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Forage yield and quality in elephant grass cv. Pioneiro harvested at different cutting height sand times

Produção e composição química do capim elefante cv. Pioneiro manejado em diferentes alturas de resíduo no ano de implantação da cultura

Danúbia Nogueira Figueira[1*]; Mikael Neumann[2]; Robson Kyoshi Ueno[3]; Sandra Galbeiro[4]; Antônio Vinícius Iank Bueno[5]

Abstract

This study aimed to evaluate the effect of cutting height and harvest time on forage yield and quality in elephant grass (*Pennisetum purpureum* Schum.) cv. Pioneiro. Experimental plots were arranged in a randomized block split-plot design. The treatments consisted of four residual heights (30, 40, 50, and 60 cm)and three successive harvest times (January, March, and May 2011). There was a significant interaction between residual height and harvest time for the proportion of stems (P<0.05) and leaves (P<0.01) in the forage. A similar result was observed for fresh (P<0.01) and dry (P<0.01) forage yield at the first and third harvests. There was a quadratic relationship between dry forage yield and residual height, with a maximum yield of5738 kg ha^{-1}ataresidual height of 50.17 cm in the second harvest. The increase in residual height from 30 to 60 cm, regardless of harvest time, reduced neutral detergent fiber (NDF)and acid detergent fiber (ADF) and increased crude protein content. Forage yield and quality were highest at 40-50 cm residual heights.

Key words: Forage components. Acid detergent fiber. Neutral detergent fiber. Forage yield. Crude protein.

Resumo

O experimento foi desenvolvido no município de Guarapuava-PR, com o objetivo de avaliar a produção e a composição química do capim elefante (*Pennisetum purpureum,* Schum) cv. Pioneiro, manejado em diferentes alturas de resíduo. O delineamento experimental foi em blocos casualizados, em esquema de parcelas subdivididas no tempo, sendo quatro alturas de resíduo: 30, 40, 50 e 60 cm associado a três épocas sucessivas de colheita (Janeiro, Março e Maio de 2010/2011). Houve interação entre altura de resíduo e época de colheita para participação de colmo (P>0,05) e folha (P>0,01) na estrutura física da forragem. O mesmo efeito foi observado para produção de massa de forragem fresca (P>0,01) e de massa de forragem seca (P>0,01) na 1 e 3ª época de colheita. Houve efeito quadrático na produção

[1] Discente, Curso de doutorado em Zootecnia pela Universidade Estadual "Júlio de Mesquita Filho", UNESP, Jaboticabal, SP, Brasil. E-mail danmedvet07@gmail.com

[2] Prof. Dr. em Zootecnia, Universidade Estadual do Centro Oeste, UNICENTRO, Guarapuava, PR, Brasil. E-mail: neumann.mikael@hotmail.com

[3] Discente do curso de doutorado em Zootecnia pela Universidade Federal do Rio Grande do Sul, UFRGS, Porto Alegre, RS, Brasil. E-mail: robsonueno@hotmail.com

[4] Profª Drª em Zootecnia, Universidade Estadual de Londrina, UEL, Londrina, PR, Brasil. E-mail: sgalbeiro@gmail.com

[5] Discente, Curso de Doutorado em Zootecnia, Universidade Estadual de Maringá, UEM, Maringá, PR, Brasil. E-mail: antonio.iank.bueno@gmail.com

[*] Author for correspondence

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de massa de forragem seca, com ponto de máxima produção de 5.738 kg ha^{-1} à altura de resíduo de 50,17 cm para a segunda época de colheita. Na média geral, a elevação da altura de resíduo do capim elefante de 30 para 60 cm, independente da época de colheita, promoveu redução nos teores de fibra em detergente neutro e fibra em detergente ácido da forragem, além de aumentar os teores de proteína bruta. O melhor equilíbrio entre potencial de produção da massa de forragem seca e composição química da forragem foi obtido quando o capim elefante foi manejado a altura de resíduo de 40 a 50 cm.
Palavras-chave: Estrutura física da forragem. Fibra em detergente ácido. Fibra em detergente neutro. Produção de massa de forragem. Proteína bruta.

Introduction

Residual height and harvest frequency are two major factors determining yield and quality of forage. Increasing harvest frequency significantly increases yield, but reduces forage quality. Low cutting heights reduce the remaining leaf area and number of apical meristems, directly affecting stand recovery, regrowth, vigor, and persistence (SANTOS et al., 2001a).

However, productivity is linked to the pasture waste time after the harvest of forage, therefore, the growth of a plant after cutting depends on the climate of the favoring and species characteristics (WIJITPHAN et al., 2009). However, as there is a higher proportion of leaves in forage mass, improvements in nutritional quality (EZEQUIEL; FAVORETTO, 2000).

Elephant grass (*Pennisetum purpureum* Schum.) is a perennial grass with caespitose growth habit and rapidly developing apical meristems, which are prone to being removed at low cutting heights. Thus, removal of apical meristems reduces plant regrowth and yield, and increases stand susceptibility to invasive plants. Moreover, plant regrowth from apical meristems is faster than growth from lateral and basal buds. Thus, improper harvesting management results from continuous removal of apical meristems (SANTOS, 1995).

Proper harvesting management over different harvest seasons is crucial for selecting forage cultivars with high yield potential per unit area with balanced proportions of stems, sheaths, and leaves in the forage to reduce costs with animal feed.

Few studies have evaluated the effect of harvest time on forage yield and quality in elephant grass (SANTOS et al., 2001b; WIJITPHAN et al., 2009; LOUNGLAWAN et al., 2014), but there are few studies that evaluated the best residue height.

This study aimed to evaluate the effect of cutting height and harvest time on forage yield and quality in elephant grass cv. Pioneiro.

Material and Methods

The study was conducted at the Animal Production Center (NUPRAN), Midwestern State University (UNICENTRO), Guarapuava, Paraná, Brazil (25°23'02"S 51°29'43'W,1,026 m elevation).

The climateis Cfb (mesothermal humid subtropical) according to the Köppen classification with mild summers and winters, no dry season and with severe frosts. The mean annual rainfall is 1,944 mm, the annual average minimum temperature 12.7 °C, and the annual average maximum temperatureis 23.5 °C. Annual average relative humidity is 77.9% (IAPAR, 2000).

Elephant grass was planted on October 12,2010in a 256 m^2area divided into 16 4 x 4 m plots (16 m^2 each) with a 3 x 3 m (9 m^2) useful area, which were randomly assigned to four treatments with four replications each.

Elephant grass was sowed manually by planting root cuttings in drills, with 0.5 m spacing between drills.NPK fertilizer (04-20-20) was applied at 600 kg ha^{-1}in the drills at planting based on soil analysis and recommendations in the Liming and Fertilization Manual for the states of Rio Grande

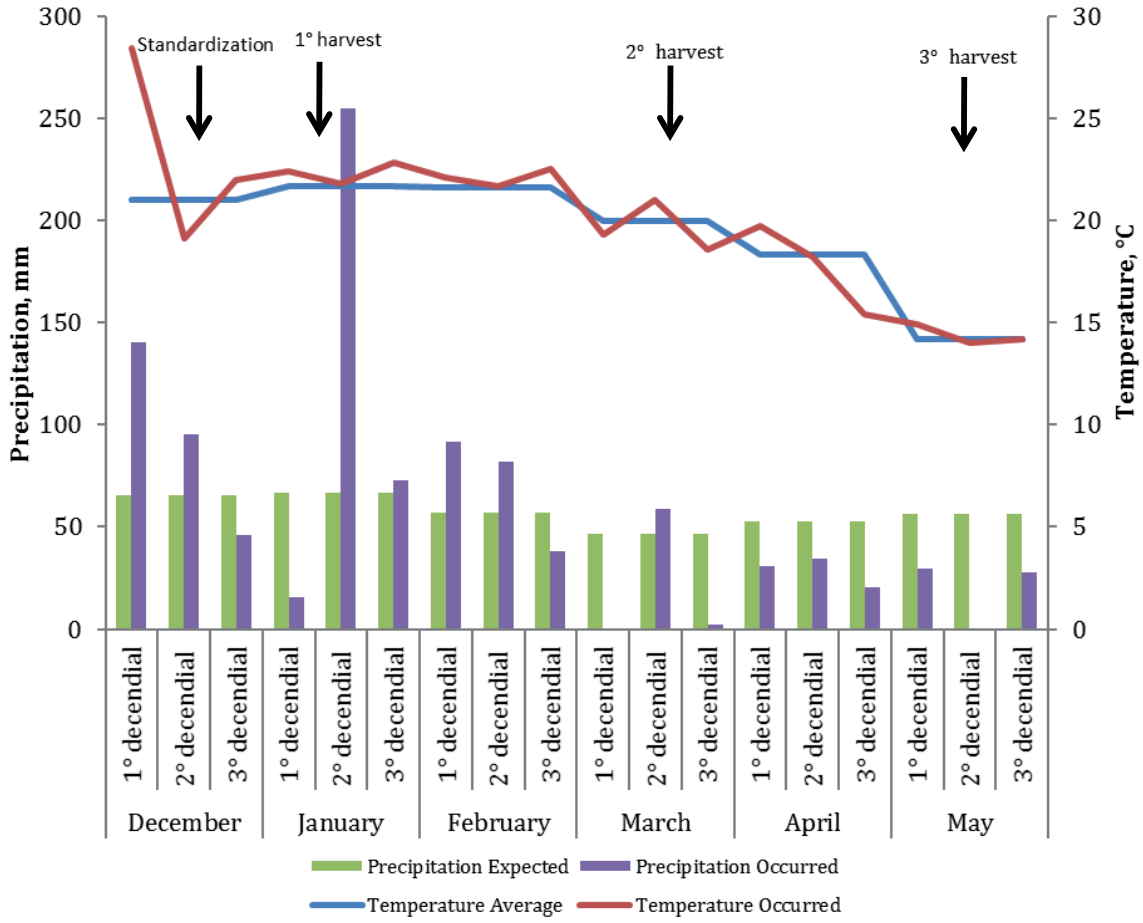
do Sul and Santa Catarina (CQFS-RS/SC, 2004). The soil in the experimental area isatypical oxisol (POTT et al., 2007) and had the following chemical characteristics at planting (0–20 cm profile): 0.01M $CaCl_2$: pH 4.9; P: 3.1 $mgdm^{-3}$; K^+: 0.2 $cmol_c dm^{-3}$; OM: 44.3g dm^2; Al^{3+}: 0.3 $cmol_c dm^{-3}$; $H^+ + Al^{3+}$: 6.41 $cmol_c dm^{-3}$; Ca^{2+}: 4.0 $cmol_c dm^{-3}$; Mg^{2+}: 3.4 $cmol_c dm^{-3}$;andbase saturation (V%): 54.0%.

Mechanical weeding practices for weed control, mowing for plant height standardization (30 cm), and nitrogen topdressing at 150 kg ha^{-1} N (45-00-00) in the form of urea were performed at the early stage of crop establishment, on November 15, 2010. Nitrogen fertilization was applied at 75 kg N ha^{-1} $year^{-1}$ in the form of urea after the first and second harvests.

The treatments consisted of four cutting heights (30, 40, 50, and 60 cm from the soil) and three successive harvests (January, March, and May 2001; mean light interception: 90-95%, at a mean height of 1.60 m). Light interception (LI) measurements were taken immediately before harvesting at four points in each plot using an AccuPARLP-80 digital linear ceptometer (Decagon Devices, Pullman, WA, USA).

Rainfall and mean temperature in the elephant grass growing season were 1041.3 mm and 19.9°C, respectively (Figure 1).

Figure 1. Expected and observed precipitation rates and mean temperatures in the elephant grass cv. Pioneiro growing period in the 2010/2011 season. Data from the SIMEPAR/UNICENTRO weather station, Guarapuava, Paraná, Brazil.



Because the experimental site was located in a region with cooler summer temperatures, only three harvests were conducted, in January, March, and May 2011. Plots were arranged in a randomized block split-plot design, with four residual heights and three consecutive harvest times.

All plots were harvested manually at the four cutting heights to obtain homogeneous composite samples representative of all plant tissues. These composite samples were separated into two 500 g-samples; the first sample was used to determine the proportion of plant parts (stem, sheath, and leaf) and the other was used to determine dry matter content for the estimation of dry matter yield (kg DM ha^{-1}). Samples were weighted and pre-dried in an oven with forced air circulation at 55 °C (AOAC, 1995).

Fresh forage yield was estimated by cutting plants to different residual heights in each plot, which were weighed and used to extrapolate fresh matter yield (kg FM ha^{-1}).

Pre-dried forage samples were used to determine total dry matter content (TDMC) at 105 °C, crude protein (CP) by the micro Kjedahl method, and mineral matter (MM) according to techniques described in AOAC (1995).Neutral detergent fiber (NDF) and acid detergent fiber (ADF) were determined according to the methods of Van Soest et al. (1991) and Goering and Van Soest (1970), respectively.

The data were analyzed using analysis of variance (ANOVA), and means for harvest periods were compared using the Tukey's test at the 5% significance level. Regression analysis was used to determine the relationship between residual heights and forage variables using the ProcReg procedure in SAS Statistical Software (1993).

Results and Discussion

Total dry matter and stem, sheath, and leaf dry matter were not affected by residual height or harvest time (P>0.05) (Table 1). Mean dry matter values for stems (9.93%), leaf blades (14.34%), and sheaths (16.95%) were not affected by cutting height. Dry matter content was highest at a cutting height of 49.64 cm (13.04%).

Mean stem dry matter was highest in the third harvest regardless of residual height (11.83%), followed by the second (10%) and first (7.92%) harvests. This result may be explained by the higher water content in young plants, which diminishes as the growth cycle progresses.

Mean sheath dry matter was not affected by harvest time regardless of residual height (P>0.05) and was highest in the second harvest (16.6%), followed by the third (15.56%) and first (10.85%) harvests. No significant differences were observed in mean leaf dry matter across harvests (P> 0.05).

Mean forage dry matter values were higher in the third harvest (13.86%) than in the first (11.58%) and second (11.46%) harvests regardless of residual height. This result may be explained by low rainfall at the third harvest (Fig. 1), with rainfall levels far below average for the period.

Acunha and Coelho (1997) evaluated yield inelephant grass cv. Mott at three harvest times and residual heights (5, 10, and 15 cm)and found that forage dry matter increased from the first to the third harvest(18.4%, 19.0%, and 19.5%, respectively) regardless of residual height. An increase in forage dry matter content is expected over time, because plant growth leads to an accumulation of photosynthates in elephant grass leaves (RAKKIYAPPAN; KRISHNAMOORTHY, 1982).

There was a significant interaction (P<0.05) between cutting height and harvest time for the proportion of stems, with a linear reduction in stem contribution to forage DM with increasing cutting height in the first harvest (Table 2): for every centimeter increase in residual height there was a 0.33% reduction in the proportion of stems.

In the second and third harvests there was a quadratic relationship between residual height and the proportion of stems, with a minimum 34.3% stems at a residual height of 45.65 cm in the second harvest and a maximum 37.97% at a residual height of 41.83 cm in the third harvest.

Table 1. Forage and stem, sheath, and leaf dry matter in elephant grass cv. Pioneiro harvested at different heights and times.

Residual height	Harvest			Mean
	first	second	third	
		Stem dry matter, %		
30 cm	7.33	9.47	11.61	9.47
40 cm	8.02	9.55	11.90	9.82
50 cm	8.82	9.61	12.34	10.25
60 cm	7.53	11.53	11.47	10.17
Mean	7.92c	10.04b	11.83a	
	sDM= 9.93% (CV: 19.44%; P= 0.3039)			
		Sheath dry matter, %		
30 cm	10.48	16.11	15.37	13.99
40 cm	11.08	15.41	15.62	14.04
50 cm	10.82	15.85	15.68	14.12
60 cm	11.02	19.03	15.58	15.21
Mean	10.85c	16.60a	15.56b	
	sDM= 14.34% (CV: 19.73%; P= 0.3046)			
		Leaf dry matter, %		
30 cm	16.03	16.98	16.88	16.63
40 cm	16.82	17.22	16.89	16.98
50 cm	16.53	16.96	16.99	16.83
60 cm	17.37	17.31	17.47	17.38
Mean	16.69a	17.12a	17.06a	
	lDM = 16.95% (CV: 8.88%; P= 0.5654)			
		Forage dry matter, %		
30 cm	10.45	10.49	13.34	11.43
40 cm	11.51	11.81	14.07	12.46
50 cm	13.16	11.82	13.95	12.98
60 cm	11.20	11.70	14.08	12.33
Mean	11.58b	11.46b	13.86a	
Regression equation[1]	fDM= 2.9358+0.4071AR-0.0041AR^2 (CV: 12.0%; R^2: 0.1291; P= 0.0447)			

Means in the same row followed by different letters are significantly different (Tukey'stest,P<0.05).CV = coefficient of variation; R^2 = coefficient of determination; P = significance value.
[1]Residual plant height: 30–60 cm.

Mean sheath proportion (16.39%) was not affected by residual height at any harvest time (P>0.05) (Table 2). The mean proportion of sheaths in the forage was highest in the second harvest (18.26%) regardless of residual height, followed by the first (14.82%) and third (16.09%) harvests.

There was a significant interaction (P<0.05) between residual height and harvest time for the proportion of leaves in forage, with a linear increase in leaf proportion in the first harvest: for every centimeter increase in residual height there was a0.34% increase in the proportion of leaves. In the second and third harvests there was a quadratic relationship between residual height and proportion of leaves, with a maximum 47.76% at a residual height of 45.97 cm in the second harvest and a maximum 47.19% at a residual height of 41.03 cm in the third harvest.

Table 2. Proportion of stems, leaves, and sheaths in elephant grass cv. Pioneiro harvested at different cutting heights and times.

Residual height	Harvest			Mean
	first	second	third	
	Stem proportion in forage, % DM			
30 cm	39.94	39.35	33.08	37.46
40 cm	37.96	34.92	37.41	36.76
50 cm	32.68	34.90	35.79	34.46
60 cm	30.51	38.59	25.96	31.69
Mean	35.27	36.94	33.06	
Regression equation[1]	1st time= 50.4125-0.3362AR (CV: 18.93%;R^2: 0.2657; P= 0.0410)			
	2nd time= 76.8212-1.8626AR+0.0204AR^2(CV: 5.66%; R^2: 0.5443; P= 0.0060)			
	3rd time= -23.8125+2.9537AR-0.0353AR^2(CV: 5.25%; R^2: 0.8863; P= 0.0001)			
	Sheath proportion in forage, % DM			
30 cm	14.34	18.54	16.95	16.61
40 cm	15.31	18.52	14.29	16.04
50 cm	15.51	17.62	15.89	16.34
60 cm	14.13	18.37	17.21	16.57
Mean	14.82b	18.26a	16.09b	
	% DM= 16.39% (CV: 9.82%; P= 0.8315)			
	Leaf proportion in forage, % DM			
30 cm	45.71	42.11	49.97	45.93
40 cm	46.73	46.56	48.31	47.20
50 cm	51.81	47.48	48.32	49.20
60 cm	55.36	43.04	56.83	51.74
Mean	49.90	44.80	50.86	
Regression equation[1]	1stharvest= 34.5625+0.3412AR (CV: 11.48%; R^2: 0.3362; P= 0.0186)			
	2ndharvest= 0.6225+2.0507AR-0.0223AR^2 (CV: 6.12%; R^2: 0.4580; P= 0.0187)			
	3rdharvest= 89.9612-2.0846AR+0.0254AR^2 (CV: 4.22%; R^2: 0.7575; P= 0.0001)			

Means in the same row followed by different letters are significantly different (Tukey's test, P<0.05).
[1]Residual plant height: 30-60 cm.

Overall, elephant grass cv. Pioneiro had a higher proportion of leaves than stems in forage at different residual heights and harvest times. Thus, increasing cutting height significantly increased leaf yield per unit area, and this additional component is the best digestible fraction or of better capacity to be used

by the animal because it has fewer lignified tissues (PEIXOTO, 2011).

Santos et al. (2001a) evaluated the proportion of leaves and stems and leaf-to-stem ratio in elephant grass cv. Purple harvested at four residual heights (0, 15, 30, and 45 cm) in two harvest seasons (dry and wet) and reported a mean proportion of leaves of 70.96, 73.91, 78.66, and 76.64% for each cutting height, respectively, and a mean proportion of stems of 29.04, 26.09, 21.34, and 23.36%, respectively. Unlike this study, Santos et al. (2001a) did not evaluate the proportion of the sheath component in forage, which increases the role of leaves in the physical structure of the forage, whereas the inclusion of sheaths may reduce the nutritional quality of elephant grass because these are higher in neutral detergent fiber and acid detergent fiber and lower in crude protein and non-fibrous carbohydrates.

There was a significant interaction ($P<0.05$) between residual height and harvest time for fresh forage yield (Table 3). In the first harvest, there was a linear reduction in yield with increasing residual height: for each centimeter increase in residual height there was a 474.47 kg ha^{-1}reduction in fresh forage yield. In the second and third harvests there was a quadratic relationship between residual height and fresh forage yield, with estimated maximum yields of 47,867 kg ha^{-1} and 16,230 kg ha^{-1}at a residual height of 49.99 cm and 53.0 cm, respectively.

Table 3. Fresh and dry forage yield in elephant grass cv. Pioneiro harvested at different cutting heights and times.

Residual height	Harvest			Mean	Cumulative
	first	second	third		
		Fresh forage, kg ha^{-1}			
30 cm	41,511	41,204	9,208	30,641	91,923
40 cm	39,490	47,980	11,807	33,092	99,277
50 cm	39,280	46,227	18,069	34,790	103,576
60 cm	25,766	46,881	14,864	29,170	87,511
Mean	36,512	45,573	13,487		
Regression equation[1]	1st time = 57863-474,4675AR (CV: 19.32%; R^2: 0.3925; P= 0.0094)				
	2nd time = 9621,8125+1530,0687AR-15,3031AR^2(CV: 14.93%; R^2: 0.1227; P= 0.4271)				
	3rd time = -24537+1538,2875AR-14,5112AR^2(CV: 23.10%; R^2: 0.5288; P= 0.0075)				
		Dry forage, kg ha^{-1}			
30 cm	4,349	4,340	1,234	3,307	9,923 A
40 cm	4,557	5,688	1,630	3,958	11,875 A
50 cm	5,306	5,457	2,513	4,425	13,276 A
60 cm	2,879	5,523	2,080	3,494	10,482 A
Mean	4,273	5,252	1,864		
Regression equation[1]	1st time= -6596,5000+556,2750AR-6,5875AR^2(CV: 28.9%; R^2: 0,3267; P= 0.0565)				
	2nd time = -2330,2750+321,6200AR-3,2050AR^2(CV: 17.65%; R^2: 0.2559; P= 0.1465)				
	3rd time = -3614,8750+220,8375AR-2,0737AR^2(CV: 21.28%; R^2: 0.5965; P= 0.0027)				
	Accumulated= 11.389 kg ha^{-1} (CV: 19.7%;R^2:0.1504; P=0.3465)				

Means in the same row followed by different lowercase letters or in the same column followed by different upper case letter sare significantly different (Tukey's test, $P<0.05$).
[1]Residual plant height: 30-60 cm.

There was a significant interaction (P<0.05) between residual height and harvest time for fresh forage yield (Table 3). There was a quadratic relationship between residual height and dry forage yield in the three harvests, with estimated maximum yields of 5147 kg ha^{-1}, 5738 kg ha^{-1}, and 2264 kg ha^{-1}, at 42.22, 50.17, and 53.24 cm cutting heights, respectively, in the first, second, and third harvests.

The lowest forage yield in the third harvest may be related to the drop in temperature from the first ten days of April to the last ten days of May (Figure 1). The optimal temperature range for elephant grass production is 20-40 °C (VILELA, 2009), and the mean temperature in the period before the third harvest was 16.6 °C, which may have negatively affected photosynthesis and plant growth.

Cumulative forage yield in the three harvests was 12,891 kg ha^{-1}at 46 cm residual height, and there was no significant difference in cumulative forage yield across residual heights (P>0.05). Nascimento et al. (2008) found a mean cumulative yield of 5650 kg ha^{-1} for 0, 25, 50, and 75 cm cutting heights in two harvest seasons (spring/summer and fall/winter). The reduced rainfall in the fall/winter harvest negatively affected dry forage yield, when temperatures were more favorable, with no time for proper tillering, thus resulting in lower forage yield than in the current study.

Pontes (2013) evaluated forage yield at two harvest times in elephant grass cv. Napier and found mean yield values of 30,075 kg ha^{-1} and 23,200 kg ha^{-1}at 30 cm cutting height for the first and second harvests, respectively.

There was no significant interaction (P> 0.05) between cutting height and harvest time for ash, crude protein, neutral detergent fiber, and acid detergent fiber content (Table 4). Mean ash content (10.4%; Table 4) was not significantly different across cutting heights (P>0.05). Conversely, mean ash content was significantly different across harvests (P<0.05): ash content was higher in the first harvest (11.29%) than in the second (10.02%) and third (9.91%) harvests, but there was no significant difference between the latter two harvests (P>0.05).

Table 4. Mean ash, crude protein, neutral detergent fiber, and acid detergent fiber in elephant grass cv. Pioneiro harvested at different cutting heights and times.

Continue ...

Residual height	Harvest			Mean
	first	second	third	
		Ash, % DM		
30 cm	11.98	10.35	9.94	10.76
40 cm	10.82	10.01	9.77	10.20
50 cm	11.04	10.22	9.95	10.40
60 cm	11.34	9.50	9.96	10.27
Mean	11.29a	10.02b	9.91b	
	Ash = 10.40% (CV: 8.17%; P= 0.3661)			
		Crude protein, % DM		
30 cm	11.94	11.42	14.13	12.50
40 cm	13.42	11.76	15.94	13.71
50 cm	14.19	11.97	16.10	14.09
60 cm	15.15	12.51	17.47	15.04
Mean	13.68b	11.92c	15.91a	
Regression equation[1]	CP = 11.9087+ 0.0377AR (CV: 17.27%; R^2: 0.3250; P= 0.0219)			

... Continuation

	Neutral detergent fiber, % DM			
30 cm	65.74	69.70	63.99	66.48
40 cm	65.47	69.77	62.81	66.02
50 cm	64.58	68.84	62.54	65.32
60 cm	63.80	68.03	60.56	64.13
Mean	64.90b	69.09a	62.47c	
Regression equation[1]	NDF = 66.5695- 0.0333AR (CV: 5.40%; R^2: 0.3095; P= 0.0511)			
	Acid detergent fiber, % DM			
30 cm	43.05	47.19	41.31	43.85
40 cm	42.45	46.64	40.48	43.19
50 cm	39.69	45.27	39.78	41.58
60 cm	39.52	44.90	37.76	40.73
Mean	41.18b	46.00a	39.83b	
Regression equation[1]	ADF = 43.5638-0.0677AR (CV: 8.11%; R^2: 0.4476; P= 0.0136)			

Means in the same row followed by different letters are significantly different (Tukey's test, P<0.05).
[1]Residual plant height: 30-60 cm.

Crude protein content was significantly affected by residual height (P<0.05). For every centimeter increase in residual height there was a 0.0377% increase in crude protein content. Additionally, crude protein content also was significantly affected (P<0.05) by harvest time and was higher in the third harvest (15.91%) than in the first (13.68%) and second (11.92%) harvests. This result may be explained by the higher proportion of leaves (Table 3) in the third harvest, which increases crude protein content in forage.

Job Queiroz Filho et al. (1998), Martins-Costa et al. (2008), and Santos et al. (2001b) reported mean crude protein levels in elephant grass harvested at different residual heights and harvest times ranging from 7.5% to 12.9%, which is lower than the range found in this study at different residual heights and harvest times. The minimum level of protein in animal feeds for proper rumen fermentation is 7% (MINSON, 1984), and all residual heights and harvest times in our study satisfactorily met the minimum protein requirements of ruminants.

The analysis of forage fiber is essential for the formulation of ruminant diets because parameters such as food intake and digestibility, and thus are required to be measured as they correlate with dry matter intake and feed efficiency. The fibrous portion of the plant is a source of carbohydrates that are used as energy by rumen microorganisms, and the minimum amount of NDF required by animals in elephant grass-based diets is 55-60% (DM basis) (VAN SOEST, 1994).

Neutral detergent fiber content was significantly affected by residual height (P<0.05): for every centimeter increase in residual height there was a 0.03% reduction in NDF content. Also, NDF was significantly different (P<0.05) across harvests: NDF content was significantly higher in the second harvest (69.09%) than in the first (64.9%) and third (62.47%) harvests.

For every centimeter increase in residual height there was a 0.07% reduction in acid detergent fiber content (Table 4). Additionally, ADF content was significantly different across harvests (P<0.05): ADF was higher in the second harvest (46.0%) than in the first (41.18%) and third (39.83%) harvests, and there was no difference between the first and third harvests. Finally, NDF and ADF were highest

in the second harvest due to the higher proportion of stems and sheaths in the forage (Table 2), which increased fibrous material content.

Conclusion

Taking in consideration the mean values of the physical structure of the forage, production of yield forage, nutritional quality of the forage, for the year it was implemented, we recommend that elephant grass cv. Pioneiro yield are managed at 40-50 cm residual heights.

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