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ORCID:

SAT: 0000-0002-8538-4060
RDC: 0000-0002-0472-8301
JdOC: 0000-0002-5387-7880
SWPC: 0000-0003-0110-420X
GAB: 0000-0001-6907-2756

Yield and quality responses of *Megathyrsus maximus* and *Cynodon* spp. forage grasses to irrigation

Sergio André Tapparo[1], Rubens Duarte Coelho[2], Jéfferson de Oliveira Costa[3,*], Sérgio Weine Paulino Chaves[4], Guilherme Augusto Biscaro[5]

[1] *Federal Institute of Mato Grosso do Sul/IFMS, Ponta Porã Campus, highway BR-463, km 14, 79909-000, Ponta Porã, MS, Brazil*
[2] *University of São Paulo/USP-ESALQ, Biosystems Engineering Department, C.P. 09, 13418-900 Piracicaba, SP, Brazil*
[3] *Minas Gerais Agricultural Research Agency/EPAMIG, Experimental Field of Gorutuba, 39525-000 Nova Porteirinha, MG, Brazil*
[4] *Federal Rural University of the Semi-Arid/UFERSA, Agronomic and Forestry Sciences Department, Francisco Mota, 572, 59625-900, Mossoró, RN, Brazil*
[5] *Federal University of Grande Dourados/UFGD, College of Agrarian Sciences, highway Dourados/Itaum, km 12, CP 364, 79804-970, Dourados, MS, Brazil*
*Corresponding author. E-mail: costajo@alumni.usp.br

Abstract. Periodic variations in rainfall have resulted in longer periods of drought in traditional rainfed livestock systems on savanna areas in Brazil. However, irrigation management techniques and rotational grazing have improved the productivity of these systems by mitigating soil water stress on forage grasses. The objectives of this research were to evaluate the response of *Megathyrsus maximus* cv. Tanzania and *Cynodon* spp. cv. Tifton 85 (*Cynodon nlemfuensis* × *Cynodon dactylon*) forage grasses to irrigation, and to determine their irrigation water productivity (IWP). The experiment was conducted at the University of São Paulo in Brazil. Plant height (PH), dry matter (DM), crude protein (CP), neutral detergent fiber (NDF) and acid detergent fiber (ADF) were measured, and IWP was calculated. Tifton 85 had a higher CP content than Tanzania but a lower average DM yield. The irrigation management (IM) treatments did not influence CP levels of both forage grasses, but in most situations, did affect their average DM yield. The IWP of Tanzania and Tifton 85 forage grasses did not differ among irrigation management treatments.

Keywords: *Cynodon* spp. cv. Tifton 85, irrigation water productivity, *Megathyrsus maximus* cv. Tanzania, soil depth.

HIGHLIGHTS

1) Pasture irrigation is a promising tool to mitigate the severe drought that has been occurring in savanna areas in Brazil;

2) *Cynodon* spp. had an average water productivity of 2.70 against 2.33 kg DM m^{-3} of *Megathyrsus maximus*;
3) Irrigation management treatments did not influence crude protein (CP) levels of forage grasses but did affect average dry matter (DM) yield;
4) *Cynodon* spp. had a higher CP content than *Megathyrsus maximus* and lower average DM yield under full irrigation.

1. INTRODUCTION

Among forage grasses, *Megathyrsus maximus* cv. Tanzania and *Cynodon* spp. cv. Tifton 85 (*Cynodon nlemfuensis* x *Cynodon dactylon*) are being used in different regions from Brazil for animal feed. These species, in particular, have been used in intensive rotational production systems, generally with high levels of fertilization and irrigation, aiming high rates of yield and forage quality (Lemos et al., 2019; Silva et al., 2019).

The use of technologies such as irrigation to increase livestock productivity is critical for meeting the growing demand for animal products; however, these technologies must be applied sustainably to minimize the impact of livestock on the environment and natural resources. The aim is to increase the pasture grass yield through rational use of irrigation, to increase milk and meat production. Irrigation of pasture is an efficient approach to minimize productivity losses due to rainfall seasonality. This strategy mitigates the effects of water stress on forages during the dry season and keeps the autumn/winter stocking rate close to that achieved in spring and summer (Neal et al., 2011; Mazzetto et al., 2015; Gheysari et al., 2017; Legesse et al., 2018; Yan et al., 2018; Balazadeh et al., 2021).

The rotational grazing method under irrigation is a complex practice in which the applied water depth must be varied according to the stage of pasture development. However, several studies have shown that irrigation practices most often use a constant depth for the total irrigated area, not taking into account the growth stage of the forage plants (Snyder et al., 2015; Rolando et al., 2017; Birendra et al., 2018).

When the irrigation depth is calculated using data collected from only one rotational grazing plot (reference plot), one can underestimate or overestimate the water consumption of pastures that present a leaf area index (LAI) different from the reference plot (Tapparo et al., 2022). The application of incorrect irrigation depth can increase the operational cost of the system, reduce the net revenue, and influence the quality of the grasses (Tapparo et al., 2019; Liao et al., 2021).

Measuring the yield and quality of irrigated forage grasses is important for improving irrigation management (IM), yet there have been no controlled studies on the effects of irrigation management treatments based on different soil depths (SD) on the yield and quality of Tanzania and Tifton 85 forage crops in irrigated savanna areas of Brazil.

Thus, this study aimed to evaluate the yield (dry matter) and quality (crude protein, neutral and acid detergent fiber) of irrigated *Megathyrsus maximus* cv. Tanzania and *Cynodon* spp. cv. Tifton 85 forage grasses, subjected to four irrigation management treatments based on four different soil depths. The effects of irrigation management treatments on yield were verified as irrigation water productivity (IWP).

2. MATERIALS AND METHODS

2.1. Description of the experimental area

The experiments were carried out in a rain out shelter at the University of São Paulo, Brazil (22°46’39”S, 47°17’45”W, altitude of 570 m). The rain out shelter had 160 m^2 of internal area, and 48 pots with a volume of 0.1 m^3 and dimensions of 0.60 × 0.40 × 0.45 m were used (Tapparo et al., 2019; Chaves et al., 2021; Almeida et al., 2022; Tapparo et al., 2022).

The soil in pots was characterized as Oxisol Typic Ustox with a sandy loam texture (17% clay, 8% silt and 75% sand). A drip irrigation system was used to apply water. The experimental design was randomized with eight treatments (two forage grasses and four irrigation management) and six replications. Irrigation management treatments were based on soil depth of 0.10 m (IM10), 0.20 m (IM20), 0.30 m (IM30), and 0.40 m (IM40). Soil depth was defined by vertical dimension in the pots, to simulate different conditions of soil fertility along the soil profile.

The meteorological data obtained over the entire period of the experiment is given in Figure 1. The maximum temperature ranged from 32.7 °C in July to 42 °C in March; the minimum temperature ranged from 12.3 °C in July to 20.5 °C in January. The monthly average of solar radiation ranged from 12.6 to 21.9 MJ m^{-2} day^{-1}. The relationship between the meteorological conditions inside a rain out shelter and the meteorological conditions outside the rain out shelter are discussed in Costa et al. (2015) and Chaves et al. (2021).

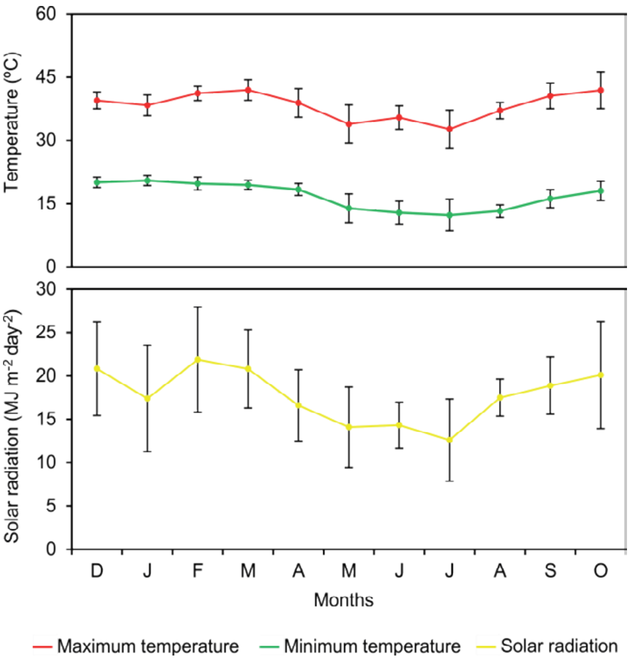

Figure 1. Monthly averages and standard deviations of weather data during the period of the experiment inside the rain out shelter.

2.2. Grass planting and experimental conditions

Before planting the forage grasses, soil samples were taken for liming and fertilization. Flow uniformity tests were also carried out on the drippers in the experimental area, and the system provided an excellent uniformity of water distribution to the plants (93%). Four months before beginning the evaluation, pots were planted with two types of grass: *Megathyrsus maximus* cv. Tanzania and *Cynodon* spp. cv. Tifton 85 (*Cynodon nlemfuensis* x *Cynodon dactylon*). Early planting was done so grasses could become well-established and cover the whole area of each pot. Pots were planted with Tanzania grass seeds, while seedlings were used for Tifton 85 grass.

Chemical analysis of the soil from the 0-0.40 m layer showed that there was no need for fertilization at planting; but after establishment, a soil analysis showed need for fertilization. Foliar chemical analysis was also performed to verify the nutritional status of the plants. The equivalent of 405 kg ha^{-1} of N, 190 kg ha^{-1} of K_2O, 115 kg ha^{-1} of P_2O_5 and 29 kg ha^{-1} of MgO was applied to each crop in five applications (three during summer and two in winter). Soil acidity correction and nutritional management were conducted according to Van Raij (1997) recommendations for grasses forage based on soil analysis results.

Tensiometers were installed at depths of 0.10, 0.20, 0.30 and 0.40 m, in the reference pots of each block. The irrigation management was based on soil matric potential, using the van Genuchten model (Van Genuchten, 1980) according to Eq. (1) to calculate the irrigation depth:

$$\theta\ (\psi m) = 0.246 + \frac{(0.564 - 0.246)}{(1 + (0.2187\ \Psi m)^{0.6068})^{0.8555}} \quad (1)$$

where θ (ψm) is the soil volumetric water content (cm^3 cm^{-3}) as a function of the matric potential (ψm) (kPa).

Irrigation management calculations were performed in a spreadsheet developed in Microsoft Excel and used in other studies (Costa et al., 2020a; Costa et al., 2020b; Quiloango-Chimarro et al., 2021; Chaves et al., 2022). Treatments were kept at a moisture level corresponding to a reading of -5 kPa, the value chosen as the field capacity soil without drainage (Costa et al., 2018; Costa et al., 2019).

The irrigation depths applied in the different irrigation management treatments (IM10, IM20, IM30, and IM40) were based on soil depths different of 0.10, 0.20, 0.30, and 0.40 m, which affect the amount and frequency of water applied to each plot. The experiments were conducted over eleven months (December/2016 to October/2017), and involved eleven cuts of each forage grass (approximately 30 days of growth cycle) to simulate rotational grazing utilization.

2.3. Leaf water potential (LWP)

A Scholander chamber (model 3005) was used. Leaf samples were taken to the laboratory packed in ice to prevent necrosis or destruction of tissues and cells (Costa et al., 2018; Costa et al., 2020a; Costa et al., 2020b).

Six to eight leaves were collected from each pot between 6h00 and 6h30. The Tifton 85 grass samples included the entire tiller, while only leaves of Tanzania grass were collected. Before reading LWP, the leaves were standardized as follows: for Tanzania grass, the central part of the leaf was used without the central rib, as it was verified that pressing on the central rib caused pressure leakage; for Tifton 85 grass, only the 2+ or 3+ leaves were used.

2.4. Biomass production

Grass cutting in each pot was performed manually. Samples were taken from 0.18 to 0.24 m and 0.06 to 0.10 m for Tanzania and Tifton 85, respectively. This cutting height is the lowest for these species in rotational grazing systems with irrigation. Plant height (PH) was non-destructively measured using a ruler and a sheet of transparent acetate film placed next to each plant.

The use of transparent film prevented compression and allowed integration of an area of approximately 0.06 m^2. It was much faster and easier to mark the average height on the film than to measure a sufficient number of points to reach the same average height (Tapparo et al., 2019; Tapparo et al., 2022). For dry matter (DM) determinations, aboveground biomass was obtained within an area of 0.24 m^2, dried for 48 h at 65 °C, and weighed.

2.5. Quality measurements

Samples for crude protein (CP), neutral detergent fiber (NDF) and acid detergent fiber (ADF) analysis were obtained by mixing material from the same treatments, at spring, summer, autumn, and winter seasons. Samples were obtained in December, January, and February (summer); in March, April, and May (autumn); in June, July, and August (winter); and in September, October, and November (spring). The collected material was ground in a Wiley mill, passed through a 1 mm diameter sieve and placed in labeled plastic bags. The CP content was determined by combustion according to the Dumas method (Saint-Denis and Goupy, 2004) using a nitrogen self-analyzer, while the NDF and ADF fractions were determined with an Ankom 200 fiber analyzer (Spanghero et al., 2010).

2.6. Irrigation water productivity (IWP)

The IWP (kg m^{-3}) was obtained as the ratio of DM yield to the total irrigation water applied using Eq. (2) (Sadras, 2009). The IWP was calculated for each cut.

$$IWP = \frac{\text{DM yield}}{\text{IWA}} \quad (2)$$

where IWA is irrigation water applied in m^3 ha^{-1}. The IWA was obtained by adding the irrigation depths throughout the cutting cycle for each irrigation management treatment. This value was converted from L per pot to volumes applied in m^3 ha^{-1}.

2.7. Statistical analysis

The statistics software SAS (Statistical Analysis System Institute, 2001) was used. Data were checked for normal distribution using the Shapiro-Wilk method and tested by analysis of variance (ANOVA) to compare the means of the studied variables. Tukey's test of means was used at the 95% confidence level following the PROC GLM procedure, and graphical representation of the data was done on Microsoft Excel version 16.0.

3. RESULTS AND DISCUSSION

3.1. Irrigation water applied and leaf water potential

The average values of irrigation water applied (IWA), in the eleven cuts, for Tanzania grass were 151, 186, 222, and 258 mm at the treatments IM10, IM20, IM30, and IM40, respectively. For Tifton grass, the average values of IWA were 80, 103, 117, and 166 mm at the treatments IM10, IM20, IM30, and IM40, respectively (Figure 2).

Irrigation management treatments resulted in significant differences for the LWP of Tanzania and Tifton 85 grasses (Table 1). In comparing the LWP of Tanzania grass at different irrigation management treatments (Figure 3A), it was observed that the IM40 treatment resulted in the highest LWP value, -0.34 MPa. For the other IMs, mean LWP values varied from -0.55 to -0.46 MPa, confirming lower water potential in terms of soil-water

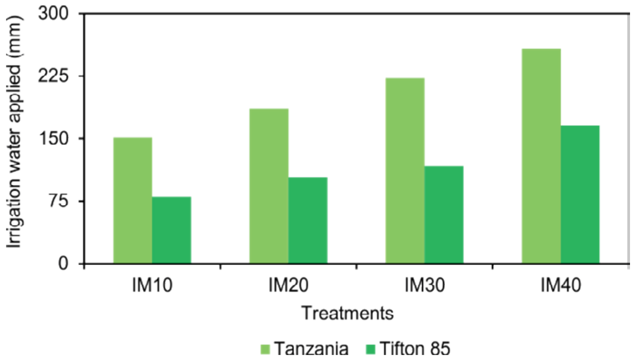

Figure 2. Average amount of irrigation water applied during the growing season of Tanzania and Tifton 85 forage grasses. Irrigation management based on soil depth of 0.10 m (IM10), 0.20 m (IM20), 0.30 m (IM30), and 0.40 m (IM40).

Table 1. Analysis of variance (ANOVA) to compare the means of the studied variables.

Variables	Sources of Variation	*p* value (Tanzania)	*p* value (Tifton 85)
Leaf water potential (LWP)	Irrigation management (IM) treatments	0.0057*	0.0401*
Plant height (PH)		0.1161^{ns}	0.2275^{ns}
Dry matter (DM) yield		0.0000*	0.0000*
Total dry matter		0.0007*	0.0031*
Crude protein (CD)		0.6864^{ns}	0.1039^{ns}
Total crude protein		0.0015*	0.0464*
Neutral detergent fiber (NDF)		0.0123*	0.0225*
Acid detergent fiber (ADF)		0.0131*	0.0327*
Irrigation water productivity (IWP)		0.2150^{ns}	0.6178^{ns}

^{ns} not significant; * significant at a probability level of 5%.

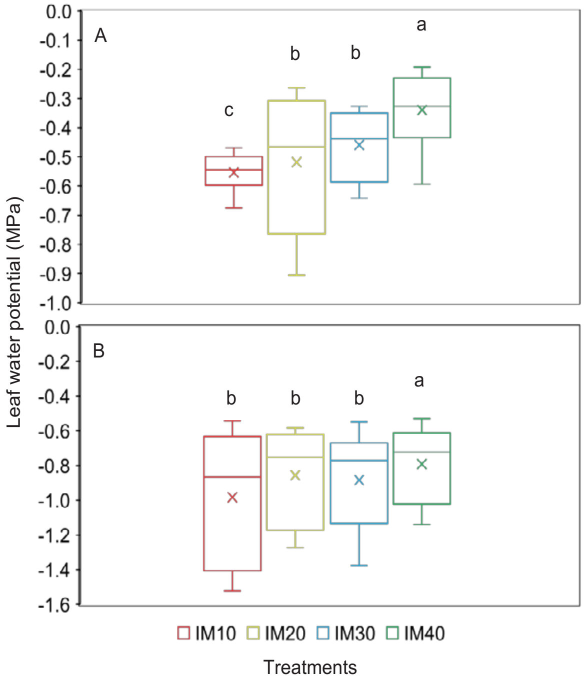

Figure 3. Leaf water potential (MPa) of Tanzania (A) and Tifton 85 (B) forage grasses subjected to irrigation management treatments. Irrigation management based on soil depth of 0.10 m (IM10), 0.20 m (IM20), 0.30 m (IM30), and 0.40 m (IM40). Treatments with same letters do not differ from each other at the 5% probability level by Tukey's test (p < 0.05).

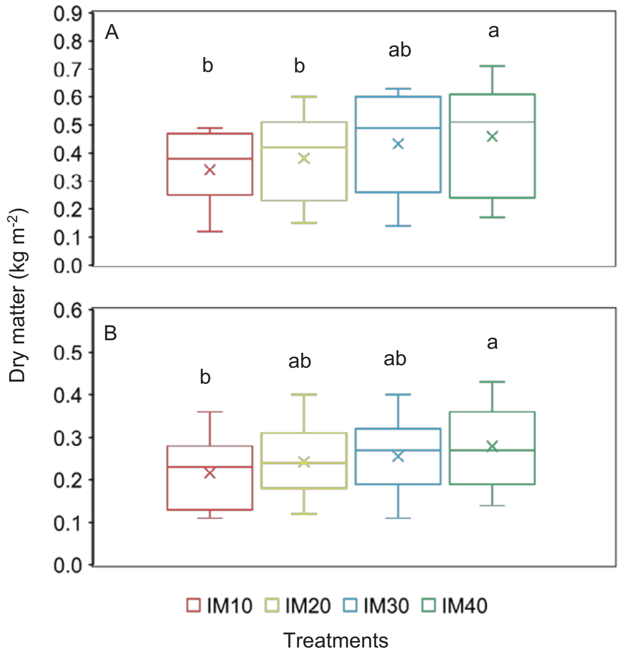

Figure 4. Mean dry matter (kg m^{-2}) yield per mowing of Tanzania (A) and Tifton 85 (B) forage grasses subjected to irrigation management treatments. Irrigation management based on soil depth of 0.10 m (IM10), 0.20 m (IM20), 0.30 m (IM30), and 0.40 m (IM40). Treatments with same letters do not differ from each other at the 5% probability level by Tukey's test (p < 0.05).

potential compared to the other treatments (Tapparo et al., 2022). In Tifton 85 grass at different irrigation management treatments (Figure 3B), mean LWP values were highest at the IM40 treatment, -0.79 MPa. Mean LWP values in plants grown at the other irrigation management treatments varied from -0.98 to -0.86 MPa. Korup et al. (2018) evaluated the LWP of perennial grasses during and after restrictive water conditions and found significant differences between irrigated and non-irrigated plants. Grasses subjected to water stress showed the lowest values, with a mean of -1.6 MPa, while the control plots had a mean LWP of -0.8 MPa. Mwendia et al. (2016) measured LWP in grass in East Africa, in the tropical environments of Muguga and Katumani, and reported mean values of -1.4 to -0.4 MPa, in agreement with the results of this research.

3.2. Grass yield responses to irrigation water

Analyzing the average height of the two grasses, it was observed that for both Tanzania and Tifton 85, there were no statistically significant differences (p> 0.05) for IM10, IM20, IM30, and IM40, which would suggest that irrigation management had little effect on PH (Table 1). The average PH values of Tanzania grass at the different irrigation management treatments were between 0.45 and 0.50 m, and 0.20 and 0.25 m for Tifton 85.

In comparing the average yields of DM, Tanzania and Tifton 85 grasses showed statistical differences (p<0.05) at the IM40 treatment when compared to the IM10 treatment (Table 1). In general, the largest DM yield was found at IM40 treatment compared to the averages obtained for the IM30, IM20, and IM10 treatments. The average DM values of Tanzania grass were 0.34, 0.38, 0.43, and 0.46 kg m^{-2} at IM10, IM20, IM30, and IM40, respectively (Figure 4A). Macedo et al. (2017) evaluated the structure and productivity of Tanzania grass under different defoliation rates in the State of Pará and observed that the forage DM was 0.23 kg m^{-2} at the 30-day frequency, similar to those found in this study. For Tifton 85, the average DM values were 0.22, 0.24, 0.26, and 0.28 kg m^{-2} at IM10, IM20, IM30, and IM40, respectively (Figure 4B). Fonseca et al. (2007) evaluated the yield of Tifton 85 grass under irrigation treatments in the State of São Paulo and observed that forage DM was 0.27 kg m^{-2} at the 30-day frequency, similar to those found in this study.

The accumulated DM yield for Tanzania grass was highest at IM40 and IM30 (Figure 5A). The average cumulative DM yield for Tanzania grass in the different treatments was 3.72, 4.18, 4.76, and 5.04 kg m^{-2} for IM10, IM20, IM30, and IM40, respectively. Pezzopane et al. (2012) determined the DM yield of Tanzania grass as a function of agrometeorological variables. They verified that the best statistical results in the development and validation of models were obtained for agrometeorological parameters that considered both the thermal and water effects as real evapotranspiration, accumulation of degree days corrected for water availability and climatic index of growth, based on average temperature, solar radiation, and water availability, showing that irrigation management treatments based on climate and soil data influence DM yield Tanzania grass.

For the Tifton 85 grass the accumulated DM yield was higher at the treatment IM40 compared to the IM10 treatment (Figure 5B). The average accumulated DM yield for Tifton 85 was 2.38, 2.74, 2.81, and 3.06 kg m^{-2} for IM10, IM20, IM30, and IM40. Oliveira et al. (2017) studied the performance of Tifton 85 grass in soils in the city of Lavras-MG and observed values of accumulated DM yield ranging from 2.3 to 4.0 kg m^{-2} over an evaluation period of 120 days. Pequeno et al. (2015) studying the forage accumulation of Tifton 85 with different cutting frequencies and irrigation, observed that the accumulated DM yield in dry conditions was, on average, 1.87 and 1.79 kg m^{-2} $year^{-1}$ for cut frequencies of 28 and 42 days, while under irrigated conditions, it was 1.97 and 2.11 kg m^{-2} $year^{-1}$.

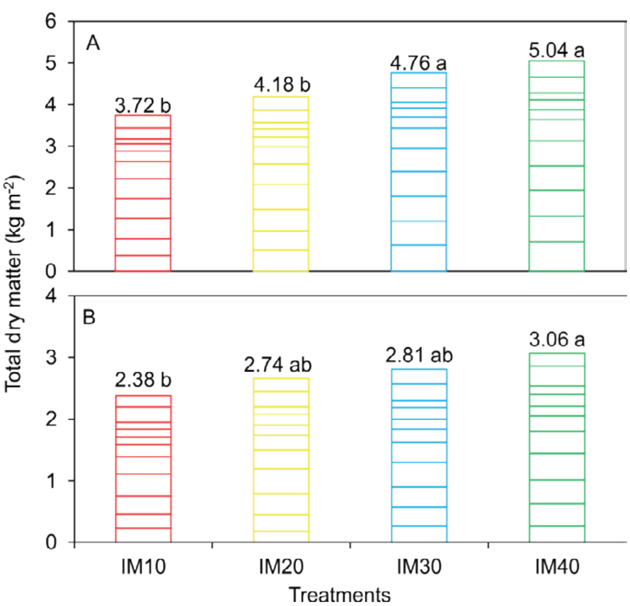

Figure 5. Total dry matter (kg m^{-2}) of Tanzania (A) and Tifton 85 (B) forage grasses subjected to irrigation management treatments. Irrigation management based on soil depth of 0.10 m (IM10), 0.20 m (IM20), 0.30 m (IM30), and 0.40 m (IM40). Treatments with same letters do not differ from each other at the 5% probability level by Tukey's test ($p < 0.05$).

3.3. Quality responses (crude protein and fiber yield) to irrigation water

The difference in % CP between Tifton 85 and Tanzania grasses was 7.2, 22.6, 16.9 and 26.7% in summer, autumn, winter, and spring, respectively (Table 2). Analyzing the average CP of the two grasses, it was observed that for both Tanzania and Tifton 85, there were no statistically significant differences ($p > 0.05$) for IM10, IM20, IM30, and IM40 (Table 1). For Tanzania grass, the average values were 11.4, 11.6, 12.2, and 11.3% for IM10, IM20, IM30, and IM40. Cecato et al. (2017), studying Tanzania grass in the State of Paraná observed that CP values from plants cut in the summer and autumn ranged from 9.2 to 11.0%.

For Tifton 85 grass, the averages values found were 13.9, 13.7, 14.2, and 14.7% for IM10, IM20, IM30, and IM40. Pequeno et al. (2015) examined the nutritional value of Tifton 85 grass and observed that the CP content under rain fed conditions was 14.6% and with irrigation it was 14%, meanwhile, Neres et al. (2011) found higher values (19.8%) and some that were close to values recorded in this research. At a forage cutting frequency of 28 days, the CP value was 15.3%, and at 42 days it was 13.4%. Comparing the amount of CP produced as a function of total DM for each forage, Tanzania grass produced total CP at the four irrigation management treatments (Figure 6) varying from 0.42 to 0.57 kg m^{-2}, while for Tifton 85 grass the range was 0.33 to 0.45 kg m^{-2}.

As for the medium values of NDF and ADF in the different periods analyzed, it was observed that Tanzania grass had an average value of 65.4% of DM and the Tifton 85 grass 66% of DM, showing that the two grass-

Table 2. Average values of crude protein at the four cutting periods.

Periods	Crude protein (%)		Difference (%)
	Tanzania	Tifton 85	
I Summer	8.66 b	9.33 b	7.2
II Autumn	9.81 b	12.68 b	22.6
III Winter	15.31 a	18.42 a	16.9
IV Spring	11.70 b	15.97 a	26.7

Treatments with same letters within a column do not differ from each other at the 5% probability level by Tukey's test ($p < 0.05$).

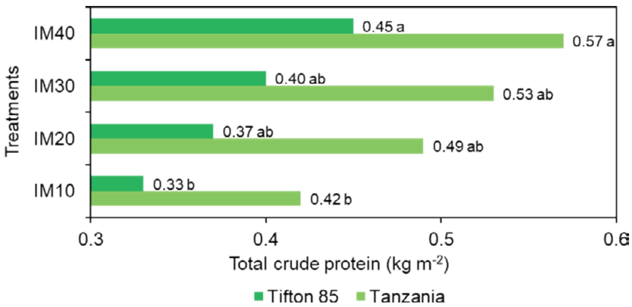

Figure 6. Total crude protein (kg m^{-2}) of Tanzania and Tifton 85 forage grasses subjected to irrigation management treatments. Irrigation management based on soil depth of 0.10 m (IM10), 0.20 m (IM20), 0.30 m (IM30), and 0.40 m (IM40). Treatments with same letters do not differ from each other at the 5% probability level by Tukey's test ($p < 0.05$), within a forage grass.

Table 3. Average values of neutral detergent and acid detergent fiber at the four cutting periods.

Periods		NDF (% DM)		ADF (% DM)	
		Tanzania	Tifton 85	Tanzania	Tifton 85
I	Summer	66.1 a	66.5 a	33.1 b	42.3 a
II	Autumn	65.6 a	65.1 a	34.3 ab	40.5 a
III	Winter	65.4 a	65.3 a	34.0 ab	38.7 a
IV	Spring	64.5 a	67.1 a	34.6 ab	40.5 a

Neutral detergent fiber (NDF), acid detergent fiber (ADF) and dry matter (DM). Treatments with same letters within a column do not differ from each other at the 5% probability level by Tukey's test ($p < 0.05$).

es studied presented similar quality responses for NDF (Table 3). For the ADF variable, it was observed that Tifton 85 grass presented medium values higher than Tanzania grass in the analyzed periods. Medium values ADF for Tifton 85 and Tanzania forage grasses were 40.5 and 34% of DM. The proportion of NDF of forage is important not only for the evaluation of its chemical composition, but also because the NDF is related to maximum DM consumption. Thus, plants with higher levels of NDF would have less consumption potential (Cecato et al., 2017; Pequeno et al., 2015).

3.4. Irrigation water productivity

Analyzing the average IWP of the two grasses, it was observed that for both Tanzania and Tifton 85, there were no statistically significant differences ($p > 0.05$) for IM10, IM20, IM30, and IM40 (Table 1). At the IM10, IM20, IM30, and IM40 treatments, the Tanzania grass had IWP averages of 2.10, 2.14, 2.51, and 2.55 kg DM m^{-3}, and Tifton 85 had IWP averages of 2.50, 2.69, 2.78, and 2.80 kg DM m^{-3}, respectively. Korup et al. (2018) found that IWP values of perennial grasses were between 3.61 and 2.62 kg DM m^{-3}, with the highest IWP in plots treated with water deficit and in sandy-clayey soil. Mazahih et al. (2016) verified that irrigation by 65% of reference evapotranspiration (ET_o) for Buffel grass gave the highest IWP value of 0.95 kg m^{-3}; and 42% of applied water can be saved to produce the same amount of DM of Rhodes grass.

Thus, our results demonstrated that IWP did not result in significant differences as a function of irrigation management for Tanzania and Tifton 85 forage grasses. However, when making a decision about the use of restrictive soil water levels, other factors must be taken into account, such as an economic analysis of the activity, where several variables such as water cost, crop production cost, can become limiting and thus must be optimized to guarantee good results. Maximum efficiency must be determined for each irrigation management.

4. CONCLUSIONS

The irrigation management (IM) treatments of irrigated Tanzania and Tifton 85 forage grasses resulted in significant differences in yield and quality responses but did not result in significant differences in irrigation water productivity (IWP).

Crude protein content varied with the cutting season, being winter the period with the highest concentration. Tifton 85 grass had higher CP content than Tanzania, although it showed a lower average dry matter (DM) yield. With respect to the amount of protein produced as a function of total DM and the protein content of each cutting, the Tanzania grass produced more total protein throughout the year. The irrigation management treatments based on different soil depth did not affect CP levels of Tanzania and Tifton 85 forage grasses in most situations; however, irrigation management treatment did changed the average DM yield of Tanzania and Tifton 85 grasses.

The IWP of Tanzanian and Tifton 85 forage grasses did not differ as a function of irrigation management treatments based on different SD. The average value found for IWP for Tanzania grass was 2.33 kg DM m^{-3} and for Tifton 85 grass it was 2.70 kg DM m^{-3}.

The irrigation management of forage grasses *Megathyrsus maximus* cv. Tanzania and *Cynodon* spp. cv. Tifton 85 (*Cynodon nlemfuensis* x *Cynodon dactylon*) based on monitoring the matric potential in the reference plot of the area under simulated grazing conditions was sufficient to maintain optimal levels of DM yield in the other irrigated plots with variable soil depth.

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