSD). For all ANOVAs, homogeneity of variance and normality were checked by the Bartlett's test and Shapiro-Wilk's test, respectively. All analyses were performed at $P < 0.05$ using the R software (R Core Team 2018).

Results

Dry matter of leaves and stems

In the dry season, leaf dry matter of *U. brizantha* cv. Piatã in the ICLF systems was significantly ($P < 0.05$) lower than that in the OP system at 0 and 84 days after the beginning of grazing (DABG) (Fig. 3a). At 0 DABG, values in the ICLF-M and ICLF-T systems were respectively 46 and 37% lower than that in the OP system. These respective differences at 84 DABG were 28 and 30%. In the rainy season, at 196 DABG, however, only leaf dry matter in the ICLF-M was significantly ($P < 0.05$) lower than that in the OP system (Fig. 3a). The ICLF-M system in this advanced grazing time already within the rainy season had a dry matter 32 and 40% lower in relation to those in the OP and ICLF-T systems, respectively. No significant difference in biomass of leaves was found between systems for the other grazing times.

For stems, there were significant differences ($P < 0.05$) in dry matter between systems only in three grazing times within the dry season (Fig. 3b). At 0 DABG, values in the ICLF-M and ICLF-T systems were 48 and 33% lower than that in the OP system, while at 28 DABG these differences were 34 and 31%, respectively. At 84 DABG, dry matter of leaves in the ICLF-T system was 41 and 36% lower than those in the OP and ICLF-M systems, respectively. There was no difference between systems for stem biomass in any other grazing time.

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Dry matter of leaves + stems differed significantly (*P* < 0.05) between systems (Fig. 3c) at the same grazing times in which biomass of leaves and stems did individually (Fig. 3a and b). At 0 DABG, values in the ICLF-M and ICLF-T systems were respectively 47 and 33% lower than that in the OP system. At 28 DABG, these respective differences were 34 and 31%. Already at 84 DABG, the ICLF-T system had a biomass of leaves + stems 39 and 31% lower in relation to those in the OP and ICLF-M systems, respectively. Dry matter of both plant parts at 196 DABG differed only between the ICLF systems, with the ICLF-M system having a value 31% lower than that in the ICLF-T system.

Leaf/stem ratio varied significantly (*P* < 0.05) between systems only in the dry season–rainy season transition (Fig. 3d). Opposite results occurred between 84 and 112 DABG, within the dry season. At 84 DABG, leaf/stem ratio in the ICLF-M system was 25 and 33% lower than those in the OP and ICLF-T systems, respectively. At 112 DABG, however, the ratio in the ICLF-M system was 53 and 35% greater than those in the OP and ICLF-T systems, respectively. In the rainy season, results also were distinct between the grazing times. At 140 DABG, ratio in both ICLF systems was the double than that in the OP system, while at 168 DABG the ICLF-M system had a ratio 29% greater than that in the ICLF-T system.

When the means of all grazing times for each season were analyzed, effects of systems were confined to the dry season. In this season, values for dry matter of leaves, stems and leaves + stems in the ICLF-M and ICLF-T systems were respectively 40, 34 and 36% and 29, 33 and 32% lower than those in the OP system, and no difference was found for leaf/stem ratio (Fig. 4a, b, c and d). There was no effect of system for any of these variables in the rainy season (Fig. 4e, f, g and h).

Dry matter of leaves, stems and leaves + stems, and leaf/stem ratio declined with the grazing time until dry season–rainy season transition (Fig. 3). The lowest values for leaf/stem ratio (0.26, 0.19 and 0.29 in the OP, ICLF-M and ICLF-T systems, respectively) and biomass

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of both leaves (295, 229 and 228 kg ha^{-1} in the OP, ICLF-M and ICLF-T systems, respectively) and stems (882, 481 and 693 kg ha^{-1} in the OP, ICLF-M and ICLF-T systems, respectively) occurred at 84, 112 and 140 DABG, respectively (Fig. 3a, b and d). After this decline, biomass and leaf/stem ratio increased until the middle of the rainy season and declined again thereafter (Fig. 3).

Nitrogen in leaves and stems

In the dry season, when the grazing began, there was a significant difference ($P < 0.05$) between systems for N concentration in Piatã grass tissues only at 84 DABG (Table 1). N concentrations in leaves, stems and leaves + stems were respectively 16%, twofold and 1.6-fold higher in the ICLF-T system in relation to the OP system. In turn, in the rainy season, N concentration in leaves and stems differed significantly ($P < 0.05$) between systems only in one grazing time different for each plant fraction (Table 1). N concentration in leaves in the ICLF-T was 24% higher than that in the OP system at 168 DABG, while the difference for stems between these systems was 1.6-fold at 140 DABG.

N accumulated in plant tissues varied significantly ($P < 0.05$) between systems in the beginning of the dry season (0 DABG) and in the middle of the rainy season (196 DABG) (Table 2). Variations, however, did not coincide with those for N concentration (Table 1) but did with changes in biomass (Fig. 3a, b and c). At 0 DABG, values for N accumulated in leaves, stems and leaves + stems in the ICLF-M and ICLF-T systems were respectively 47, 45 and 45% and 30, 23 and 28% lower than those in the OP system. In this grazing time there were also differences between the ICLF systems for N accumulated in leaves and leaves + stems. In the ICLF-T system N accumulation in these plant fractions was 23-24% greater than in the ICLF-M. At 196 DABG, values for N accumulated in leaves and leaves + stems in the ICLF-M were respectively 28 and 39% and 30 and 35% higher than those in the OP and ICLF-T systems.

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ANOVAs performed with the mean of all grazing times within each season reveled seasonal trends for system effects on both N concentration and N accumulated in plant tissues (Tables 3 and 4). In the rainy season, N concentrations in leaves, stems and leaves + stems were 9, 26 and 18% higher ($P < 0.05$) in the ICLF-T as compared with the OP system, and the ICLF-T system also had a N concentration in leaves + stems 14% higher than the ICLF-M system. No significant difference ($P > 0.05$) was found for N concentration between systems in the rainy season. N accumulation in any plant fraction also did not change between systems in the rainy season. However, in the dry season, amounts of N accumulated in leaves in the ICLF-M and ICLF-T systems were respectively 37 and 23% lower than that in the OP system. For N accumulation in leaves + stems, difference was observed only between ICLF-M and OP systems, with ICLF system having 34% less N accumulated. There was no difference between systems for N accumulated in stems in the dry season and N accumulated in any plant fraction in the rainy season (Table 4).

Considering results of all systems over the grazing time, the highest N concentrations occurred at 140 DABG for leaves and 168 DABG for stems (Table 1). For leaves + stems, the greater N concentrations were found at 140 DABG in the ICLF systems and at 168 DABG in the OP system (Table 1). The greatest amounts of N accumulated were observed at 0 DABG for leaves and leaves + stems in the OP system, at 168 DABG for leaves and leaves + stems in the ICLF systems and at 196 DABG for stems in all systems (Table 2).

Discussion

Influence of production systems on grass leaf and stem biomass

The results of this work show lower dry matter of leaves, stems and leaves + stems of *U. brizantha* cv. Piatã grazed in the ICLF systems as compared with the OP system in the dry

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season (Figs. 4a, b and c). In the rainy season, however, there was no consistent difference between the systems (Figs. 4e, f and g). Similar result was obtained by Santos et al. (2018) for forage dry matter of the same grass cultivar in silvopastoral systems with *Eucalyptus*, but consistently for both seasons. Decrease in dry matter in the two seasons may be related to the lower spacing between the tree strips. In the work of these authors the spacings were 12 and 22 m, while in our study the spacing was wider (Fig. 2). Thus, trees in shorter spacing can have shaded more severely the sward, decreasing the forage dry matter also in the rainy season.

Shading had been pointed as the primary factor for decreasing tropical grass biomass in pastures integrated with trees (Carvalho et al. 2002; Paciullo et al. 2007; Santos et al. 2018; Lima et al. 2019). In addition, our results show that this decrease can be due to decreasing in biomass of both leaves and stems. Decrease in dry matter of both plant parts has also been observed by other authors for artificially-shaded *Urochloa* grasses (Guenni et al. 2008;Gómez et al. 2012) including *U. brizantha* (Guenni et al. 2008). This response has been accompanied by a drastic decrease in the number of tillers (Dias-Filho 2000; Guenni et al. 2008; Martuscello et al. 2009; Paciullo et al. 2011). Thus, low tillering decreases the number of leaves and stems and consequently the biomass of these plant structures. However, decrease in biomass of individual leaf and stem could not be discarded. Calculations with data from Guenni et al. (2008) for number and dry matter of leaves and stems suggest this possibility. In our work, tree shade was the likely cause of the decrease in leaf and stem dry matter in the ICLF systems. Although the level of shading was not measured as in the study by Lima et al. (2019), shade covered about 1/3 of the paddock area, which can be considered a relevant shaded pasture area.

Leaf/stem ratio differences between systems were erratic in different grazing times over the dry season–rainy season transition (Fig. 3d), and there were no differences between systems for each full season (Fig. 4d and h). Santos et al. (2018) also found similar leaf/stem ratio for Piatã grass grazed in silvopastoral systems and OP system within either dry or rainy season. No

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difference was also observed by Gobbi et al. (2009) and Gómez et al. (2012) for this ratio in *U. decumbens* under different shade levels. This means that shading affect the biomass of leaves and stems similarly.

Decline in dry matter of leaves, stems, leaves + stems and leaf/stem ratio over the dry season for all systems (Fig. 3) was a consequence of grazing combined with a slow sward regrowth due to the low rainfall in this period (Fig. 1). This is consistent with the fact that *U. brizantha* is poorly drought tolerant as compared with other *Urochloa* species (Guenni et al. 2002). The lowest biomass was the one of leaves, which arrived to a minimum of 228 kg ha^{-1} (Fig. 3) in the driest month (November) of the dry season (Fig. 1). This value is very below the residual leaf dry matter (829 kg ha^{-1}) found by Rezende et al. (2008) for maximum forage allowance of *U. brizantha* cv. Marandu grazed under rotational stocking. Therefore, such leaf dry matter could be considered very low. Thus, concern arises from this limited biomass, because the leaves are the main photosynthetic organs directly responsible by the sward recovery after defoliation of plants by grazing animals.

Despite the reduced biomass in the dry season, dry matter of leaves, stems, leaves + stems and leaf/stem ratio for all systems increased with the return of abundant rainfall in the rainy season (Fig. 3). This corroborates the role of normal water resupplying in recovering defoliated plants even after severe decrease in leaf biomass due to a relatively long drought period. Recovery of leaves seems to have particularly been expressive given the high leaf/stem ratio observed in the rainy season (Fig. 3d). ICLF systems achieved levels of leaf and stem biomass near those from the beginning of grazing (Fig. 3a and b), which could be considered an advantage of these systems by decreasing the large fluctuation in forage availability normally existing between the dry and rainy seasons in OP systems.

Influence of production systems on grass nitrogen status

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Higher N concentrations in leaves, stems and leaves + stems of *U. brizantha* cv. BRS Piatã in the ICLF-T system in relation to the OP system in the dry season (Tables 1, 2) was likely caused by shading of trees. Carvalho et al. (2002) also observed higher N concentrations in leaves of *U. brizantha* cv. Marandu shaded by trees compared with the grass at full sun. Linear increases in leaf and stem N concentrations of this same cultivar as a function of shade levels was found by Castro et al. (1999). Similar results were also found by Guenni et al. (2008) for the same grass species even with external N supply.

The highest N concentration in both leaves and stems in the ICLF-T system compared with the OP system could have been caused by the N concentration effect, which occurs when the N uptake rate is less reduced than the growth rate by some limiting factor to plant growth (Jarrell and Beverly 1981). Leaf and stem biomass in the ICLF-T system was lower than that in the OP system likely due to shading as a limiting factor to the plant growth as already discussed (Fig. 3a and b). As a consequence of lower biomass, N was concentrated in leaves and stems in the ICLF-T system. This greater N concentration is important because it could help plants to tolerate subsequent low soil N availability or any other situation of restriction to N cycling in the pasture.

N concentrations in leaves and stems in the ICLF-M system were similar to the ICLF-T system, but this also was similar to the OP system (Tables 1 and 2). Such intermediate position for ICLF-M system may be due to a less intense shading of sward than that in the ICLF-T system. Lower shade intensity was likely a result of the African mahogany canopy less dense than that of the teak. Thus, more sunlight should have arrived to the sward, limiting the decrease in biomass of plants and consequently the N concentration effect in grass tissues in the ICLF-M system.

The leaf N concentrations available in Table 1 provide a unique opportunity for N nutrition diagnosis. However, diagnostic tools for evaluation N status in tropical forage plants

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are scarce. The critical N range suggested by Werner et al. (1997) is likely one of the most used tools to interpret N concentrations in *U. brizantha*. This range considers concentrations between 13 and 20 g kg^{-1} N in dry matter of green leaves collected in the active growing season of sward as being suitable for grasses of this species. In turn, concentrations below this range indicate deficiency and above luxury uptake.

In our work, active growing season was defined from December to April due to the more intense rainfall in this period (Fig. 1). Within this interval, we chose the N concentrations from January (i.e., 168 DABG, Table 1) because of the highest leaf dry matter (Fig. 3a), which could better reflect the N status of the grass under defoliation by grazing animals. Thus, N concentration in leaves in the OP system in January (i.e., 168 DABG, Table 1) was slightly below the lower limit of the N critical range (13 g kg^{-1} N), suggesting a discreet N deficiency. On the other hand, leaf N concentrations in the ICLF systems at the same month (Table 1) were within of the range, indicating N sufficiency. These interpretations, however, should be considered with caution, since the critical N range from Werner et al. (1997) was not originally developed for shaded plants as in ICLF systems. Even so, use of such a range is justified because it consists of the only available robust tool for interpretation of N status in *U. brizantha* grazed under continuous stocking in tropical environment at least in Brazil.

These N-diagnosis results indicate need for N application to pasture in the OP system but not in the ICLF systems. As a consequence, N-fertilizer management should be differentiated between the systems, likely with lower N-application rate and/or greater N-application interval in the ICLF systems than in the OP system. This would be a great advantage for ICLF systems by decreasing N-fertilizer intensive use in tropical pastures. Thus, lower GHG emissions (Bøckman and Olfs 1998), N leaching (Doole 2015) and soil acidification (Cai et al. 2014) due to N-fertilizer could be expected. From this, a higher level of sustainability in pastures under ICLF systems could also be achieved.

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Persistence of grass-N deficiency in the OP system for a long time can indicate a deficient N cycling and lead the pasture to decline if the stocking rate is not decreased (Boddey et al. 2004). As biomass in the rainy season was much lower as compared with that in the dry season (Fig. 3a, b and c) and stocking rate was not decreased over the study time, occurrence of an early stage of this decline cannot be discarded for the OP system.

The greater N accumulated in leaves, stems and stems + leaves in the OP system as compared with the ICLF systems immediately before the grazing (0 DABG, Table 2) was an exclusive result of the greater dry matter of these plant parts in the OP system in relation to the ICLF systems (Fig. 3), since no difference was found in tissue N concentrations between the systems (Table 1). In the curse of grazing, at 196 DABG, lower N accumulation in leaves and consequently in leaves + stems in the ICLF-M system in relation to the other systems (Table 2) was caused by lower dry matter of leaves in such a system (Fig. 3a).

N accumulation in aerial grass biomass is an important characteristic for sustainability of pastoral systems because it represents one of the pools that maintains the N cycle in grazed pastures (Boddey et al. 2004). N accumulated in leaves + stems varied considerably over the grazing time for all systems (Table 2) and it was most of the time below the lower limit of the range (30–60 kg ha^{-1} N) used by Boddey et al. (2004) to describe quantitatively the N cycle for a grazed *U. humidicola* pasture. This lower N accumulation could be due to differences between works in terms of climate, soil, production system, grass species and management, but it could also indicate some N cycling deficit. This possibility is consistent with the fact that no N-fertilizer was applied to pasture over the grazing time. The last application (50 kg N ha^{-1}) was performed two months before the beginning of grazing (see Materials and methods) and it seems to have been insufficient to maintain a high N accumulation in biomass. N contribution from tree leaves to grass N was not measured, but it could be considered of secondary importance in this work due to the long spacing between tree strips (50 m, Fig. 2). However,

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inputs of N from tree leaves deposited on the pasture can be as high as 19.7 kg ha^{-1} N year^{-1} (Xavier et al. 2014), but for legume tree and shorter spacing between tree strips.

Conclusion

In relation to the OP system, ICLF-M and ICLF-T systems decreased leaf and stem biomass of the grass but in compensation improved plant N nutrition in the first year of pasture exploration with beginning of grazing in the dry season.

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Table 1 Nitrogen (N) concentration in leaves, stems and leaves + stems of *Urochloa brizantha* cv. BRS Piatã grazed by buffaloes under continuous stocking in open pasture system (OP), integrated crop-livestock-forest system with African mahogany (ICLF-M) and ICLF system with teak (ICLF-T) over a 252-days grazing period across the dry (Jul-Nov 2017) and rainy (Dec 2017-Apr 2018) seasons

System	Days after the beginning of grazing									
	0 (Jul 2017)	28	56	84	112 (Nov 2017)	140 (Dec 2017)	168	196	224	252 (Apr 2018)
	N in leaves (g kg^{-1})									
OP	12.2 ± 0.8	11.2 ± 0.8	15.4 ± 0.4	14.8 ± 0.2b	13.5 ± 0.3	21.5 ± 1.0	12.8 ± 0.9b	15.4 ± 0.5	12.2 ± 0.7	14.7 ± 0.3
ICLF-M	11.9 ± 0.2	14.0 ± 0.4	16.3 ± 0.3	15.6 ± 0.3ab	12.9 ± 0.8	19.2 ± 1.1	14.7 ± 0.8ab	16.3 ± 0.7	13.5 ± 0.5	14.6 ± 0.3
ICLF-T	12.5 ± 0.4	13.8 ± 0.6	15.0 ± 1.1	17.2 ± 0.6a	14.5 ± 0.8	20.2 ± 0.2	15.9 ± 0.5a	16.0 ± 0.9	13.8 ± 0.2	15.7 ± 0.3
	N in stems (g kg^{-1})									
OP	4.5 ± 0.3	4.4 ± 0.7	4.4 ± 0.4	2.2 ± 0.1b	3.6 ± 0.4	5.5 ± 0.6b	11.2 ± 0.4	8.2 ± 1.0	6.8 ± 0.1	7.6 ± 0.2
ICLF-M	5.0 ± 0.1	4.2 ± 0.1	4.3 ± 0.1	2.8 ± 0.4ab	4.3 ± 0.5	7.1 ± 0.3ab	9.2 ± 0.8	7.3 ± 0.6	6.1 ± 0.2	7.1 ± 0.3
ICLF-T	5.1 ± 0.2	5.2 ± 0.3	4.3 ± 0.2	4.5 ± 0.8a	4.8 ± 0.4	8.7 ± 0.9a	9.2 ± 0.3	7.7 ± 0.4	6.7 ± 0.3	7.7 ± 0.3
	N in leaves + stems (g kg^{-1})									
OP	7.5 ± 0.4	6.6 ± 1.0	6.7 ± 0.6	4.7 ± 0.1b	5.6 ± 0.2	11.0 ± 0.6	12.1 ± 0.5	10.7 ± 0.6	8.7 ± 0.2	9.4 ± 0.9
ICLF-M	7.8 ± 0.2	6.9 ± 0.2	7.0 ± 0.1	4.9 ± 0.3b	6.6 ± 0.7	13.1 ± 0.8	12.3 ± 0.8	10.0 ± 0.4	9.0 ± 0.4	8.5 ± 0.3
ICLF-T	8.1 ± 0.3	7.9 ± 0.2	7.0 ± 0.2	7.3 ± 0.9a	7.0 ± 0.4	14.4 ± 0.8	12.6 ± 0.4	10.7 ± 0.4	9.6 ± 0.1	9.9 ± 0.7

Values are means ± SE ($n = 4$). Means followed by different letters within a column for each plant part are significantly different according to LSD ($P < 0.05$). Means that are not followed by letters indicate *F* test from ANOVA not significant ($P > 0.05$).

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Table 2 Nitrogen (N) accumulated in leaves, stems and leaves + stems of *Urochloa brizantha* cv. BRS Piatã grazed by buffaloes under continuous stocking in open pasture system (OP), integrated crop-livestock-forest system with African mahogany (ICLF-M) and ICLF system with teak (ICLF-T) over a 252-days grazing period across the dry (Jul-Nov 2017) and rainy (Dec 2017-Apr 2018) seasons

System	Days after the beginning of grazing									
	0 (Jul 2017)	28	56	84	112 (Nov 2017)	140 (Dec 2017)	168	196	224	252 (Apr 2018)
	N in leaves (kg ha^{-1})									
OP	26.2 ± 1.3a	15.7 ± 3.3	9.4 ± 0.7	7.6 ± 0.6	4.0 ± 0.4	10.2 ± 2.0	17.0 ± 1.5	13.6 ± 1.0a	7.6 ± 0.5	13.7 ± 1.8
ICLF-M	14.0 ± 1.4c	9.9 ± 1.3	8.3 ± 0.8	5.7 ± 1.0	2.9 ± 0.1	8.9 ± 0.7	21.1 ± 2.7	9.7 ± 1.0b	7.2 ± 0.7	10.8 ± 0.9
ICLF-T	18.3 ± 2.3b	12.1 ± 1.4	8.7 ± 1.0	6.3 ± 1.6	3.1 ± 0.9	12.6 ± 2.2	24.5 ± 1.8	16.1 ± 1.2a	8.5 ± 0.9	10.7 ± 0.8
	N in stems (kg ha^{-1})									
OP	14.7 ± 0.7a	12.2 ± 1.3	10.8 ± 1.6	4.8 ± 0.6	4.3 ± 0.7	4.8 ± 0.4	12.8 ± 1.4	14.6 ± 2.9	8.0 ± 1.0	6.8 ± 0.9
ICLF-M	8.6 ± 1.3b	7.9 ± 1.5	7.6 ± 0.6	5.3 ± 0.6	2.6 ± 0.2	3.4 ± 0.4	10.0 ± 1.7	10.1 ± 1.4	5.5 ± 1.0	5.3 ± 0.4
ICLF-T	11.3 ± 2.2b	10.3 ± 1.7	7.3 ± 1.1	6.0 ± 1.8	4.3 ± 2.1	6.1 ± 2.2	13.6 ± 1.2	14.5 ± 2.5	6.2 ± 1.1	5.1 ± 0.7
	N in leaves + stems (kg ha^{-1})									
OP	40.9 ± 1.6a	27.9 ± 4.5	20.2 ± 1.9	12.3 ± 1.2	8.2 ± 0.8	15.0 ± 2.0	29.8 ± 2.3	28.2 ± 2.1a	15.5 ± 0.9	20.5 ± 2.5
ICLF-M	22.6 ± 2.7c	17.8 ± 2.8	15.9 ± 1.4	11.0 ± 1.3	5.5 ± 0.3	12.2 ± 1.0	31.1 ± 4.3	19.8 ± 1.8b	12.7 ± 1.5	16.0 ± 1.3
ICLF-T	29.6 ± 4.3b	22.4 ± 1.7	15.9 ± 2.0	12.2 ± 3.4	7.4 ± 3.1	18.7 ± 4.3	38.1 ± 2.8	30.6 ± 3.2a	14.8 ± 1.9	15.8 ± 1.4

Values are means ± SE ($n = 4$). Means followed by different letters within a column for each plant part are significantly different according to LSD ($P < 0.05$). Means that are not followed by letters indicate F test from ANOVA not significant ($P > 0.05$).

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Table 3 Nitrogen (N) concentration in leaves, stems and leaves + stems of *Urochloa brizantha* cv. BRS Piatã grazed by buffaloes under continuous stocking in open pasture system (OP), integrated crop-livestock-forest system with African mahogany (ICLF-M) and ICLF system with teak (ICLF-T) in the dry (Jul-Nov 2017) and rainy (Dec 2017-Apr 2018)

	Dry season			Rainy season		
System	N in leaves (g kg^{-1})	N in stems (g kg^{-1})	N in leaves + stems (g kg^{-1})	N in leaves (g kg^{-1})	N in stems (g kg^{-1})	N in leaves + stems (g kg^{-1})
OP	13.4 ± 0.3b	3.8 ± 0.1b	6.7 ± 0.2b	14.7 ± 0.3	7.6 ± 0.2	10.6 ± 0.1
ICLF-M	14.1 ± 0.2ab	4.1 ± 0.2ab	6.9 ± 0.3b	14.6 ± 0.3	7.1 ± 0.3	10.6 ± 0.3
ICLF-T	14.6 ± 0.2a	4.8 ± 0.2a	7.9 ± 0.2a	15.7 ± 0.3	7.7 ± 0.3	11.3 ± 0.3

Values are means ± SE ($n = 4$). Means followed by different letters within a column are significantly different according to LSD ($P < 0.05$). Means that are not followed by letters indicate F test from ANOVA not significant ($P > 0.05$).

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Table 4 Nitrogen (N) accumulated in leaves, stems and leaves + stems of *Urochloa brizantha* cv. BRS Piatã grazed by buffaloes under continuous stocking in open pasture system (OP), integrated crop-livestock-forest system with African mahogany (ICLF-M) and ICLF system with teak (ICLF-T) in the dry (Jul-Nov 2017) and rainy (Dec 2017-Apr 2018)

	Dry season			Rainy season		
System	N in leaves (kg ha^{-1})	N in stems (kg ha^{-1})	N in leaves + stems kg ha^{-1})	N in leaves (kg ha^{-1})	N in stems (kg ha^{-1})	N in leaves + stems kg ha^{-1})
OP	13.4 ± 0.3a	9.2 ± 0.8	22.6 ± 1.0a	12.8 ± 0.5	9.2 ± 0.7	22.0 ± 1.0
ICLF-M	8.4 ± 0.7b	6.4 ± 0.6	14.9 ± 1.3b	11.7 ± 0.9	6.8 ± 0.8	18.4 ± 1.7
ICLF-T	10.3 ± 1.2b	7.8 ± 1.8	18.1 ± 2.9ab	14.3 ± 0.7	9.0 ± 1.4	23.3 ± 2.1

Values are means ± SE (*n* = 4). Means followed by different letters within a column are significantly different according to LSD ($P < 0.05$). Means that are not followed by letters indicate *F* test from ANOVA not significant ($P > 0.05$).

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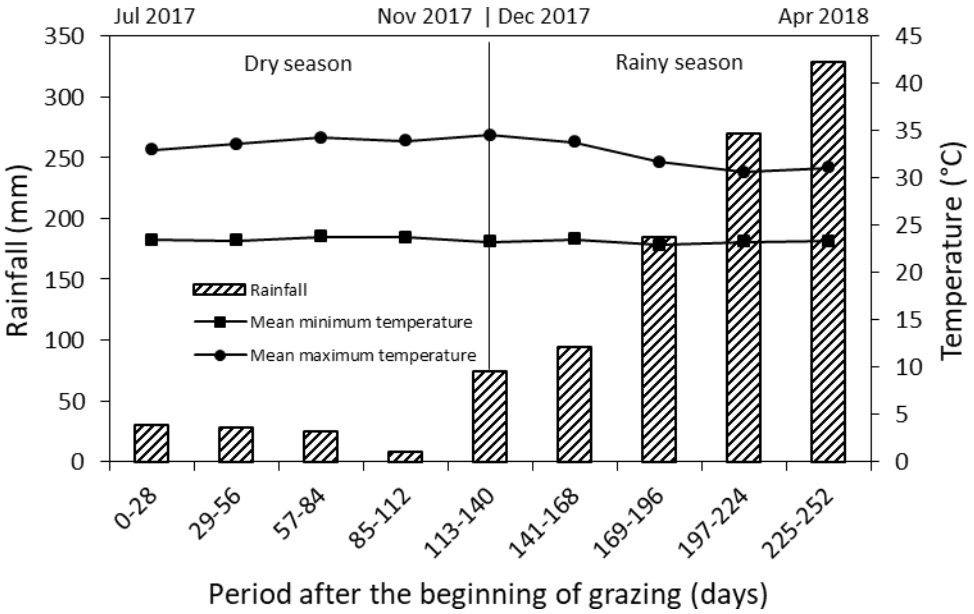

Fig. 1 Rainfall distribution and mean minimum and maximum temperatures over the grazing period

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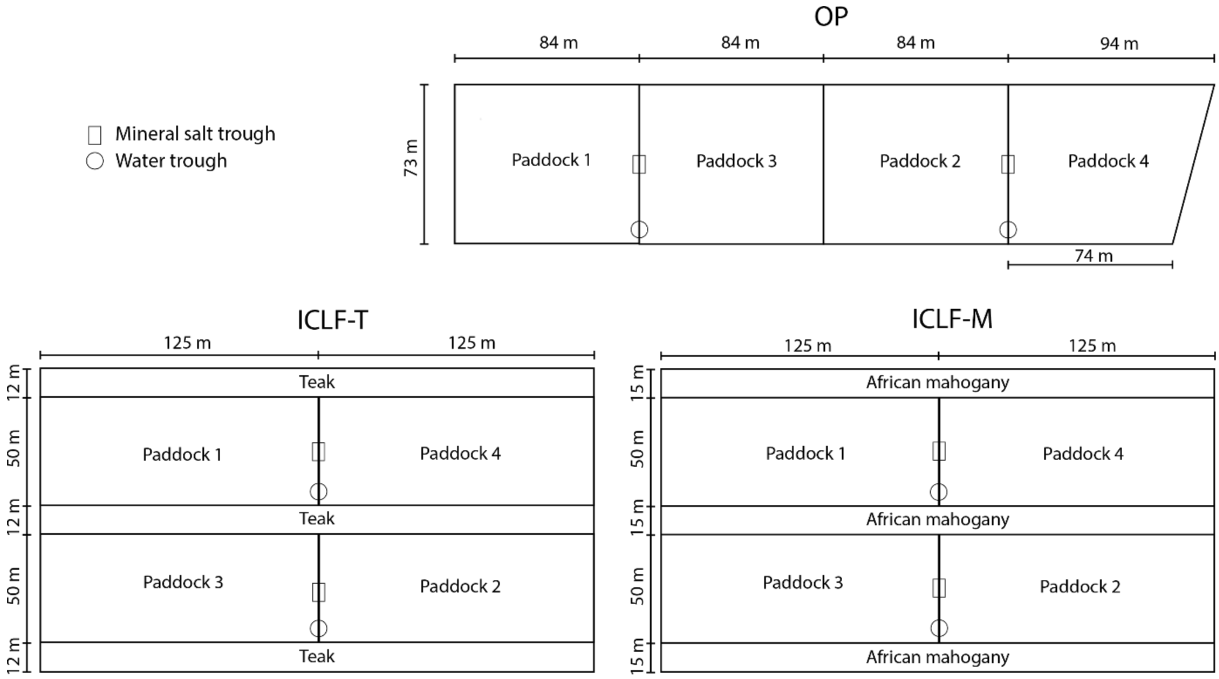

Fig. 2 Representation of the production systems in the field. OP: open pasture system. ICLF-M: integrated crop-livestock-forest system with African mahogany. ICLF-T: ICLF system with teak. Within the area of each system, paddocks of different blocks were distributed alternately. Paddocks with the same number in different systems corresponded to a same block

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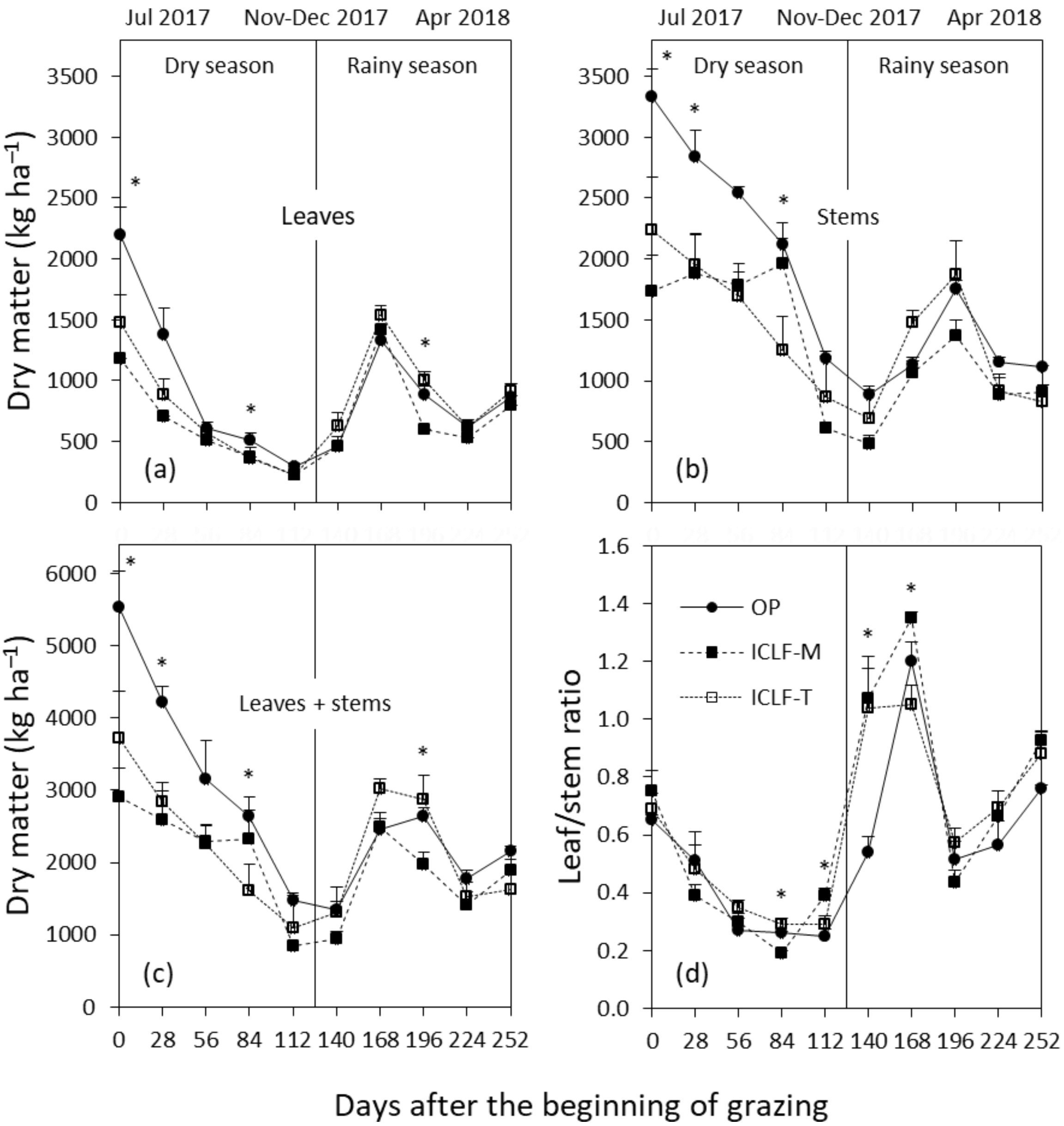

Fig. 3 Dry matter of leaves (a), stems (b) and leaves + stems (c), and leaf/stem ratio (d) for *Urochloa brizanta* cv. Piatã grazed by buffaloes under continuous stocking in open pasture system (OP), integrated crop-livestock-forest system with African mahogany (ICLF-M) and ICLF system with teak (ICLF-T) over a 252-days grazing period across the dry (Jul-Nov 2017) and rainy (Dec 2017-Apr 2018) seasons. Bars represent SEs (*n* = 4). Asterisks indicate means between systems significantly different by the LSD test (*P* < 0.05) within each grazing time.

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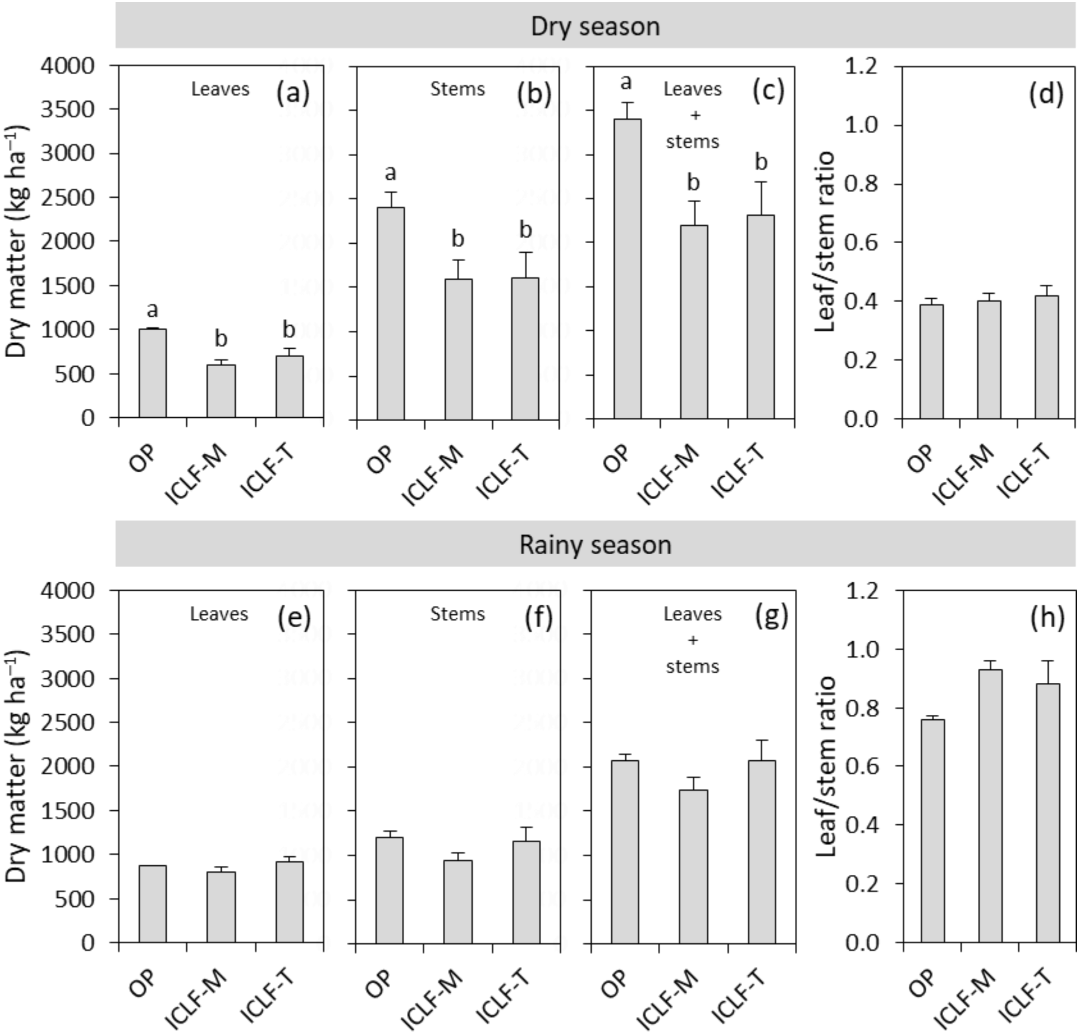

Fig. 4 Dry matter of leaves (a, e), stems (b, f) and leaves + stems (c, g), and leaf/stem ratio (d, h) for *Urochloa brizanta* cv. Piatã grazed by buffaloes under continuous stocking in open pasture system (OP), integrated crop-livestock-forest system with African mahogany (ICLF-M) and ICLF system with teak (ICLF-T) in the dry (Jul-Nov 2017) and rainy (Dec 2017-Apr 2018) seasons. Lines on the bars represent SEs (*n* = 4). Different letters on the bars for each plant part indicate difference between means according to LSD ($P < 0.05$). Bars without letters indicate *F* test from ANOVA not significant ($P > 0.05$)

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4. CONCLUSÕES GERAIS

Os sistemas ILPF podem ser menos produtivos em forragem do que o sistema PA, na estação seca. No entanto, podem fornecer forragem com o maior teor de proteína bruta nesta estação, dependendo das espécies de árvores que compõem o sistema. Na estação chuvosa, todas essas diferenças tendem a ser eliminadas. Independentemente do sistema, a massa de forragem diminui ao longo do tempo nas estações seca e chuvosa como efeito do pastejo sob lotação contínua. A proteína bruta da forragem também pode diminuir, mas dentro de cada estação. Apesar desse declínio, o teor de proteína bruta é maior na estação chuvosa do que na estação seca. Forragem de melhor qualidade pode levar a um maior ganho de peso diário e maior taxa de lotação de búfalos na estação chuvosa, independentemente do sistema. A estação altera a produtividade e a qualidade da forragem, bem como o desempenho animal, enquanto o pastejo determina a dinâmica da pastagem nos sistemas ILPF. Em relação ao sistema PA, os sistemas ILPF-M e ILPF-T diminuíram também a biomassa da folha e do colmo da gramínea, mas em compensação melhoraram a nutrição nitrogenada da planta no primeiro ano de exploração das pastagens com o início do pastejo na estação seca.