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EFEITO DE LÂMINAS DE IRRIGAÇÃO SUBSUPERFICIAL NA EXTRAÇÃO DE NUTRIENTES E PRODUTIVIDADE EM PASTAGEM

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1 RESUMO

O risco eminente de escassez hídrica que cresce de maneira alarmante em várias regiões do mundo tem fomentado a adoção de métodos de irrigação mais eficientes, assim como mudanças estratégicas no manejo da irrigação. Como alternativa destacam-se o gotejamento subsuperficial e a irrigação deficitária. Objetivou-se avaliar a produtividade, teor, extração de nutrientes e produtividade da água, em *Brachiaria brizantha* cv. Marandu, submetida a cinco potenciais de água no solo: 0, 50, 75, 100 e 125% da evapotranspiração potencial da cultura (ET_c). O trabalho foi conduzido no campo em área experimental da Universidade Federal de Viçosa – *Campus* de Rio Paranaíba, MG. Foi utilizado um delineamento inteiramente casualizado com quatro repetições e as médias foram comparadas por regressão e pelo teste Tukey a 5% de probabilidade. Os resultados demonstraram que o déficit hídrico reduziu até 54% da produtividade, mas aumentou 27% da eficiência no uso da água. A produtividade da lâmina 75% ET_c foi semelhante a irrigação plena, podendo esta, ser uma alternativa para locais que apresentem restrições hídricas. Por outro lado, as lâminas de irrigação por gotejamento subsuperficial não influenciaram o teor de NPK, no entanto, reduziram a quantidade de nutriente extraído.

Palavras-chave: *Brachiaria brizantha* cv. Marandu, irrigação deficitária, eficiência do uso da água, nutrientes.

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EFFECT OF SUBSUPERFICIAL IRRIGATION SLIDES ON NUTRIENT EXTRACTION AND PRODUCTIVITY ON PASTURE

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2 ABSTRACT

The imminent risk of growing water scarcity in many regions of the world has encouraged the adoption of more efficient irrigation methods and strategic changes in irrigation management. Alternatively, subsurface drip irrigation and deficit irrigation. This work aimed to evaluate the productivity, water productivity, nutrient content and extraction in Brachiaria brizantha cv. Marandu, submitted to five soil water potentials: 0, 50, 75, 100, and 125% of potential crop evapotranspiration (ETc). The study was conducted in the field in the experimental area of the Federal University of Viçosa - Rio Paranaíba Campus, MG. A completely randomized design with four replicates was used, where averages were compared by regression and by the Tukey test at 5% probability. The results demonstrate that water deficit reduced up to 54% of productivity, but increased 27% water use efficiency. The productivity of the 75% ETc blade was similar to that of full irrigation, and this could be an alternative for sites with water restrictions. However, sub-surface irrigation slides did not influence the NPK content, however, they reduced the amount of nutrient extracted.

Keywords: *Brachiaria brizantha* cv. Marandu, deficit irrigation, water use efficiency, nutrients.

3 INTRODUCTION

Irrigation projects aim to improve crop agronomic performance. However, given the alarming increase in water scarcity in several regions of the world, strategic changes in irrigation techniques and water management are essential to achieve efficient and economically viable consumption. This is because, in many cases, the amount of water applied to achieve maximum profitability is less than that required to fully meet crop evapotranspiration requirements. Thus, the application of controlled water deficits has become an alternative for reducing irrigation and energy costs while simultaneously achieving greater economic water productivity (GAVA et al., 2015; DU et al., 2016).

According to the Irrigation Atlas of the National Water Agency (ANA, 2021), Brazil has 8.2 million hectares of irrigated land, corresponding to 49.8% of its water demand. In contrast, Brazilian agribusiness accounted for 26.6% of Brazil's GDP in 2020 (CEPEA, 2021). Despite its high water consumption, irrigation represents the most efficient way to increase food production, as irrigated crops account for more than 40% of global food production in just 21% of the planet's agricultural land (FAO, 2016). Therefore, one of the greatest challenges facing the world today is rationalizing water resource use while maintaining or increasing crop productivity.

Under this scenario, more efficient irrigation methods, as well as changes in irrigation management, particularly subsurface drip and deficit irrigation, have emerged. Subsurface drip irrigation systems apply water with unique precision and economy, making the use and application of water resources unparalleled in efficiency (TESSLER, 2021), as evaporation, surface runoff, and deep percolation are minimized (DALRI et al., 2008).

With respect to management, a commonly used strategy to increase water use efficiency is deficit irrigation, which is a good option for producers facing water constraints. According to JUSTINO et al. (2019), this technique involves applying water depths lower than those essential to meet a crop's water needs, thus affecting evapotranspiration and productivity.

However, water productivity will only be truly beneficial if it is associated with acceptable yields (GRAFTON et al., 2018).

It is believed that the combination of efficient irrigation and skillful management can increase water productivity, enabling satisfactory yields even with reduced water availability. However, even if such a combination is efficient enough to reduce the amount of water required to achieve satisfactory yields, the importance of water in nutrient transport and absorption must not be overlooked, since the movement of nutrients from the soil to the roots depends on the presence of water (SILVA et al., 2017).

According to PAES (2016), a decrease in soil water content reduces the movement of nutrients transported both by mass flow and diffusion. This occurred because stomatal closure reduces transpiration flow and mass flow, thus directly affecting NPK absorption by plants.

Therefore, this study aims to determine whether applying water directly to the root system can minimize the effects of water deficit on nutrient absorption. However, only a careful analysis of the nutrient content in plant tissue can explain the extent to which controlled water deficits can compromise nutrient extraction and utilization efficiency. Furthermore, it is necessary to determine the feasibility of this type of management and its practical effects on fertilization.

This research is warranted to answer these questions and propose viable water resource management alternatives. Furthermore, few studies in the national literature illustrate the viability of this irrigation management approach for intensive irrigated forage production.

4 MATERIALS AND METHODS

The work was conducted in the experimental field area of the Federal University of Viçosa – *Campus* de Paranaíba River, MG, located at coordinates 19° 12' 34" S and 46° 07' 53" W with an average altitude of 1,100 meters (m), originating from the dissertation by Silva (2018). The climate of the region is classified as Cwa (KÖPPEN, 1948), and the soil is classified as a typical dystrophic Red Yellow Latosol with a moderate, clayey texture, cerrado phase and flat relief (SANTOS et al., 2018). After soil preparation and installation of the irrigation system, soil samples were collected at depths ranging from 0.0–0.20 m for physical and water characterization, the results of which are presented in Table 1.

Table 1. Physical and water characteristics of the soil in the experimental area

Prof	**Θ_s**	**Θ_{cc}**	**Θ_{pmp}**	**D_s**	**Sand**	**Silt**	**Clay**	**Ksat**
m	--------- cm^3 cm^{-3} ---------			g cm^{-3}	--------- g kg^{-1} ----------			cm s^{-1}
0-0.20	0.66	0.43	0.12	1.37	180	120	700	2.5 x 10^{-3}

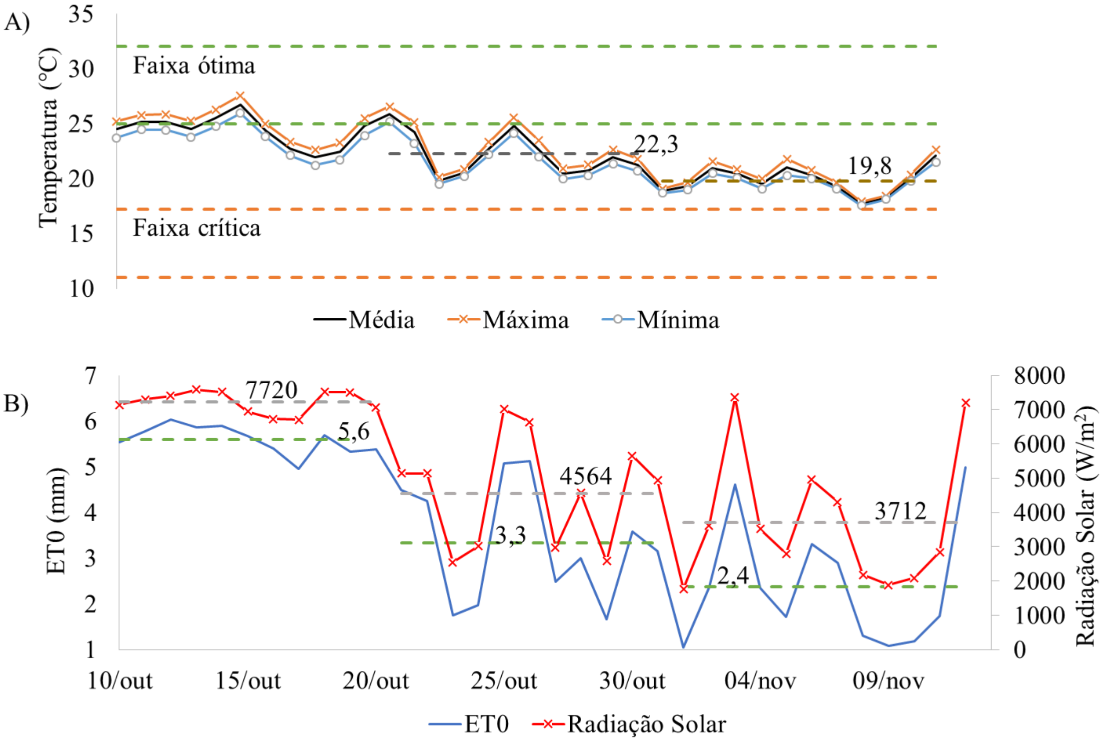
*Prof. = depth; Ds = soil density; Θs, Θcc and Θpmp refer to moisture at saturation, field capacity and the permanent wilting point, respectively; Ksat = saturated hydraulic conductivity of the soil.

The total experimental area was 238 m^2, with each experimental unit corresponding to 47.74 m^2. The irrigation system used was an automated subsurface drip (NaanDanJain®, Top Drip model) buried at a depth of 0.2 m. The spacing between drip tapes was 1 m, and the spacing between drippers was 0.3 m, forming a continuous wet strip with a tube flow rate equal to 1.6 L h^{-1}.

Irrigation management was carried out through daily collection of meteorological data from the agroclimatic station installed 50 m from the irrigated area, which provided data for estimating reference evapotranspiration (ET_0) via the Penman–

Monteith method (FAO 56), as proposed by Allen et al. (1998), as well as other meteorological data used in the research, such as rainfall, maximum, minimum and average temperatures and solar radiation, as shown in Figure 1.

Figure 1. Climatic data from the experimental period in Rio Paranaíba in 2017, including A) maximum, average and minimum temperatures and B) solar radiation and reference evapotranspiration (ET_0).



The experiment was carried out in a completely randomized design consisting of 5 treatments, with one forage species being *Brachiaria brizantha* cv. Marandu and five water depths; 0, 50, 75, 100 and 125% of the crop's potential evapotranspiration (ET_c), with four replicates, totaling 20 sampling units. The treatments consisted of five management systems: T1, control; T2, moderate water deficit; T3, mild water deficit; T4, full irrigation; and T5, additional irrigation. The irrigation rates were determined via Equation 1.

$$ET_C = K_C \times ET_0 \quad (1)$$

where ET_c is the crop evapotranspiration, (mm); Kc is the cultivation coefficient; and ET_0 is the reference evapotranspiration, (mm). Irrigation was applied according to the accumulated crop evapotranspiration (ETcac), according to Equation 2.

$$ETc_{ac} = (ET_{diária}) \quad (2)$$

where: ETc_{ac} – accumulated crop evapotranspiration, (mm); ET daily – daily evapotranspiration, (mm).

Irrigation was applied when the accumulated crop evapotranspiration (ETcac) reached values of up to 15 mm, with the daily ETc determined for each treatment, as shown in Table 2.

Table 2. Daily ET of each treatment

T1	Witness	
T2	Moderate water deficit	Daily ETc = (ET $_c$) x 0.50
T3	Mild water deficit	Daily ETc = (ET $_c$) x 0.75
T4	Complete irrigation	Daily ETc = (ET $_c$) x 1.00
T5	Additional irrigation	Daily ETc = (ET $_c$) x 1.25

Generally, localized irrigation only wets one to two-thirds of the area; therefore, it requires correction due to the location, which consists of multiplying the ET $_c$ by a specific adjustment coefficient KL (KELLER, 1978).

$$\mathrm{ETc} = (\mathrm{K_C} \times \mathrm{ET_0}) \times \mathrm{K_L} \quad (3)$$

where K $_L$ is the location coefficient. For the buried drip system, a K $_L$ equal to 1 was adopted, following the model proposed by Fereres (1981), who adopted this value in irrigation systems that provide more than 65% of the wetted area.

The forage was broadcast in March 2017 at a rate of 15 kg ha $^{-1}$ two weeks after soil correction (geox limestone, PRNT 125% at a dose of 4.2 t ha $^{-1}$) to increase water saturation. base for 70%**).** The crop establishment period was 180 days because of the harsh winter of that year. From September 15, 2017, to November 20 of the same year, the plants received irrigation as recommended for each treatment. Irrigation was carried out depending on the amount of rainfall. The irrigation levels and precipitation data are shown in Table 3.

Table 3. Precipitation and total volume of water used for each treatment throughout the cycles

		Total Water Volume (mm)				
		T1	T2	T3	T4	T5
Cycle 1	Precipitation	47.0	47.0	47.0	47.0	47.0
	Irrigation	0.00	36.91	55.37	73.88	92.28
	Total	47.0	83.91	102.38	120.83	139.38
Cycle 2	Precipitation	92.8	92.8	92.8	92.8	92.8
	Irrigation	0.00	35.5	53.2	71.0	88.7
	Total	92.8	128.3	146	163.8	181.5

Fertilization was based on a chemical soil analysis performed in the months preceding the start of the experiment (Table 4). Liming was applied on the basis of this analysis to correct acidity and increase base saturation to 70%. Other nutrients were broadcast monthly according to crop needs (Table 5).

Table 4. Results of the soil chemical analysis at depths of 0.0–0.20 m

P	MO	pH	K	Here	Mg	Al	H+Al	SB	CTC	V
mg dm $^{-3}$	gd m $^{-3}$					cmol $_c$ dm $^{-3}$				%
17	41	4.8	0.14	2.5	0.7	0.05	9	3.35	6.6	27.1

Table 5. Chemical fertilization performed in the experiment (kg ha $^{-1}$)

Application	Urea	Monoammonium phosphate	Potassium Chloride	Ammonium sulfate
Monthly	125	21	73	18
Annual	1500	250	880	220

The pasture was managed to simulate intensive grazing under rotational stocking, following pregrazing height targets of 0.25–0.30 m and postgrazing of 0.12 m, with rest periods ranging from 25--30 days. The period between pre- and postgrazing was called the cycle. Dry matter (DM) was evaluated from the cut in a 0.25 m² square frame (0.5 × 0.5 m), with a stubble height of 0.12 m. The collected plant biomass was weighed in the field to determine the green or fresh mass. A 100 g sample of fresh material was subsequently taken to determine the dry matter of the forage through drying in an oven with forced air circulation at 65 °C for 72 hours (GARDNER, 1986). Using the value obtained in the frame area, the dry matter per hectare was estimated via simple extrapolation.

To calculate water productivity, the model described by Pereira et al., 2009, was adopted, where water productivity (WP) was defined as the ratio between the production achieved by the crop (dry mass) and the amount of water used, according to Equation (4).

$$WP = \frac{Y_a}{TWU} \quad (4)$$

where WP is the water productivity, (kg m ^{3}); Y_a is the silage production achieved by the crop, (kg ha $^{-1}$); and TWU is the total water used to achieve Y_a, including rainfall, (m³). This study can also be carried out taking into account only the water used for irrigation, in accordance with Equation 5.

$$WP_{irri} = \frac{Y_a}{IWU} \quad (5)$$

where WP_{irri} - irrigation water productivity *WP* $_{irri}$, (kg m ^{3}); IWU - irrigation water used to reach Y_a.

Chemical analyses of plant tissues were performed according to the methodologies described by Silva (2009). Sulfuric digestion followed by Kjeldahl distillation was used to determine N. The remaining nutrients were subjected to nitroperchloric digestion and analyzed by spectrophotometry (P) and flame photometry (K). The data were subsequently subjected to outlier analysis guided by the standardized residual method. The results with discrepant values associated with unexplained factors were eliminated.

The data were subjected to analysis of variance (ANOVA) via the R statistical program (R Development Core Team, 2014), and the means were compared via the Tukey test at the 5% probability level.

5 RESULTS AND DISCUSSION

The occurrence of concentrated rainfall during the evaluation period reestablished soil water storage throughout the plant's root system, which minimized the effects of the treatments.

The productivity of *Brachiaria grass brizantha* varied depending on subsurface drip irrigation management (Table 6), with treatments 4 and 5 outperforming treatments 1 and 2, which presented the lowest average values. This is due to water deficiency, which, according to Duarte et al. (2019), results in a reduction in several physiological and biochemical processes in the plant, such as photosynthesis, cell elongation, and the herb accumulation rate.

The results presented are in accordance with those of Amaral (2019), who, when evaluating the production of Tifton 85 conducted under irrigation management conditions with 100, 80, 60, 40 and 20% of the water available in the soil at the time of irrigation, concluded that 80% of the water available in the soil did not harm forage production.

Table 6. Average productivity (ton ha^{-1}), water productivity (WP) and irrigation water productivity (WP_{irri}) ($kg\ m^{-3}$) of *Brachiaria brizantha* cv. Marandu under different irrigation management practices

Treatment	Productivity (t ha^{-1})	WP ($kg\ m^{-3}$)	WP_{irri} ($kg\ m^{-3}$)
T1	1.17 c	20.44 a	-
T2	1.33 c	13.15 b	36.92 a
T3	1.74 bc	13.42 b	32.06 ab
T4	2.41 ab	15.82 ab	33.4 ab
T5	2.53 a	14.97 b	27.26 b
F	12.93 **	5.83 *	36.88 **
Average	1839.88	15.58	25.93
CV (%)	18.60	15.71	18.93

Means followed by the same letter in the same column do not differ from each other according to the Tukey test at the 5% probability level. ** F significant at the 1% probability level. * F significant at the 5% probability level. ns - F not significant at 10% probability.

These results corroborate those reported by Ismail and Almarshadi (2013), who, working with deficient subsurface irrigation in alfalfa cultivation, obtained savings in the corresponding water use. However, in the studies of these authors, there was a reduction in crop productivity with decreasing irrigation depth. Gargantini et al. (2005) evaluated the productive responses of Mombaça grass subjected to increasing irrigation depths and reported greater forage production with increasing irrigation depth, which varied between 73% and 114% of ET_0. However, the best response to water replacement, in most cycles, was limited to values close to 100% of ET_0.

Importantly, when comparing the recommended depth (T4) in relation to the mild water deficit (T3), it is possible to verify that they are statistically equal, although T3 allows for a savings of 25% of the amount of water applied, suggesting its use in water deficit conditions, since the reduction in productivity was not significant for the conditions tested, thus maintaining the economic return of the irrigated crop. These results can be explained by the better use of rainfall in treatment 3. The irrigation of the subsurface also possibly contributed to the observed results, as it reduced water loss through direct evaporation from the soil and, consequently, allowed the use of a shallower water depth without a significant reduction in productivity. Similar results were reported by Mendonça (2017), who, when studying the effects of deficient subsurface irrigation on tomato crops, concluded that the productivity of full irrigation was similar to that of a treatment with 75% available water capacity.

The results revealed that the highest water productivity (WP) was observed in T1, with 20.44 kg m^{-3} for DM production. These values differ statistically from those of T2, T3, and T5, which were less efficient in terms of water use. This may be associated with better utilization of rainfall. In other words, in the treatments with high water contents throughout the crop cycle, the effective precipitation may have been lower than that in the control, resulting in lower precipitation utilization.

Martins et al. (2012), studying the efficiency of water use for corn silage production, reported that the highest water productivity was observed for the treatment with 50% $ETc_{replacement}$. Notably, maximum water use efficiency does not always translate to the highest economic return from crops. Furthermore, high rainfall minimized the control effect. Therefore, dispensing with irrigation is not recommended, as the control treatment did not yield the best economic performance.

The irrigation water productivity (WPirri) data in Table 6 indicate that T2 presented the highest average DM production, with 36.92 kg m $^{-3}$, whereas T5 presented a productivity of 27.26 kg m $^{-3}$. These values indicate that water deficit treatments can be more efficient in terms of the use of irrigation water. These results corroborate those of Zwirtes et al. (2015), who evaluated the effects of various deficit irrigation practices with surface drip and water productivity in sorghum and concluded that deficit irrigation resulted in a linear reduction in height, leaf area index, and grain yield, despite an increase in irrigated water productivity.

With respect to nutrient absorption, the nitrogen (N), phosphorus (P) and potassium (K) contents of the grass *Brachiaria brizantha* did not vary as a function of subsurface drip irrigation management (Table 7). It is believed that applying water directly to the root system may have minimized the effects of the deficit on nutrient extraction. However, it is also possible that irrigation does not directly influence this.

Table 7. Averages, regression equations and coefficients of determination of the nitrogen (N), phosphorus (P) and potassium (K) contents (g kg $^{-1)}$ ^{of} *Brachiaria brizantha* cv. Marandu depending on the irrigation depth during the evaluated period:

	Blades (%) ET $_c$					Average	Regression equations	R^2	CV
	0	**50**	**75**	**100**	**125**				
N content	26.7 a	23.6 a	24.1 a	25.4 a	26.8 a	25.3	$\hat{Y}$= 25.38	ns	6.54
P content	1.3 to	1.4 to	1.2 to	1.2 to	1.1 a	1,2	$\hat{Y}$= 1.25	ns	17.3
K content	21.3 years	22.1 a	22.1 a	20.8 a	21.7 a	21.6	$\hat{Y}$= 21.66	ns	14.2

Means followed by the same letter on a line do not differ from each other according to the Tukey test at the 5% probability level. ** F significant at the 1% probability level. * F significant at the 5% probability level. ns - F not significant at 10% probability.

These results are similar to those of Rezende et al. (2006), who, when evaluating the influence of different fertilizers and irrigation management practices on growth, flowering and foliar NPK levels in alpinia, concluded that irrigation did not influence foliar NPK levels at different times of the year.

The nutritional contents presented in this work corroborate those described by Aguiar (2011) for the genus *Brachiaria brizantha* CV Marandu, with 18, 1.9 and 21 kg ton $^{-1}$ DM extracted from the aerial part for N, P and K, respectively.

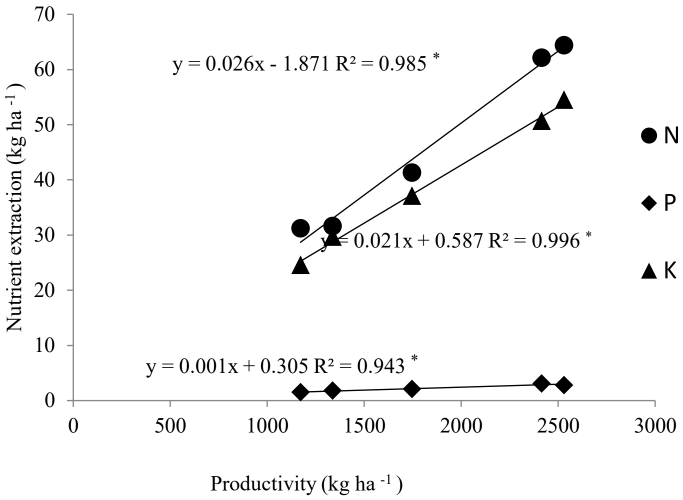
The extraction of N, P, and K as a function of irrigation depth fit the cubic regression model, with depths of 100 and 125% ET $_c$ resulting in maximum accumulation of these nutrients. In contrast, depths of 0 and 50% ET resulted in a reduction in these nutrients (Table 8). This can be explained by the linear relationship between the nutrients extracted and the achieved productivity (Figure 2). In contrast to expectations, the main consequence of the increase in nutrient extraction was production, since the N, P, and K contents were not influenced by irrigation. In this sense, irrigation begins to exert a secondary effect, contributing to increased absorption efficiency.

Table 8. Means, regression equations and coefficients of determination of extraction (kg ha $^{-1}$) of nitrogen (N), phosphorus (P) and potassium (K) and *Brachiaria productivity of brizantha* cv. Marandu (ton ha $^{-1}$) depending on the irrigation depth during the evaluated period

	Blades (%) ET $_c$					Average	R^2	CV
	0	50	**75**	**100**	**125**			
N extraction	31.2 b	31.6 b	41.3 ab	62.1 a	64.4 a	46.1	0.98 *	25
Regression Equation	$y = 63.44 - 51.28x + 21.88x^2 - 2.31x^3$							
Extraction of P	1.5 b	1.8 ab	2.1 ab	3.1 a	2.8 to	2.2	0.92 *	25
Regression Equation	$y = 2.45 - 1.47x + 0.70x^2 - 0.79x^3$							
K extraction	24.6 b	29.7 b	37.1 ab	50.7 a	54.5 to	39.3	0.99 *	20
Regression Equation	$y = 34.01 - 17.51x + 9.43x^2 - 1.02x^3$							
Productivity	1.1 c	1.3 c	1.7 bc	2.4 ab	2.5 to	1.8	0.99 *	18
Regression Equation	$y = 1897.93 - 1257.65x + 609.62x^2 - 66.46x^3$							

Means followed by the same letter do not differ from each other according to the Tukey test at the 5% probability level. ** F significant at the 1% probability level. * F significant at the 5% probability level. ns - F not significant at 10% probability.

Figure 2. Correlations between productivity and total accumulation of nitrogen (N), phosphorus (P) and potassium (K)



* significant at the 0.05 level

These results corroborate those described by Silva et al. (2017), who evaluated different deficit irrigation management methods in sugarcane crops and their relationships with transpiration, N, P, and K contents and accumulation in the aerial part of the plant. The authors concluded that there are strong positive correlations between N, P, and K accumulation in plants and dry matter production, whereas there are only intermediate correlation coefficients between plant transpiration and nutrient uptake in plants subjected to water deficit.

Similar results were also reported by Crusciol et al. (2003), who studied the export, absorption, and efficiency of nutrient use in rice, using 0.5, 1.0, 1.5, and 1.95 of the reference value Kc (cultural coefficient). They reported that the greatest nutrient extraction occurred at the greatest depth, largely due to greater dry matter production, since the nutrient contents were similar to those obtained in the other treatments. The recommended water depth provided greater efficiency of use for all the nutrients analyzed. In contrast, the greatest depth resulted in low nutrient use efficiency.

Thus, deficit irrigation can be an excellent strategy for reducing water use in agriculture and may be recommended for areas where water scarcity affects agricultural production. In these cases, the level of maximum economic efficiency must consider the added value of the crop, the availability or value of the water resource, and its consideration on a case-by-case basis.

6 CONCLUSION

Water deficits reduced productivity by up to 54% but increased water use efficiency by 27%. The productivity at 75% ET was statistically equal to that under full irrigation.

Subsurface drip irrigation depth did not influence the nitrogen, phosphorus or potassium contents of *Brachiaria brizantha* cv. Marandu. Furthermore, there are strong correlations between the extraction of N, P, and K from the aerial parts of plants and dry matter production.

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