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RENDIMENTO DE ETANOL, PRODUTIVIDADE DA ÁGUA E PRODUTIVIDADE ECONÔMICA DA ÁGUA PARA MILHO E SORGO

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1 RESUMO

O objetivo deste trabalho foi avaliar o efeito da irrigação na produtividade de etanol (PE), produtividade da água (PA) e produtividade econômica da água (PEA) para produção de etanol a partir das culturas de milho e sorgo granífero. O estudo foi realizado em duas safras na área experimental do Colégio Politécnico da UFSM. O delineamento experimental foi um arranjo bifatorial em faixas com blocos ao acaso e quatro repetições. Sendo avaliadas no fator "A", três lâminas de irrigação por aspersão: 0%, 50% e 100% da evapotranspiração de referência (ETo), e no fator "D", cultivares de milho e sorgo granífero. Para a determinação da produtividade das culturas, foram coletadas as plantas de cinco metros lineares. A PE de cada tratamento foi obtida pelo produto da produtividade de grãos pelo rendimento médio de etanol. O milho apresentou incremento de 60,23% e 27,37% na PE quando comparado ao sorgo nas duas safras. O uso da irrigação apresentou diferença significativa, a lâmina de 100% resultou em um incremento de 48,25% e 10,08% para a PE quando comparada com a testemunha e a lâmina de 50% da ETo, respectivamente. A PA e a PEA apresentaram os melhores resultados na lâmina de 50% de reposição hídrica.

Palavras-chave: irrigação, eficiência do uso da água, biocombustível.

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2 ABSTRACT

The objective of this work was to evaluate the effect of irrigation on ethanol yield (EY), water productivity (WP) and economic water for ethanol production from corn and grain sorghum crops. The study was carried out in two growing seasons in the experimental area of Colégio Politécnico da UFSM. The experimental design was a two-factor arrangement in strips with randomized blocks and four replications. In the "A" factor, three sprinkler irrigation levels were evaluated: 0%, 50%, and 100% of the reference evapotranspiration (ETo), and in the "D" factor, maize and grain sorghum cultivars. For the determination of the crop's productivity, the plants of five linear meters were collected. The EY of each treatment was obtained by the product of grain yield by average ethanol yield. Corn presented an increase of 60.23% and 27.37% in EY when compared to sorghum in both growing seasons. The use of irrigation showed a significant difference, the water depth of 100% resulted in an increase of 48.25% and 10.08% for EY when compared to the control and the water depth of 50% of the ETo, respectively. The WP and EWP presented the best results in the 50% water replacement depth.

Keywords: irrigation, water use efficiency, biofuel

3 INTRODUCTION

The global energy matrix is undergoing a process of change; the need to replace the use of fossil fuels with renewable sources has encouraged research and development into various high-performance, low-cost crops, techniques and technologies (ZHANG *et al*., 2016).

An alternative to mitigate environmental impacts and increase the price of fossil fuels while still meeting new energy demands is the use of biofuels, such as ethanol, which stimulate agricultural growth and provide better economic conditions (ECKERT *et al*., 2018; MACEDO *et al*., 2020).

Brazil is the world's second-largest ethanol producer, with corn and sugarcane as its main raw materials (DAR *et al*., 2018). The country's climate favors corn production in more than one annual harvest. Furthermore, the crop has a high yield per planted area and well-established production and postharvest technologies (ECKERT *et al*., 2018).

Sorghum has become an important alternative feedstock for ethanol production. It adapts to a variety of conditions, is tolerant to high temperatures and water excesses or deficits, and has a shorter growing season and water consumption than other crops do. For example, under water scarcity conditions, sorghum tolerates a reduction of up to 25% in crop evapotranspiration, saving water and increasing productivity and ethanol production (AYDINSAKIR *et al*., 2021).

The ethanol yield per ton of grain from corn and sorghum crops ~~has~~ been reported in several studies published in the scientific literature. Works such as those by Gumienna *et al*. (2016), Szambelan *et al*. (2018), Kumar *et al* . (2018), Kurambhatti *et al*. (2018), Kumar *et al.* (2020) and Silva and Castañeda-ayarza (2021) reported that ethanol production from these crops can vary from 310 to 430 $L.ton^{-1}$.

In regions where rainfall quantity and distribution do not meet crop water needs, the use of irrigation as a supplementary water source is a viable alternative to ensure the sustainability of agricultural production systems (GAJIĆ *et al*., 2018). Water waste is common in irrigation due to several factors, such as inadequate management, excessive or restricted water availability, and inadequate runoff control, creating opportunities to improve water efficiency and productivity in this sector (IBIDHI *et al*., 2020).

For efficient management in irrigated agriculture, water productivity and economic water productivity are evaluation elements that enable irrigation qualifications, providing rational use of water resources and lower costs (HAN *et al*., 2018; CETIN; KARA, 2019). Irrigation can reduce producer earnings because of increased costs associated with the water pumping system; therefore, economic water productivity is important in defining technologies that provide water savings in irrigation (CETIN; AKINCI, 2021).

Given the above, the present study aims to evaluate the effects of irrigation on ethanol productivity, water productivity and economic productivity of water for ethanol production from corn and sorghum grain crops.

4 MATERIALS AND METHODS

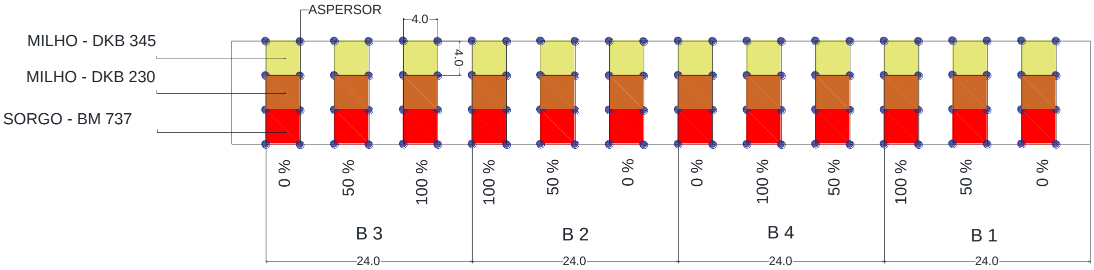
This study was carried out over two harvests, with sowings on December 15, 2019, and December 17, 2020. The grain sorghum cultivar, biomatrix BM 737, and the corn cultivars, DKB345 IPRO3 RR and DKB230 IPRO3, were cultivated with sowing densities of 180,000 and 90,000 plants per hectare, respectively.

The experimental area is located at the Polytechnic College of the Federal University of Santa Maria (UFSM), in the physiographic region of the Central Depression of the state of Rio Grande do Sul - RS, latitude 29° 42' 55.20" S, longitude 53° 44' 22.60" W and altitude of 120 meters. The soil was classified as a typical dystrophic red argisol (EMBRAPA, 2006). The climate is classified according to Köeppen (MORENO, 1961) as type Cfa - humid subtropical, without a dry season and with average temperatures of approximately 16.1 °C in winter and 22.5 °C in summer, with an average annual precipitation of 1,688 mm.

The experimental design was a two-factorial strip arrangement with randomized blocks and four replicates. Factor "A" evaluated the influences of two irrigation depths—50% and 100% of the reference evapotranspiration (ETo) and the control without irrigation—and factor "D" evaluated the responses of the corn and grain sorghum cultivars. Each experimental unit was irrigated by four Agrojet P5 sprinklers, each with a four-meter radius. The applied overlap was 100%. The experimental units were four meters wide and four meters long, totaling an area of 16 ^{m2}.

Figure 1 shows a sketch of the experimental area with the arrangement of crops and sprinklers.

Figure 1. Sketch of the experimental area



Source: Authors (2022).

The soil water infiltration rate was 15 mm h $^{-1}$, and the field capacity and permanent wilting point limits of the soil were 0.30 and 0.16 m ^{3} m $^{-3}$, respectively.

Irrigation management was determined via the water balance method by monitoring meteorological variables and calculating reference evapotranspiration via the Penman–Monteith method. When rainfall occurred between irrigations, effective precipitation was determined via the methodology proposed by Millar (1978), which considers soil textural class parameters, area slope (%), and vegetation cover. For the experimental area, a fraction of water lost 30% of the total precipitation.

A fixed seven-day irrigation schedule was adopted when the actual rainfall did not meet the crop water demand during the period. The irrigation system was calibrated at an application rate of 13 mm h $^{-1}$, as determined by the Christiansen uniformity test (CUC). Different irrigation depths were obtained by varying the water application time, with the irrigation time determined via Equation (1).

$$Ti = \frac{Ln}{Lr\ .\ Ef}\ 100 \qquad (1)$$

where Ti is the irrigation time (h); Ln is the required depth (mm); Lr is the reference depth (mm h $^{-1}$); and Ef is the application efficiency (%).

To determine crop productivity, plants were collected from a five-meter area, threshed, cleaned, weighed, and the moisture content was corrected to 13%. The ethanol productivity for each treatment was calculated by multiplying the grain yield by the average ethanol yield. Thus, an average ethanol yield of 390 L ton $^{-1}$ was adopted (KUMAR *et al*., 2020).

To determine water productivity, a methodology that involves relating the total volume of water applied (effective precipitation + water depth) with the total grain production (Equation 2) was used.

$$PA = \frac{Y}{W} \qquad (2)$$

where PA is the water productivity, (L.ha $^{-1}$.mm $^{-1}$); Y is the crop productivity in liters of ethanol, (L.ha $^{-1}$); and W is the total water depth applied during the crop cycle, (mm).

Furthermore, the economic productivity of water was determined via Equation 3.

$$PEA = \frac{p\ .\ Y}{W} \qquad (3)$$

where PEA is the economic productivity of water (R \$.ha $^{-1}$.mm $^{-1}$) and p is the average price per liter of ethanol (R\$. L $^{-1}$).

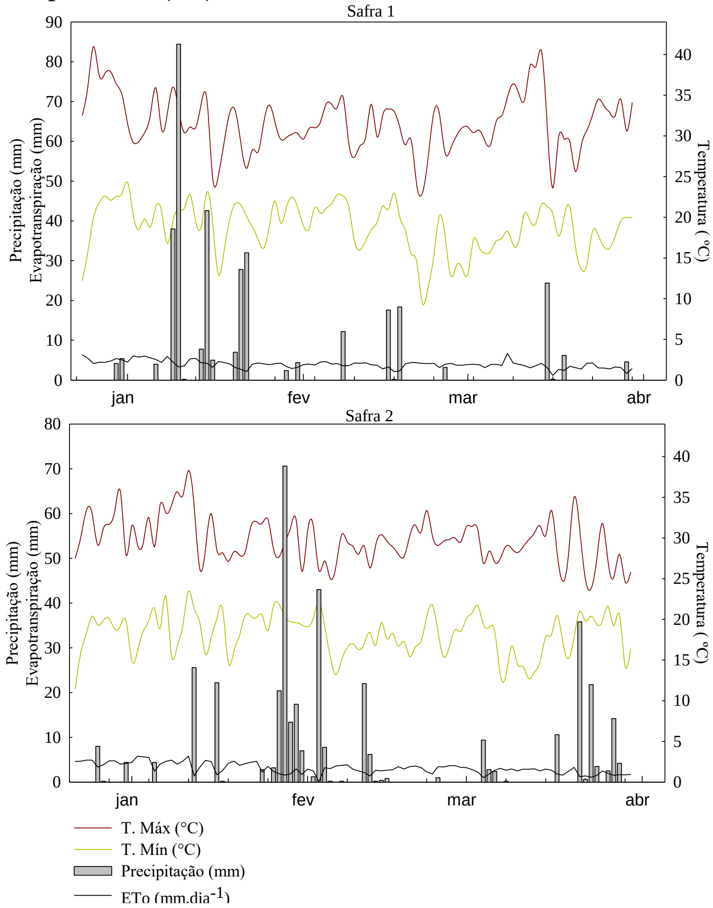
For the ethanol marketing price, the average marketing value for the study period was obtained, which was equal to R\$ 3.00 L $^{-1}$, according to data provided by the Center for Advanced Studies in Applied Economics - CEPEA.

The results were subjected to analysis of variance (ANOVA) at a 5% probability of error level via the Sisvar 5.6 program. If there was interaction between the crop and irrigation depth factors, regression analysis and maximum technical efficiency were performed. In cases of no interaction between the factors, the means were compared via the Tukey test at a 5% probability of error level.

5 RESULTS AND DISCUSSION

Meteorological data on the maximum and minimum temperatures, evapotranspiration and precipitation for the two harvests are shown in Figure 2.

Figure 2. Evapotranspiration (mm), precipitation (mm), maximum temperature (°C) and minimum temperature (°C) for the two harvests evaluated.



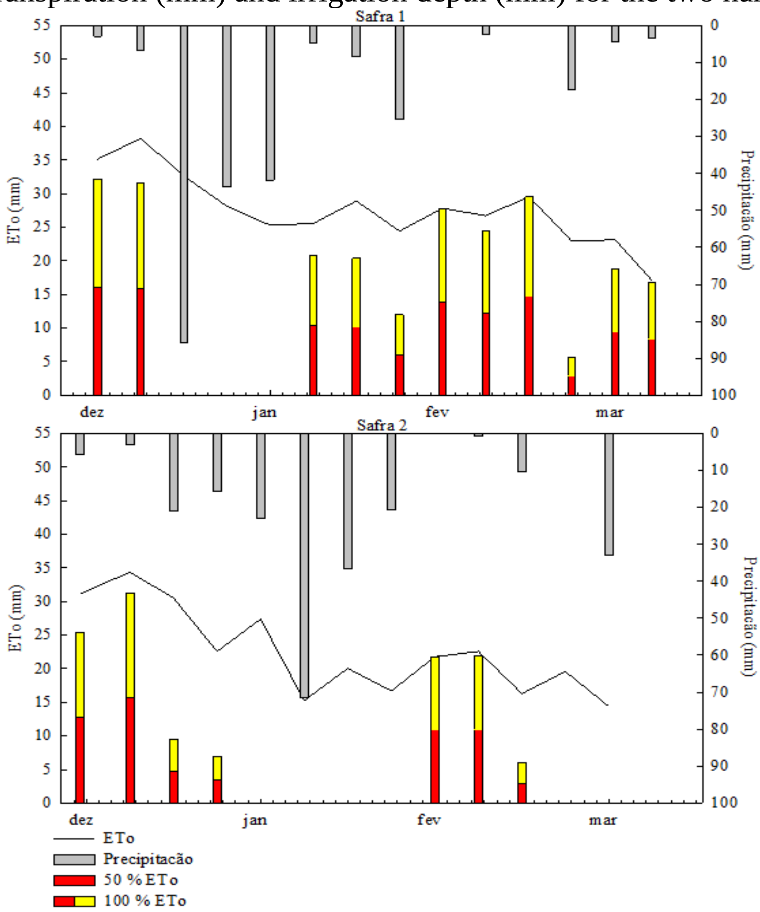
Evaluating the meteorological data for the two harvests revealed that the average maximum and minimum temperatures were 30.65 and 18.75 °C, respectively, for the first harvest and 29.75 and 18.22 °C, respectively, for the second harvest. The ideal temperature for corn development is between 10 and 32 °C (RENATO *et al.*, *2013). For* sorghum, temperatures below 19 °C and above 32.5 °C reduce crop yield (HOFFMAN *et al*., 2020). Therefore, the temperatures observed at both harvests were within the range considered ideal for corn and sorghum.

The accumulated evapotranspiration was 388.43 mm at harvest 1 and 304.60 mm at harvest 2. Values higher than those found at both harvests were reported by Niaghi *et al*. (2019), who, over four years of evaluation, obtained accumulated evapotranspiration values for corn crops in the range of 460 mm--550 mm. Araya *et al*. (2019), corroborating the present study, reported that the evapotranspiration of grain sorghum crops ranged from 336 mm to 469 mm.

Precipitation showed little variation across the years of the experiment. At harvest 1, the accumulated total was 334.2 mm, and at harvest 2, it was 377.8 mm, with the events with the highest volume of precipitation occurring in an accumulated manner in the initial period of crop development, presenting an irregular distribution throughout the cycle and requiring, under these conditions, an irrigation contribution to guarantee production.

In the first harvest, eleven irrigations were required throughout crop development, with total water depths of 228.10 mm and 114.05 mm applied for the treatments with 100% and 50% water replacement, respectively. In the second harvest, seven irrigations with total water depths of 136.40 mm and 68.20 mm were applied for the treatments with 100% and 50% water replacement, respectively, as shown in Figure 3.

Figure 3. Accumulated values every seven days of effective precipitation (mm), evapotranspiration (mm) and irrigation depth (mm) for the two harvests.



Under the conditions of the two years of this study, the irrigation needs were in accordance with those of previous studies. Araya et al. (2017) recommended supplementary irrigation for corn crops of 150 mm, 300 mm, and 450 mm, depending on the water regime of each year: rainy, normal, and dry, respectively. For sorghum grain crops, Araya et al. (2019) reported that a supplementary irrigation volume of 100 to 250 mm is ideal for crop yield.

Analysis of variance revealed no interaction effect between irrigation depth and ethanol-producing crop type at the 5% significance level. However, there were significant differences in ethanol productivity, water productivity, and economic water productivity between the two harvests evaluated, as shown in Table 1.

Table 1. Ethanol productivity (PE, L.ha $^{-1}$), water productivity (PA, L.ha $^{-1}$.mm $^{-1}$) and economic water productivity (PEA, R $.ha $^{-1}$.mm $^{-1)}$ for corn and sorghum grain crops at harvests 1 and 2.

Cultures	HARVEST 1			HARVEST 2		
	FOOT	SHOVEL	PEA	FOOT	SHOVEL	PEA
DKB 345 Corn	5,114.28a*	14.86a	44.59a	4,320.75a	12.78a	38.34a
DKB 230 Corn	4,960.19th	14.35a	43.07a	4,137.31a	12.44a	37.33a
Sorghum BM 737	2,003.05b	5.59b	16.77b	3,071.36b	9.15b	27.46b
**CV (%)	11.18	11.49	11.50	13.09	13.84	13.83

*Means followed by lowercase letters in vertical bars differ significantly from each other at the 5% probability level. **CV = coefficient of variation.

The grain sorghum cultivar BM 737 showed statistically inferior results compared to the two corn cultivars in both years evaluated, with no significant difference between the corn varieties. Corn showed increases of 60.23% and 27.37% in ethanol productivity, 61.72% and 27.44% in water productivity, and 62.17% and 27.42% in economic water productivity at harvests 1 and 2, respectively.

In agreement with the present study, Zhang *et al*. (2018) also reported that, in two harvests, there was no significant difference in ethanol yield for the two corn cultivars evaluated. The results for both corn varieties were statistically equal, with a difference only between the crops. The results of the present study are also in line with the results of Khalaf *et al*. (2019), who reported similar water productivity values for two varieties of sorghum.

Bhattarai *et al*. (2020), when evaluating water productivity in the production of sorghum, millet, and corn for silage, higher values were observed for sorghum under limited irrigation conditions, followed by millet and, finally, corn. In the present study, which aimed at ethanol production, the behavior among the crops was different, with corn presenting the best water productivity.

Table 2 presents the results obtained for ethanol productivity, water productivity and economic water productivity according to the different irrigation depths used.

Table 2. Ethanol productivity (PE, L.ha $^{-1}$), water productivity (PA, L.ha $^{-1}$.mm $^{-1}$) and economic water productivity (PEA, R $.ha $^{-1}$.mm $^{-1}$) for water replacement depths equivalent to 100%, 50% and 0% of the reference evapotranspiration (ETo) at harvests 1 and 2.

Blades (% ETo)	HARVEST 1			HARVEST 2		
	FOOT	SHOVEL	PEA	FOOT	SHOV EL	PEA
0	2,586.24c	11.06b	33.20b	2,713.41c	10.28b	30.85b
50	4,493.82b	12.92nd	38.77a	4,024.41b	12,12a	36,36a
100	4,997.46a	10.82b	32.46b	4,791.59a	11.97a	35.91a
CV (%)	11.18	11.49	11.50	13.09	13.84	13.83

*Means followed by lowercase letters in vertical bars differ significantly from each other at the 5% probability level. **CV = coefficient of variation.

In the first harvest, irrigation use significantly differed among the treatments tested, and the use of 100% water resulted in increases of 48.25% and 10.08% in ethanol productivity compared with the control and the water depth with 50% water replacement, respectively. For PA and PEA, the best results were obtained with a water depth of 50% water replacement. Compared with the control and water depth with 100% water replacement, PA increased by 14.40% and 16.25%, respectively, whereas for PEA, the increases were 14.36% and 16.27%, respectively.

In the second harvest, ethanol productivity showed the same behavior as the first, with productivity increases of 45.42% and 16.02% compared to the control and the 50% water replacement level, respectively. However, for PA and PEA, the difference occurred between the use of irrigation and the rainfed conditions, with similar values between the irrigated treatments. When the irrigated treatments were compared with the nonirrigated treatments, the increase in PA was 14.69%, and for PEA, it was 14.64%.

Aydinsakir et al. reported increased ethanol production. (2021), when comparing full irrigation treatments with nonirrigated treatments, reported an increase in ethanol production of 56.70% in the first year and 37.53% in the second year of the experiment. Pang et al. (2018) and Zhang et al. (2018) also reported increases in ethanol productivity as the frequency of irrigation for sorghum and corn crops increased.

The treatments with water supplementation resulted in the best results for BP, with intermediate irrigation resulting in the highest values. These results are similar to those reported by Bell *et al.* (2018), who, working with grain sorghum, obtained maximum water productivity in treatments with depths of 75% and 100% full irrigation. As in this study, Zou *et al.* In two harvests, (2021) reported that the best water productivity occurred at irrigation depths that met 66% and 77% of the crop's water needs, with the worst levels observed in the treatment with full irrigation (100% water replacement).

The best yield was obtained for blades with 100% water replacement; however, the best PA was observed for blades with 50% water replacement, with a 10% reduction in yield, which is in agreement with the findings of Kothari *et al.* (2020), who reported that deficit irrigation with 20% full irrigation presented the best results for water productivity, even with an 11% decrease in grain yield.

In contrast to the results of the present study, those of Chico *et al.* (2015), when working with sugarcane ethanol production, higher values of water economic productivity were observed in full irrigation treatments. On the other hand, the lower values are in agreement with those in the present study, which were those found for the nonirrigated treatment.

6 CONCLUSION

Compared with the control, the irrigation depth with 100% water replacement resulted in a 46.8% increase in ethanol productivity for the crops.

Water supplementation is necessary for greater ethanol productivity, and the 50% water replacement depth yielded 15.3% greater water productivity and economic productivity than the other depths did. These indicators can help implement efficient irrigation that reduces water use and ensures economic returns.

Compared with sorghum, corn presented the best performance in terms of ethanol yield, water productivity and economic water productivity, with statistically significant differences.

7 ACKNOWLEDGMENTS

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