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Production and nutritive value of pastures in integrated livestock production systems: shading and management effects

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ABSTRACT: This study aimed to evaluate the production characteristics of pastures in integrated livestock production systems. For that, an experiment was carried out in São Carlos, SP, Brazil, from 2013 to 2015. Forage development, production and nutritive value were evaluated in five beef cattle production systems: extensive continuous stocking (*Urochloa decumbens*) = EXT; intensive = INT; crop-livestock = iCL; livestock-forest = iLF and crop-livestock-forest = iCLF. Rotational stocking pastures in INT, iCL, iLF and iCLF systems were established with *Urochloa brizantha* cv. BRS Piatã. In iCL and iCLF, pastures were renovated by resowing the grass simultaneously with corn. In iLF and iCLF, eucalyptus (*Eucalyptus urograndis* clone GG100) was planted in Apr 2011 in single rows with 15 × 2 m spacing. In the 2013/2014 crop season, INT, iCL, and iCLF pastures were more productive than in iLF and EXT. Shading increase in the 2014/2015 season reduced pasture production in iLF and iCLF, compared with INT and iCL, but increased crude protein content and digestibility. In the shaded systems, pasture production was affected by proximity to trees, mainly due to reductions in solar radiation transmission. The principal component analyses showed that forage accumulation and leaf area index were associated with the position in the middle of the inter-row, and nutritive value was associated with the position at 1.5 m from the trees. In iCLF, solar radiation transmission greater than 60 % maintained forage accumulation similar to iCL, while in iLF, it reduced forage accumulation, evidencing that pasture renovation minimized shading effects in these systems.
Keywords: *Urochloa brizantha*, *Eucalyptus urograndis*, solar radiation, competition, sustainability

Introduction

The integration of crops and trees in rotation, succession, or association with pastures may improve sustainability of livestock production systems. In Brazil, the use of these systems has increased in the last decade (Balbino et al., 2011), mainly as an option to recover degraded pastures or intensify livestock production (Salton et al., 2014).

In crop-livestock (iCL) and crop-livestock-forest (iCLF) integrated systems, production potential of pastures is affected by the interactions between their components. These interactions may be positive, neutral or negative (competition) (Ong, 1996). According to Carvalho et al. (2010), iCL systems can provide adequate forage production and nutritive value (e.g., corn silage and renovated pastures) in autumn and winter. During these seasons, a decline in forage production is typical, which is a challenge for traditional pasture systems, especially in central Brazil.

In integrated systems with trees, changes in pasture production may occur due to changes in light quantity and quality (Lin et al., 1998). These changes may reduce animal production, despite shade tolerance of some forage species (Dias Filho, 2002). Morphological adaptations, such as an increase in shoot/root ratio and specific leaf area and reduction in tillering, have been reported for grasses under light restriction (Souza et al., 2007; Guenni et al., 2008 and Paciullo et al., 2011a).

Although there have been a number of trials on productivity of forages when trees are integrated into tropical pastures, little information is available on the productivity of these systems when fertilizer is applied to forages (Paciullo et al., 2011b). In integrated systems, pasture production is usually dependent on the residual effects of fertilizers applied during crop cultivation. Considering the high production potential of tropical grasses and their production response to soil pH adjustment and fertilization (Oliveira et al., 2004; Johnson et al., 2001), it is necessary to evaluate their responses to fertilization in integrated systems. The objective of this study was to evaluate the production characteristics of intensively managed pastures in integrated livestock production systems, with and without trees. Intensive and extensive traditional pasture systems were included as controls.

Materials and Methods

The experiment was carried out in areas of livestock production in São Carlos, Brazil (21°57′ S, 47°50′ W, 860 m), from Aug 2013 to Sept 2015, in 22 grazing cycles. The terrain is flat to mildly hilly and the soil is classified as Dystrophic Red-Yellow Latosol with a medium clay texture (Calderano Filho et al., 1998). The climate is classified as Cwa (Köppen) with two well defined seasons: dry season (Apr to Sept) with average temperature and precipitation of 19.9 °C and 250 mm, respectively, and rainy season (Oct to Mar) with average temperature and precipitation of 23.0 °C and 1,100 mm, respectively. Evaluations included aspects related to vegetative development, yield and nutritive value of five pasture systems: i) Intensive system (INT) - pasture under rotational stocking; ii) Livestock-forest system (iLF) - pasture under rotational stocking + eucalyptus trees; iii) Crop-livestock system (iCL) - pasture under rotational stocking in rotation with corn; 4) Crop-livestock-forest system (iCLF) - similar to iCL, but including eucalyptus trees; 5) Extensive system (EXT) - pasture under continuous stocking.

Pastures in the intensive (INT) and integrated (iLF, iCL, and iCLF) systems were established in 2010 with Piatã palisadegrass (*Urochloa* (*syn*. *Brachiaria*) *brizantha* (*Hochst ex A. Rich.*) *Stapf* cv. BRS Piatã). Pasture in the extensive system (EXT) was established more than 20 years ago with *Urochloa* (*syn*. *Brachiaria*) *decumbens* and has not been limed or fertilized. Eucalyptus trees (*Eucalyptus urograndis* clone GG100) were planted in the iLF and iCLF systems in Apr 2011, arranged in single rows with a 2 × 15 m spacing (333 trees ha^{-1}), and in East-West orientation.

All pasture systems were contiguous and composed of two replicate areas of 3 ha each. Each replicate area of the intensively managed pastures (INT, iLF, iCL, and iCLF) was divided into six paddocks (0.5 ha each), which were grazed under rotational stocking with 6 d of occupation and 30 d of rest. In these systems, lime and fertilizer recommendations were calculated based on the soil analysis. Lime was applied to increase base saturation to 60 %, P fertilizer (single uperphosphate, 18 % P_2O_5) to increase soil P to 12 mg dm^{-3} and K fertilizer (KCl, 60 % K_2O) to increase exchangeable K to 3 % of soil cation exchange capacity. Nitrogen fertilization of the pastures was top-dressed during the rainy season as i) 2013/2014 season: 157 kg of N, split into four applications (two as urea – 45 % N and two as ammonium sulfate – 20 % N); and ii) 2014/2015 season: 202 kg N applied as urea, split into five applications.

All pastures were grazed by castrated males of Canchim breed (3/8 Nellore + 5/8 Charolais), which were 11 months old and weighed 200 kg, when they were put in the system, and remained there for 15 months. At the end of this period, another herd with the same characteristics was put into the system. The pastures were submitted to stocking rate adjustments using the "put and take" technique (Mott and Lucas, 1952) and visual evaluation of forage availability. At the integrated systems with crops (iCL and iCLF), one-third of the pasture areas were renovated in each agricultural year (two paddocks per replicate area) by sowing the grass simultaneously with corn (var. DKR 390 PRO 2) cultivated for silage. Lime and fertilizer recommendations for maize crop were based on the soil analysis and calculated according to Raij et al. (1997). In the first crop season, corn was sown simultaneously with the grass on 07/11/2013 and harvested on 07/03/2014. In the second crop season, sowing was performed on 17/11/2014 and harvesting on 07/03/2015. During those periods, grazing dynamics at the paddocks in which corn was not sown was changed to 9 d of occupation and 27 d of rest per cycle.

In each cycle, forage accumulation at pastures under rotational stocking (INT, iLF, iCL, and iCLF) was calculated by subtracting post-grazing forage mass (at the beginning of the rest period), from pre-grazing forage mass (FM_{pre}) (at the end of the rest period). Forage mass values were obtained by cutting the forage within a metallic 0.5 × 0.5 m square frame, at 15 cm above the ground. The frame was randomly positioned at four sites within a pre-determined paddock of each replicate area. Then, the forage samples were weighed and those collected at the four positions of the same replicate area were mixed. From each mixed sample, a subsample was taken for determining dry matter (DM) content and another for morphological composition (leaf, stem and dead material) and leaf area assessments. DM content and morphological composition data were used to calculate forage mass (kg DM ha^{-1}). In the iLF and iCLF systems, evaluations were made at four positions relative to the eucalyptus rows: 1.5 m (P1); 3.75 m (P2); 7.5 m (P3) and 11.25 m (P4), from the northern rows (Figure 1). In this case, assessments were performed in one site per position, distributed in a pre-determined paddock per replicate area and the average of four samples was considered as representative of paddock average. In pastures under continuous stocking (EXT), forage mass was assessed every 12 d (three samplings per 36 d) in four grazing exclusion cages (0.5 × 0.5 m) randomly distributed in each replicate area. In this case, forage accumulation was calculated by subtracting the forage mass when the exclusion cage was installed from the forage mass at the end of the exclusion period (12 d), and summing the accumulation of the three periods. Plant height was measured at three random points within the frame or the cage with a measuring tape, from ground level to the top of the most recently expanded leaf.

Leaf area was determined using a leaf area meter. All morphological components were weighed separately, and their DM content determined by drying in an oven (65 °C) for 72 h. Leaf area and leaf mass data were used to calculate leaf area index (LAI) and specific leaf area (SLA) (m^2 g^{-1}).

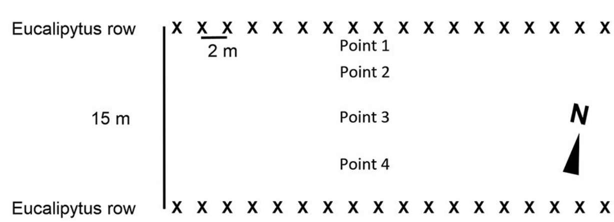

Figure 1 – Schematic representation of the experimental area indicating where the data were collected in the silvopastoral system.

The samples used to determine DM content were also used for crude protein content (CP) and *in vitro* DM digestibility (IVDMD) determinations. Dried samples were ground in a Wiley mill with a 0.5 mm screen and analyzed by FT (Fourier Transform)-NIR technique using a spectrometer model NIRFlex N-500 with polarization interferometer. These measurements were performed using a calibration model, developed and validated by Embrapa Pecuária Sudeste (R^2 = 0.944 for CP and R^2 = 0.923 for IVDMD), specifically for species and cultivars of *Urochloa* spp.

In the systems with trees, photosynthetically active radiation (PAR) was measured continuously at 70 cm above ground using quantum linear sensors allocated in the same positions described for forage evaluation in these systems (P1 to P4). In the systems without trees, PAR was measured at a single point using a quantum sensor. These sensors were connected to an automated data acquisition system, scheduled for measurements every 10 s. PAR transmission at each position of iCLF was calculated by dividing its PAR incidence by the PAR incidence at the systems without trees.

Rainfall data were collected at approximately 200 m from the experiment in standard conditions (Allen et al., 1998). The climatological water balance (Thornthwaite and Mather, 1955) was calculated in a 10-day step (Figure 2), using the reference evapotranspiration calculated by the Penman-Monteith method (Allen et al., 1998) and rainfall data, and considering a soil water holding capacity of 100 mm.

Data were analyzed through a randomized block design with repeated measures and a 2 × 4 × 5 (year × season of the year × pasture system) factorial arrangement. A mixed model was adopted using the PROC MIXED of SAS (Statistical Analysis System, v. 9.2), considering the fixed effects of pasture system and time (year and season). Block was included in the model as a random effect. The Tukey test analyzed effects of pasture system and time at 5 % probability ($p \leq 0.05$).

Forage data were submitted to a multivariate analysis performed through the principal components analysis (PCA) and based on grouping evaluations to determine response divergences, using the software PAST (Hammer et al., 2001). For this analysis, the production systems were grouped in "full sun", meaning those systems intensively cultivated without trees (INT and iCL), and "shaded", those with trees (iLF and iCLF). The same analysis was performed to evaluate response divergences for the production and vegetative variables at positions P1 to P4 of the systems with trees.

The regression analysis using PAR transmission and relative forage accumulation was carried out using the PROC REG of SAS (2009). For that, the annual averages (2013/2014 and 2014/2015 periods) of these variables were calculated for positions P1 to P4 of ILF and iCLF.

Results

Meteorological conditions were substantially different between the two crop seasons. The 2013/2014 crop season was substantially drier than the 2014/2015 crop, especially during the summer and the autumn, with a soil water deficit of 141.3 mm during the first crop season (Figure 2). PAR transmission was greater in the first year in the systems with trees, presenting the maximum value of 70 % in Jan and minimum of 30 % in May and June, while maximum and minimum PAR transmissions of 60 % and 20 %, respectively, were observed in the second year. The differences of PAR transmission between years were attributed to differences in tree height, which was 13.0 m in Oct 2013, 15.6 m in Apr 2014, 17.3 m in Oct 2014 and 19.9 m in Apr 2015. PAR transmission fluctuations throughout the year were credited to the East-West orientation of the tree rows (Figure 1), which caused greater PAR transmission during the summer and lower during the winter, because of the "inclination" of the sun towards the North during the winter.

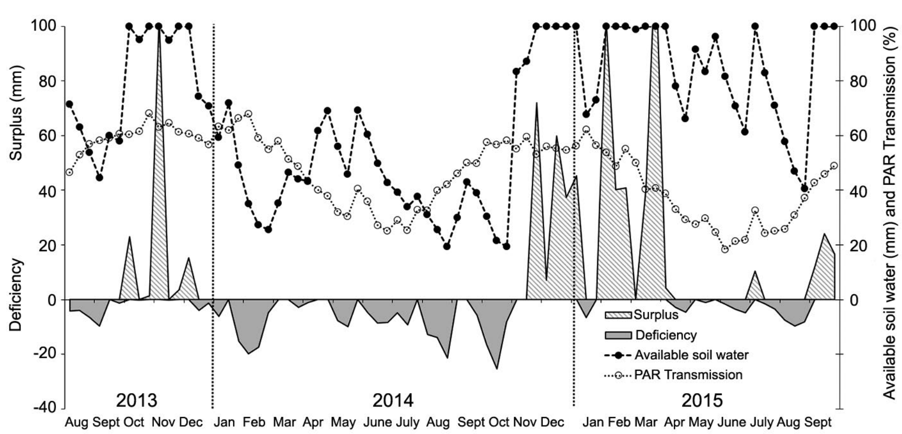

Figure 2 – Climatological water balance for the experimental site during the experiment (Aug 2013 to Sept 2015), and photosynthetically active radiation (PAR) transmission in the shaded systems in São Carlos, Brazil.

All pasture variables were affected by pasture system, season and interaction between these two factors. The CP content of pastures was also affected by year. FM_{pre} was affected by a 3-way pasture system × year × season interaction (Table 1).

In the 2013/2014 period, during the spring, summer and autumn, the pasture systems INT, iCL and iCLF presented greater FM_{pre} than the systems iLF and EXT (Table 2). Pastures in intensive systems (iLF, iCL, iCLF, and INT) had greater FM_{pre} than the pasture in the extensive system (EXT), in all seasons except for winter when FM_{pre} was similar for all pasture systems. In the intensive systems (iLF, iCL, iCLF, and INT), FM_{pre} was greater in the spring and summer followed by autumn and winter, respectively (Table 2). In the extensive system (EXT), in all seasons FM_{pre} was similar during all seasons.

In the 2014/2015 period, during all seasons, the pasture systems without trees (INT and iCL) presented greater FM_{pre} than the systems with trees (iCLF and iLF) (Table 2). Pastures in the shaded systems (iLF and iCLF) had greater FM_{pre} than the pasture in the extensive system (EXT) during summer and autumn. In the INT, iCL and iLF systems, FM_{pre} was greater in summer and autumn followed by spring and winter. In iCLF, FM_{pre} was greater in spring and summer followed by autumn and winter. As in the previous year, FM_{pre} in the extensive system (EXT) was similar during all seasons.

In the INT and iCL production systems, in the summer of 2014/2015, FM_{pre} was greater than in the summer of 2013/2014 period (Table 2). In both systems, FM_{pre} was 3375.69 and 3290.51 kg ha^{-1} in summer of 2014/2015 period, respectively, resulting in the highest FM_{pre} during the experimental period. For the iCL system, FM_{pre} was also greater in the summer of 2014/2015. For all other systems and all year seasons, there were no differences between FM_{pre} during the experimental years.

Statistical results for forage accumulation (Table 3) were similar to those obtained for FM_{pre} except during the winter when there was no difference between systems for this variable. In the 2013/2014 period, forage accumulation was greater in iCLF, INT, and iCL, followed by iLF and EXT. The total accumulated forage during the ten grazing cycles in that crop season in iCLF, INT, iCL, iLF, and EXT was 11,426; 10,630; 10,589; 6,980 and 4,962 kg ha^{-1} yr^{-1}, respectively. In the 2014/2015 crop season, the systems with trees presented lower forage accumulation compared with iCL and INT. In this period, the total accumulated forage in iCL, INT, iCLF, iLF

Table 1 – Summary of the analysis of variance for pasture variables in different livestock production systems in the 2013/2014 and 2014/2015 growing seasons, in São Carlos, Brazil.

Cause of variation	*p*-value		
	Forage accumulation	Pre-grazing forage mass	Crude protein content
System	< 0.0001	< 0.0001	0.0003
Year	0.0757	0.0783	< 0.0001
System*Year	0.0057	0.0011	0.0007
Season	< 0.0001	< 0.0001	< 0.0001
System*Season	< 0.0001	< 0.0001	< 0.0001
Year*Season	0.7394	< 0.0001	0.4299
System*Year*Season	0.0602	0.0117	0.0977

Table 2 – Pre-grazing forage mass (kg DM ha^{-1}) of *Urochloa decumbens* in the extensive system (EXT) and *Urochloa brizantha* cv. BRS Piatã in the intensive system (INT), crop-livestock system (iCL), livestock-forest system (iLF) and crop-livestock-forest system (iCLF) in the 2013/2014 and 2014/2015 growing seasons, in São Carlos, Brazil.

Years	System	Pre-grazing forage mass (kg DM ha^{-1})			
		Season of the year			
		Spring	Summer	Autumn	Winter
2013/2014	EXT	520.64 Ca (A)	503.77 Ca (A)	799.24 BCa (A)	363.26 Aa (A)
	INT	2025.36 Aba (A)	2359.94 Aa (B)	1930.27 Aab (A)	1173.99 Ab (A)
	iCL	2123.65 Aa (A)	2291.56 Aa (B)	1551.54 ABb (B)	1016.25 Ab (A)
	iLF	1515.35 BCa (A)	1527.45 Ba (A)	1220.82 Bab (A)	552.9 Ab (A)
	iCLF	2196.33 Aa (A)	2093.58 Aba (A)	1524.32 ABb (A)	575.39 Ac (A)
2014/2015	EXT	509.61 Ba (A)	708.1 Ca (A)	359.07 Ca (A)	318.94 Ba (A)
	INT	1634.54 Ab (A)	3375.69 Aa (A)	2736.34 Aa (A)	1756.27 Ab (A)
	iCL	1711.36 Ab (A)	3290.51 Aa (A)	2984.35 Aa (A)	1651.97 Ab (A)
	iLF	846.06 Bbc (A)	1986.87 Ba (A)	1234.64 Bab (A)	406.01 Bc (A)
	iCLF	1362.35 ABab (A)	1849.64 Ba (A)	1162.81 Bb (A)	362.64 Bc (A)

Means followed by the same lowercase letter within a row and those followed by the same uppercase letter within a column for each year are similar ($p > 0.05$) by the Tukey test. Mean followed by the same uppercase letter between parentheses for each year season and production system are similar ($p > 0.05$) by the Tukey test. Standard error of interaction System*Season = 138.94; Standard error of interaction System*Year = 112.64 and Standard error of interaction System*Year*Season = 187.46.

and EXT were 16,378; 15,251; 7,904; 7,408 and 4,728 kg ha^{-1} yr^{-1}, respectively.

Crude protein content was greater in the systems with trees in the summer and autumn, compared to all other systems (Table 4). During the summer, iCLF and iLF achieved 13 % of CP content, while iCL, INT, and EXT presented 9 %. Crude protein content in iCLF (13 %) was greater in spring, compared to all other systems. Pastures in all systems had greater CP content in the second compared to the first crop season except for EXT in which the opposite occurred.

The production systems were classified as "full sun", meaning those intensively managed systems cultivated without trees (INT and iCL), and "shaded", those with trees (iLF and iCLF). These two groups (full sun and shaded) were considered for the PCA of vegetative, production and bromatological variables, during the eight seasons considered in the study (Figures 3A, B, C and D). The primary and secondary components were responsible for 64 % and 20 % (total 84 %) of the results, respectively. In quadrant B, the summer and autumn cycles of the full sun systems are predominant in the subgroups, such as the autumn cycles of the shaded systems. This quadrant is associated with production characteristics, such as FM_{pre}, forage accumulation, LAI, and proportion of stems. In quadrant D, the shaded system subgroups are predominant. This quadrant is associated to bromatological characteristics, such as CP content and IVDMD, and proportion of leaf and SLA. The winter cycles of both crop seasons are shown in Figures 3A and C for all systems, as well as the spring cycles of 2013 for the full sun systems, associated to lower forage accumulation and greater dead material content.

The PCA for positions P1 to P4 in the systems with trees is presented in Figures 4A, B, C, D, E, F, G and H. The analysis indicates that primary and secondary components were responsible for 65 and 18 % (total of 83 %), respectively, of the 2013/2014 results. In the 2013/2014 period, FM_{pre}, forage accumulation, stem content and LAI are associated with the autumn cycles for all positions (P1 to P4) in iCLF, and for the summer cycles for P3 and P4 in iLF and iCLF (quadrant B). In quadrant D, P1 and P2 are presented for the summer cycles and all positions for the spring cycles. For the points in this quadrant, bromatological characteristics, the proportion of leaves and LAI are associated with greater shading. Plant height is at an intermediary position between quadrants B and D. During the winter cycles, all positions in iLF and iCLF were concentrated on the opposite side of the graph (quadrants A and C) and associated with the proportion of dead material.

Table 3 – Forage accumulation (kg DM ha^{-1} cycle^{-1}) of *Urochloa decumbens* in the extensive system (EXT) and *Urochloa brizantha* cv. BRS Piatã in the intensive system (INT), crop-livestock system (iCL), livestock-forest system (iLF) and crop-livestock-forest system (iCLF) in the 2013/2014 and 2014/2015 growing seasons, in São Carlos, Brazil.

System	Forage accumulation (kg DM ha^{-1} cycle^{-1})					
	Time					
	Season of the year				Year	
	Spring	Summer	Autumn	Winter	2013/2014	2014/2015
EXT	498.98 Ca	605.94 Ca	539.73 Da	293.60 Aa	496.27 Ba	472.85 Ca
INT	1203.35 Ab	1870.29 Aa	1480.21 ABab	622.41 Ac	1063.02 Ab	1525.10 Aa
iCL	1174.58 ABb	1862.86 Aa	1788.07 Aa	567.99 Ac	1058.96 Ab	1637.80 Aa
iLF	751.50 BCab	996.12 BCa	695.23 CDab	435.03 Ab	698.06 Ba	740.87 BCa
iCLF	1177.04 ABa	1122.23 Ba	1121.74 BCa	445.18 Ab	1142.68 Aa	790.42 Bb

Means followed by the same lowercase letter within a row for each time (Season or Year) and those followed by the same uppercase letter within a column are similar ($p > 0.05$) by the Tukey test. Standard error of interaction System*Season = 122.52 and Standard error of interaction System*Year = 119.5.

Table 4 – Crude protein content (%) of *Urochloa decumbens* in the extensive system (EXT) and *Urochloa brizantha* cv. BRS Piatã in the intensive system (INT), crop-livestock system (iCL), livestock-forest system (iLF) and crop-livestock-forest system (iCLF) in the 2013/2014 and 2014/2015 growing seasons, in São Carlos, Brazil.

System	Crude protein content (%)					
	Time					
	Season of the year				Year	
	Spring	Summer	Autumn	Winter	2013/2014	2014/2015
EXT	10.25 Ba	8.59 Bab	7.73 Bb	7.42 ABb	9.32 Aa	7.68 Db
INT	9.35 Ba	9.41 Ba	9.18 Ba	6.89 Bb	7.90 BCb	9.51 Ca
iCL	9.38 Ba	8.50 Ba	8.49 Ba	6.46 Bb	7.52 Cb	8.91 CDa
iLF	10.27 Bb	12.55 Aa	12.16 Aa	7.72 ABc	9.22 ABb	12.13 Ba
iCLF	12.66 Aa	13.23 Aa	11.86 Aa	9.21 Ab	9.47 Ab	14.02 Aa

Means followed by the same lowercase letter within a row for each time (Season or Year) and those followed by the same uppercase letter within a column are similar ($p > 0.05$) by the Tukey test. Standard error of interaction System*Season = 0.5603 and Standard error of interaction System*Year = 0.5102

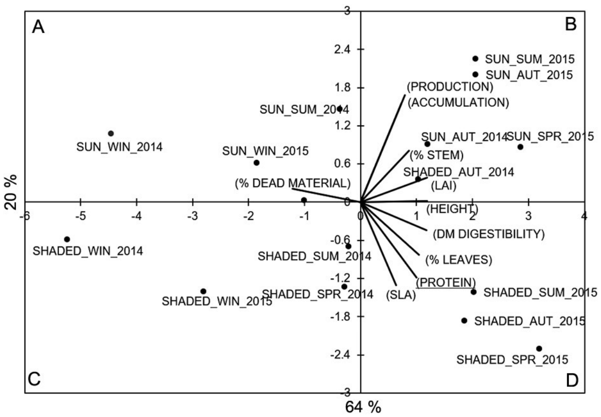

Figure 3 – Principal component analysis for vegetative, production and nutritive value variables associated to full sun (SUN) and shaded (SHADED) systems in different seasons (winter = WIN, autumn = AUT, spring = SPR, summer = SUM) for *Urochloa brizantha* cv. BRS Piatã in the 2013/2014 (2014) and 2014/2015 (2015) growing seasons.

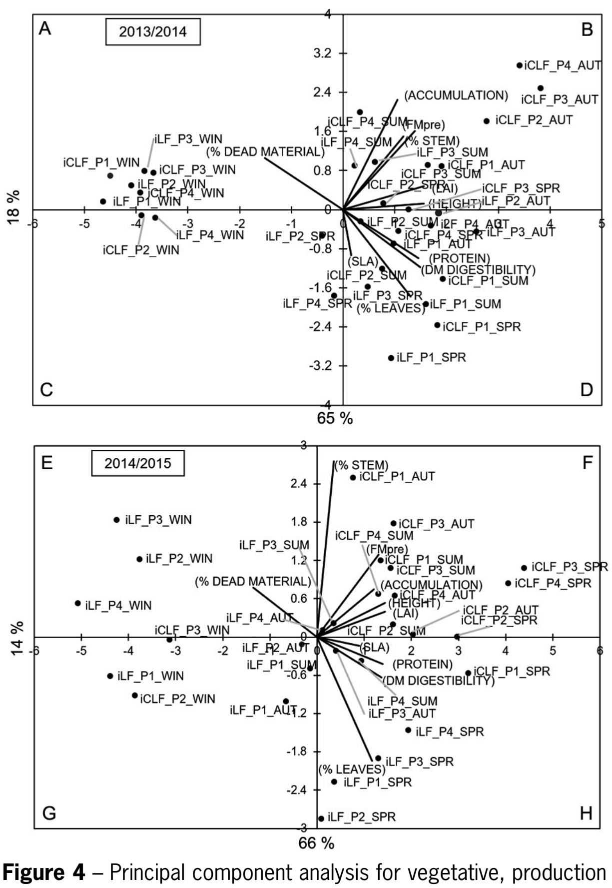

Figure 4 – Principal component analysis for vegetative, production and nutritive value variables associated to four positions (P1 to P4) at the shaded systems (iLF and iCLF) in different seasons (winter = WIN, autumn = AUT, spring = SPR, summer = SUM) for *Urochloa brizantha* cv. BRS Piatã in the 2013/2014 and 2014/2015 growing seasons.

The relationship between variables and sampling positions were different in the 2014/2015 compared with the previous crop season. The pasture renovated early in 2014 presented adequate production characteristics in all four sampling positions during spring (quadrant F). Pasture production in iCLF was lower in autumn 2015 pasture renovation cycle than in autumn 2014, due to increase in shading. In the summer and autumn cycles, sampling positions P1 to P4 in iCLF were also associated with the production variables, but with lower intensity. In this crop season, no iLF sampling positions are present in this group. Positions P1 to P4 in iLF for spring, summer and autumn are associated with nutritive value and leaf production. For nutritive value and LAI, the position was intermediate between quadrants F and H. In winter 2015, all points remained on the opposite side of the graph (quadrants E and G) and associated with the proportion of dead material, as in the 2013/2014 period.

The relationship between PAR transmission in the four sampling positions and the relative forage accumulation (accumulation at the shaded systems/accumulation at the full sun systems) was different in iLF and iCLF during the two crop seasons (Figures

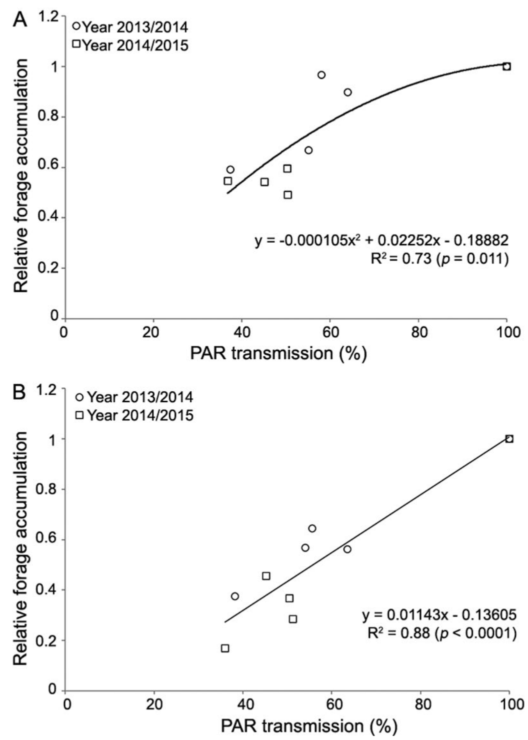

Figure 5 – Relationship between photosynthetically active radiation (PAR) transmission and relative forage accumulation in the iLF system [accumulation at the integrated livestock-forest (iLF) system/ accumulation at the intensive system (INT)] (A) and relative forage accumulation at the iCLF system [accumulation at the integrated crop-livestock-forest (iCLF) system/ accumulation in integrated crop-livestock (iCL)] (B) in the 2013/2014 and 2014/2015 growing seasons.

5A and B). In the iLF system (Figure 5A), reduction of PAR transmission caused more significant impact on relative forage accumulation than in iCLF, which is evident in the two regression equations obtained for the systems. In the first crop season, relative forage accumulation values in iLF and iCLF were around 0.6 and 1.0, respectively, for positions with greater PAR transmission. In the second crop season, shading caused a more significant impact on both systems. Nonetheless, the relative production in iCLF (Figure 5B) remained around 0.6 for the most shaded positions while in iLF, it remained around 0.4.

Discussion

The production characteristics of pastures were affected by management and climatic factors during the experimental period. For the systems without trees, the greater forage mass and accumulation rates in the 2014/2015 crop season may be attributed to the greater water availability during the summer and autumn cycles compared with 2013/2014, which was characterized by a severe drought (Figures 3A, B, C and D). For systems with trees, yield increase in the second crop season was lower than in the full sun systems, which may be attributed to an increase in shading in those systems compared to the 2013/2014 period (50 % vs. 42 %), despite greater water availability (Figure 2). The decrease of PAR transmission in the systems with trees, in 2014/2015, was a consequence of tree growth. Average tree height in the first and second crop seasons was 15 and 19 m, respectively. The decrease of PAR transmission in shaded systems changes forage accumulation and morphological composition, increasing SLA and decreasing LAI (Peri et al., 2007; Pandey et al., 2011; Bosi et al., 2014; Lopes et al., 2017).

Crude protein content and proportion of leaf were greater in pastures of the shaded systems, especially in the 2014/2015 period (Table 3 and Figures 3A, B, C and D), such as observed by Baruch and Guenni (2007), Sousa et al. (2010) and Pandey et al. (2011), which may be attributed to greater nutrient recycling (e.g., N) promoted by microclimatic alterations, making nutrients more available to pastures (Wilson, 1996). The greater N concentration caused by growth limitations of pastures in shaded systems is another possibility to explain greater CP content.

Paciullo et al. (2007) observed that production responses of integrated systems with trees depend on the season. In our study, the results were affected by variation of PAR transmission during the year caused by tree growth. Macroclimatic conditions, such as winter drought, increased the proportion of dead material, eliminating differences between the full sun and shaded systems (Figures 3A, B, C and D) and reducing CP content of pastures in all systems (Table 4).

The PCA for positions P1 to P4 (Figures 4A, B, C, D, E, F, G and H) indicates the significant variability of morphological components and forage mass and accumulation in the systems with trees, with or without pasture renovation. The central positions between tree rows (P3 and P4) were more associated to production factors, especially in the iCLF system in autumn and spring of 2014. The autumn cycle in iCLF corresponds to the initial period of use of renovated pasture. In autumn of 2015, increased shading limited potential production of renovated pastures. Lower forage accumulation in shaded pastures was also observed by Paciullo et al. (2011a); Bosi et al. (2014) and Lopes et al. (2017).

In spring of 2014, forage accumulation in iCLF was similar to intensive full sun systems due to the greater light transmission in that season and benefits of pasture renovation, highlighting the importance of this process in crop-livestock-forest systems, as indicated by Balbino et al. (2011). Predominant macroclimatic conditions, such as low soil water availability during the winter, impaired the differences between pasture systems (Figures 3A, B, C and D) and positions (Figures 4A, B, C, D, E, F, G and H), consequently, production in this season was associated to the proportion of dead material.

The relationship between PAR transmission and relative forage accumulation for systems with trees highlights the importance of pasture renovation for livestock production intensification. PAR transmission reductions between 35 % and 40 % allowed satisfactory forage accumulation in iCLF at the two central positions (P3 and P4) (Figures 5A and B). This PAR transmission reduction seems to be the limit of light interception for renovated pastures. For iLF, where pastures were established five years before the experiment, PAR transmission of around 60 % resulted in reductions in forage accumulation.

Literature on forage grasses grown in field and greenhouse conditions indicate variation in yield response to light intensity (Paciullo et al., 2011a; Pandey et al., 2011; Bosi et al., 2014 and Lopes et al., 2017). In most trials, reductions of up to 35 % in light intensity did not reduce pasture production significantly. Nonetheless, as observed in our trial, these limits may be lower for established pastures under natural shading and after successive grazings. These differences may be attributed to the increase in competition between trees and grasses (Wilson et al., 1998) and morphological and structural alterations in pastures (Paciullo et al., 2011a). According to Reynolds et al. (2007), above these shading levels, tree management, such as the removal of some tree rows or some trees in the rows, must be performed to reestablish satisfactory pasture production by reducing competition for light and soil water. Nicodemo et al. (2016) suggested the removal of lower branches (pruning) as an alternative to reduce competition for light.

Conclusion

The interaction between trees and production characteristics of forages in integrated crop-livestock-forest or livestock-forest systems addressed in this study proved to be dynamic due to environmental modifications caused by trees. Variations in solar radiation transmission, throughout the time (number of years from the system implementation) and space (distance from the tree lines) affected pasture productivity in systems with an arboreal component. These changes in production characteristics were more evident in summer and autumn, mainly at positions near the tree rows. In these systems, the pasture renovation process, with resowing of pasture simultaneously with corn, minimized the adverse effects of shading on forage production.

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