Scientia Agricola
http://dx.doi.org/10.1590/0103-9016-2015-0039

Xaraés palisadegrass remains productive after the disappearance of stylo in tropical legume-grass pasture

Rodrigo Carvalho Menezes, Eveline Bueno Alves, Daniel Rume Casagrande, Márcio André Stefanelli Lara, Antônio Ricardo Evangelista, Thiago Fernandes Bernardes*

Federal University of Lavras – Dept. of Animal Science, C.P. 37 – 37200-000 – Lavras, MG – Brazil.
*Corresponding author <thiagobernardes@dzo.ufla.br>

Edited by: James Pierre Muir

Received February 04, 2015
Accepted May 15, 2015

ABSTRACT: Gradual reduction of legumes in mixed tropical pastures requires periodic oversowing. Exploiting the carrying capacity of grass for an extra year after the disappearance of legumes can be economically advantageous to the farmer. This study aimed to evaluate the productivity of Xaraés palisadegrass (*Brachiaria brizantha*) pastures in response to its historical association with stylo (*Stylosanthes guianensis*) under two canopy heights to determine whether different grazing management conditions affect the defoliation pattern left by grazing animals. The split-plot experimental design was used, with the historical botanical composition (HBC) (24, 34, 45 and 52 % legume composition) corresponding to the main plots and the canopy frequency of defoliation determined at heights of 30 and 45 cm for Xaraés palisadegrass corresponding to the subplots with two replicates (500 m^2) grazed by Tabapuã cows. Pastures with over 34 % stylo in the botanical composition remained productive for one year after legume disappearance, accumulating more than 8 mg ha^{-1} of forage per year. Xaraés palisadegrass pastures at a height of 30 cm provided better canopy structure, with 64 % less stem production and 43 % less dead material. The 30-cm pre-grazing canopy height provided a grazing environment conducive to forage intake by animals that resulted in efficient use of the pasture. In response to the improved canopy structure, the cows grazed an average of 60 fewer minutes. A HBC greater than 34 % of legumes in the pastures allows for the postponement of legume oversowing until the next growing season.
Keywords: *Brachiaria brizantha*, *Stylosanthes guianensis*, mixed pastures, animal behavior

Introduction

Using legumes mixed with grasses allows the nitrogen fertilizers to be replaced by biological nitrogen fixation (Ledgard and Steele, 1992). Studies have shown that under mixed pastures conditions in the tropics, the input of biologically fixed nitrogen ensures a positive balance in the soil-plant-animal system (Herridge et al., 2008). The greatest obstacle to adopting this technique is the complex management of mixed pastures (Lascano, 2000) due to difficulties in the establishment, productivity and persistence of legumes (Nyfeler et al., 2009), especially in warm regions (Muir et al., 2014). The persistence of legumes is related to grazing tolerance and natural reseeding capacity (Hodgson, 1990).

The Mineirão stylo (*Stylosanthes guianensis*) is considered a perennial legume and can be associated with grasses, but when this legume is subjected to frequent and intense grazing, the population density reduces dramatically within three to four years due to low seed production capacity, lowering the potential plant propagation and, consequently, its maintenance (Paciullo et al., 2014).

Stylo oversowing raises production costs, and it is essential to determine whether oversowing is a must. The use of nutrients derived from the decomposition of legume residues (i.e., litter, roots and nodules) can ensure pasture productivity for an extra rainy season.

Variations in the efficiency of forage utilisation can alter the rate of nutrient cycling and the optimal time for legume oversowing. In addition, grazing management affects canopy structure, which can change defoliation patterns left by grazing animals.

Consequently, this study aimed to determine the productivity of Xaraés palisadegrass (*Brachiaria brizantha*) managed under two different canopy heights and in response to historical botanical composition (HBC). A secondary aim was to determine whether changes in grazing management affect the defoliation patterns left by grazing animals.

Materials and Methods

This study was carried out at an experimental farm in Lavras, in the state of Minas Gerais, Brazil (21°14' S and 45°00' W and 918.8 m altitude). The experimental period began in the late summer of 2011, and continued for 15 months. Weather data were obtained from a meteorological station, 1.5 km away from the experimental site (Figure 1).

Experimental site

In November 2007, 16 plots with Xaraés palisadegrass/Mineirão stylo were established, each 500 m^2 in size. From the time of establishment until the spring of 2010, the areas were managed with botanical legume compositions of 24, 34, 45 and 52 % in the forage mass (FM) varying stocking rate. These ratios resulted from different legume FMs because the grass mass in the pastures was similar (on average 5,900 ± 970 kg ha^{-1}). The legume

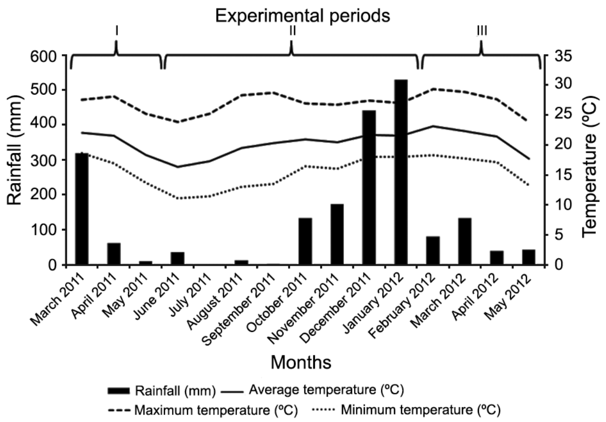

Figure 1 – Rainfall and air temperature (average, maximum and minimum) variation during the three experimental periods.

FM was on average 1,900 ± 325, 3,100 ± 210, 4,900 ± 663 and 6,400 ± 775 kg ha^{-1} for the ratios of 24, 34, 45 and 52 %, respectively. In the early summer of 2010/2011, 40 months after the establishment of the pastures, the legume FM had decreased to 14 ± 3 % of total FM, due to intense defoliation at the first grazing. At the end of that season, legumes were no longer observed in the botanical composition of the canopy.

At that time, the chemical conditions of the soil were as follows: pH (H_2O) = 5.8, organic matter = 3.6 %, P (Mehlich) = 5.9 mg dm^{-3}, K = 78.7 mg dm^{-3}, Ca = 2.4 cmol$_c$ dm^{-3}, Mg = 0.73 cmol$_c$ dm^{-3}, H + Al (SMP extractor) = 3.1 cmol$_c$ dm^{-3}, Al = 0.08 cmol$_c$ dm^{-3}, cation exchange capacity = 6.4 cmol$_c$ dm^{-3} and base saturation = 50 %. The annual maintenance fertilisation was 60 kg ha^{-1} of P_2O_5, 80 kg ha^{-1} of K_2O and 50 kg ha^{-1} of a commercial fertilizer, FTE BR-12 which contains Ca, S, Bo, Cu, Mn, Mo and Zn.

Treatments and experimental management

The treatments were comprised four HBCs, which contained 24, 34, 45 and 52 % Mineirão stylo (HBC24, HBC34, HBC45 and HBC52, respectively) and were associated with two pre-grazing canopy heights (CH) of 30 and 45 cm (CH30 and CH45, respectively) which define the frequencies of rotational grazing evaluated in this study. Two replicates were performed under each condition.

CH30 and CH45 were used because they correspond to 95 and 100 % light interception, respectively (Pedreira et al., 2009). The mob-stocking method (Allen et al., 2011) was adopted for the current study and the stocking period was variable according to the post-grazing height of the Xaraés palisadegrass, proposed by Sousa et al. (2011), namely 15 cm for all the treatments. Six Tabapuã cows were used for grazing with average body weight of 504 ± 48 kg per paddock.

The CH was monitored twice a week in the spring and summer and once a week in the fall and winter. The CH was defined as the average of 27 readings taken randomly in each experimental unit, using the sward surface height method (Braga et al., 2009).

In the pre- and post-grazing periods, nine FM samples per experimental unit were harvested at ground level with hand-held electric clippers at representative locations in the paddock with a frame of 0.5 m^2. After harvesting, the samples were sorted into fractions (leaf, stem and dead material) to determine the morphological composition. After sorting, the dry matter was measured in terms of difference in weight before and after drying using a convection oven. The forage accumulation rate (FAR) was calculated as the difference between the pre-grazing FM and the previous post-grazing FM divided by the number of days. The stocking rate was calculated by considering the animal unit (AU = 450 kg body weight) in each paddock and dividing by the area required to complete a grazing cycle (rest period + occupation period).

Observations of animal behaviour were recorded on the first day of each grazing event by a group of three trained observers for a period of 24 h. Animal behavior was examined via intermittent observations taken every 10 min, in accordance with the focal method proposed by Martin and Bateson (2007), the animals being identified by numbers on their dorsal region. The activities observed included grazing, chewing and resting.

Statistical analysis

This study employed a completely randomized design with a split-plot arrangement. The HBCs were allocated to eight main plots, and the CHs to subplots, and two replicates of each were examined, totalling 16 paddocks. The experimental data were grouped into three evaluation periods according to CH45, which corresponded to less frequency between grazing. The first evaluation period took place from Mar 2011 to May 2011, the second continued until Jan 2012 and the third continued until May 2012. The data were subjected to analysis of variance, and the means compared using Tukey's test at 10 % probability..

The following model was used for data analysis:

$$Y_{ijk} = \mu + HBC_i + e_a + CHj + HBC{*}CHij + e_b + P_k + HBC{*}P_{ik} + CH{*}P_{jk} + HBC{*}CH{*}P_{ijk} + e_c$$

where: Y_{ijk} = the observed botanical composition value i and canopy height j during period k;μ = the overall constant (population average); HBC_i = the effect of the historical botanical composition; i = 1, 2, 3, 4; e_a = the error whereby the HBC will be tested; CH_j = the effect of canopy height j; j = 1, 2; $HBC{*}CH_{ij}$ = the interaction between historical botanical composition and canopy height j; e_b = the error whereby CHj and HBC*CHij will be tested; P_k = the effect of period k; k = 1, 2, 3; $HBC{*}P_{ik}$ = the interaction between botanical composition level i and period k; $CH{*}P_{jk}$ = the interaction between pre-grazing height j and period k; $HBC{*}CH{*}P_{ijk}$ = the interaction between historical botanical composition, canopy height j and period k; and e_c = the error whereby P_k, $HBC{*}P_{ik}$, $CH{*}P_{jk}$ and $HBC{*}CH{*}P_{ijk}$ will be tested.

Results

The effects of historical botanical composition

There was an interaction between HBC and the evaluation periods that affected the FAR ($p < 0.10$) (Table 1). In the second period, which covered the entire winter and spring seasons, no effects of the HBC on the FAR were observed. However, the FAR was higher in the canopies of HBC34, HBC45 and HBC52 during the third study period.

The stocking rate was lower in HBC24 pastures compared to HBC52 pastures ($p < 0.10$), but it was no different from any of the other treatments throughout the experimental periods. In the first and third period, the stocking rates were similar (an average of 6.0 AU ha^{-1}) and greater than that observed in the second period (2.3 AU ha^{-1}, $p < 0.10$) (data not shown). Neither the FM nor its morphological components were affected by HBC or by the interaction of this factor with the experimental periods or CH ($p > 0.10$).

The effects of pre-grazing canopy height

The FAR was influenced by the interaction between experimental periods and CH ($p < 0.10$). During the second period, the FAR was 28.2 kg ha^{-1} d^{-1} in CH30, which was higher than that observed in CH45 (15.4 kg ha^{-1} d^{-1}). However, the FAR was higher in CH45 pastures (57.6 kg ha^{-1} d^{-1}) compared to CH30 pastures (44.3 kg ha^{-1} d^{-1}) in the third period. The rest periods were lower ($p < 0.10$) in CH30 (60, 157 and 69 days) than in CH45 (72, 245 and 86 days) for the first, second and third periods, respectively. The stocking rate was higher in CH30 pastures (5.2 AU ha^{-1}) than in CH45 pastures (4.5 AU ha^{-1}) (data not shown).

In all experimental periods, the pre- and post-grazing FMs were higher in CH45 pastures (Table 2). Throughout the experimental period, no increases in the pre-grazing FM in CH30 pastures were observed. An increase in the post-grazing FM was observed in the last period in CH30 pastures compared to the first period, but no differences were observed when compared to the second period. In CH45, the pre- and post-grazing FM increased in succeeding periods ($p < 0.10$).

Table 1 – Effects of historical botanical composition (HBC) and experimental periods (EPs) on the forage accumulation rate (FAR) and stocking rate (SR) of Xaraés palisadegrass pastures.

EPs	HBC				SEM	*p*-value		
	24†	34	45	52		EPs	HBC	EPs × HBC
	FAR							
II	20.4^{Aa}	30.7^{Ab}	12.2^{Ab}	21.9^{Ab}	5.47	< 0.01	0.27	0.03
III	36.9^{Ba}	51.6^{Aa}	56.9^{Aa}	58.4^{Aa}	5.48			
	SR							
Mean of EPs	4.33^{B}	4.77^{AB}	4.94^{AB}	5.16^{A}	0.166	< 0.01	0.08	0.15

†Mineirão stylo compositions of 24, 34, 45 and 52 % in the forage mass. EPII = second experimental period (from June 2011 to Jan 2012). EPIII = third experimental period (from Feb 2012 to May 2012). Forage accumulation rate data are expressed as kg dry matter ha^{-1} d^{-1} and stocking rate data as animal unit ha^{-1}. Value within each line (upper case) and column (lower case) with different superscripts differ at $p < 0.10$. SEM = standard error of the mean.

Leaf mass was greater in CH45 pastures compared to CH30 pastures ($p < 0.10$) (Table 3). In both CHs, leaf mass was less in the first period than in the other two periods. The dead material mass in the first period was similar under all conditions, regardless of CH. However, the dead material mass was greater in CH45 pastures than in CH30 pastures for the two later periods. No increases in dead material mass over time were observed in CH30 pastures. In contrast, the dead material mass increased from periods one to three in CH45 pastures. In all periods, the stem mass was greater in CH45 pastures than in CH30 pastures ($p < 0.10$). No increases in stem mass were observed in CH30 pastures throughout the experimental periods. However, in CH45 pastures, the stem mass was less than in the first period compared to the remaining two periods.

Table 2 – Effects of canopy height (CH) and experimental periods (EPs) on the pre- and post-grazing forage mass of Xaraés palisadegrass pastures.

EPs	CH		SEM	*p*-value		
	30	45		EPs	CH	CH × EPs
	Pre-grazing forage mass					
I	4891^{Ba}	619^{Ab}	155	< 0.01	< 0.01	< 0.01
II	5244^{Ba}	8060^{Aa}	270			
III	5779^{Ba}	8954^{Aa}	431			
	Post-grazing forage mass					
I	2553^{Bb}	3433^{Ac}	104	< 0.01	< 0.01	< 0.01
II	2703^{Bab}	4010^{Ab}	143			
III	2972^{Ba}	5282^{Aa}	66			

EPI = first experimental period (from Mar 2011 to May 2011). EPII = second experimental period (from June 2011 to Jan 2012). EPIII = third experimental period (from Feb 2012 to May 2012). Canopy height is expressed in centimetres and pre- and post-grazing forage mass data as kg ha^{-1}. Value within each line (upper case) and column (lower case) with different superscripts differ at $p < 0.10$. SEM = standard error of the mean.

Table 3 – Effects of canopy height (CH) and experimental periods (EPs) on the leaf. stem and dead material mass of Xaraés palisadegrass pastures.

EPs	CH		Mean	SEM	*p*-value		
	35	45			EPs	CH	CH × EPs
	Leaf mass						
I	2299	2960	2629^{b}	75.5	< 0.01	< 0.01	0.980
II	2869	3539	3204^{a}	67.0			
III	2688	3400	3043^{a}	120			
Mean	2620^{B}	3300^{A}					
	Stem mass						
I	1339^{Ba}	1768^{Ab}		101	< 0.01	< 0.01	< 0.01
II	1477^{Ba}	2487^{Aa}		101			
III	1544^{Ba}	2510^{Aa}		101			
	Dead material mass						
I	1234^{Aa}	1399^{Ac}		67.9	< 0.01	< 0.01	< 0.01
II	1078^{Ba}	2032^{Ab}		152			
III	1369^{Ba}	3002^{Aa}		195			

EPI = first experimental period (from Mar 2011 to May 2011). EPII = second experimental period (from June 2011 to Jan 2012). EPIII = third experimental period (from Feb 2012 to May 2012). Canopy height is expressed in centimetres and pre- and post-grazing forage mass data as kg ha^{-1}. Value within each line (upper case) and column (lower case) with different superscripts differ at $p < 0.10$. SEM = standard error of the mean.

The HBCs did not influence the behavior of cows in the pasture ($p > 0.10$) (Table 4). The CHs influenced the time spent grazing, chewing and resting, and the animals spent more time grazing and chewing in CH45 pastures than in CH30 pastures ($p < 0.10$).

Discussion

The percentage of legumes in mixed pastures is directly related to the amount of nitrogen fixed per unit area (Thomas et al., 1997). Most of the nitrogen fixed by legumes is transferred to grasses through the deposition and decomposition of litter, roots and nodules (Cadisch et al., 1994). Plant residue decomposition occurs gradually over time (Rezende et al., 1999), which maintains pasture productivity even after the disappearance of legumes. An example of this was observed in the present study, in which the FAR was higher in HBC34, HBC45 and HBC52 pastures in the third period one year after legume disappearance. Using the CROPGRO forage model (DSSAT 5.1 software), which has been validated for use with *B. brizantha* (Pedreira et al., 2011), it was estimated that it would be necessary to apply 130-150 kg ha^{-1} of nitrogen to obtain FARs similar to HBC34, HBC45 and HBC52 for the environmental conditions during the third experimental period. The similarity of the FAR in all HBCs during the second period is due to unfavorable environmental conditions (temperature and low rainfall; Figure 1) at the beginning of the period.

The highest FAR in the HBC34, HBC45 and HBC52 pastures resulted in average stocking rates of 4.9 AU ha^{-1}, which can be considered advantageous under tropical production systems with low inputs. In grasses, nitrogen is the primary nutrient that modulates morphogenetic characteristics and growth rate (Gastal and Nelson, 1994). Conversely, structural characteristics are not affected by this nutrient, especially when the defoliation criteria established are based on forage plants, such as CH (Silva et al., 2009). Thus, the HBCs did not affect characteristics such as FM and morphological compositions, a fact that can explain the similar behavior of cows grazing in different HBCs.

The second objective of this study was to determine the best strategy for forage use from the moment when the legume disappears until the following rainy season, at which time oversowing would be performed. For this purpose, two CHs were selected, one featuring the best canopy structure with a greater level of nutrient uptake due to a greater stocking rate (CH30) and the other with lower nutrient uptake (CH45) (Boddey et al., 2004).

In CH30 pastures, the FAR was highest during the second period (winter and spring). In contrast, the FAR was highest during the third period (summer) in CH45 pastures. In the second period, there were 1.56 more grazing cycles in CH30 pastures than in CH45 pastures. Therefore, CH30 pastures were defoliated sooner than CH45 pastures in the transition from winter to spring (i.e., under more favorable environmental conditions). Defoliation stimulates the renewal of tillers. Young tillers have greater forage growth rates compared to mature and old tillers (Paiva et al., 2011). Thus, in CH30 pastures, the FAR may have been higher due to a greater population density of young tillers. The third period began after defoliation of CH45 pastures; thus, tiller renovation occurred in both CH30 and CH45 pastures during this period. The higher FARs observed in CH45 pastures can be explained by a greater input of resources for plant regrowth, especially non-structural carbohydrates (Pedreira et al., 2011). Even with the variability in FARs between the periods and the two CHs, the average FAR was similar in CH30 and CH45 pastures at the end of the experimental period. Thus, the higher stocking rate in CH30 pastures resulted from shorter rest periods.

Longer intervals between grazing accumulate greater FM and increase the mass of its components (pre- and post-grazing). However, the greater leaf mass in CH45 pastures was accompanied by greater stem mass and increased dead material mass during the pre-grazing period. Pedreira et al. (2009) evaluated Xaraés palisadegrass that had been subjected to defoliation strategies (95 and 100 % light interception) and obtained similar results to those observed in this study. This likely resulted from the fact that tropical grasses elongate their stems in response to competition for light. In addition to the stem elongation process, leaf senescence occurs because the rest periods are longer than their lifespan.

Although the post-grazing height was 15 cm in both treatments, it was not possible to reach this residue height in CH45 pastures. The average residue heights obtained were 20.6, 24.3 and 26.8 cm in the first, second and third period, respectively (data not shown). CH45 pastures were more likely to be rejected by the cows because of their higher ratio of stems to dead material, a fact that highlights the difficulty of managing Xaraés palisadegrass pastures with CH45.

Changes in canopy structure affect the behavior of grazing animals, especially with regard to forage intake (Amaral et al., 2013). These effects are more pronounced in tropical grass pastures due to the reduction in the leaf-stem ratio, even with plants that are in the vegetative stage of development (Wade and Carvalho, 2000). In the present study, the grazing times of 359 to 720 minutes per day in each CH are within the range of values suggested by Hodgson (1990) and Krysl and Hess (1993). Howev-

Table 4 – Effects of historical botanical composition (HBC) and canopy height (CH) on the behaviour of Tabapuã cows in Xaraés palisadegrass pastures.

Item	HBC				SEM	*p*-value	CH		SEM	*p*-value
	24[†]	34	45	52			30	45		
Grazing time	452	443	464	488	15.1	0.29	433	492	10.8	0.05
Chewing time	476	453	485	459	9.52	0.29	457	483	6.63	0.03
Resting time	511	544	492	491	15.5	0.15	550	474	11.0	0.01

[†]Mineirão stylo compositions of 24, 34, 45 and 52 % in the forage mass. Grazing, chewing and resting data are expressed as min d^{-1} and canopy height is expressed in centimeters. SEM = standard error of the mean.

er, cows in CH30 pastures spent an average of 60 fewer minutes grazing. This indicates that these cows found the canopy structure more appropriate for grazing, which is consistent with the fact that these pastures had a higher ratio of leaves and a lower ratio of stems and dead material. The instantaneous intake rate is directly related to canopy structure (Amaral et al., 2013); therefore, animals require more grazing time when they graze on pastures with unfavorable canopy structures (e.g., CH45).

To our knowledge, this is the first study to evaluate the productivity of tropical grass pastures as a function of the HBC under mixed conditions. Our study shows that pastures with over 34 % stylo in their botanical composition remain productive even 15 months after legume disappearance. This allows for legume oversowing to be postponed until the following growing season (spring and summer), regardless of the CH at which the pasture was managed. This can be considered advantageous from both an operational and an economic standpoint.

In addition, it was shown that Xaraes palisadegrass managed with a pre-grazing CH of 30 cm provided a superior forage resource to that of this species with a 45-cm pre-grazing canopy height. The 30-cm pre-grazing canopy height provided a grazing environment conducive to forage intake by animals which resulted in efficient use of the pasture.

Acknowledgements

The authors thank the members of NEFOR (Brazilian Forage Team) for their contributions during the field trial setup. This work was funded by the Minas Gerais State Foundation for Research Support (FAPEMIG) and the Brazilian National Council for Scientific and Technological Development (CNPq).

References

Allen, V.G.; Batello, C.; Berretta, E.J.; Hodgson, J.; Kothmann, M.; Li, X.; McIvor, J.; Milne, J.; Morris, C.; Peeters, A.; Sanderson, M. 2011. An international terminology for grazing lands and grazing animals. Grass and Forage Science 66: 2-28.

Amaral, M.F.; Mezzalira, J.C.; Bremm, C.; Trindade, J.K.; Gibb, M.J.; Suñe, R.W.M.F.; Carvalho, P.C. 2013. Sward structure management for a maximum short-term intake rate in annual ryegrass. Grass and Forage Science 68: 271-277.

Boddey, R.M.; Macedo, R.; Tarré, R.M.; Ferreira, E.; Oliveira, O.C.; Rezende, C.P.; Cantarutti, R.B.; Pereira, J.M.; Alves, B.J.R.; Urquiaga, S. 2004. Nitrogen cycling in Brachiaria pastures: the key to understanding the process of pasture decline. Agriculture, Ecosystems & Environment 103: 389-403.

Braga, G.J.; Pedreira, C.G.S.; Herling, V.R.; Luz, P.H.C.; Marchesin, W.A.; Macedo, F.B. 2009. Quantifying herbage mass on rotationally stocked palisadegrass pastures using indirect methods. Scientia Agricola 66: 127-131.

Cadisch, G.; Schunke, R.M.; Giller, K.E. 1994. Nitrogen cycling in a pure grass pasture and a grass-legume mixture on a red latosol in Brazil. Tropical Grasslands 28: 43-52.

Gastal, F.; Nelson, C.J. 1994. Nitrogen use within the Growing Leaf Blade of Tall Fescue. Plant Physiology 105: 191-197.

Herridge, D.F.; Peoples, M.B.; Boddey, R.M. 2008. Global inputs of biological nitrogen fixation in agricultural systems. Plant and Soil 311: 1-18.

Hodgson, J. 1990. Grazing Management: Science into Practice. Longman Scientific and Technical, Essex, UK.

Krysl, L.J.; Hess, B.W. 1993. Influence of supplementation on behavior of grazing cattle. Journal of Animal Science 71: 2546-2555.

Lascano, C.E. 2000. Selective grazing on grass-legume mixtures in tropical pastures. p. 249-263. In: Lemaire, G.; Hodgson, J.; Moraes, A.; Carvalho, P.C.F.; Nabiger, C., eds. Grassland ecophysiology and grazing ecology. CAB International, Wallingford, UK.

Ledgard, S.F.; Steele, K.W. 1992. Biological nitrogen fixation in mixed legume/grass pastures. Plant and Soil 141: 137-153.

Martin, P.; Bateson, P. 2007. Measuring behavior: an introductory guide. Cambridge University Press, Cambridge, UK.

Muir, J.P.; Pitman, W.D.; Dubeux Jr., J.C.; Foster, J.L. 2014. The future of warm-season, tropical and subtropical forage legumes in sustainable pastures and rangelands. African Journal of Range & Forage Science 31: 1-12.

Nyfeler, D.; Huguenin-Elie, O.; Suter, M.; Frossard, E.; Connolly, J.; Lüscher, A. 2009. Strong mixture effects among four species in fertilized agricultural grassland led to persistent and consistent transgressive overyielding. Journal of Applied Ecology 46: 683-691.

Paciullo, D.S.C.; Pires, M.F.A.; Aroeira, L.J.M.; Morenz, M.J.F.; Maurício, R.M.; Gomide, C.A.M.; Silveira, S.R. 2014. Sward characteristics and performance of dairy cows in organic grass–legume pastures shaded by tropical trees. Animal 8: 1264-1271.

Paiva, A.; Silva, S.; Pereira, L. 2011. Morphogenesis on age categories of tillers in marandu palisadegrass. Scientia Agricola 68: 626-631.

Pedreira, B.C.; Pedreira, C.G.S.; Boote, K.J.; Lara, M.A.S.; Alderman, P.D. 2011. Adapting the CROPGRO perennial forage model to predict growth of *Brachiaria brizantha*. Field Crops Research 120: 370-379.

Pedreira, B.C.; Pedreira, C.G.S.; Silva, S.C. 2009. Herbage accumulation during regrowth of Xaraés palisadegrass submitted to rotational stocking strategies. Revista Brasileira de Zootecnia 38: 618-625 (in Portuguese, with abstract in English).

Rezende, C.P.; Cantarutti, R.B.; Braga, J.M.; Gomide, J.A.; Pereira, J.M.; Ferreira, E. 1999. Litter deposition and disappearance in Brachiaria pastures in the Atlantic forest region of the south of Bahia, Brazil. Nutrient Cycling in Agroecosystems 54: 99-112.

Silva, S.C.; Bueno, A.A.O.; Carnevalli, R.A.; Uebele, M.C.; Bueno, F.O.; Hodgson, J.; Matthew, C.; Arnold, G.C.; Morais, J.P.G. 2009. Sward structural characteristics and herbage accumulation of Panicum maximum cv. Mombaça subjected to rotational stocking managements. Scientia Agricola 66: 8-19.

Sousa, B.M.L.; Nascimento, D.; Rodrigues, C.S.; Monteiro, H.C.F.; Silva, S.C.; Fonseca, D.M.; Sbrissia, A.F. 2011. Morphogenetic and structural characteristics of xaraes palisadegrass submitted to cutting heights. Revista Brasileira de Zootecnia 40: 53-59.

Thomas, R.J.; Asakawa, N.M.; Rondon, M.A.; Alarcon, H.F. 1997. Nitrogen fixation by three tropical forage legumes in an acid-soil savanna of Colombia. Soil Biology and Biochemistry 29: 801-808.

Wade, M.H.; Carvalho, P.C.F. 2000. Defoliation patterns and herbage intake on pastures. CABI, Wallingford, UK.