ISSN 1519-9940
Revista Brasileira de Saúde e Produção Animal
http://dx.doi.org/10.1590/S1519-994020230006

Received: 06/03/2023
Accepted: 11/04/2024

Forestry and Grassland
Editor: Carlos P. Cavalheiro

Silvopastoral system with high-density of trees accelerates degradation of tropical grass

Sistema de silvipastoril com alta densidade de árvores acelera a degradação de capim tropical

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ABSTRACT Tree density is an important aspect in silvopastoral system (SPS) planning, since low luminosity can limit forage perenniality, especially for tropical forages of C4 metabolism. The objective with this study was to verify if an SPS with high tree density accelerates the pasture degradation process and changes the forage chemical composition. The experiment was carried out by comparison of marandu palisade grass [*Urochloa brizantha* (Hochst. ex A. Rich.) R. D. Webster] pasture in two systems: silvopastoral and open pasture. In the SPS, teak (*Tectona grandis*) was planted with a density of 750 trees ha^{-1}. Evaluations were carried out over three years (2015, 2016 and 2017). SPS shading reduced herbage mass, tiller density and soil cover over the years. In the marandu palisade grass in the SPS there was a greater stem proportion, which favoured lesser potential digestible dry matter in the first year. Even with a higher amount of stem, higher crude protein concentration and minerals were observed in the SPS. Due to the high density of trees, excessive shading accelerated the process of degradation of the pasture, which demonstrates that planning of the spatial arrangement of tree species is crucial.

Keywords forest, integration, shading

RESUMO *A densidade de árvores é um aspecto importante no planejamento de sistemas silvipastoris (SPS), uma vez que a baixa luminosidade pode limitar a perenidade da forragem, principalmente para forrageiras tropicais de metabolismo C4. O objetivo com este estudo foi verificar se um SPS com alta densidade de árvores acelera o processo de degradação da pastagem e altera a composição química da forragem. O experimento foi realizado comparando a pastagem de capim-marandu [Urochloa brizantha (Hochst. ex A. Rich.) R. D. Webster] em dois sistemas: silvipastoril e pastagem aberta. No SPS foi plantada teca (Tectona grandis) com densidade de 750 árvores ha*$^{-1}$*. As avaliações foram realizadas ao longo de três anos (2015, 2016 e 2017). O sombreamento SPS reduziu a massa de forragem, a densidade de perfilhos e a cobertura do solo ao longo dos anos. No capim-marandu no SPS houve maior proporção de colmos, o que favoreceu menor potencial digestível de matéria seca no primeiro ano. Mesmo com maior quantidade de colmo, maior concentração de proteína bruta e minerais foram observados no SPS. Devido à alta densidade de árvores, o sombreamento excessivo acelerou o processo de degradação da pastagem, o que demonstra que o planejamento da ordenação espacial das espécies arbóreas é fundamental.*

Palavras-chave *floresta, integração, sombra*

1. Introduction

Integrated production between silviculture and livestock increases sustainability in the system through nutrients cycling (Salton et al., 2014; Hoosbeek et al., 2018), improving land use capacity, which reduces the demand for native areas opening. Nutrient cycling mitigates the use of fertilizers and inputs (Xavier et al., 2011), which is important from an environmental and economic perspective. In addition, there are mutual benefits for animals and trees (Pontes et al., 2018; Améndola et al., 2019), which contributes to the system being environmentally sustainable and economically viable.

The exploration of secondary attributes of agroforestry generated by ecosystem diversification, helps producers in the inputs production from litter deposition in the soil, providing an increase in soil biodiversity, besides generating extra income from wood exploitation (Paciullo et al., 2017). Forage species may benefit from increased nutritive value, mainly by increasing leaf/stem ratio of shaded plants (Lima et al., 2019), which may benefit grazing animals. Possible benefits found in forage species in SPS should be better studied and explored.

In order for the SPS to have more synergistic interactions, it is necessary to carry out careful planning, especially regarding the forage choice and the spacing used in the forest (Rodrigues et al., 2016; Paciullo et al., 2017). This is particularly important because luminosity is a limiting factor for forage perenniality of forage grasses, especially those of C4 metabolism, which are the most common in tropical farming systems.

Light incidence can be altered by some factors such as tree spacing, arboreal component selection as a function of canopy characteristics, management by thinning and selecting forage species that are more tolerant to shading (Santos et al., 2016). As a result of the shade projected by SPS treetops, forages reduce tillering and productivity (Abraham et al., 2014; Paciullo et al., 2017; Faria et al., 2018), accelerating the pasture degradation process.

In systems with high tree density, these effects that reduce forage development are more accentuated due to the high interception of light by the trees, which can reduce the life cycle of grazing system. In this context, the objective with this study was to verify if an SPS with high tree density accelerates the pasture degradation process and changes forage chemical composition. The introduction should briefly state the context of the study and why it is important. The current state of the research must be carefully reviewed, and key publications must be cited. At the end of the introduction, the purpose of the work must be clear. Please keep the introduction comprehensible for scientists from different fields of research.

2. Material and methods

The experiment was carried out in Indiavaí, Mato Grosso, Brazil (15º27 'S, 58º34'W; altitude of 194 m), in a system with Marandu palisade grass in open pasture and integration with teak, with a total area of 5 ha. The experimental period covered three consecutive years: 2015 (1st year), 2016 (2nd year) and 2017 (3rd year).

The climate of the region, according to Koppen classification, is Aw characterized as tropical humid, with rainy summer and dry winter, with average annual precipitation of 1503 mm. The soil is classified as Red-Yellow Ultisol (Brasil, 2009).

The experimental area was established with marandu palisade grass in 1998. In January 2009, part of the pasture was desiccated for teak implantation in spacing of 3 m between trees, 4 m between rows, and a spacing of 6 m between every five rows, which guaranteed a population of 750 trees ha^{-1}. Parallel to tree development was reestablishment of marandu palisade grass between rows, establishing the SPS. The open pasture system (OP) was defined as marandu palisade grass in full sun, without the arboreal component. The design was completely randomized, with two treatments (SPS and OP) and 12 replicates.

In the SPS, the pruning was performed when the trees reached seven meters. In January 2015, thinning was carried out, removing 40% of the trees. The grazing system adopted was alternating intermittent stocking, with 75 Nellore heifers, with a mean weight of 315 kg, receiving mineral salt and water ad libitum. Animals were removed from both systems in February of each experimental year, considering a height of residue of 30 cm.

In all years, 40 d after animals were introduced, simultaneous evaluation of forage and soil sampling was carried out. A soil sample was collected near each forage sampling site. The samples collected in each system were homogenized for the chemical and granulometric analysis (Teixeira et al., 2017; Table 1). There was no fertilization in the area during the experimental period.

Twelve samples were collected at 20 cm of height, in locations representative of the average canopy height in each system, using a metal frame (0.25 m²). After cutting, forage was weighed and separated into two subsamples. A subsample was submitted to drying in a forced air circulation oven at 55 ± 5ºC, for 72 h to obtain dry weight and forage mass (FM). The other subsample was used to determine botanical composition (weed separation) and the morphological components: leaf (leaf blades), stem (stem + sheath) and dead material.

Table 1 – Chemical and granulometric characterization of the soil, in the 0–20 cm layer.

System	pH	P	K	Ca	Mg	H+Al	T	OM	V
	$CaCl_2$	mg dm^{-3}		cmol dm^{-3}				g dm^{-3}	%
				1st year					
OP	5.4	10.4	90.0	3.3	0.7	2.3	6.5	21.0	64.5
SPS	5.7	12.2	66.0	3.5	0.5	1.5	5.7	15.0	73.5
				2nd year					
OP	5.6	21.0	93.6	3.0	1.1	2.3	6.6	27.9	65.7
SPS	5.7	16.1	65.4	3.2	1.2	2.3	6.8	28.7	66.4
				3rd year					
OP	5.5	23.8	83.2	2.6	1.0	2.6	6.4	27.1	59.5
SPS	5.8	28.1	78.0	4.5	1.6	2.2	8.5	35.8	74.6

OP: open pasture; SPS: silvopastoral; pH: hydrogenation potential; P (Mehlich^{-1}): phosphorus; K: potassium; Ca: calcium; Mg: magnesium; H + Al: hydrogen + aluminum; T: cation exchange capacity at pH 7; OM: organic matter; V: base saturation.

Chemical composition analyses were performed on the subsamples collected for FM evaluation. Samples were ground in a Willey mill with 1.0 mm mesh and subjected to analysis of dry matter (DM), crude protein (CP) and mineral matter (MM), according to Silva and Queiroz (2002); neutral detergent insoluble fiber (NDF) and neutral detergent fiber corrected for ash and protein (NDFap; Mertens, 2002); acid detergent insoluble fiber (ADF; van Soest et al., 1991); and indigestible neutral detergent fiber (iNDF), according to Valente et al. (2011), quantified by in situ incubation procedures with Ankon® bags (F57) for 288 hours in samples sieved at 2 mm.

In order to evaluate the degradation level of marandu palisade grass protein, the CP content in the wall and in the cellular content was estimated at the beginning and at the end of the three years under shading. Ground samples were submitted for analysis of neutral detergent insoluble protein (NDIP; Silva and Queiroz, 2002), which was designated crude protein in cell wall (CP_{CW}). Fast digestion fractions, being non-protein nitrogen (NPN) and true protein not associated with cell wall, were quantified by the difference between CP and NDIP, which was designated crude protein in cellular content (CP_{CC}).

Potentially digestible dry matter (DMpd) was estimated according to the following equation (Paulino et al., 2008):

$$DMpd = 0.98\,(100 - NDFap) + (NDFap - iNDF)$$

To assess pasture degradation, the following were evaluated: FM, forage participation (Pfor), and soil cover as described by Bauer et al. (2004). Tiller density (TD) was estimated by counting the tillers present in a 0.30 × 0.30 m (0.09 m^2) metal frame. In each year, all these evaluations were repeated 12 times in each system.

Data were analyzed using the PROC MIXED in SAS software (SAS Institute Inc., Cary, North Carolina, USA) with a model that included system, year (time-repeated measure) and its interaction, as fixed effect, as follows the model:

$$Y_{ijk} = \mu + S_{i(j)} + e_{ij} + A_k + SA_{ik(j)} + \epsilon_{ijk}$$

Y_{ijk} = expected response; μ = average / general constant, associated with the experiment; $S_{i(j)}$ = fixed effect of system i; e_{ij} = error associated with system i, NID (0, σ2e); A_k = fixed effect of year k ~ ND (0, σ2A); $SA_{ik(j)}$ = effect of system and year interaction; ϵ_{ijk} = experimental error ~ ND (0, σ2Є).

Quantile-quantile graphs and Shapiro-Wilk test were used to verify the residue normality and, if necessary, discrepant data withdrawals were performed. Covariance structure was chosen based on the Akaike Information Criterion (AIC; Wolfinger and O'Connell, 1993). Least squares mean of treatments were compared by Tukey-Kramer test (P < 0.05).

3. Results

There was interaction year*system for FM (P = 0.0007) and foliar leaf mass (MFol; P = 0.0075). In the third year, FM and MFol were lesser in SPS compared to OP (Table 2). Weed mass increased (P = 0.0002) over the years, independently of the evaluated system, with averages of 0.0, 80, and 220 kg DM ha^{-1} for the first, second, and third year, respectively.

Table 2 – Forage and leaf mass of marandu palisade grass in open pasture (OP) and silvopastoral system (SPS) in three consecutive years (2015, 2016, 2017).

Year	Treatments		SEM
	OP	SPS	
	kg DM ha^{-1}		
	Forage mass		
1	3080 ^{Aa}	2580 ^{Aa}	195
2	1620 ^{Ab}	1620 ^{Ab}	167
3	1750 ^{Ab}	420 ^{Bc}	179
SEM	180	174	
	Leaf mass		
1	1700 ^{Aa}	1260 ^{Aa}	109
2	1170 ^{Ab}	840 ^{Ab}	99
3	1150 ^{Ab}	290 ^{Bc}	99
SEM	102	102	

Means followed by different letters, upper case in the row and lowercase in column differ by Tukey-Kramer test (P < 0.05); DM: dry matter; SEM: standard error of the mean.

For morphological composition variables, year*system interaction was significant (P < 0.0001; Table 3). In the first year there was the same proportion of leaf blades in OP and SPS. Leaf blade ratio was higher in OP in the second year and greater in SPS in the third year. In SPS, stem participation was higher than in OP system from the second year evaluation. The percentage of dead material was lower in SPS only in the third year.

Table 3 – Leaf (leaf blade), stem (stem + sheath) and dead material ratios of Marandu palisade grass in open pasture (OP) and silvopastoral system (SPS) in three consecutive years (2015, 2016, 2017).

Year	Treatments		SEM
	OP	SPS	
	g kg^{-1} DM		
	Leaf		
1	538 ^{Ab}	489 ^{Ab}	26.1
2	733 ^{Aa}	524 ^{Bb}	23.3
3	580 ^{Bb}	729 ^{Aa}	24.2
SEM	24.5	24.8	
	Stem		
1	276 ^{Aa}	342 ^{Aa}	16.8
2	190 ^{Bb}	395 ^{Aa}	15.1
3	152 ^{Bb}	210 ^{Ab}	15.6
SEM	15.8	16.2	
	Dead material		
1	186 ^{Aa}	169 ^{Aa}	23.7
2	77 ^{Ab}	81 ^{Aab}	21.2
3	268 ^{Aa}	61 ^{Bb}	22.0
SEM	22.0	22.6	

Means followed by different letters, upper case in the row and lowercase in column differ by Tukey-Kramer test ($P < 0.05$); DM: dry matter; SEM: standard error of the mean.

The effect of year*system interaction was significant for NDF ($P < 0.0001$), CP ($P = 0.0050$) and ADF ($P < 0.0001$; Table 4). Mineral matter (MM) differed only between systems ($P < 0.0001$), with a mean of 94.3 and 101.0 g kg^{-1} DM for OP and SPS, respectively. Higher levels of NDF were observed for the OP system. Marandu palisade grass in SPS presented higher CP levels in all evaluated years. ADF was higher in the first year for forage in SPS and reduced over the years for both systems.

Shading altered the fractions of CP_{CW} ($P = 0.0382$), CP_{CC} ($P = 0.0263$) and DMpd ($P = 0.0108$; Table 5) of marandu palisade grass. In the first year, marandu palisade grass SPS presented greater CP_{CW} and CP_{CC}, however, in the third year, there was an increase only in CP_{CC} content. Marandu palisade grass in OP, in the first year, obtained a greater DMpd concentration, however, in the last year there was no difference between OP and SPS.

There was a year*system interaction for TD ($P < 0.0001$) and Pfor ($P = 0.0046$; Table 6). For soil cover, there was a significant difference between system ($P < 0.0001$) with a mean of 91 and 58% for the OP and SPS, respectively. Shading reduced tillering of marandu palisade grass in the second year.

4. Discussion

In the first year of evaluation, thinning was performed on the tree component, removing 40% of the trees, which explains the productivity equality between SPS and OP (Table 2). In the other years, both systems reduced productivity, which may be associated with a lack of nutrient replacement in the soil. The greater FM production of the OP can be attributed to the conditions more favorable to accumulation of dry mass in this system, since in the SPS there was more intense shading, which implied a reduction in the amount of light (Santos et al., 2016; Geremia et al., 2018).

Changes in light environment can result in adaptive changes in plants, to maintain their growth and development. Depending on the levels of reduction in incident solar radiation, forages may decrease their yield (Santos et al., 2018). Changes in patterns of photosynthetically active radiation (PAR) of SPS, change the light spectrum (red:far red) incident on forage grasses (Yang et al., 2018), thus, much of the wavelength in the range from blue to red is absorbed by the treetops leaves, altering the amount and quality of PAR that the forage would use for its growth (Baldassini et al., 2018).

Table 4 – Neutral detergent fiber (NDF), crude protein (CP) and acid detergent fiber (ADF) of marandu palisade grass in open pasture (OP) and silvopastoral system (SPS) in three consecutive years (2015, 2016, 2017).

Year	Treatments		SEM
	OP	SPS	
	g kg^{-1} DM		
	NDF		
1	653 ^{Ac}	655 ^{Ab}	5.19
2	750 ^{Aa}	694 ^{Ba}	4.51
3	702 ^{Ab}	645 ^{Bb}	4.65
SEM	4.78	4.78	
	CP		
1	57 ^{Bc}	83 ^{Ac}	2.53
2	82 ^{Bc}	122 ^{Ab}	2.15
3	121 ^{Ba}	157 ^{Aa}	2.22
SEM	2.34	2.31	
	ADF		
1	409 ^{Ba}	443 ^{Aa}	4.25
2	397 ^{Aa}	395 ^{Ab}	3.71
3	326 ^{Ab}	317 ^{Ac}	3.82
SEM	3.91	3.91	

Means followed by different letters, upper case in the row and lowercase in column differ by Tukey-Kramer test ($P < 0.05$); DM: dry matter; SEM: standard error of the mean.

Table 5 – Crude protein in cell wall (CP_{CW}), crude protein in cellular concentration (CP_{CC}) and potentially digestible dry matter (DMpd) of marandu palisade grass in open pasture (OP) and silvopastoral system (SPS) in the first and last year (year 3) of evaluation.

Year	Treatments		SEM
	OP	SPS	
	g kg^{-1} DM		
	CP_{CW}		
1	8.9 ^{Bb}	17.0 ^{Ab}	2.13
3	34.5 ^{Aa}	38.9 ^{Aa}	1.83
SEM	1.95	1.95	
	CP_{CC}		
1	48.1 ^{Bb}	65.6 ^{Ab}	3.55
3	89.2 ^{Ba}	118.2 ^{Aa}	3.11
SEM	3.30	3.30	
	DMpd		
1	802 ^{Aa}	769 ^{Ba}	7.88
3	775 ^{Ab}	781 ^{Aa}	6.75
SEM	7.25	7.25	

Means followed by different letters, upper case in the row and lowercase in column differ by Tukey-Kramer test ($P < 0.05$); DM: dry matter; SEM: standard error of the mean.

In addition to the reduction in FM during the evaluation years, weeds appeared. This increase was gradual over the years, demonstrating that to prolong the perennial pasture, management practices and nutrient replacement should be prioritized, regardless of the system used. The lack of nutrient replacement caused by the fertilization restriction interfered with the productivity of leaf blades over the years (Table 2).

Due to the elongation of the stem in the SPS in relation to the OP, the stem proportion was higher, from the second year. Stem elongation is a mechanism by which the plant seeks light by raising its leaves in the canopy (Carnevalli et al., 2006; Peri et al., 2006), possibly leading to a lower proportion of leaves and a higher proportion of stem in SPS. Besides that, stem proportion interferes in nutritive value of the forage, reducing digestibility and CP content (Paciullo et al., 2007).

Table 6 – Tiller density (TD, tiller m^2), forage participation (Pfor, %) of marandu palisade grass in open pasture (OP) and silvopastoral system (SPS) in three consecutive years (2015, 2016, 2017).

Year	Treatments		SEM
	OP	SPS	
	TD		
1	509 ^{Ab}	429 ^{Aa}	36.40
2	890 ^{Aa}	283 ^{Bb}	32.55
3	944 ^{Aa}	474 ^{Ba}	32.55
SEM	33.83	33.55	
	Pfor		
1	98 ^{Aa}	88 ^{Aa}	4.56
2	94 ^{Aa}	73 ^{Ba}	4.07
3	94 ^{Aa}	55 ^{Bb}	4.07
SEM	4.23	4.12	

Means followed by different letters, upper case in the row and lowercase in column differ by Tukey-Kramer test (P < 0.05); SEM: standard error of the mean.

The SPS presented a higher proportion of stem in relation to the OP, besides a lower proportion of dead material, in the third year (Table 3). The high density of trees leads to the light incident reduction on the canopy, leading to a reduction of leaf to stem ratio (Baldissera et al., 2016). In addition, forages that develop in OP present higher photosynthetic rates than shaded forage. The reduction of photosynthetic rates in these shaded leaves decreases the tissue renewal processes in the plant and may lead to reduction of dead material in FM (Lopes et al., 2017; Lima et al., 2019).

Despite the greater stem elongation, SPS presented higher CP levels, which is associated with lower FM production (Table 2). As a result of low productivity in the shaded system, nutrient concentration is higher (Soares et al., 2009), a factor also observed in minerals, which justifies the greater amount of MM in shaded forage.

Other factors contribute to the increase of CP levels in shaded forages, such as the effect of nitrogen dynamics on soil, since the increase in soil moisture accelerates the recycling of this nutrient, which may lead to increases in CP levels (Wilson, 1996) and the smaller cells size caused by the reduction in the amount of light may increase the concentration of N in leaves (Kephart and Buxton, 1993). Belesky et al. (2006) reported that plants grown under shade tend to be metabolically younger than plants grown in full sun and thus remain physiologically younger and with better nutritional value.

In the first and third year of evaluation, increases in CP_{CC} concentration were observed in the SPS (Table 5). This fraction of CP is associated with a rapid and intermediate rate of degradation, corresponding to NPN and true non-cell wall associated protein (Licitra et al., 1996). In the third year, there was no change in the contents of CP_{CW}, demonstrating that SPS with high tree density did not provide changes in the nitrogen dynamics associated with the cell wall. The shading provided a greater CP content of fast and intermediate degradation, which could lead to a mismatch between the degradation of the fast digestion protein and the fibrous carbohydrates present in the forage.

Highest NDF concentration for OP system may be associated with the proportion of sclerenchyma tissue, which is greater in full sun (Deinum et al., 1996). Studies indicate that the light incidence activates the genes expression associated with lignin synthesis, which promotes lignification and wall stiffening (Rogers et al., 2005; Moura et al., 2010). Lower levels of NDF in shaded environments are associated with possible restriction of photo assimilates, leading to the reduction of secondary cell wall (Kephart and Buxton, 1993).

Due to the alteration in physiological mechanisms of forage with light restriction, it is suggested that the ADF concentration in OP and SPS forages are similar but occur for different reasons. In the OP, the highest photosynthetic activity, cell wall thickening and lignification in all plant tissues (leaves and stem) occurs faster, since lignin is synthesized by secondary metabolism and is more intense the greater the photosynthetic activity (Chapman et al., 2014). In shaded forage, stem elongation due to the light restriction causes a lower rate of leaf appearance (Baldissera et al., 2016), because the stem is a more lignified forage structure, with a higher content of ADF and lower digestibility (Paciullo et al., 2007), compared to leaf blade.

Shading minimized TD of marandu palisade grass in the second year (Table 6). Tillering is influenced by the amount and quality of light, since for phytochrome activation, pigment responsible for tiller emission, the presence of red-light band is necessary (Williamson et al., 2012). As a result of the decline in the mass production of forage canopy, a higher incidence of light at the canopy base is expected, inducing the tillering of the forage plant as a strategy to mitigate the degradation process (Santana et al., 2016). In the second year, there was an increase in TD in the OP, explained by the FM reduction (Table 1). TD in shaded environments may reduce to the detriment of the formation of new tillers (Paciullo et al., 2017; Lima et al., 2019).

Lower soil cover in SPS was observed in all years, compared to forage in OP system, which is justified by the lesser TD, resulting from shading. This lower soil cover leads to a greater weed emergence, which reduces Pfor, also evidenced in this study (Table 6).

Thus, in systems with high tree density, rapid pasture degradation is observed, since there is a reduction in HM, TD, soil cover and Pfor. Therefore, the planning of the spatial arrangement of the trees is fundamental for the system perenniality. In addition, under high shading conditions, changes in CP content and DMpd occur, which may require nutritional adjustments through supplementation to optimize fiber degradation.

5. Conclusions

Despite the increase in nutritive value, continuous tree growth and the intensification of the shading over the years, even with thinning, results in pasture degradation, with reduction in forage mass and tropical forage tillering. Thus, systems with high tree density provide low luminosity, which reduces the life cycle of silvopastoral system.

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