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Limiting Dynamics of pastures grazed under continuous stocking in integrated crop-livestock-forest systems

Dinâmica de pastagens sob lotação contínua em sistemas integrados de lavoura-pecuária-floresta

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Resumo:

A estação e o pastejo podem alterar as respostas das pastagens, mesmo em sistemas inovadores e sustentáveis, como os de integração lavoura-pecuária-floresta (ILPF). O objetivo deste trabalho foi avaliar a dinâmica inicial de pastagens de *Urochloa brizantha* cv. Piatã sob pastejo contínuo, por búfalos, em sistema de pastagem aberta (PA), em ILPF com mogno africano (*Khaya ivorensis*) (ILPF-M) e em ILPF com teca (*Tectona grandis*) (ILPF-T), ao longo do tempo, durante as primeiras estações seca e chuvosa. A massa e a proteína bruta da forragem foram avaliadas a cada 28 dias ao longo de um período de 252 dias. A massa da forragem foi menor nos sistemas ILPF do que no sistema PA na estação seca. Em contraste, no sistema ILPF-T, a forragem apresentou o maior teor de proteína bruta nesta estação. Na estação chuvosa, nenhuma diferença entre os sistemas foi observada. A massa da forragem diminuiu em todos os sistemas ao longo do tempo, durante as estações seca e chuvosa, devido ao pastejo. Os teores de proteína bruta também diminuíram dentro de cada estação, mas esses teores foram maiores na estação chuvosa do que na estação seca. A estação altera a produtividade e a qualidade da forragem, enquanto o pastejo determina a dinâmica inicial de pastagens em sistemas ILPF.

Palavras-Chave: sistema agrossilvopastoril, *Urochloa brizantha*, proteína bruta, pastagem tropical

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 initial dynamics of *Urochloa brizantha* 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 first dry and rainy seasons. Mass and crude protein of forage were evaluated every 28 days over a 252-days 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. The season changes the productivity and quality of forage while the grazing determinates the initial dynamics of pastures in ICLF systems.

Keywords: agrosilvopastoral system, *Urochloa br*izantha, 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. By combining different economic activities, ICLF systems have been found to be a low risk, economically viable enterprise (Meo-Filho *et al*., 2022). 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 (Almeida *et al*., 2019). Furthermore, decrease in greenhouse gas emission (GHG) is a potential benefit of integrated systems for animal production, as found by Meo-Filho *et al*. (2022). 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 17 million ha (ICLF Network, 2023).

However, shade of trees can consecutively decrease photosynthesis and growth of tropical forage plants (Santos *et al*., 2023) 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 *et al*. (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.

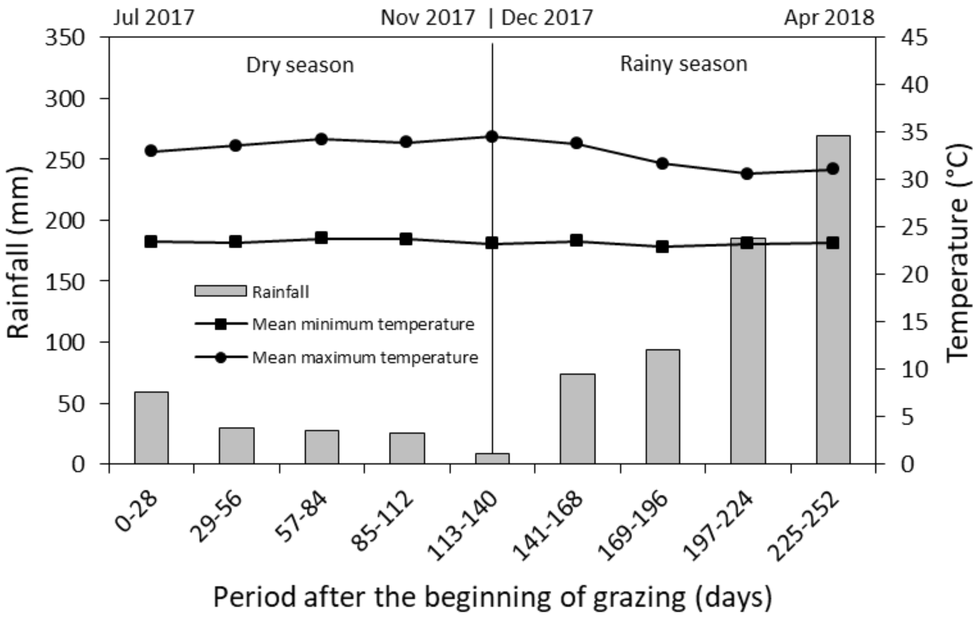
A forage dynamics analysis can for example reveal that grazing is the determining factor for decreasing both supply and forage quality in a pasture over time even when whether conditions are not limiting to plant growth. It can also indicate in advance if grazing intensity in a specific time is leading 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 forage quality between ICLF and OP systems can depend on the season. Moreover, grazing is believed to determine the pasture dynamics regardless of system and season. Effects of season and grazing can be more evident in the initial pasture use stage since the plants are adapting to defoliation performed by animals. This work aimed to evaluate the initial 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 first dry and rainy seasons.

2. Materials and Methods

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 the regional climate is Am (tropical monsoon) by the Köppen's classification. Rainfall and temperature during the study period are presented in Figure 1. The data used in this figure are from the Castanhal municipality (Inmet, 2023), since Terra Alta does not have available climatic records and these municipalities are adjacent to each other.

Figure 1. Rainfall distribution and mean minimum and maximum temperatures over the study period
Figura 1. Distribuição das chuvas e temperaturas mínimas e máximas médias durante o período de estudo



The soil in this area is an *Argissolo Amarelo Distrófico textura arenosa/média* (Gama et al., 2000) by the Brazilian Soil Classification System, corresponding to Ultisol in Soil Taxonomy (Soil Survey Staff, 2022).

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 (Moraes Neto, 2019; Tomaselli & Hirakuri, 2023). 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.

In both ICLF systems, maize (*Zea mays* L. cv. BRS 1030) was cultivated in the areas between tree strips from 2009 to 2013. Cowpea [*Vigna unguiculata* (L.) Walp cv. BRS Guariba] was sown in the first year after harvest of maize as a second crop.

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. 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, 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 and OP system were divided into four subareas. Thus, the three production systems (OP, ICLF-M and ICLF-T) were replicated four times.

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 weighing 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.

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.

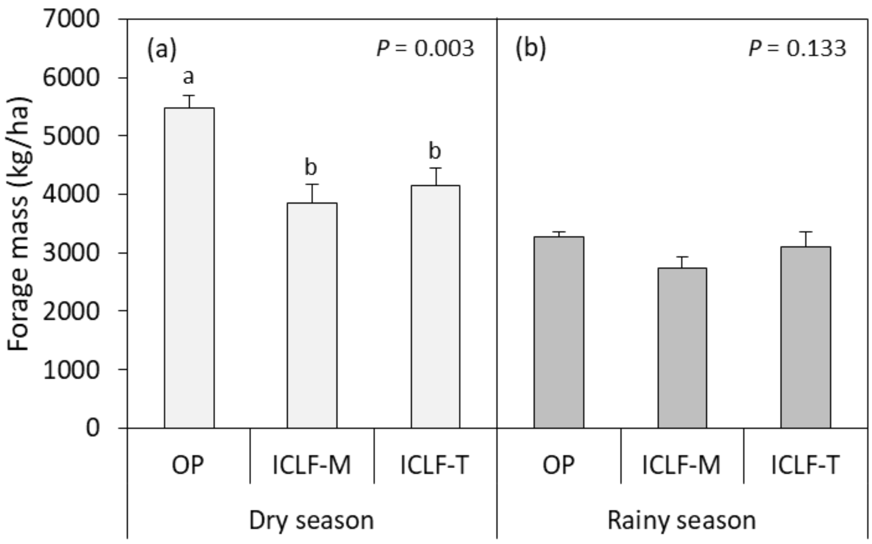
Data were analyzed using a randomized complete block design with four replicates, each one allocated in a paddock. Replicates were considered as blocks in order to capture possible variability among paddocks. Effects of production systems were tested using an analysis of variance (ANOVA) performed for each variable in each evaluation time. Additional ANOVA was run for production systems within each season (dry and rainy). When the 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 heteroscedasticity 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 using Spearman's 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, 2019).

3. Results and discussion

There was difference in forage mass between production systems but only for the dry season (Figure 2a). In general, OP had greater forage mass compared with the ICLFs systems. For the rainy season, no difference was observed (Figure 2b). 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, $p < 0.001$, $n = 60$).

Figure 2. Forage mass of *Urochloa brizantha* 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 the dry season indicate difference between means according to LSD ($p < 0.05$). Bars without letters within the rainy season indicate *F* test from ANOVA not significant ($P > 0.05$). Lines on the bars represent standard error of the mean

Figura 2. Massa de forragem de *Urochloa brizantha* cv. Piatã pastejada por búfalos sob lotação contínua em sistema de pastagem aberta (PA), sistema integrado lavoura-pecuária-floresta com mogno africano (ILPF-M) e sistema ILPF com teca (ILPF-T) nos períodos seco (Jul-Nov 2017) e chuvoso (Dez 2017-Abr 2018). (b). *P*-valor: probabilidade para o teste *F* da ANOVA. Letras diferentes nas barras dentro de cada estação indicam diferença entre as médias de acordo com o LSD ($p < 0,05$). As linhas nas barras representam o erro padrão da média



The greater forage mass in the OP system compared with ICLF systems (Figure 2a) 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 et al. (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.

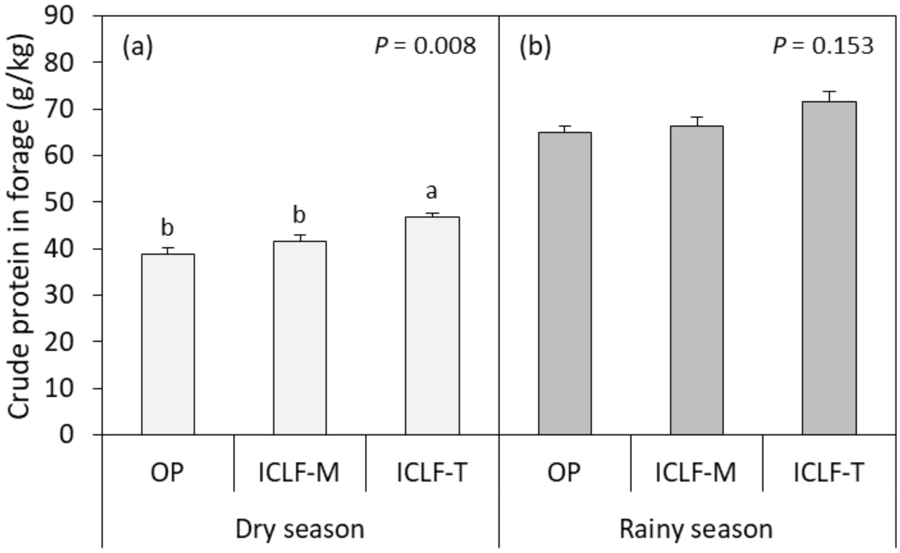
It can be explained by the decline in net photosynthesis rate (Gomes *et al*., 2019) accompanied by less tillering and reduced relative growth rate resulting in lower shoot dry matter (Brunetti *et al*., 2022; Lima *et al*., 2021) have been observed in shaded *U. brizantha*. In addition, this species submitted to shading has shown lower total nonstructural carbohydrate (TNC) content in stem base due to negative impact on photosynthesis derived from decrease in incident light (Lima *et al*., 2021). 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 grazing animals, especially when a considerable proportion of leaves are removed (Tahmasebi *et al*., 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 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 1 and Figure 2a), which suggests a seasonal fluctuation for the effect of shading on forage mass.

No system influenced the crude protein content in forage in each evaluation time. Nevertheless, as a mean for the dry season, crude protein in the ICLF-T system was higher than those in the OP and ICLF-M systems (Figure 3a). But within the rainy season, no difference was observed between systems (Figure 3b). 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, $n = 60$).

Figure 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) 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 the dry season indicate difference between means according to LSD ($p < 0.05$). Bars without letters within the rainy season indicate *F* test from ANOVA not significant ($P > 0.05$). Lines on the bars represent standard error of the mean.

Figura 3. Proteína bruta de *Urochloa brizanta* cv. Piatã pastejada por búfalos sob lotação contínua em sistema de pastagem aberta (PA), sistema integrado lavoura-pecuária-floresta com mogno africano (ILPF-M) e sistema ILPF com teca (ILPF-T) nos períodos seco (Jul-Nov 2017) e chuvoso (Dez 2017-Abr 2018). (b). *P*-valor: probabilidade para o teste *F* da ANOVA. Letras diferentes nas barras dentro de cada estação indicam diferença entre as médias de acordo com o LSD ($p < 0,05$). Barras sem letras na estação chuvosa indicam que o teste *F* da ANOVA não é significativo ($p > 0.05$). As linhas nas barras representam o erro padrão da média.



Shading also seems to have been the cause of the highest crude protein content in forage in the ICLF-T system for the dry season (Figure 3a). Increase in crude protein in *Urochloa*-grass pastures shaded by trees at silvopastoral systems have been found in other studies (Lima *et al*., 2019; Moreno *et al*., 2022; Santos *et al*., 2023). 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, 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.

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-days period, forage mass decreased with the grazing time in all systems (Figure 4). Decrease for the OP system was progressive in the dry season but with a tendency of stabilizing in the rainy season (Figure 4a). 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 4b, 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 4b). 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 4b) 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 4c).

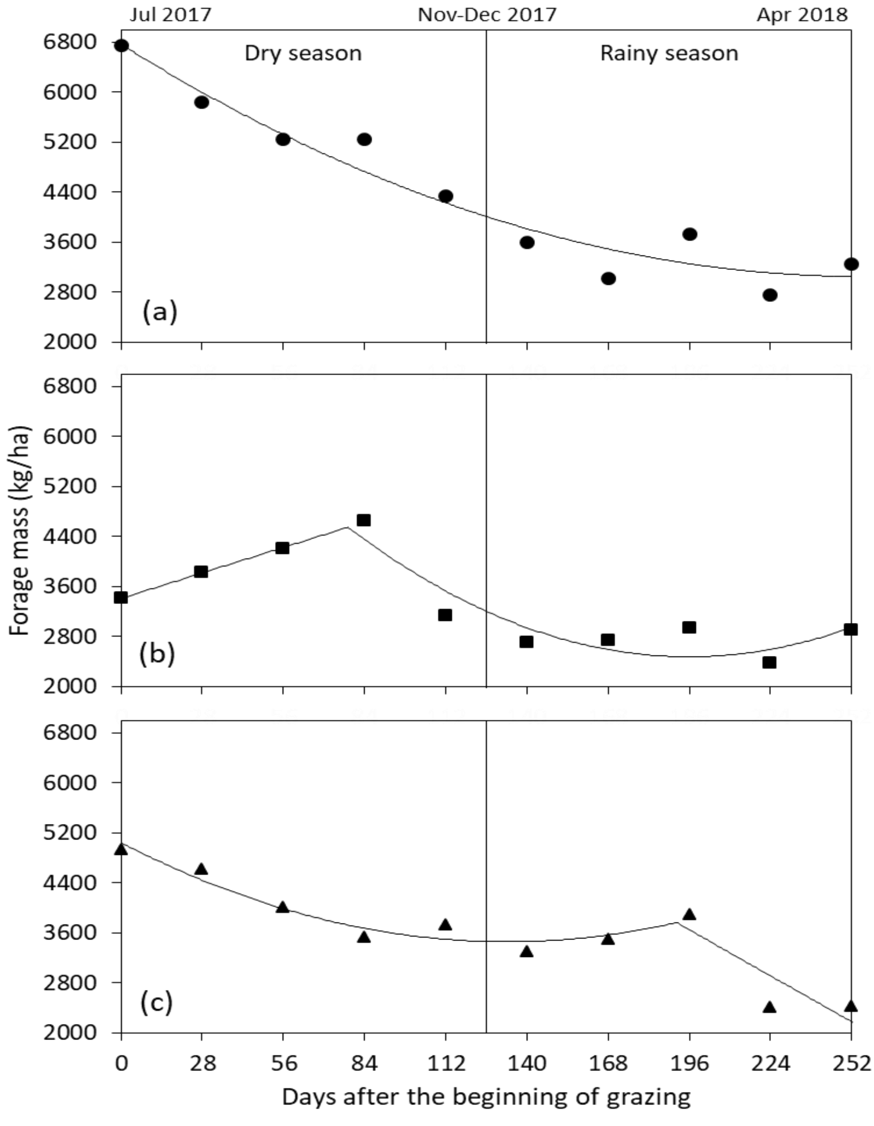
Decrease in forage mass with the time of grazing across the dry and rainy seasons in all production systems tested in this work (Figure 4) shows an imbalance between removal of forage by animals and regrowth of defoliated plants. Defoliation decreased the foliar area and less photosynthesis was carried 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 4a). 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 4b) was due to the lesser 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 4b). 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 4c) probably due to a higher forage intake by grazing animals.

Figure 4. 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. ● $\hat{y} = 6767.7300 - 28.9909^{***}x + 0.0565^{**}x^2$ | $R^2 = 0.9394$ | $0 \leq x \leq 252$. ■ $\hat{y} = 3409.9750 + 14.5571^{**}x$ | $R^2 = 0.9990$ | $0 \leq x \leq 78$. ■ $\hat{y} = 8229.4700 - 58.7631^{***}x + 0.1500^{***}x^2$ | $R^2 = 0.8227$ | $79 \leq x \leq 252$. ▲ $\hat{y} = 5043.9580 - 23.8463^{***}x + 0.0896^{**}x^2$ | $R^2 = 0.9307$ | $0 \leq x \leq 192$. ▲ $\hat{y} = 8797.8330 - 26.2634^{***}x$ | $R^2 = 0.7402$| $193 \leq x \leq 252$. ** $p < 0.01$. *** $p < 0.001$

Figura 4. Dinâmica da massa de forragem para *Urochloa brizanta* cv. Piatã pastejada por búfalos sob lotação contínua em sistema de pastagem aberta (PA) (a), sistema integrado lavoura-pecuária-floresta com mogno africano (ILPF-M) (b) e sistema ILPF com teca (ILPF-T) (c) ao longo do tempo de pastejo nas estações seca (Jul-Nov 2017) e chuvosa (Dez 2017-Abr 2018). ● $\hat{y} = 6767.7300 - 28.9909^{***}x + 0.0565^{**}x^2$ | $R^2 = 0.9394$ | $0 \leq x \leq 252$. ■ $\hat{y} = 3409.9750 + 14.5571^{**}x$ | $R^2 = 0.9990$ | $0 \leq x \leq 78$. ■ $\hat{y} = 8229.4700 - 58.7631^{***}x + 0.1500^{***}x^2$ | $R^2 = 0.8227$ | $79 \leq x \leq 252$. ▲ $\hat{y} = 5043.9580 - 23.8463^{***}x + 0.0896^{**}x^2$ | $R^2 = 0.9307$ | $0 \leq x \leq 192$. ▲ $\hat{y} = 8797.8330 - 26.2634^{***}x$ | $R^2 = 0.7402$| $193 \leq x \leq 252$. ** $p < 0.01$. *** $p < 0.001$



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 that stimulate the regrowth of defoliated plants should be adopted. Specific studies on modeling of defoliated plant regrowth (Parsons *et al.*, 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.

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 5a). 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 5b). 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 5c). 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.

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).

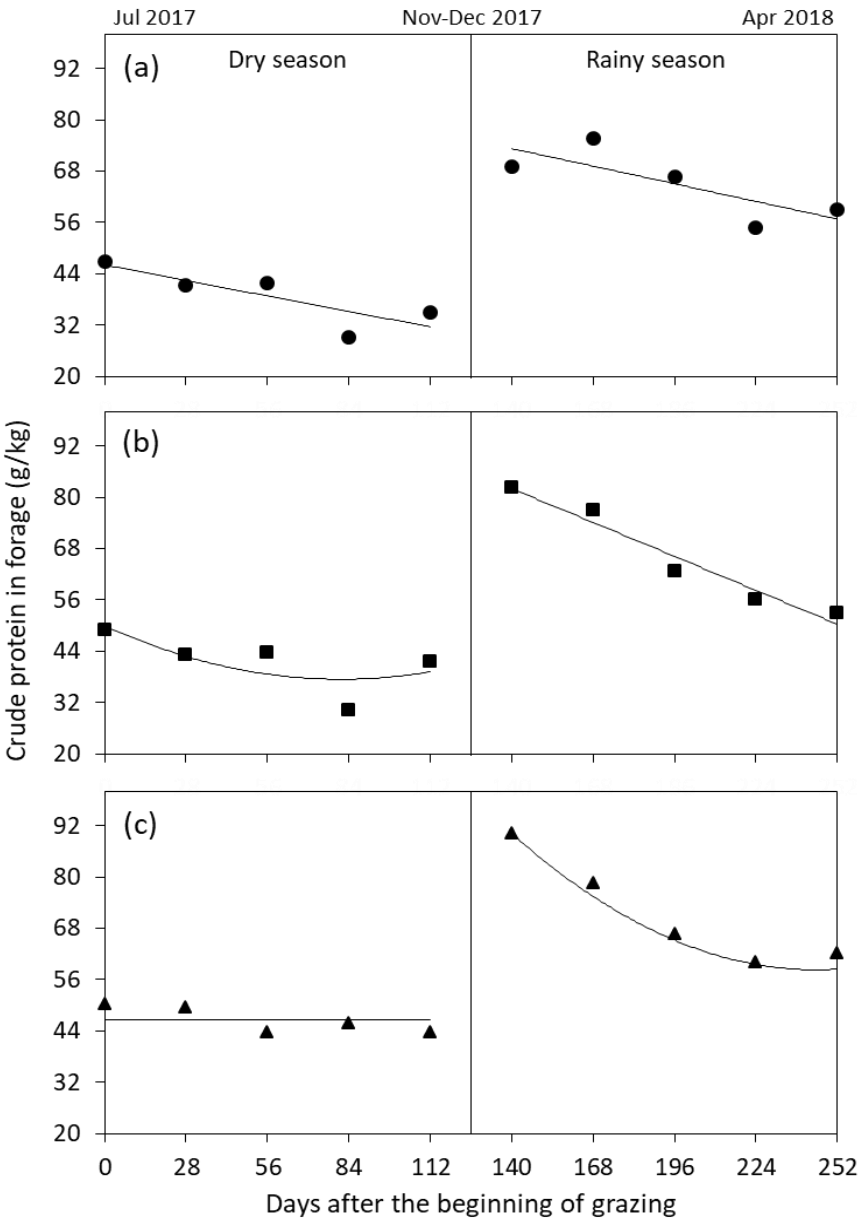
The pasture dynamics pattern for the crude protein was clearly related with the season. The greater crude protein content in the rainy season relatively to the dry season (Figure 5) is probably related to a greater available N concentration in soil. The increase in N availability may have occurred due 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 and that mineralized N is correlated with N uptake by plants (Ali et al., 2021; Chen et al., 2024). 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. Carvalho, et al. (2022) also observed higher crude protein levels with increased rainfall and the resulting availability of water in the soil.

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 5a, 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 5c), 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 5) 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. 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 in the dry season (Figure 5) 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 70 g/kg (Van Soest, 1994), no forage met this standard level in the dry season. On the other hand, the crude protein contents in the rainy season (Figure 5) were always sufficient for buffalos and occasionally sufficient for cattle.

Figure 5. Crude protein in forage of *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. ● $\hat{y} = 46.0650 - 0.1292^{**}x$ | $R^2 = 0.6971$ | $0 \leq x \leq 112$. ● $\hat{y} = 93.8545 - 0.1470^{**}x$ | $R^2 = 0.6097$ | $140 \leq x \leq 252$. ■ $\hat{y} = 49.9761 - 0.3086^{**}x + 0.0019^{*}x^2$ | $R^2 = 0.5681$ | $0 \leq x \leq 112$. ■ $\hat{y} = 121.6121 - 0.2828^{***}x$ | $R^2 = 0.9503$ | $140 \leq x \leq 252$. ▲ $\hat{y} = 46.63$ | $0 \leq x \leq 112$. ▲ $\hat{y} = 232.2817 - 1.4207^{**}x + 0.0029^{**}x^2$ | $R^2 = 0.9872$| $140 \leq x \leq 252$. * $p < 0.05$. ** $p < 0.01$. *** $p < 0.001$

Figura 5. Proteína bruta em forragem de *Urochloa brizanta* cv. Piatã pastejada por búfalos sob lotação contínua em sistema de pastagem aberta (PA) (a), sistema integrado lavoura-pecuária-floresta com mogno africano (ILPF-M) (b) e sistema ILPF com teca (ILPF-T) (c) ao longo do tempo de pastejo nas estações seca (Jul-Nov 2017) e chuvosa (Dez 2017-Abr 2018). ● $\hat{y} = 46.0650 - 0.1292^{**}x$ | $R^2 = 0.6971$ | $0 \leq x \leq 112$. ● $\hat{y} = 93.8545 - 0.1470^{**}x$ | $R^2 = 0.6097$ | $140 \leq x \leq 252$. ■ $\hat{y} = 49.9761 - 0.3086^{**}x + 0.0019^{*}x^2$ | $R^2 = 0.5681$ | $0 \leq x \leq 112$. ■ $\hat{y} = 121.6121 - 0.2828^{***}x$ | $R^2 = 0.9503$ | $140 \leq x \leq 252$. ▲ $\hat{y} = 46.63$ | $0 \leq x \leq 112$. ▲ $\hat{y} = 232.2817 - 1.4207^{**}x + 0.0029^{**}x^2$ | $R^2 = 0.9872$| $140 \leq x \leq 252$. * $p < 0.05$. ** $p < 0.01$. *** $p < 0.001$



4. Final Considerations

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. The season changes the productivity and quality of forage while the grazing determinates the initial dynamics of pastures in ICLF systems.

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