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Forage yield and quality of marandugrass fertigated with treated sewage wastewater and mineral fertilizer

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ABSTRACT: The high consumption of water in irrigated agriculture and lack of alternative water sources make reusing sewage water a highly promising option for irrigation. This paper is aimed at evaluating *Brachiaria brizantha* cv. Marandu forage quality and yield when fertigated with treated sewage wastewater (TSW) and mineral fertilizer, in the 2013 and 2014 crop years in Jaboticabal, São Paulo State, Brazil. A homogeneous water depth was applied using a triple-line sprinkling irrigation system under a gradual TSW application, using the following TSW and water ratios: E5 = 1.0; E4 = 0.87; E3 = 0.6; E2 = 0.31, E1 = 0.11, and E0 = 0.0. Annual biomass yield increased with the TSW application, ranging from 31.3 to 47.4 Mg ha^{-1} in 2013 and from 25.7 to 56.9 Mg ha^{-1} in 2014, for E1 and E5, respectively. Forage yield had marked seasonality, with the highest values in summer (35.9 to 44.7%) and spring (35.7 to 38.4%) and the lowest ones during the fall-winter seasons (19.6 to 25.7%). Despite the high nitrogen rates (1,132 kg ha^{-1}), maximum forage yield was not achieved, hence further nitrogen increments would still enhance yield. Forage improved quality has counterbalanced the low fall-winter yields in terms of crude protein (CP) and neutral detergent fibre (NDF).

Keywords: wastewater, irrigation, pasture, forage quality.

Rendimento e qualidade de forragem de capim-marandu fertirrigado com água residuária de esgoto tratado e adubo mineral

RESUMO. O alto consumo de água na agricultura irrigada e falta de fontes alternativas de água tornar a reutilização da água de esgoto uma opção altamente promissora nesta atividade. Este trabalho teve como objetivo avaliar o rendimento e a qualidade da forrageira *Brachiaria brizantha* cv. Marandu fertirrigada com águas residuais de efluente de esgoto tratado (EET) e fertilizante mineral, nos anos de 2013 e 2014, em Jaboticabal, Estado de São Paulo, Brasil. A lâmina homogênea da água foi aplicada por um sistema de irrigação por aspersão em linha tripla, mas sob aplicação gradual EET, usando os seguintes EET e água proporções: E5 = 1,0; E4 = 0,87; E3 = 0,6; E2 = 0,31, E1 = 0,11 e E0 = 0,0. O rendimento anual de biomassa aumentou com aplicação EET, variando 31,3-47,4 Mg ha^{-1} em 2013 e 25,7-56,9 Mg ha^{-1} em 2014, para E1 e E5, respectivamente. Houve sazonalidade na produção de forrageira, com os valores mais elevados no verão (35,9 a 44,7%) e primavera (35,7 a 38,4%) e as mais baixas durante a temporada de outono-inverno (19,6 a 25,7%). Apesar das altas doses de nitrogênio (1.132 kg ha^{-1}), o rendimento máximo de forragem não foi alcançado, de modo que novos aumentos de nitrogênio ainda possam melhorar o rendimento. As baixas produtividades no outono-inverno foram compensadas pela melhor qualidade da forrageira em proteína bruta (PB) e fibra em detergente neutro (FDN).

Palavras-chave: águas residuais, irrigação, pasto, qualidade da forragem.

Introduction

Applying treated sewage effluent to crops is a common practice that dates back to before the BC period, starting from Germany and England within the sixteenth and seventeenth centuries (Veloso, Duarte, & Silva, 2004). These countries have had a primary goal of preventing pollution in waterways instead of raising agricultural yield.

Nations such as China and Mexico are pioneers in the use of wastewater in agriculture. In Brazil, wastewater usage is performed spontaneously and in an uncontrolled way, mainly due to the lack of wastewater treatment plants in most cities. However, it is expected that controlled applications will increase in the coming years because of economic development as well as environmental and public health pressures.

The major limitation of TSW usage in farming systems is trace elements, often present in irregular effluent. TSW pathogens such as streptococcus, *Salmonella* sp., *Shigella* sp., larvae, protozoa (cysts) and viruses (enteroviruses and rotaviruses) cannot withstand soil environment conditions for more than a few hours, except for helminth eggs.

Forage plants have been sorted for cultivation under TSW application because of their long growth cycle associated with high annual water consumption, nutrient absorption and the ability to prevent soil erosion (Fonseca, Herpin, Paula, Victoria, & Melfi, 2007a; Oliveira Filho et al., 2011). Moreover, grasses belonging to the *Brachiaria* genus meet the tolerance requirements of high soil moisture, salinity, organic matter content and possible toxic effects of TSW.

Grass growth in the tropics is often restrained by soil nitrogen deficiency (Vitor et al., 2009; Serafim & Galbiatti, 2012). Low forage yields are caused by a lack of scientific expertise as reflected in herd characteristics, animal weight fluctuations (i.e., within animal breeding, raising or finishing, low milk or meat yields), and consequently a lower market value. Furthermore, nitrogen is the most limiting factor in biomass production after water (Nogueira et al., 2013).

TSW is rich in macro and micronutrients essential for the growth of most crops, making its use convenient in farming (Bertoncini, 2008; Oliveira Filho et al., 2011; Silva, Matos, Borges, & Previero, 2012; Nogueira et al., 2013; Pinto, Cruz, Frigo, Frigo, & Hermes, 2013). Additionally, it also provides an increase in irrigated areas, even in those under jeopardized water use conditions (river basins under critical conditions).

The management of pastures with wastewater has been providing higher forage nutritional quality (Alencar et al., 2009, Teixeira et al., 2011; Serafim & Galbiatti, 2012; Matos, Silva, Lo Monaco, & Pereira, 2013; Nogueira et al., 2013). In addition to enhanced yield (Drumond, Zanin, Aguiar, Rodriguês, & Fernandes, 2006; Fonseca et al., 2007b; Silva et al., 2012), it is also good for supplying water and nutrient demands in a sustainable way and avoiding direct TSW discharge into water bodies (Bertoncini, 2008).

Leaf protein synthesis is assigned to water availability and soil fertility, mostly nitrogen, which reflects in higher digestible protein (CP) and reduces levels of less digestible fibre (NDF) for forages (Freitas et al., 2007; Geron et al., 2014), producing a forage of better quality for animal consumption.

Studying urban development, water resource management and the use of wastewater for irrigation in India, Van Rooijen, Biggs, Smout, and Drechsel (2010) concluded that wastewater use in agricultural lands is a contribution to food security and public health, in addition to improving the quality of water downstream of cities as well as reducing the demand for underground water in agriculture.

Reduced production costs associated with decreasing the use of mineral fertilizer may justify the economic feasibility of wastewater use in agriculture (Alencar et al., 2010; Nogueira et al., 2013). Additionally, fertigated areas should be connected to sewage treatment plants, thereby minimizing transportation costs.

Increased yields and forage quality are expected when using nitrogen fertigation with TSW in *Brachiaria brizantha* cultivation, coupled with reducing input costs and underground water use in agricultural lands. Investigations under these conditions would provide guidelines for wastewater use in Brazilian agriculture. Based on this research, we aimed to evaluate the response (forage yield and quality) of *Brachiaria brizantha* cv. Marandu to fertigation with various treated sewage wastewater rates and mineral fertilizer during the years of 2013 and 2014 in Jaboticabal, São Paulo State, Brazil.

Material and methods

The experiment was carried out in 2013 and 2014 at the College of Agricultural and Veterinarian Sciences at the São Paulo State University (FCAV-UNESP), in Jaboticabal, São Paulo State, Brazil (21°14'41,9" S and 48°16'25.2" W).

The soil is classified as Eutrophic Red Latosol – Lve (Red Oxisol), with a clayey texture (> 50%), high iron content, gentle landforms and high fertility (Table 1).

Table 1. Soil chemical characteristics of samples collected from the experimental area within a depth of 0 to 1.0 m, in November of 2012, Jaboticabal, São Paulo State, Brazil.

pH	OM	K	Ca	Mg	H+Al	BS	CEC	Al	P	B	Cu	Fe	Mn	Zn	S	V
	g dm^{-3}	---- mmol dm^{-3} ------							----------- mg dm^{-3} ----------							%
5.5	20	4	25	12	27	40	68	0	53	0.3	3.4	12	18	2	24	57

In this study, we used treated sewage wastewater from a sewage treatment plant (STP) near the experimental area. Treatments performed in this STP consist of a mixed system (aerobic and anaerobic) composed of an up-flow anaerobic digester and facultative lagoons. This plant collects sewage from Jaboticabal, with an average flow of 202 L hab^{-1}. The city has approximately 71,662 inhabitants, in an area of 707 km^2 and a population density of 101.4 inhabits km^{-2}.

The experiment was performed over a floor area of 345.6 m^2, consisting of 24 plots (2.4 m wide and 6.0 m long) of 14.4 m^2. Homogeneous distribution of water depth and gradual application of TSW were carried out by a triple-line sprinkling system (Lauer, 1983) at 30 m.c.a working pressure (0.042 ksi). Uniformity coefficients of Christiansen (CUC) and distribution (DU) were 88.8% and 83.5%, respectively; thus, it was possible to define six treatments with four replications by applying the following TSW water ratios: E5 = 1.0; E4 = 0.87; E3 = 0.6; E2 = 0.31; E1 = 0.11, and E0 = 0.0 and distribution model of TSW ($Y = 0.0015 X^3 - 0.029 X^2 + 0.057 X + 0.99$; $R^2 = 0.98$; Figure 1).

TSW monthly samples were collected to analyse nitrogen concentration, and at the end of each season, complete analyses of nutrients were made using TSW samples.

Prior to the experiment, *Brachiaria brizantha* cv. Marandu seeds were sown into 0.2 m rows and at a rate of 10 kg ha^{-1}. During this operation, fifty kilograms of superphosphate were applied per hectare.

Fertigation control was in accordance with plant nutritional demand, according Dantas et al. (2016), and consisted of 15 kg ha^{-1} nitrogen (N), 3.5 kg ha^{-1} phosphorus (P) and 18 kg ha^{-1} potassium (K) per dry biomass megagram (Mg). However, water demand followed the FAO 56 method in the reference treatment (E3), which was considered the criterion of greatest value within a 28-day interval. In the E0 treatment, a mineral fertilizer (NPK) equivalent to nutrient demand in the reference treatment (E3) was applied. Higher rates in E3 in the same season were utilized to supply crop water requirements. The application of TSW in the experimental area considered the criteria established by the Technical Standard P4.230 (CETESB, 1999).

Dry biomass yield was assessed by harvesting grass. Grass was cut at 0.15 m height, except for the three first harvests when it was at 0.2 m, every 28 days (from Feb. 5, 2013 to Jan. 6, 2014). Eight summer harvests, 10 fall-winter harvests and 8 spring harvests were performed. The adopted management enabled 13 cut cycles and 2 harvests per year, which were done in a single month, one at the beginning and the other at the end.

Cuttings were aided by 0.25 m^2 templates randomly thrown three times (replications) over each plot and four times per treatment. Replications were homogenized and one sample was withdrawn for weighing. Then, the selected sample was dried in a forced circulation air oven at 65°C up to constant weight for dry biomass determination (Lacerda, Freitas, & Silva, 2009). Before being collected, plant height was measured using acetate sheets thrown randomly onto the lawn in six replications per plot.

Nitrogen yield was calculated by the ratio between dry biomass production and the amount of nitrogen applied.

A forage qualitative study analysing crude protein (CP) and neutral detergent fibre (NDF) was conducted in a quarterly basis per respective season using a methodology proposed by Silva and Queiroz (2006).

Forage yield data were analysed per season according to Johnson, Chaudhuri, and Kanemasu (1983), using the GLM procedure of SAS software, and the averages were compared by Tukey's test at 1% and 5% probability. Response functions were adjusted between dry biomass yield and qualitative characteristics according to the amount of nitrogen applied via TSW.

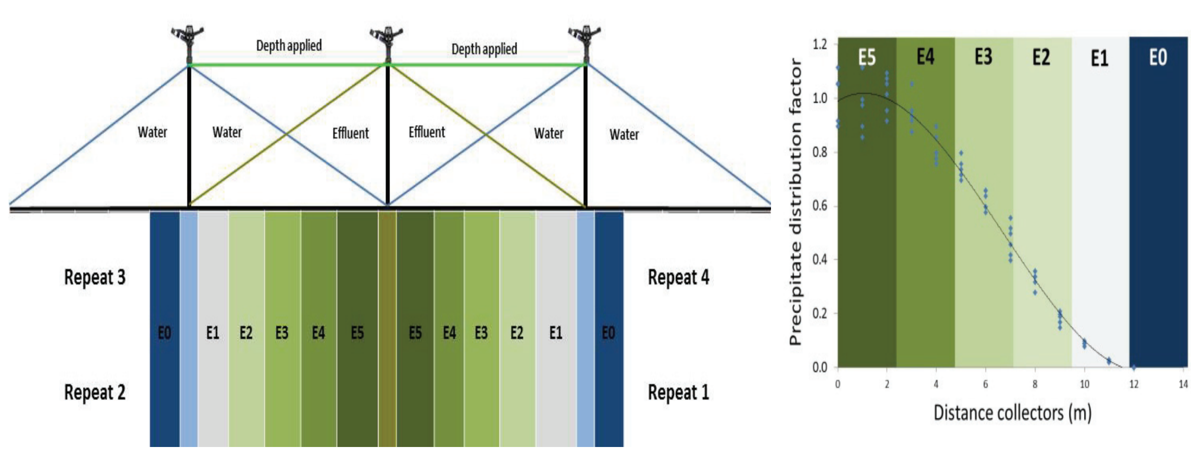

Figure 1. Experimental diagram showing the lines of gradual distribution of TSW in water (left) and the distribution ratio of rainfall on the distance of irrigation lines (right).

Results and discussion

TSW analyses confirmed high annual average concentrations of essential nutrients for *Brachiaria* growth, such as total nitrogen (52.9 ± 7.0 mg L^{-1}). Concentrations of potassium (20.3 ± 7.2 mg L^{-1}) and phosphorus (1.1 ± 0.4 mg L^{-1}) were, respectively, ideal and low for forage fertigation purposes (Table 2). Although TSW salinity was low (< 0.46 dS m^{-1}) by electrical conductivity evaluation, low sodium concentrations were observed (58.8 ± 8.7 mg L^{-1}) but in a low adsorption ratio (SAR = 3.3 ± 0.6), which is above the critical level. In addition, there was also a high total coliform count and the presence of Escherichia coli in the effluent.

Other nutrients were applied in the following amounts in E5: P = 27, K = 314, Ca = 258, Mg = 92, Na = 894, SO = 369, Fe = 6, Mn = 1, and Zn = 11, in 2013, and P = 21, K = 463, Ca = 358, Mg = 108, Na = 1,428, SO = 421, Fe = 17, Mn = 2, and Zn = 3, in 2014, in kg ha^{-1}. The remaining treatments were given quantities proportional to application ratios as defined for each treatment.

Mineral fertilizers (E0) were applied in summer, fall-winter and spring at the rates of 189, 85, and 182 kg ha^{-1} N in 2013, and 200, 157, and 292 kg ha^{-1} N in 2014. Superior nitrogen levels in E3 were applied in the same seasons to fulfil the crop water requirements.

Irrigation water depths for summer, fall-winter and spring were, respectively, 678, 500, and 675 mm in 2013, and 750, 661, and 842 mm in 2014. The total depth of irrigation and precipitation is shown in Table 3.

Mineral P and K fertilizers at the respective rates of 96 and 554 kg ha^{-1} (2013) and 136 and 696 kg ha^{-1} (2014) supplemented all treatments. Fertilizations were scheduled as needed for each cutting cycle of the crop (28 days).

Thus, an amount of 931 and 1,132 kg ha^{-1} nitrogen was applied to the E5 treatment (Table 4). Moreover, a greater nitrogen increment in the second year stemmed from the higher dry biomass yield.

Rising temperatures, reduced rainfall, and consequently, greater water demand in 2014 led to higher forage yields. During 2013 and 2014, the average temperatures were 22.2, and 23.3°C, respectively, with maximum values of 34.1, and 36.5°C and minimum values reaching 8.2, and 11.9°C; however, annual average rainfall was 1,393 mm, and 721 mm with an evapotranspiration of 1,398 mm, and 1,616 mm.

Table 2. Chemical, physical and microbiological characteristics of treated sewage wastewater (TSW) from a sewage treatment plant (STP) in Jaboticabal, São Paulo State, Brazil, in the summer, fall-winter and spring seasons of 2013 and 2014.

Factors	Unit of measure	Summer	Fall-Winter	Spring	Average	Acceptable level
pH	-	6.7	7.2	7.1	7.0±0.3	5-9[a]
EC	dS m^{-1}	0.44	0.49	0.42	0.46±0.01	<3[b]
TOC	mg L^{-1}	56.1	48.0	45.0	49.4±19.1	-
NO_3	mg L^{-1}	2.1	5.8	4.5	4.5±2.4	<10[c]
NO_2	mg L^{-1}	1.0	0.04	0.04	0.25±0.8	<0.02[c]
NH_3	mg L^{-1}	31.4	35.7	31.6	33.3±15.8	1-40[c]
Total N	mg L^{-1}	44.3	57.8	51.7	52.9±7.0	-
Total Fe	mg L^{-1}	0.28	0.62	0.60	0.53±0.3	<5[b]
K	mg L^{-1}	25.3	19.1	17.2	20.3±7.2	10-40[c]
P	mg L^{-1}	1.3	1.0	1.0	1.1±0.4	<2[b]
Ca	mg L^{-1}	9.3	15.9	21.2	15.5±6.4	20-120[c]
Mg	mg L^{-1}	7.5	4.9	7.0	6.2±2.6	10-50[c]
Zn	mg L^{-1}	0.1	0.5	0.2	0.27±0.32	<5[a]
Na	mg L^{-1}	60.3	54.1	64.3	58.8±8.7	50-250[c]
SAR	-	3.7	2.9	3.2	3.3±0.6	4.5-7.5[c]
TCC	MPN 100^{-1} ml	9,450	102,666	16,350	51,371±62,795	<10,000[c]
EC	MPN 100^{-1} ml	495	6,370	11,650	6,200±8,267	<1,000[c]

Obs.: pH: Hydrogen ionic potential; EC: Electrical conductivity; TOC: Total organic carbon; NO_3: Nitrate; NO_2: Nitrite; NH_3: Ammonium; Total N: Total nitrogen; Total Fe: Total iron; K: Potassium; P: Phosphorus; Ca: Calcium; Mg: Magnesium; Mn: Manganese; Zn: Zinc; Na: Sodium; SAR: Sodium absorption rate; TCC: Total coliform count; EC: Escherichia coli. MPN: Most probable number. Source: [a]Brasil (2011); [b]Ayers and Westcot (1976); [c]Feigin, Ravina, and Shalhevet (1991).

Table 3. Total water depth (water and effluent) and precipitation applied in the experiment in the summer, fall-winter and spring seasons of 2013 and 2014.

Year	Season	Precipitation	Irrigation	Irrigation depth
			(mm)	
2013	Summer	748	678	1,426
	Fall-winter	221	500	721
	Spring	424	675	1,089
	Total	1,393	1,853	3,246
2014	Summer	348	750	1,098
	Fall-winter	102	661	763
	Spring	271	842	1,113
	Total	720	2,252	2,974

Table 4. Nitrogen fertilization through TSW (kg ha^{-1}) in the summer, fall-winter and spring seasons of 2013 and 2014.

Year	Season	E5	E4	E3	E2	E1
	Summer	307	270	186	95	34
2013	Fall-winter	258	227	156	80	28
	Spring	365	321	221	112	40
	Total	931	817	564	287	102
	Summer	346	304	210	107	38
2014	Fall-winter	366	321	222	113	40
	Spring	420	369	255	130	46
	Total	1,132	994	687	350	124

Wastewater application increased the organic matter content, calcium, base saturation and cation exchange capacity (Table 5). Additionally, reductions of phosphorus, potassium and magnesium contents were observed, where plants absorbed some of the minerals and the remainder leached into the soil. Soil B concentration remained at an average content over time. During the evaluation period, the soil retained a low Al content, a medium to high content of Zn and Fe, and high amounts of Cu, Mn, and S-SO_4.

Table 5. Average chemical characteristics of the soil in the experimental area at 0-1.0 m depths in September of 2014, Jaboticabal, São Paulo State, Brazil.

Treatment	pH	OM	P resin	K	Ca	Mg	H+Al	BS	CEC	V
		g dm^{-3}	mg dm^{-3}	mmol dm^{-3}						%
E5	5.7	21.0	41.5	3.7	31.7	13.7	24.0	49.1	73.1	65.5
E4	5.7	18.5	31.5	3.2	30.0	13.7	22.3	46.9	69.2	65.7
E3	5.6	21.0	43.8	3.8	32.2	14.2	23.7	50.1	73.8	66.0
E2	5.6	18.5	29.8	3.3	26.5	12.3	23.5	42.1	65.6	61.5
E1	5.5	17.3	26.5	3.5	22.8	10.7	24.3	37.0	61.3	57.7
E0	5.5	20.7	34.2	3.4	27.7	12.3	26.0	43.4	69.4	60.0

Treatment	B	Cu	Fe	Mn	Zn	S-SO$_4$	Al
	mg dm^{-3}					mmol dm^{-3}	
E5	0.3	3.7	13.2	17.7	1.7	42.0	0.0
E4	0.3	3.3	11.8	12.7	1.4	42.0	0.0
E3	0.3	3.5	14.7	9.9	1.7	39.8	0.0
E2	0.3	3.1	14.2	9.5	1.4	32.7	0.0
E1	0.2	2.8	13.2	8.5	1.0	31.5	0.0
E0	0.2	3.3	15.2	15.2	1.5	25.3	0.0

Seasonal effects marked forage production, with high values present from October to April and low ones between May and September (Tables 6). High yields were reported in summer (44.7%) and spring (35.7%) of 2013, due to climatic factors that increased plant metabolic activities and, thus, promoted forage growth. In contrast, the low yield in autumn-winter (19.6%) was due to sub-optimal conditions for crop growth.

Table 6. Dry biomass yield during cutting cycles in 2013.

Month	Date	Cycle	(Mg ha^{-1}) E5	E4	E3	E2	E1	E0
February	02/05/13	1st	6,826	6,224	6,543	6,272	5,996	6,028
March	03/05/13	2nd	2,774	2,998	2,650	2,397	2,841	3,242
April	04/03/13	3rd	5,131	4,166	3,783	3,485	2,700	4,874
May	05/01/13	4th	1,397	1,639	1,495	1,390	1,405	1,957
May	05/28/13	5th	2,036	1,959	1,376	968	880	1,657
June	06/25/13	6th	2,444	2,530	1,834	1,184	1,058	1,941
July	07/23/13	7th	2,211	1,899	1,688	1,430	1,104	2,071
August	08/20/13	8th	1,526	1,440	1,120	896	920	1,201
September	09/17/13	9th	1,529	1,287	914	716	761	1,130
October	10/15/13	10th	5,376	4,356	2,823	2,080	1,936	3,167
November	11/12/13	11th	6,358	5,665	3,898	3,778	3,303	5,270
December	12/10/13	12th	5,512	6,001	4,470	4,939	4,032	5,417
January	01/07/14	13th	4,265	5,025	4,266	4,305	4,323	4,963
Total			47,385	45,189	36,862	33,840	31,260	42,918

In 2014, high values of average yields were obtained in spring (38.4%), followed by summer (35.9%) and fall-winter (25.7%) (Table 6). Cumulative results per season showed that in 2013, the highest average of forage performance occurred in summer (17.7 Mg ha^{-1}), followed by spring (14.1 Mg ha^{-1}) and fall-winter (7.8 Mg ha^{-1}) (Table 7).

Rainfall reduction (672 mm) and an increase in temperature (1.1°C) and solar radiation (312.5 MJ m^{-2} year^{-1}), mainly from March to November of 2014, resulted in improved dry biomass yield, with a sharper production gradient in 2013. Furthermore, in 2014, there was an increase in biomass production from 25.7 Mg ha^{-1} (E1) to 56.9 Mg ha^{-1} (E5), corresponding to an increase of 121%. These results agree with Fonseca et al. (2007b) and Matos et al. (2013).

Table 7. Dry biomass yield per treatment over the cutting cycles in 2014.

Month	Date	Cycle	(Mg ha^{-1}) E5	E4	E3	E2	E1	E0
February	02/04/14	14th	4,332	3,285	3,169	3,369	3,026	4,610
March	03/04/14	15th	5,074	4,761	2,973	3,707	3,125	3,837
April	04/01/14	16th	3,611	4,077	3,247	2,732	2,850	4,293
April	04/29/14	17th	4,985	4,541	4,232	4,054	3,842	3,908
May	05/27/14	18th	2,816	2,768	2,037	1,717	1,686	2,590
June	06/24/14	19th	1,958	1,803	1,649	1,241	852,0	1,896
July	07/22/14	20th	2,397	1,955	1,251	797,0	626,0	1,915
August	08/19/14	21st	2,278	1,512	1,287	993	682	1,536
September	09/16/14	22nd	3,183	2,806	1,431	1,004	717	2,203
October	10/14/14	23rd	6,834	5,687	3,563	2,363	1,455	3,833
November	11/11/14	24th	7,127	6,462	4,789	3,055	2,106	7,030
December	12/09/14	25th	6,813	7,152	5,132	3,657	2,793	6,910
January	01/06/15	26th	5,497	4,444	3,902	3,503	1,974	6,237
Total			56,907	51,253	38,662	32,191	25,736	50,797

A variance analysis of summer forage yield revealed that the factors cultivation year, TSW rate and TSW x year interaction were significant (Table 8). The coefficient of variation was 9.6%, which shows high experimental accuracy.

Table 8. Variance analysis summary (ANOVA) and comparison of biomass yield averages of *Brachiaria brizantha* fertigated with treated sewage wastewater (TSW) in the summer of 2013 and 2014.

Variation source	DF	Mean square	Pr (>F)
Block (B)	3	2,132,262.5^{ns}	0.4801
Year (Y)	1	69,547,860.1*	<0.0001
Interaction BxY	3	5,984,640.0^{ns}	0.0901
TSW	5	41,835,894.5**	<0.0001
Interaction TSWxY	5	7,312,756.4*	0.0299
V.C. (%)			9.6

Year	Average yield of dry biomass (Mg ha^{-1})
2013	17.7 a
2014	15.3 b

Treatment	2013 (Mg ha^{-1})		2014 (Mg ha^{-1})		Average (Mg ha^{-1})
E5	19.0	a	18.5	a	18.9
E4	18.4	a	16.6	ab	17.5
E3	17.2	a	13.3	bc	15.3
E2	16.5	a	13.3	bc	14.9
E1	15.8	a	10.9	c	13.4
E0	19.1	a	19.0	a	19.0
Average	17.7		15.3		-

DF – degree of freedom; Significant at 0.05 (*) and at 0.01 (**) of probability; (^{ns}) non-significant; V.C. – variation coefficient; Averages followed by the same letter in the upper right do not differ by Tukey's test (p < 0.05).

The average comparisons showed a higher forage yield in 2014 compared to 2013. Statistical breakdown of the TSW x year interaction showed similar yield averages in the summer of 2013.

Initial fertilization standardized forage production at the beginning of the experiment. In the summer of 2014, the highest average yields were observed for E5, E4, and E0; however, E3, E2, and E1 had the lowest averages, but the E4 and E3 averages did not differ significantly.

During the fall-winter season, we observed significant results for the year and TSW rates; however, there was no interaction between them (Table 9). The coefficient of variation was 13.5%. Moreover, biomass yield in 2014 surpassed the findings for 2013.

Table 9. Variance analysis summary (ANOVA) and comparison of biomass yield averages of *Brachiaria brizantha* fertigated with treated sewage wastewater (TSW) during the fall-winter of 2013 and 2014.

Variation source	DF	Mean square	Pr (>F)
Block (B)	3	6,222,510.2^{ns}	0.018
Year (Y)	1	122,212,110.0**	<0.0001
Interaction B x Y	3	1,631,663.1^{ns}	0.3949
TSW	5	36,929,215.3**	<0.0001
Interaction TSW x Y	5	1,432,577,0^{ns}	0.4932
V.C. (%)			13.5
Year		Average yield of dry biomass (Mg ha^{-1})	
2013		7.8 b	
2014		11.0 a	
Treatment	2013 (Mg ha^{-1})	2014 (Mg ha^{-1})	Average (Mg ha^{-1})
E5	9.6	14.5	12.0 a
E4	9.5	12.6	11.0 a
E3	7.5	10.5	9.0 bc
E2	5.9	8.8	7.4 cd
E1	5.4	7.7	6.6 d
E0	8.8	11.8	10.3 ab
Average	7.8	11.0	-

DF – degree of freedom; Significant at 0.05 (*) and at 0.01 (**) of probability; (ns) non-significant; V.C. – variation coefficient; Averages followed by the same letter in the upper right do not differ by Tukey's test ($p < 0.05$).

When comparing TSW rates, we noticed higher yields for E5, E4, and E0, with no significant differences between E3 and E0. In addition, relatively low rates of nitrogen (E1) reduced biomass yield by up to 84.2% compared with the maximum rates (E5). During this season, biomass yield did not reach the minimal level for cattle grazing, which is 1,200 kg ha^{-1} (Silva et al., 2012), within the 28-day intervals. This yield drop is associated with low temperatures, humidity and light, which are limiting factors for grass development, unlike what is observed in summer and spring. The growth of C4 grasses is highly demanding of temperature and luminosity (Matos et al., 2013). Maranhão et al. (2010) proved this fact in a study of nitrogen levels on *Brachiaria*, observing a 78.9% reduction in dry biomass from summer to winter. Similar results were obtained by Alencar et al. (2009) and Oliveira Filho et al. (2011).

As for spring data, we observed significant effects of year, TSW rates and their interaction, with a variation coefficient of 10.3% (Table 10). In 2014, biomass yield was higher than in 2013 (41%). Furthermore, in 2014, peaks of higher and lower biomass yield for E5 (24 Mg ha^{-1}) and E1 (7 Mg ha^{-1}) were recorded, respectively. It is worth mentioning that in warmer periods with high solar radiation, as in 2014, increased yields occurred.

Table 10. Variance analysis summary (ANOVA) and comparison of biomass yield averages of *Brachiaria brizantha* fertigated with treated sewage wastewater (TSW) in the spring of 2013 and 2014.

Variation source	DF		Mean square		Pr (>F)
Block (B)	3		11,248,379**		0.0091
Year (Y)	1		59,748,413**		<0.0001
Interaction BxY	3		10,628,428*		0.0116
TSW	5		207,980,458**		<0.0001
Interaction TSWxY	5		25,456,396**		<0.0001
V.C. (%)					10.3
Year			Average yield of dry biomass (Mg ha^{-1})		
2013			16.3 a		
2014			14.1 a		
Treatment	2013 (Mg ha^{-1})		2014 (Mg ha^{-1})		Average (Mg ha^{-1})
E5	18.8	Abc	24.0	a	21.4
E4	17.3	Bc	22.1	ab	19.7
E3	12.1	De	14.9	de	13.5
E2	11.5	De	10.0	fg	10.8
E1	10.0	Ef	7.0	g	8.5
E0	15.0	Cd	20.0	bc	17.5
Average	14.1		16.3		-

DF – degree of freedom; Significant at 0.05 (*) and at 0.01 (**) of probability; (ns) non-significant; V.C. – variation coefficient; Averages followed by the same letter in the upper right do not differ by Tukey's test ($p < 0.05$).

The average rates of dry biomass growth in 2013 were 158, 56, and 126 kg ha^{-1} day^{-1} in the summer, fall-winter and spring, respectively. The highest rates were observed in E0 (171 kg ha^{-1} day^{-1}) and E5 (170 kg ha^{-1} day^{-1}) during the summer, and the lowest rate was observed for E1 (38 kg ha^{-1} day^{-1}) in the winter. Similar results were obtained by Dupas et al. (2010), Matos et al. (2013) and Dantas et al. (2016).

In 2014, the lowest average rates of biomass growth occurred in treatments with lower inputs of TSW (E1 and E2), corresponding to 136, 78, and 146 kg ha^{-1} day^{-1} in the summer, fall-winter and spring, respectively. On the other hand, the largest rates were observed for E5 and E4 with 214 and 197 kg ha^{-1} day^{-1}, respectively, during the spring; and the lowest rate was observed in E1 (55 kg ha^{-1} day^{-1}) in the winter. These results agree with those of Andrade et al. (2012).

The dry biomass yield increased according to the nitrogen applied to the soil via TSW in all assessed seasons for the years of 2013 and 2014. Despite the high levels of nitrogen applied via TSW, in 2013 (931 kg ha^{-1}; $Y = 0.016 X^2 + 2.53 X + 31{,}071$; $R^2 = 0.99$) and 2014 (1,132 kg ha^{-1}; $Y = 0.014 X^2 + 12.53 + 24{,}628$; $R^2 = 0.99$), forage yield peaks were not reached. Equivalent rates of organic and mineral nitrogen resulted in yields greater than or equal to E0 compared to E3. Similar results were obtained by Drumond et al. (2006), Silva et al. (2012), Nogueira et al. (2013) and Dantas et al. (2016).

Nitrogen yield for treatments receiving TSW were 173.8, 77.9 and 102.5 kg of biomass per kg of N in the summer ($Y = 0.0098 X^2 - 4.64 X + 585.5$; $R^2 = 0.95$), fall-winter ($Y = 0.0053 X^2 - 2.09 X + 231.49$; $R^2 = 0.93$) and spring ($Y = 0.0038 X^2 - 2.05 X + 312.81$; $R^2 = 0,95$) and 117 ($Y = 0.0046 X^2 - 2.46 X + 361.7$; $R^2 = 0.96$), 79 ($Y = 0.0014 X^2 - 0.87 X + 182.65$; $R^2 = 0.93$) and 81.3 kg of biomass per kg of N ($Y = 0.0027 X^2 - 1.51 X + 236.7$; $R^2 = 0.95$), in 2014, respectively. Regardless of the higher yield in 2014, the lowest nitrogen efficiency is related to the increase in TSW rates. Serafim and Galbiatti (2010) argued that lower rates had better nitrogen performance, thus confirming the results of our research. For Fonseca et al. (2007b), low water tension in soil derived from regular irrigation favours nitrogen performance and, as a consequence, enhances forage yield.

An improved leaf quality, in terms of CP (> 12%) and NDF (< 60%), was provided when forage had low yield. Therefore, in the fall-winter, low yields associated with a smaller leaf area and larger leaf-stem ratio resulted in higher CP content and lower NDF in both years (Tables 11 and 12). Furthermore, we observed a gradual increase in herbage quality in 2014, which occurred due to the increased TSW rates applied. Similar results were obtained by Dantas et al. (2016).

Table 11. Crude protein (%) of dry biomass of *Brachiaria brizantha* due to the application rates of TSW and mineral fertilizing in 2013 and 2014.

Year	Season	Treatments						Average
		E5	E4	E3	E2	E1	E0	
2013	Summer	10.6	11.1	10.3	10.5	10.5	11.1	10.7
	Fall-winter	16.4	15.0	14.0	13.4	12.6	13.9	14.2
	Spring	12.3	11.0	11.8	10.7	13.2	13.6	12.1
	Average	13.1	12.4	12.0	11.5	12.1	12.9	-
2014	Summer	15.0	14.9	13.0	10.9	12.2	12.8	13.1
	Fall-winter	17.7	17.8	15.7	14.4	12.7	17.5	16.0
	Spring	15.5	12.0	10.6	10.2	8.1	11.8	11.4
	Average	16.1	14.9	13.1	11.8	11.0	14.0	-

Table 12. Neutral detergent fibre (%) of dry biomass of *Brachiaria brizantha* due to the application rates of TSW and mineral fertilizing in 2013 and 2014.

Year	Season	Treatments						Average
		E5	E4	E3	E2	E1	E0	
2013	Summer	65.8	61.0	66.7	65.2	58.1	66.4	63.9
	Fall-winter	57.1	56.8	60.4	61.5	61.2	55.5	58.8
	Spring	62.6	60.5	62.9	57.8	64.9	62.4	61.9
	Average	61.8	59.4	63.3	61.5	61.4	61.4	-
2014	Summer	55.1	55.8	57.0	60.6	61.1	55.1	57.5
	Fall-winter	52.8	52.7	56.0	57.6	59.5	56.4	55.8
	Spring	58.4	62.0	62.4	67.3	61.4	63.5	62.5
	Average	55.4	56.8	58.4	61.8	60.7	58.3	-

Foliar analysis showed that the reference treatment (E3) had an ideal CP content, albeit below average, for every season except fall-winter. This high content, shown in 2013, could be attributed to higher leaf production against stems since leaves carry the most nutrients, as shown in some previous reports. These results agree with those of Matos et al. (2013), Silva and Queiroz (2006), Castro et al. (2007), Serafim and Galbiatti (2012), Geron et al. (2014) and Dupas et al. (2010).

Forage fertigation with TSW has the potential to supply nitrogen and potassium to crops; however, this also causes phosphorus limitation and an average potential for soil salinization because of large concentrations of sodium and coliforms within this effluent. However, it has promoted high levels of good quality forage production, favourable for cattle feeding, weight gain per animal, reducing the use of underground water and mineral fertilizers, in addition to social and environmental benefits.

Using wastewater in agriculture enables irrigated areas to be extended and reduces the amount of sewage disposed of in receiving water bodies. It denotes an alternative to control pollution of water sources, lowering underground water and fertilizer demands, in addition to a sustainable agricultural management tool.

Conclusion

Brachiaria brizantha had positive responses to TSW application, increasing annual dry biomass production from 31.3 to 47.4 Mg ha^{-1} in 2013 and from 25.7 to 56.9 Mg ha^{-1} in 2014, between E1 and E5, respectively.

There was a marked seasonality in forage performance; the highest yields occurred in the summer (35.9 to 44.7%) and spring (35.7 to 38.4%), and the lowest yields (19.6 to 25.7%) with improved forage quality were observed in the fall-winter.

The constant use of TSW combined with growing levels resulted in forage production with an enhanced nutritional quality concerning crude protein and neutral detergent fibre.

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