R. Bras. Zootec., 48:e20180134, 2019
https://doi.org/10.1590/rbz4820180134

Forage crops
Full-length research article

Revista Brasileira de Zootecnia

Brazilian Journal of Animal Science
ISSN 1806-9290
www.rbz.org.br

Canopy structure and forage nutritive value of elephantgrass subjected to different stocking rate and N fertilization in the "Mata Seca" ecoregion of Pernambuco

Diego Loiola Dourado[1], José Carlos Batista Dubeux Junior[2*], Alexandre Carneiro Leão de Mello[3], Mércia Virginia Ferreira dos Santos[3], Mário de Andrade Lira[4], Erinaldo Viana de Freitas[4], Valéria Xavier de Oliveira Apolinário[5], Erick Rodrigo da Silva Santos[2]

[1] Módulo Rural, Feira de Santana, BA, Brasil.
[2] University of Florida, North Florida Research and Education Center, Marianna, FL, USA.
[3] Universidade Federal Rural de Pernambuco, Departamento de Zootecnia, Recife, PE, Brasil.
[4] Instituto Agronômico de Pernambuco, Recife, PE, Brasil.
[5] Universidade Estadual do Maranhão, Departamento de Zootecnia, São Luís, MA, Brasil.

***Corresponding author:**
dubeux@ufl.edu

Received: May 30, 2018
Accepted: February 27, 2019

How to cite: Dourado, D. L.; Dubeux Junior, J. C. B.; Mello, A. C. L.; Santos, M. V. F.; Lira, M. A.; Freitas, E. V.; Apolinário, V. X. O. and Santos, E. R. S. 2019. Canopy structure and forage nutritive value of elephantgrass subjected to different stocking rate and N fertilization in the "Mata Seca" ecoregion of Pernambuco. Revista Brasileira de Zootecnia 48:e20180134. https://doi.org/10.1590/rbz4820180134

ABSTRACT - The objective was to evaluate the effect of three stocking rates (2, 3.9, and 5.8 animal units ha^{-1}) and three fertilization levels (0, 150, and 300 kg N ha^{-1} yr^{-1}) on herbage mass and nutritive value of elephantgrass (*Pennisetum purpureum* Schum.) cv. IRI-381. The experiment was conducted from May to August of 2009 and 2010 in Itambé, PE, Brazil, during the rainy season. Treatments were allocated in a split-plot arrangement in a completely randomized block design. The variables measured included leaf mass (pre- and post-grazing), botanical composition, soil cover, leaf area index, light interception, leaf angle, and concentrations of dry matter, organic matter, N, and *in vitro* digestible dry matter. When fertilized with 300 kg N ha^{-1} yr^{-1}, leaf mass reached 18,560 kg ha^{-1}. Leaf area index decreased with increasing stocking rate. The relationship between sward height and light interception was R^2 = 0.0126. Increased stocking rate resulted in greater contribution of signalgrass [*Brachiaria decumbens* (Stapf.) R.D. Webster] in the botanical composition, with a contribution up to 29% in 2010. Elephantgrass nutritive value is directly affected by the fertilization levels and stocking rate, with highest nutrient concentrations observed with 2 AU ha^{-1} and 300 kg N ha^{-1} yr^{-1}.

Keywords: grazing, livestock, nitrogen, pasture, *Pennisetum purpureum*

Introduction

Animal production on pastures is directly linked to forage potential to adapt to the ecosystem and management practices. Greater productivity often occurs in years immediately after pasture establishment; over time, mostly due to poor management, pasture productivity decreases as fewer desirable plants dominate and soil cover decreases (Boddey et al., 2004).

Brazil has millions of hectares of degraded pastures, mostly as a result of decreased soil fertility and inadequate management practices, notably overgrazing (Costa et al., 2010). To reverse this process, fertilizers, especially N, are needed to maximize plant growth (Andrade et al., 2003; Liu et al., 2011a,b). Factors such as forage mass, overstocking, and inefficient N cycling can reduce pasture production (Dubeux Jr. et al., 2011).

Additionally, factors as climate, soil characteristics (such as fertility), and soil nutrient management (Vitor et al., 2009; Silva et al., 2015) affect forage nutritive value because of changes in chemical composition, digestibility, and digestion of products that occur with morphological and physiological development (Allen et al., 2011; Cunha et al., 2011). As a result, management of soil fertility and grazing animals can be used to enhance ruminant production in grazing systems (Cunha et al., 2007; Vitor, 2009).

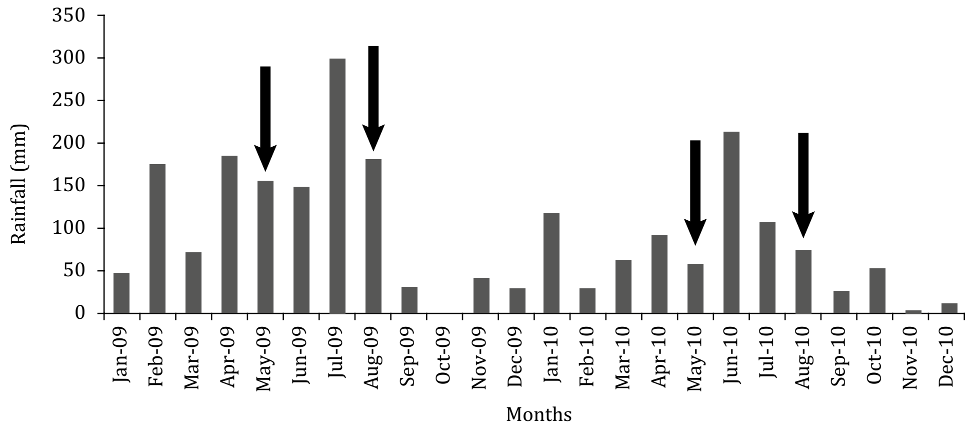
Stocking rate (SR) is the single most important management practice in grasslands, affecting vegetation, livestock, and economic responses (McCollum et al., 1999). Nitrogen fertilization is another important management practice, especially in warm-climate C4 grasslands (Johnson et al., 2001). These two practices might interact, affecting important responses such as herbage allowance and animal performance. There is limited information on the literature associating these two important management practices in the same grazing trial, especially with elephantgrass (*Pennisetum purpureum* Schum.).

Elephantgrass is one of the most important tropical forages due mostly to its biomass production potential (Dubeux Jr. et al., 2010), nutritive value, and acceptability by ruminants, as well as positive response to N fertilizer (Saraiva et al., 2014; Silva et al., 2015). Andrade et al. (2003) measured elephantgrass responses to N fertilizer and observed linear responses in leaf dry matter (DM) accumulation during the rainy season and leaf:stem ratio in the dry season.

The purpose of this research was to evaluate the effect of three stocking rates (2, 3.9, and 5.8 AU ha^{-1}) and three N fertilizer levels (0, 150, and 300 kg N ha^{-1} y^{-1}) on herbage accumulation and nutritive value on elephantgrass cv. IRI-381.

Material and Methods

The experiment was conducted in Itambé, Pernambuco, Brazil (7°23' S, 35°10' W, 189 m asl), in the "Mata Seca" ecoregion of the state. The total rainfall for 2009 and 2010 (Figure 1) was 1290 and 847 mm, respectively, while the 30-yr annual average rainfall is 1290 mm (Beltrão et al., 2005). The experiment was conducted on a Red-Yellow Argissoil, Acrisol according to FAO – WRB, or Oxisol according to Soil Taxonomy (EMBRAPA, 2006). Soil analyses for samples collected from 0 to 20-cm depth indicated the following results: pH$_{(water,\ 1:2.5)}$ = 5.7; Mehlich-1 P = 19.3 mg dm^{-3}; Na^+ = 0.2 cmolc dm^{-3}; K^+ = 0.4 cmolc dm^{-3}; Ca^{2+} + Mg^{2+} = 4.7. cmolc dm^{-3}; Al^{3+} = 0.1 cmolc dm^{-3}; H + Al = 5.4 cmolc dm^{-3}; organic C = 18 g kg^{-1}; and organic matter = 34.9 g kg^{-1} (EMBRAPA, 2009). These results indicated that there was no agronomic need to apply P, K, or Ca amendments. From 1977 to 1980, the site was used for sorghum trials; from 1981 to 2001, as a signalgrass [*Brachiaria decumbens* (Stapf.) R.D. Webster] pasture; from 2001 to 2006, to grow elephantgrass clones; and from 2006 until the time of the experiment,



Arrows indicate the beginning (May) and the end (August) of the evaluation period in each year (ITEP, 2011).

Figure 1 - Monthly rainfall at the research site in 2009 and 2010.

as elephantgrass IRI-381 pasture. The cultivar IRI-381 is from the group Cameroon (Pereira, 1993); it is inserted in the tall group, and when well-managed, has adequate leafiness. It can be managed in cut-and-carry or grazing systems.

The trial was performed from May to August of 2009 and 2010. This period corresponds roughly to the rainy season in the costal forest of Pernambuco State, Brazil. Treatments were allocated in a split-plot arrangement in a completely randomized block design, with three blocks. Main plots measured 833 m^2 and received three target stocking rates: two, four, and six animal units (AU = 450 kg BW); subplots measured 278 m^2 and received fertilization levels of 0, 150, or 300 kg N ha^{-1} yr^{-1} as urea-N, applied in five equal amounts in each growing season, immediately after grazing cycles. Each subplot contained drinking water and mineral salts *ad libitum*. Average stocking rates were 2, 3.9, and 5.8 AU ha^{-1} yr^{-1}.

Grazing occurred during 2009 and 2010 growing seasons. Data were collected from the start of the season until fresh herbage mass declined to 1,500-2,000 kg ha^{-1} at the end of the season. Paddocks were not used from October 2009 to April 2010 (dry season). Rotational stocking consisted of 35-d rest and 1-d grazing. This grazing cycle was based on previous research at the same location using elephantgrass under grazing. In the previous research, the grazing period was 32 days (Viana et al., 2015). In the current trial, we used 34 days to have a grazing cycle lasting five weeks and optimize sampling efforts. Mixed breed (*Bos* spp. 5/8 Freisan × 3/8 Zebu) cows weighing an average 436 kg were used. Each experimental unit was individually fenced, and groups of livestock were organized to graze always the same treatment to avoid N transfer from paddocks with higher N fertilization rate.

Plant height was measured at 40 random sites within each paddock, from the soil surface to the top of the plant before grazing. Leaf mass was determined every grazing cycle in each paddock, before and after grazing events, using the double-sampling technique described by Haydock and Shaw (1975). For each experimental unit, leaf mass was measured in two 1-m^2 quadrats. The forage in the quadrat was cut at the soil surface, weighed, and fresh weight was recorded. A subsample was hand-separated into stem, sheath, leaf blade, and inflorescence. These were weighed fresh, placed in paper bags, and placed in a forced-air oven at 65 °C to constant weight, then weighed again to determine plant fraction DM percentage and DM mass per hectare. Herbage and leaf mass were regressed with fertilizer level to determine R^2.

Leaf:stem ratios, leaf area index (LAI), light interception (LI), and leaf mass accumulation and rate, were determined before and after grazing for each cycle. The LAI, LI, and leaf mean angles were estimated using a LI-COR model LAI 2000 (LI-COR, Lincoln, NE, USA), which allowed non-destructive measurements (Welles and Norman, 1991). Measurements were taken pre- and post-grazing at three points in each paddock. At each location, three readings were taken below and three above the plant canopy. The three points below the canopy were taken at different points around the tuft base, 10 cm above ground level.

Botanical composition and soil cover were characterized at the beginning and end of each grazing season using the dry weight rank method for the botanical analysis of pastures, described by Mannetje and Haydock (1963). Forty points were randomly chosen in each paddock; at each point, the species present within a 1-m^2 quadrat were counted and assigned to a rank. Soil cover was determined along the botanical composition, by visually quantifying bare soil within the 40 quadrats, excluding plant litter and fecal material.

Plant samples to determine nutritive value were collected prior to each grazing cycle with the hand-plucked technique, described by Sollenberger and Cherney (1995). This technique mimics cattle bites, in which only leaf sheaths and blades are collected. These samples were dried as described above for herbage mass data. Samples were then ground to pass through a 1- or a 2-mm screen in a sheer mill. Samples ground at 1-mm were used to determine N concentration, whereas those ground at 2-mm were used to determine *in vitro* digestible dry matter (IVDDM). Nitrogen was analyzed according to Kjeldahl method described by EMBRAPA (2009), while IVDDM was carried out as described by Moore and Mott (1974).

Data were subjected to analyses of variance using PROC MIX procedure of SAS (Statistical Analysis System, version 9.2.). Fertilizer level, stocking rate, grazing cycle, year, and their interactions were considered fixed factors in the model. Blocks and block × stocking rate were considered as random factors. Means, when appropriate, were compared using the PDIFF procedure of SAS, adjusted by Tukey's test at a 5% probability. The statistical model was as follows:

$$y_{ijklm} = \mu + \beta_k + \alpha_i + (\alpha\beta)_{ik} + \tau_j + (\alpha\tau)_{ij} + \varphi_l + (\alpha\varphi)_{il} + (\tau\varphi)_{jl} + \alpha\tau\varphi_{ijl} + \lambda_m + (\alpha\lambda)_{im} + (\tau\lambda)_{jm} + (\varphi\lambda)_{lm} + (\alpha\tau\lambda)_{ijm} + (\alpha\varphi\lambda)_{ilm} + (\tau\varphi\lambda)_{jlm} + (\alpha\tau\varphi\lambda)_{ijlm} + \varepsilon_{ijklm},$$

in which y = dependent variable; μ = intercept; β_k = effect of level *k* of factor β (block); α_i = effect of level *i* (2, 3.9, and 5.8 AU ha^{-1} y^{-1}) of factor α (stocking rate); τ_j = effect of level *j* (0, 150, and 300 kg N ha^{-1} y^{-1}) of factor τ (N fertilization); φ_l = effect of level *l* (May, June, July, and August) of factor φ (grazing cycle); λ_m = effect of level *m* (2009 and 2010) of factor λ (year); and ε_{ijklm} = experimental error.

When responses were significant, they were subjected to regression analyses to fertilizer and stocking rates by an F test. All responses were considered significant at $P \leq 0.05$.

Results

There was a significant effect for the interaction between year and fertilization level for pre-grazing leaf blade mass (Table 1). There was a linear effect in 2010 among the fertilization levels, with a proportional increase in leaf blade mass occurring with increasing levels of N fertilization, highlighting the importance of N fertilization in the system.

In the post-grazing, leaf blade mass was affected significantly by the stocking rate, presenting a negative linear effect (P = 0.0171), with a reduction in leaf blade mass occurring with increasing stocking rates (Table 2). There was no significant effect (P>0.05) for the treatments on herbage accumulation (16,648 kg DM ha^{-1}) and herbage accumulation rate (376 kg DM ha^{-1} d^{-1}).

Table 1 - Elephantgrass (*Pennisetum purpureum* Schum.) cv. IRI-381 leaf blade mass pre-grazing at three N fertilization levels in Pernambuco, Brazil (averaged over stocking rates and grazing cycles)

N fertilizer	2009	2010	Standard error	P>|t|
	Leaf blade mass (kg dry matter/ha)			
0	7890	10012	3656	0.56
150	19121	11825	3736	0.05
300	10769	18560	3656	0.04
Effect	NS	L*		
Standard error	5443	2382		

NS - not significant.
* Linear; 5% probability (P≤0.05).

Table 2 - Elephantgrass (*Pennisetum purpureum* Schum.) cv. IRI-381 leaf blade mass post-grazing at three stocking rates in Pernambuco, Brazil (averaged over fertilizer rates and grazing cycles)

Stocking rate (animal units/ha)	Leaf blade mass (kg dry matter/ha)	Percentage from pre-grazing leaf blade mass (%)	Percentage of reduction (%)
2.0	6078	31	69
3.9	2543	18	82
5.8	1670	15	85
Effect	L*		
Standard error	741		

* Linear; 5% probability (P≤0.05).

Pre-grazing leaf:stem ratio was affected by the interaction year × grazing months (Table 3). There was a greater leaf:stem ratio in 2009 than in 2010 (P<0.05). During the first year, there was a significant effect (P<0.05) among the grazing months, with the least leaf:stem ratio (0.75) occurring in the last month of the rainy season (August). In the post-grazing, there was a triple interaction among year × month × fertilization rate (Table 4). In the first year, there was a quadratic effect (P = 0.0805) for the first grazing month. Yet, during the first year, there was a significant difference in the levels of 150 and 300 kg N ha^{-1}, with the lowest ratios occurring in the last month.

In addition to the elephantgrass and signalgrass, the botanical composition presented other undesired species. There was a year × evaluation interaction for elephantgrass and other species participation in the botanical composition (Table 5). Participation of other species identified in the experimental area had a different behavior in the two years, with a significant difference occurring during the two first evaluations in the first growing season (Table 5).

There was an interaction among year × evaluation × stocking rate for the signalgrass participation in the botanical composition (Table 6). In 2009, there was a quadratic (P = 0.002) effect in the first evaluation (April) and a linear effect (P<0.0001) in the second evaluation (September), resulting in a significant effect for treatments on signalgrass participation in the botanical composition (Table 6). It is possible to observe that there was a significant effect for stocking rate on the participation of signalgrass, with a direct positive response, in which the signalgrass participation is increased with increasing stocking rates. Soil cover varied with year and with evaluation, but no interaction was found. In 2009, there was 5.1% of bare ground (i.e., 94.1% of soil cover) and in 2010 only 2.9% bare ground. Soil cover was

Table 3 - Elephantgrass (*Pennisetum purpureum* Schum.) cv. IRI-381 leaf blade:stem ratio pre-grazing at four grazing cycles in Pernambuco, Brazil (averaged over fertilizer rates and stocking rates)

Cycle	2009	2010	P>|t|
May	1.31AB	0.73A	<0.01
June	1.08B	0.51A	<0.01
July	1.50A	0.58A	<0.01
August	0.75C	0.56A	0.18

Means followed by the same letter in the same column do not differ significantly (P≤0.05) according to PDIFF adjusted by Tukey.

Table 4 - Elephantgrass (*Pennisetum purpureum* Schum.) cv. IRI-381 leaf blade:stem ratio post-grazing at four grazing cycles subjected to three N fertilizer rates in Pernambuco, Brazil (averaged over stocking rates)

Grazing cycle	Nitrogen fertilizer rate (kg N/ha)			Effect
	0	150	300	
2009				
May	0.36A	0.25B	0.74A	P = 0.08
June	0.42A	0.57A	0.85A	P = 0.12
July	0.41A	0.38AB	0.18B	P = 0.25
August	0.24A	0.30B	0.16B	P = 0.55
2010				
May	0.25A	0.23A	0.17A	P = 0.70
June	0.12A	0.10A	0.09A	P = 0.74
July	0.19A	0.24A	0.16A	P = 0.78
August	0.21A	0.17A	0.17A	P = 0.64

Means followed by the same letter in the same column do not differ (P≤0.05) according to PDIFF adjusted by Tukey.

greater in April (3.5% bare ground) than in September (4.5% bare ground). In general, elephantgrass protected well the soil, reducing the risks for soil erosion.

Pre-grazing LAI and LI were both affected by the year × SR interaction. For both responses, there was no effect of SR in the first year (P>0.05). Light interception, however, reduced linearly in the second year with the increase in SR (data not shown). Both LAI and LI were also affected by year × month interaction, indicating the seasonal effect on herbage growth. There was a strong association between LI and LAI (Figure 2A); however, the association of plant height with LAI (Figure 2B) and plant height with LI (Figure 2C) were both low, with $R^2 = 0.01$.

Nitrogen concentration varied across season and increased from year 1 (23 g kg^{-1}) to year 2 (33.7 g kg^{-1}), as well as decreased within each growing season, peaking at the beginning of the growing season.

Table 5 - Contribution of elephantgrass (*Pennisetum purpureum* Schum.) cv. IRI-381 and other species [excluding brachiaria (*Brachiaria decumbens* Stapf.)] in a pasture subjected to different N fertilizer and stocking rates in Pernambuco, Brazil

	Elephantgrass (%)		Other species (%)	
	2009	2010	2009	2010
April	91.5Aa	91.0Aa	5.2Aa	2.2Ab
September	92.2Aa	76.5Bb	3.4Bb	3.7Aa
Standard error	2.7	3.0	0.6	0.7

Other species	Scientific name	Family
Mata-pasto	*Senna tora* (L.) Roxb.	Leguminosae Caesalpinioideae
Guizo de cascavel	*Crotalaria retusa* L.	Leguminosae Papilionoideae
Calopogônio	*Calopogonium velutinum* (Benth.) Amschoff	Leguminosae Papilionoideae
Espinheiro	*Machaerium aculeatum* Raddi	Leguminosae Papilionoideae
-	Sida sp.	Malvaceae
Capim ciperácia	-	Cyperaceae
Indigofera	*Indigofera macrocarpa* Desv.	Leguminosae Papilionoideae

Means followed by the same letter in the same column do not differ (P≤0.05) according to PDIFF adjusted by Tukey.

Table 6 - Contribution of brachiaria *(Brachiaria decumbens* Stapf.) to botanical composition of an elephantgrass (*Pennisetum purpureum*, Schum) cultivar IRI-381 pasture subjected to three stocking rates in Pernambuco, Brazil (averaged over grazing cycles and N fertilization rates)

Stocking rate (AU ha^{-1})	April 2009	SD	September 2009	SD
2	1.9A	4.3	2.0A	4.3
3.9	5.7A	4.3	4.1A	4.3
5.8	2.1A	4.3	6.9A	4.3
Effect	P = 0.01		P<0.01	
Standard error	0.23		0.20	
Stocking rate (AU ha^{-1})	April 2010		September 2010	
2.0	3.6B	4.3	10.3A	4.3
3.9	6.8B	4.3	29.4A	4.3
5.8	9.5A	4.3	19.8Aa	4.3
Effect	P = 0.95		P = 0.63	
Standard error	5.3		12.4	

AU - animal unit; SD - standard deviation.
Means followed by the same letter in the same column do not differ (P≤0.05) according to PDIFF adjusted by Tukey.

Variation within season was clearer in year 2 (Table 7). Leaf blade N concentration was affected by SR×N fertilization interaction. Nitrogen fertilization significantly affected leaf blade only at the higher SR, with a quadratic response (Figure 3).

In vitro digestible dry matter was affected by a triple interaction year × month × SR. In 2009, IVDDM increased with increasing SR in May, but not in the other months. In 2010, in two out of four evaluations there was a linear effect of SR on IVDDM. In May, lower SR resulted in higher IVDDM; however, in July, increasing SR resulted in higher IVDDM (data not shown). The IVDDM ranged from 430 to 490 g kg^{-1}.

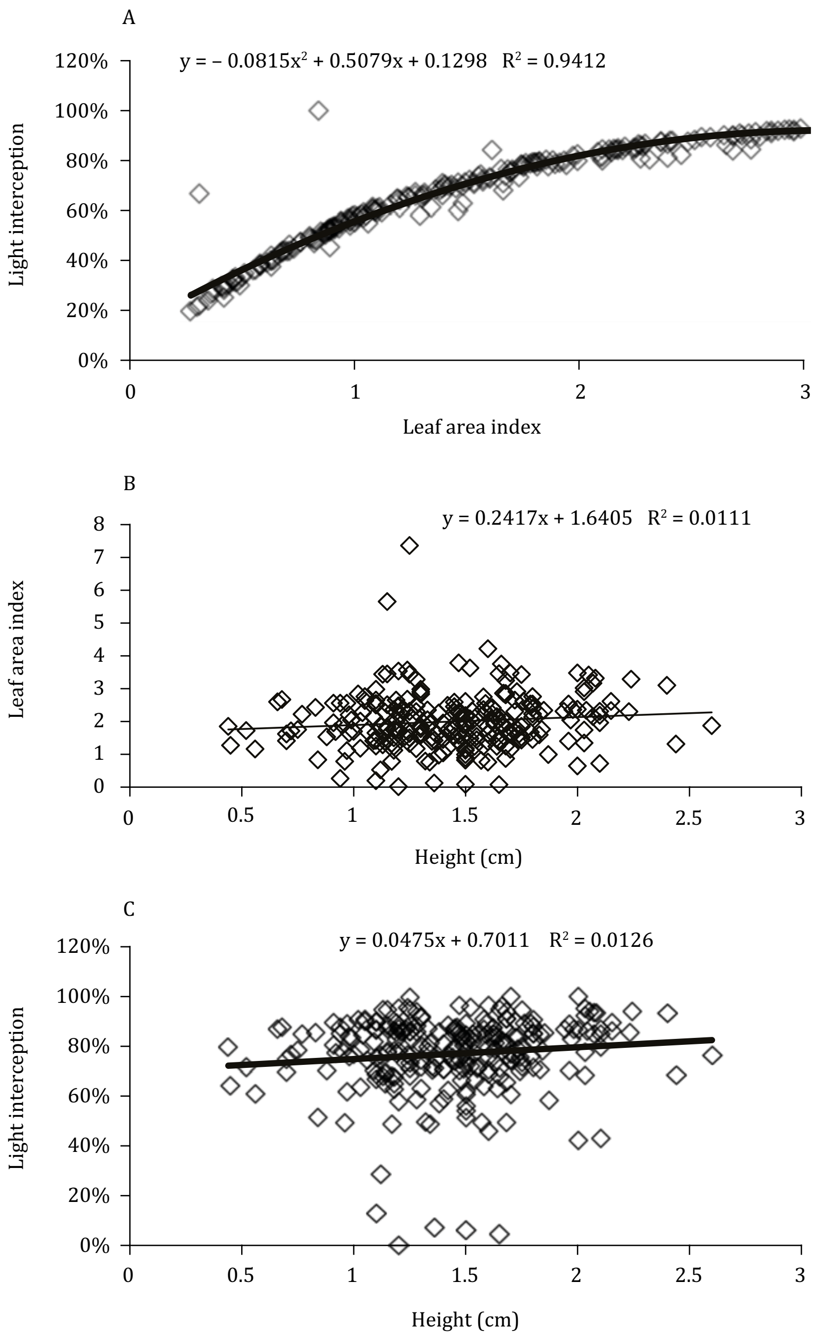
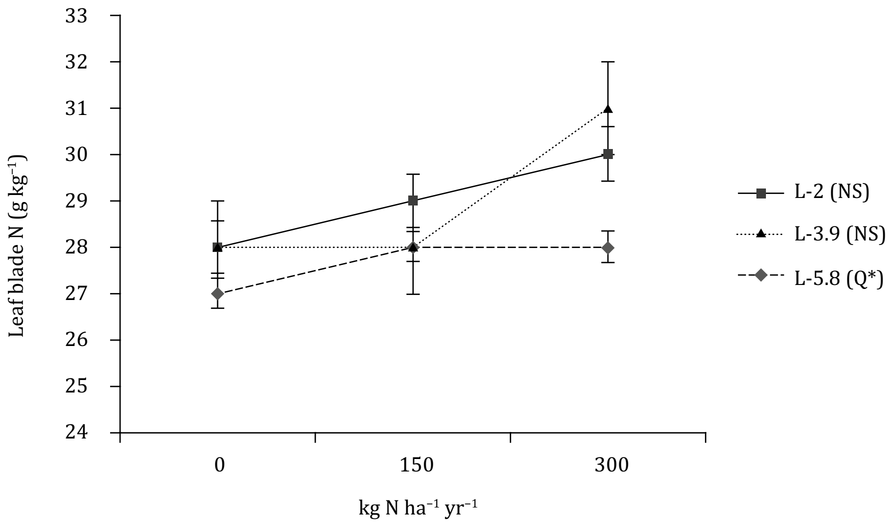


Figure 2 - Relationship between light interception (LI) and leaf area index (LAI), LAI and mean plant height, and LI and mean plant height of elephantgrass (*Pennisetum purpureum*, Schum) cultivar IRI - 381 in Pernambuco, Brazil (averaged over years, grazing cycles, fertilizer rates, and stocking rates).

Table 7 - *Pennisetum purpureum* (Schum) cultivar IRI-381 N concentration (g kg^{-1}) at four grazing cycles in Pernambuco, Brazil (averaged over stocking and N fertilizer rates)

Cycle	Year		Standard error	2009 vs. 2010
	2009	2010		P>|t|
	N concentration (g kg^{-1})			
May	24A	39A	1	<0.01
June	23AB	36B	1	<0.01
July	24A	32C	1	<0.01
August	21B	28D	1	<0.01

Means followed by the same letter in the same column do not differ (P≤0.05) according to PDIFF adjusted by Tukey.



NS - not significant.
* Orthogonal contrast at P≤0.05.

Figure 3 - Nitrogen concentration in elephantgrass (*Pennisetum purpureum*, Schum) leaf blades fertilized at 0, 150, and 300 kg N ha^{-1} yr^{-1} (averaged over year, grazing cycle, and stocking rate).

Discussion

Besides being an essential element in plant metabolism, N acts as a molecular constituent in plant tissues and plays an important role in forage leaf blade mass increase. In tropical pastures, the lack of essential nutrients in the soil are usually the most limiting factor retarding the productivity (Apolinário et al., 2013). Leaf tissue N concentration is also affected by the level of this nutrient in the soil (Vitor et al., 2009).

Great rainfall could also affect litter decomposition rate, accelerating availability of N and other nutrients to the plants (Sanches et al., 2009), consequently generating a cumulative effect, reflecting in greater leaf blade mass response to N fertilization in the second year. In addition, at the beginning of the rainy season, a boost of mineralization occurs and a greater rate of internal remobilization of N from senescent tissues to new tissues (Dubeux Jr. et al., 2006b). It is important to recognize greater standard error in the first year. Elephantgrass presents large spatial variability that makes it difficult to sample, especially under grazing conditions where typically there is greater canopy heterogeneity.

Probably, the reduction in leaf blade mass when increasing the stocking rate (Table 2) occurred due to more intense grazing. The applied definition of animal intake per area equals to the product consumed by the animal per amount of animals per unit of area (Allen et al., 2011), considering that the leaf blade is the structural component most consumed by the animals. Thus, the greater the stocking rate in a determined area, the greater reduction of leaf blades is expected. It is important to recognize that intake per animal might be reduced or compromised because of reduction on herbage allowance and forage quality at greater SR when combined with low herbage allowance. Dubeux Jr. et al. (2006a) also found similar results, in which the greater grazing pressure resulted in a greater proportion of removed forage.

Overall, leaf blade mass values such as accumulation and accumulation rate presented high values, considering that they refer to the production of leaf blades. In contrast to our study, Paciullo et al. (2005) reported leaf blade accumulation in an elephantgrass pasture of 126 to 9 kg of DM ha^{-1} d^{-1}, according to the period of the year. A possible explanation for the high values is that tiller density population (variable used to estimate leaf biomass accumulation) could be in an advanced stage of development and with a larger amount of leaves.

The greatest ($P<0.05$) leaf:stem ratio observed in August (Table 3) probably refers to the growth of these plants and reflected in greater stem elongation, decreasing leaf proportion. The intense stem elongation might have been triggered by greater pre-grazing stubble height. Rapid elongation of stem and internodes is a process that leads to the reduction of leaf:stem ratio, and this relationship is key in forage nutritional value evaluation (Viana et al., 2015).

The reduction of leaf:stem ratio in the last month of grazing (Table 4) was probably caused by greater intake frequency in the previous months combined with the decrease in rainfall (Figure 1). There were no required intervals for the development of new leaves, reflecting in a decrease in leaf:stem ratio. The values found for leaf:stem ratio in this study were lower than those found by Viana et al. (2015), who evaluated the stability and adaptability of eight *Pennisetum* spp. entries, and among them, the IRI-381 presented an average value for 16 grazing cycles of 0.86.

Participation of elephantgrass and other species in the botanical composition (Table 5) indicates that, despite the presence of weeds, the pasture was in a good state of conservation; therefore, the pasture presented a good persistence and adaptability to the adopted management (Cavalcanti Filho et al., 2008). The year × month interaction occurred, in part, because there was no effect among evaluations in the first year, whereas in the second year, there was a variability in the participation of elephantgrass in the pasture. Nevertheless, over time, the participation of elephantgrass in the botanical composition of the pasture decreased. The participation of signalgrass in the botanical composition can be explained by the change in abundance of signalgrass due to no significant difference in its participation against the other species in the first year, allowing other species to appear in the pasture. In the second year, signalgrass presented a more aggressive behavior, occupying more space and making the appearance of other species (undesirable ones) more difficult. The management adopted may have provided unfavorable conditions for the development of elephantgrass in the northern coastal region of Pernambuco State, since a significant increase in weeds was evident.

Undesirable species (Table 5) are difficult to eradicate due to the large reserve of seeds deposited in the soil over the years. Some of these species found in these management conditions are indicators of degraded soils, such as the mata-pasto (*Cassia occidentalis* L.) (Alvarenga et al., 1996; Silva and Saliba, 2007). The presence of pioneer species in the process of succession and species that are typical of the Atlantic Forest, such as Espinheiro (*Machaerium aculeatum* Raddi) stands out. The presence of this species indicates the natural return of the previously existing vegetation in the area and the need for a more adequate management to keep the stand and prevent a decrease of the cultivated species (Cavalcanti Filho et al., 2008).

Signalgrass was the most prominent invasive species in the elephantgrass pastures. It is very aggressive and competitive for essential resources as water and soil nutrients. Oliveira et al. (2008), also working at the Itambé Experimental Station, evaluated the botanical composition and uncovered soil of *B. decumbens* pastures, under different stocking rates. These authors reported average values for signalgrass participation in the botanical composition of 90% of the pastures, with greater stocking rates contributing to reduce their participation, consequently motivating the greater appearance of undesirable species in these pasture areas.

The relationship between LI × LAI (Figure 2A), height × LAI, and height × LI (Figures 2B and 2C) can be explained by the wide variation in the structural characteristics of elephantgrass pastures. Thus, both, tall plants with low density and short plants with high density can occur with high values of LAI and LI. Viana et al. (2009) estimated the coefficients of repeatability, determination (R^2), and minimum number of measurements necessary to predict the real value of morphophysiological and productive variables, as well as short-type elephantgrass responses to sheep grazing. They observed that for the variables LAI, LI, and mean plant height, only one measurement (R^2 = 80%) was necessary to classify them as an easy predictor to elephantgrass entries in long cycle. They concluded that short-type elephantgrass canopies intercept more incident radiation with taller plants and greater LAI.

The high N values, ranging from 20 to 30 g kg^{-1} (Figure 3), indicate that elephantgrass is a forage of considerable protein value when handled under ideal conditions. Typically, grazed elephantgrass has crude protein levels higher than 7%. This is a critical value predicted by Minson and Wilson (1994) to not limit voluntary intake by ruminants, promoted by metabolic restrictions in the energy process (Fisher, 2002).

The increase in N concentration from year 1 to year 2 (Table 7) was possibly caused by the residual effect of the treatments, as well as to the recycling occurring, since the sum of the fertilization with the increase of the animal excretions probably enabled greater availability in the soil for this nutrient. Leaf blade N showed a quadratic response within the greatest SR (Figure 3), but no significant response under the other two SR. This might have happened because overgrazing limited the growth of elephantgrass and had a concentration effect at the greatest SR. Apolinário et al. (2014) evaluated the litter chemical composition and observed that there was a higher concentration of litter N in the second year of grazing, consequently, decreasing the C:N ratio of this component and favoring litter decomposition. Silva et al. (2015) evaluated root decomposition and chemical composition in elephantgrass pastures under three different stocking rates (2.0, 3.9, and 5.8 AU ha^{-1}) and three N fertilization rates (0, 150, and 300 kg N ha^{-1} yr^{-1}) and observed an average value for N concentration of 9.04 and 10.0 g kg^{-1} OM in 2009 and 2010 before the incubation.

Results were considered low (430 to 490 g kg^{-1}) for elephantgrass IVDDM, mainly when we consider that the samples were hand-plucked, with a predominance of sheath and leaf blade, which are the more digestible parts of the plant. In contrast to our work, Deresz et al. (2006) found a 638 g kg^{-1} average IVDDM concertation for elephantgrass on dairy cattle pastures fertilized with 200 kg N ha^{-1} yr^{-1} during the rainy season. Meinerz et al. (2011) evaluated the herbage mass and nutritive value of elephantgrass grown in conventional and agroecological systems and found a low variation in IVDDM during the agricultural year, with values ranging from 664 to 724 g kg^{-1}. Nitrogen fertilizer application at greater rates, such as the 300 kg N ha^{-1} yr^{-1} applied in one of the treatments, can potentially increase the risks of N losses to the environment. Nitrate leaching, denitrification, and ammonia volatilization are common pathways of N losses in N-fertilized pastures (Dubeux Jr. et al., 2007). Although N losses were not measured in this research, they must be considered before suggesting better management practices. Combining great N rates with low stocking rate also leads to aboveground biomass accumulation and, ultimately, to litter deposition. This might have positive (e.g., reduced nutrient losses via litter compared to excreta and better nutrient spatial distribution upon return) and negative effects (e.g., reduced light intensity negatively affecting basal tillering and nutrient immobilization).

Conclusions

Increasing stocking rates in elephantgrass leads to greater leaf blade intake and less post-grazing leaf blade mass. It also decreases elephantgrass proportion in the pasture as it increases signalgrass contribution to total biomass. Plant height is not a good indicator to predict light interception.

Nitrogen fertilization has a positive effect on forage nutritive value, regardless of stocking rate. The best combination of N fertilization level and stocking rate for grazing elephantgrass cv. IRI-381 in the Mata Seca ecoregion of PE State is 300 kg N ha^{-1} yr^{-1} and 2 AU ha^{-1}.

Acknowledgments

The authors acknowledge the funding provided by Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) and Fundação de Amparo à Ciência e Tecnologia do Estado de Pernambuco (FACEPE) for the development of this research.

References

Allen, V. G.; Batello, C.; Berretta, E. J.; Hodgson, J.; Kothmann, M.; Li, X.; McIvor, J.; Milne, J.; Morris, C.; Peeters, A. and Sanderson, M. 2011. An international terminology for grazing lands and grazing animals. Grass and Forage Science 66:2-28. https://doi.org/10.1111/j.1365-2494.2010.00780.x

Alvarenga, R. C.; Costa, L. M.; Moura Filho, W. and Regazzi, A. J. 1996. Crescimento de raízes de leguminosas em camadas de solo compactadas artificialmente. Revista Brasileira de Ciência Solo 20:319-326.

Andrade, A. C.; Fonseca, D. M.; Queiroz, D. S.; Salgado, L. T. and Cecon, P. R. 2003. Adubação nitrogenada e potássica em capim-elefante (*Pennisetum purpureum* Schum. cv. Napier). Revista Ciência e Agrotecnologia (Edição Especial):1643-1651.

Apolinário, V. X. O.; Dubeux Jr., J. C. B.; Mello, A. C. L.; Vendramini, J. M. B.; Lira, M. A., Santos, M. V. F. and Muir, J. P. 2013. Deposition and decomposition of signal grass pasture litter under varying nitrogen fertilizer and stocking rates. Agronomy Journal 105:999-1004.

Apolinário, V. X. O.; Dubeux Jr., J. C. B.; Mello, A. C. L.; Vendramini, J. M. B.; Lira, M. A.; Santos, M. V. F. and Muir, J. P. 2014. Litter decomposition of signalgrass grazed with different stocking rates and nitrogen fertilizer levels. Agronomy Journal 106:622-627.

Beltrão, B. A.; Mascarenhas, J. C.; Miranda, J. L. F.; Souza Junior, L. C.; Galvão, M. J. T. G. and Pereira S. N. 2005. Projeto cadastro de fontes de abastecimento por água subterrânea Estado de Pernambuco. Diagnóstico do município de Itambé. CPRM/PRODEEM, Recife.

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. and Urquiaga, S. 2004. Nitrogen cycling in *Brachiaria* pastures: the key to understanding the process of pasture decline. Agriculture, Ecosystems and Environment 103:389-403. https://doi.org/10.1016/j.agee.2003.12.010

Cavalcanti Filho, L. F. M.; Santos, M. V. F.; Lira, M. A.; Modesto, E. C.; Dubeux Jr., J. C. B.; Ferreira, R. L. C. and Silva, M. J. 2008. Caracterização de pastagem de Brachiaria decumbens na Zona da Mata de Pernambuco. Archivos de Zootecnia 57:391-402.

Costa, K. A. P.; Faquin, V. and Oliveira, I. P. 2010. Doses e fontes de nitrogênio na recuperação de pastagens do capim-marandu. Arquivo Brasileiro de Medicina Veterinária e Zootecnia 62:192-199. https://doi.org/10.1590/S0102-09352010000100026

Cunha, M. V.; Lira, M. A.; Santos, M. V. F.; Freitas, E. V.; Dubeux Jr., J. C. B.; Mello, A. C. L. and Martins, K. G. R. 2011. Association between the morphological and productive characteristics in the selection of elephant grass clones. Revista Brasileira de Zootecnia 40:482-488. https://doi.org/10.1590/S1516-35982011000300004

Cunha, M. V.; Santos, M. V. F.; Lira, M. A.; Mello, A. C. L.; Freitas, E. V. and Apolinário, V. X. O. 2007. Genótipos de capim-elefante sob pastejo no período de seca na Zona da Mata de Pernambuco: fatores relacionados à eficiência de pastejo. Revista Brasileira de Zootecnia 36:291-300. https://doi.org/10.1590/S1516-35982007000200004

Deresz, F.; Cóser, A. C. and Martins, C. E. 2006. Formação e utilização de pastagens de capim-elefante. 2.ed. Embrapa Gado de Leite, Juiz de Fora. (Instrução técnica).

Dubeux Jr., J. C. B.; Muir, J. P.; Santos, M. V. F.; Vendramini, J. M. B.; Mello, A. C. L. and Lira, M. A. 2011. Improving grassland productivity in the face of economic, social, and environmental challenges. Revista Brasileira de Zootecnia 40(supl. especial):280-290.

Dubeux Jr., J. C. B. and Mello, A. C. L. 2010. Aspectos morfofisiológicos do capim-elefante. p.31-67. In: Capim-elefante: fundamentos e perspectivas. Lira, M. A.; Santos, M. V. F.; Dubeux Jr., J. C. B.; Mello, A. C. L., orgs. IPA/UFRPE, Recife.

Dubeux Jr., J. C. B.; Sollenberger, L. E.; Vendramini, J. M. B.; Stewart Jr., R. L. and Interrante, S. M. 2006a. Litter mass, deposition rate, and chemical composition in bahiagrass pastures managed at different intensities. Crop Science 46:1299-1304. https://doi.org/10.2135/cropsci2005.08-0262

Dubeux Jr., J. C. B.; Sollenberger, L. E.; Interrante, S. M.; Vendramini, J. M. B. and Stewart Jr., R. L. 2006b. Litter decomposition and mineralization in bahiagrass pastures managed at different intensities. Crop Science 46:1305-1310. https://doi.org/10.2135/cropsci2005.08-0263

Dubeux Jr., J. C. B.; Sollenberger, L. E.; Mathews, B. W.; Scholberg, J. M. and Santos, H. Q. 2007. Nutrient cylcing in warm-climate grasslands. Crop Science 47:915-928. https://doi.org/10.2135/cropsci2006.09.0581

EMBRAPA - Empresa Brasileira de Pesquisa Agropecuária. 2006. Centro Nacional de Pesquisa de Solos. Sistema brasileiro de classificação de solos. 2.ed. Rio de Janeiro.

EMBRAPA - Empresa Brasileira de Pesquisa Agropecuária. 2009. Manual de análises químicas de solos, plantas e fertilizantes. Embrapa Informação Tecnológica, Brasília.

Fisher, D. S. 2002. A review of a few key factors regulating voluntary feed intake in ruminants. Crop Science 42:1651-1655.

Haydock, K. P. and Shaw, M. H. 1975. The comparative yield method for estimating dry matter yield of pasture. Australian Journal of Experimental Agriculture and Animal Husbandry 15:663-670.

ITEP - Instituto de Tecnologia de Pernambuco. 2011. Banco de dados meteorológicos de Pernambuco. Available at: <http://www.itep.br/itep_lamepe/site/index.php>. Accessed on: Jan. 10, 2011.

Johnson, C. R.; Reiling, B. A.; Mislevy, P. and Hall, M. B. 2001. Effects of nitrogen fertilization and harvest date on yield, digestibility, fiber, and protein fractions of tropical grasses. Journal of Animal Science 79:2439-2448. https://doi.org/10.2527/2001.7992439x

Liu, K.; Sollenberger, L. E.; Silveira, M. L.; Newman, Y. C. and Vendramini. J. M. B. 2011a. Grazing intensity and nitrogen fertilization affect litter responses in 'Tifton 85' bermudagrass pastures: I. Mass, deposition rate, and chemical composition. Agronomy Journal 103:156-162. https://doi.org/10.2134/agronj2010.0319

Liu, K.; Sollenberger, L. E.; Silveira, M. L.; Vendramini, J. M. B. and Newman, Y. C. 2011b. Distribution of nutrients among soil–plant pools in 'Tifton 85' bermudagrass pastures grazed at different intensities. Crop Science 51:1800-1807. https://doi.org/10.2135/cropsci2010.04.0209

Mannetje, L. T. and Haydock, K. P. 1963. The dry-weight-rank method for the botanical analysis of pasture. Grass and Forage Science 18:268-275.

McCollum, F. T. III; Gillen, R. L.; Karges, B. R. and Hodges, M. E. 1999. Stocker cattle response to grazing management in tall grass prairie. Journal of Range Management 52:120-126. https://doi.org/10.2307/4003504

Meinerz, G. R.; Olivo, C. J.; Agnolin, C. A.; Dullius, A. P.; Moraes, R. S.; Mombach, G.; Foletto, V. and Machado, P. R. 2011. Produção e valor nutritivo da forragem de capim-elefante em dois sistemas de produção. Revista Brasileira de Zootecnia 40:2673-2680. https://doi.org/10.1590/S1516-35982011001200009

Minson, D. J. and Wilson, J. R. 1994. Prediction of intake as on element of forage quality. p.533-563. In: Forage quality, evaluation, and utilization. Fahey Jr., G., ed. American Society of Agronomy, Madison.

Moore, J. E. and Mott, G. O. 1974. Recovery of residual organic matter from in vitro digestion of forages. Journal of Dairy Science 57:1258-1259.

Oliveira, O. F.; Santos, M. V.; Lins, M. M.; Lira, M. A.; Dubeux Jr, J. C. B.; Mello, A. C. L. and Silva, M. J. F. B. 2008. Composição botânica e solo descoberto em pastagens de *Brachiaria decumbens* sob diferentes lotações animais. In: Anais do 5º Congresso Nordestino de Produção Animal, Aracaju, SE.

Paciullo, D. S. C.; Aroeira, L. J. M.; Morenz, M. J. F. and Heinemann, A. B. 2005. Morfogênese, características estruturais e acúmulo de forragem em pastagem de *Cynodon dactylon*, em diferentes estações do ano. Ciência Animal Brasileira 6:233-241.

Pereira, A. V. 1993. Escolha de variedades de capim-elefante. p.47-62. In: 10º Simpósio sobre Manejo da Pastagem. Peixoto, A. M.; Moura, J. C.; Faria, V. P., eds. FEALQ, Piracicaba.

Saraiva, F. M.; Dubeux Jr., J. C. B.; Lira, M. A.; Mello, A. C. L.; Santos, M. V. F.; Cabral, F. D. A. and Teixeira, V. I. 2014. Root development and soil carbon stocks of tropical pastures managed under different grazing intensities. Tropical Grasslands-Forrajes Tropicales 2:254-261. https://doi.org/10.17138/tgft(2)254-261

Sanches, L.; Valentini, C. M. A.; Biudes, M. S. and Nogueira, J. S. 2009. Dinâmica sazonal da produção e decomposição de serrapilheira em floresta tropical de transição. Revista Brasileira de Engenharia Agrícola e Ambiental 13:183-189.

Silva, H. M. S.; Dubeux Jr., J. C. B.; Silveira, M. L.; Freitas, E. V.; Santos, M. V. F. and Lira, M. A. 2015. Stocking rate and nitrogen fertilization affect root decomposition of elephantgrass. Agronomy Journal 107:1331-1338. https://doi.org/10.2134/agronj14.0618

Silva, J. J. and Saliba, E. O. S. 2007. Pastagens consorciadas: Uma alternativa para sistemas extensivos e orgânicos. Veterinária e Zootecnia 14:8-18.

Sollenberger, L. E. and Cherney, D. J. R. 1995. Evaluating forage production and quality. p.97-110. In: The science of grassland agriculture. Iowa State University Press, Ames.

Viana, B. L.; Mello, A. C. L.; Lira, M. A.; Guim, A.; Dubeux Jr., J. C. B.; Santos, M. V. F. and Cunha, M. V. 2015. Adaptability and stability analysis for selection of elephantgrass clones under grazing. Crop Science 55:950-957. https://doi.org/10.2135/cropsci2014.05.0406

Viana, B. L.; Mello, A. C. L.; Lira, M. A.; Dubeux Jr., J. C. B.; Santos, M. V. F.; Cunha, M. V. and Ferreira, G. D. G. 2009. Repetibilidade e respostas de características morfofisiológicas e produtivas de capim-elefante de porte baixo sob pastejo. Pesquisa Agropecuária Brasileira 44:1731-1738. https://doi.org/10.1590/S0100-204X2009001200024

Vitor, C. M. T.; Fonseca, D. M.; Cóser, A. C.; Martins, C. E.; Nascimento Júnior, D. and Ribeiro Júnior, J. I. 2009. Produção de matéria seca e valor nutritivo de pastagem de capim-elefante sob irrigação e adubação nitrogenada. Revista Brasileira de Zootecnia 38:435-442. https://doi.org/10.1590/S1516-35982009000300006

Welles, J. M. and Norman, J. M. 1991. Instrument for indirect measurement of canopy architecture. Agronomy Journal 83:818-825. https://doi.org/10.2134/agronj1991.00021962008300050009x