Different water availability in the economic water productivity in soybean cultivars[1]

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ABSTRACT

The present work aims to evaluate grain productivity, water productivity, and economic water productivity of three soybean cultivars under supplementary irrigation. Two experiments were conducted during the 2018 and 2019 harvests in Santa Maria/RS, Brazil. The experimental design consisted of a random bifactorial block design with six irrigation depths as the first factor and three soybean cultivars (*Glycine max* L.) as the second. The irrigation system used was the conventional fixed sprinkler, with a fixed irrigation shift of seven days. Crop productivity, water productivity, and economic water productivity were evaluated. The highest productivity was for 100% of reference evapotranspiration (ETo) in both harvests. Maximum technical efficiency was obtained for depths of 73.03% (Harvest 1) and 77.94% (Harvest 2) of ETo. Both harvests presented higher water productivity and economic water productivity in the 50% and 25% ETo depths respectively. Productivity is increased with irrigation, and the economic water productivity is maximized with reduction of depth.

Keywords: irrigation; *Glycine max* L; water use efficiency; maximum technical efficiency.

INTRODUCTION

Soybean is the main crop in Brazil's production volume, reaching 124.8 million tons in the 2019/20 harvest with a planted area of 36.9 million hectares (CONAB, 2020). This crop has an important role in the production chain due to its many forms of use, including animal feed, oil, bran, and biodiesel.

Water deficit is the main source of the soybean productivity gap, becoming a significant concern for increasing Brazilian production in current and future climatic conditions (Battisti & Sentelhas, 2017). One of the leading causes for the oscillations in the pluviometric regime is the ENSO phenomenon (El Niño Southern Oscillation), which causes severe problems for Brazilian agriculture, such as floods and droughts, depending on its phase (El Niño or La Niña) (Nóia Júnior & Sentelhas, 2019).

When this pluviometric regime does not meet the crop's total demands, both quantitatively and temporally, it is necessary to use water supplementation as an alternative to seeking greater productivity (Gajić *et al.*, 2018). A major challenge still facing soybean producers is how much and when to irrigate. Therefore, the relationship between crop productivity and irrigation water applied in conjunction with knowledge of the region's pluviometric demands and crop deficits can efficiently answer these questions (Zhang *et al.*,

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2018). According to Battisti *et al.* (2018), irrigation increases soybean productivity in different climatic scenarios.

However, many factors define the development, growth, and productive potential of the crop, being influenced by genetic (the type of growth, relative maturity group, and presence of the juvenile gene) and climatic factors (photoperiod, solar radiation, temperature, and water availability) and management (sowing time and soil physicochemical characteristics) (Pires *et al.*, 2005; Zanon *et al.*, 2016).

According to Ribeiro *et al.* (2017), crop productivity can vary widely depending on the cultivar chosen and the region of study. These authors also state that there is no difference in the soybean yield components for the sowing densities of 300 to 600 thousand plants per hectare. With a lack of answers when comparing soybean cultivars according to water availability, it is important that restrictive factors, such as irrigation, field management, soil, and climate conditions, be considered in addition to selecting the best cultivars in each year of cultivation (Araji *et al.*, 2018).

Montoya *et al.* (2017) report that supplementary irrigation in soybean crops provided an increase in grain productivity, maximizing yield and profit margin. Adeboye *et al.* (2015) found that irrigation with total water replacement showed a better response when evaluating the economic productivity of water in soybean crops submitted to water deficits at different development stages. Additionally, Tewelde (2019) reports the importance of obtaining economic water productivity to deduct the farmers' gains concerning water consumption. Thus, evaluating irrigation management and its increases in crop yield shows the importance of water productivity in the management of irrigated agriculture (Kirchner *et al.*, 2019).

Management alternatives aimed at higher yields, with correct management of water resources are essential for the soybean production chain. Therefore, the efficiency of water application per crop area makes production sustainable, economical and consequently more profitable.

Given the above, the present work aims to evaluate grain productivity, water productivity, and economic water productivity of three soybean cultivars under supplementary irrigation.

MATERIAL AND METHODS

The experiment was conducted during the 2018 (Harvest 1) and 2019 (Harvest 2) harvests in an experimental area belonging to the Colégio Politécnico da UFSM, located in Santa Maria-RS, Brazil. The experimental area coordinates are 29°42'55.7"S 53°44'21.4"W, and an altitude of 120 m. According to the Köppen-Geiger classification, the region's climate is type Cfa (humid subtropical climate), with well-defined seasons (Alvares *et al.*, 2013).

According to INMET, the average annual precipitation in the region ranges from 1450 to 1650 mm with an average temperature of 18-20 °C. In this region, the distribution of rainfall during the summer is usually irregular and may not be sufficient to meet the water needs in certain periods of the crop cycle (Nied *et al.*, 2005). The soil of the experimental area is classified as 'Argissolo Vermelho Distrófico Típico' (Santos *et al.*, 2018).

Chemical and physical soil analyzes were performed in the area. The collection of soil samples for chemical soil analysis was conducted according to Arruda *et al.* (2014). The samples were analyzed at the Soil Analysis Laboratory of the Universidade Federal de Santa Maria (UFSM), where the macro and micronutrient soil requirements were determined.

Soil chemical analysis showed the following results: potential of hydrogen (pH) of 5.6, 8.1 $\text{cmol}_c\ \text{dm}^{-3}$ of calcium (Ca), 3.3 $\text{cmol}_c\ \text{dm}^{-3}$ of magnesium (Mg), 0.0 $\text{cmol}_c\ \text{dm}^{-3}$ of aluminium (Al), effective cation exchange capacity (CEC) of 11.7 $\text{cmol}_c\ \text{dm}^{-3}$, CEC at pH7 of 15.2 $\text{cmol}_c\ \text{dm}^{-3}$, base saturation of 77%, soil matric potential (SMP) index of 6.2, 2.3% of organic matter, 28% of clay, 9.7 mg dm^{-3} of phosphorus (P) (Mehlich) and 96 mg dm^{-3} of potassium (K) (Mehlich).

Fertilization was performed after chemical analysis in the quantities recommended by the Comissão de Química e Fertilidade do Solo do RS/SC (2016). The physical soil analyzes were performed at the Soil Analysis Laboratory of UFSM (Table 1).

The experiment site's meteorological data were obtained through the National Institute of Meteorology's automatic meteorological station, located at UFSM, situated approximately 2 km of the area. The data collected daily were maximum and minimum temperatures (ºC), relative humidity (%), wind speed (m s^{-1}), and solar radiation (kJ m^{-2}). Already the precipitation (mm) was collected in the experimental area using rain gauges.

Sowing for Harvests 1 and 2 was done on 12/14/2017 and 11/23/2018. The experimental design consisted of a random bifactorial block design, with four blocks, being six irrigation depths (L factor) and three soybean cultivars (*Glycine max* L., C factor), totaling 72 experimental units (UE). Each UE has dimensions of 4 x 4 m (16 m^2), this area was considered a useful area of 12.25 m^2. Between each UE there was a space of 4 meters, so that in the application of irrigation there was no overlapping of depths.

Thirty days before sowing, the herbicide glyphosate was applied at a dose of 3 L ha^{-1}. The fertilization was carried out at sowing, applying 380 kg ha^{-1} in the commercial formulation 5-20-20, of nitrogen (N), phosphorus (P_2O_5) and potassium (K_2O).

Two fungicide applications were carried out (0.5 L ha^{-1}), in a preventive manner, active ingredients bixafen (125 g L^{-1}), trifloxystrobin (150 g L^{-1}) and prothioconazole (175 g L^{-1}). Two applications of insecticide (0.75 L ha^{-1}), imidacloprid (100 g L^{-1}) and beta-cyfluthrin (12.5 g L^{-1}) were also carried out. The L factor was 0%, 25%, 50%, 75%, 100%, and 125% of the reference evapotranspiration and the C factor the cultivars NS 6909 PRO RR, BRASMAX Ponta IPRO 7166 RSF, and BRASMAX Valente RR 6968 RSF. The three cultivars have an indeterminate growth habit and medium cycle.

A fixed conventional sprinkler irrigation system was used for the irrigation management, consisting of the mainline of 92 meters and 24 lateral lines of 24 meters. The spacing between the lateral lines was 4 m. The sprinklers Agrojet, P5 model, were distributed on the lateral lines with a 4 m spacing and installed on an elevation of 1.5 m in height (Figure 1).

Table 1: Hydro-physical characteristics of the soil in the experimental area

Soil Profundity (m)	Soil Density (g cm^{-3})	Soil Field Capacity (m^3 m^{-3})	Permanent Wilt Point (m^3 m^{-3})	Basic Infiltration Speed (mm h^{-1})	Soil Texture
0-0.2	1.42	0.31	0.14	15	Loam
0.2-0.4	1.38	0.34	0.17		Clay loam
0.4-0.6	1.36	0.37	0.23		Clay

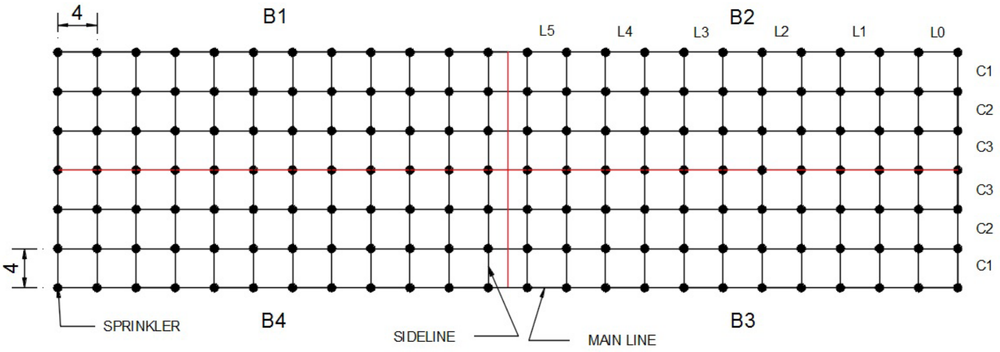


Figure 1: Sketch of the experimental area.

Christiansen's Uniformity Coefficient test (CUC) was used to verify the irrigation uniformity and calibrate the system's irrigation rate (mm h^{-1}). The irrigation uniformity was 82%, and the system's application rate was 11.5 mm h^{-1}.

Irrigation was conducted with a fixed shift of seven days between irrigations when there was no precipitation to supply the crop's water demand of the crop in the period and was started soon after its emergence. Irrigation management was based on reference evapotranspiration (ETo), calculated using the Penman-Monteith-FAO equation (Allen *et al.*, 1998).

The need for irrigation was determined according to Equation 1:

$$NI = ETo - P_{ef} \tag{1}$$

where *NI* – is the irrigation requirements (mm), *ETo* – is the reference evapotranspiration for seven days (mm), and P_{ef} – is the effective precipitation (mm).

According to Millar (1978), the effective precipitation was determined, which considers the parameters of the textural class of the soil, declivity (%), and vegetation cover. The fraction of precipitation lost by runoff considered was 30% of the total precipitate for the place where the work was conducted.

The irrigation depths were applied for the irrigation times, according to Equation 2:

$$IT = \frac{Ln}{Lr\ .Ua}.100 \tag{2}$$

where IT – is the irrigation time (h); L_n – is the required depth (mm); Lr – is the reference depth (mm h^{-1}); and U_a – is the application uniformity (%).

Plants from a 4.5 m² usable area were collected at the end of the crop cycle and subsequently traced, cleaned of impurities, weighed, and the humidity was corrected to 13%.

Water productivity was determined using the methodology described by Adeboye *et al.* (2015), which consists of relating the total volume of water applied (effective precipitation + water depth) to the total grain production (Equation 3).

$$WP = \frac{Y}{W} \tag{3}$$

where WP – is the water productivity (kg ha^{-1} mm^{-1}), Y – is the crop productivity (kg ha^{-1}), and W – is the total water depth applied during the crop cycle (mm).

Furthermore, the economic productivity of the water was determined through Equation 4.

$$EWP = \frac{p.Y}{W} \tag{4}$$

where EWP – is the economic water productivity (US\$ ha^{-1} mm^{-1}), and p – is the average grain price (US\$ kg^{-1}), Y – is the crop productivity (kg ha^{-1}), and W – is the total water depth applied during the crop cycle (mm).

Soybean commercialization price was determined using the averages for the state of Rio Grande do Sul in April of 2018 and 2019, following the harvesting, with values of R$ 74.18 and R$ 68.18 per bag, respectively. Prices were converted into dollars and during this period the average quotation was R$ 3.64.

The results were subjected to analysis of variance (ANOVA) at the 5% error probability level using the Sisvar program 5.6. Regression analysis and maximum technical efficiency were performed when there was an interaction between the cultivar factors and irrigation depths. When there was no interaction, the means were compared by the Tukey test for qualitative data (soybean cultivars) and regression analysis and maximum technical efficiency for quantitative data (irrigation depths). The regression analysis was performed using the SigmaPlot 11.0 software.

RESULTS AND DISCUSSION

Figure 2 shows the average maximum and minimum temperatures, effective precipitation, and daily evapotranspiration for Harvests 1 and 2. The average daily air temperature fluctuated between 15 ºC and 32 °C for the studied harvests. There were no significant differences for both the maximum average temperature and the minimum average temperature, considering that the appropriate thermal conditions for the growth and development of soybeans are between 20 and 30 °C (Battisti & Sentelhas, 2014).

The effective precipitation showed approximate values for both harvest years, with 369.18 mm and 374.55 mm for Harvests 1 and 2, respectively. These values were insufficient to supply the crop requirements, demanding an irrigation input to ensure production. According to Grassini *et al.* (2015), soybean crops require 450 to 700 mm of water to supply their water needs. For the southern region of Brazil, studies indicate that a water supply of approximately 800 mm (Zanon *et al.*, 2016) and between 765 and 875 mm (Tagliapietra *et al.*, 2021) are enough to maximize soybean productivity. The evapotranspiration values during the entire crop cycle in Harvests 1 and 2 were 336.60 and 315.76 mm, respectively. Bariviera *et al.* (2020) obtained evapotranspiration of 267.06 mm and precipitation of 922.28 mm with 62 precipitation events throughout the crop cycle when studying irrigated soybean crops in the 2015/16 harvest, in Mato Grosso state, which justifies the difference in evapotranspiration demand observed in the present study.

During the development of the crop, seven (Harvest 1) and six (Harvest 2) irrigations were required (Figure 3). The irrigations for each treatment of Harvest 1 totaled 30.28, 60.56, 90.84, 121.12, and 151.40 mm for depths of 25%, 50%, 75%, 100%, and 125% of ETo, respectively. The irrigation depths for each treatment of Harvest 2 were 30.17, 60.34, 90.51, 120.68, and 150.85 mm for 25%, 50%, 75%, 100%, and 125% of ETo, respectively.

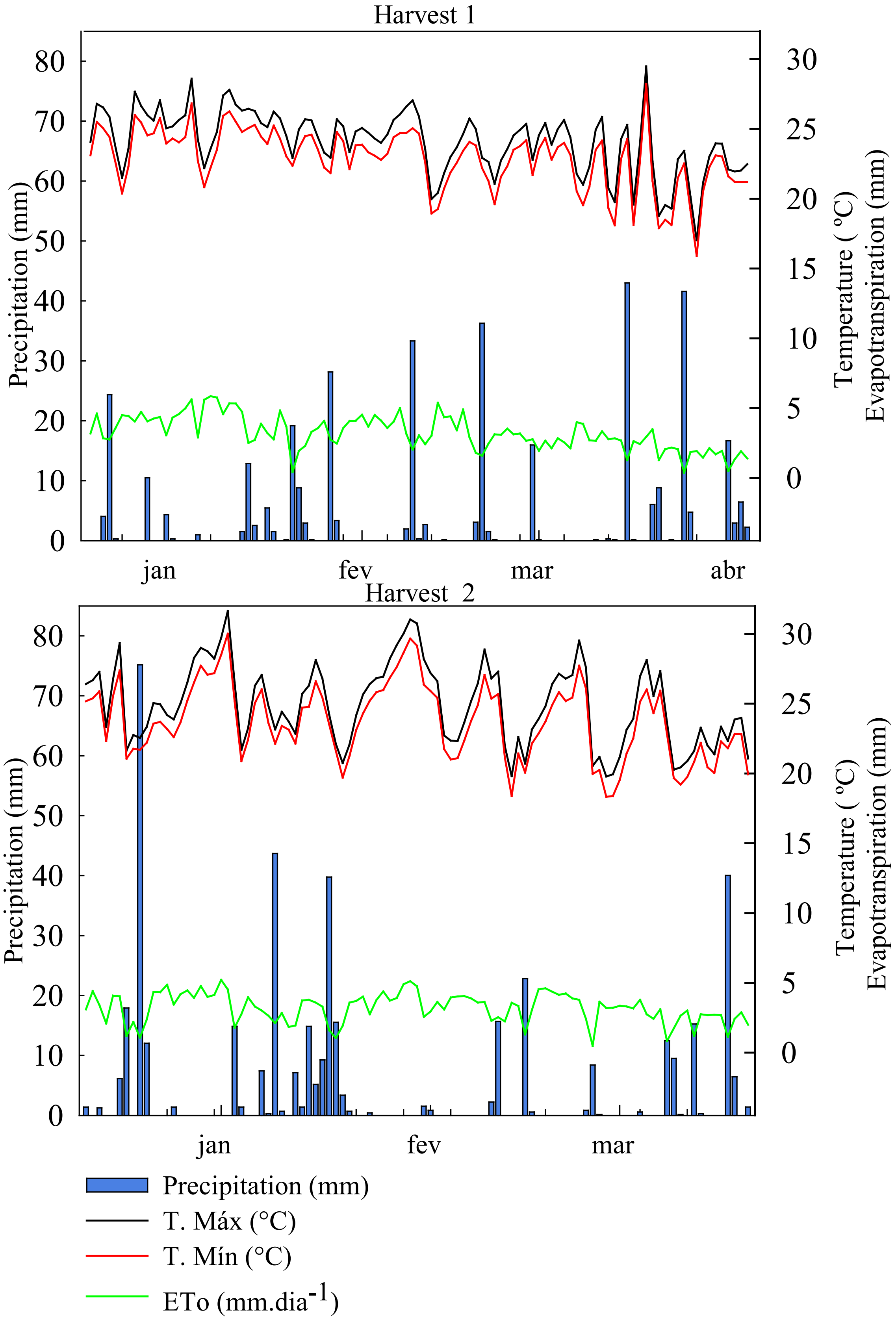


Figure 2: Maximum and minimum temperature (°C), precipitation (mm), and evapotranspiration (mm) data for both analyzed harvests.

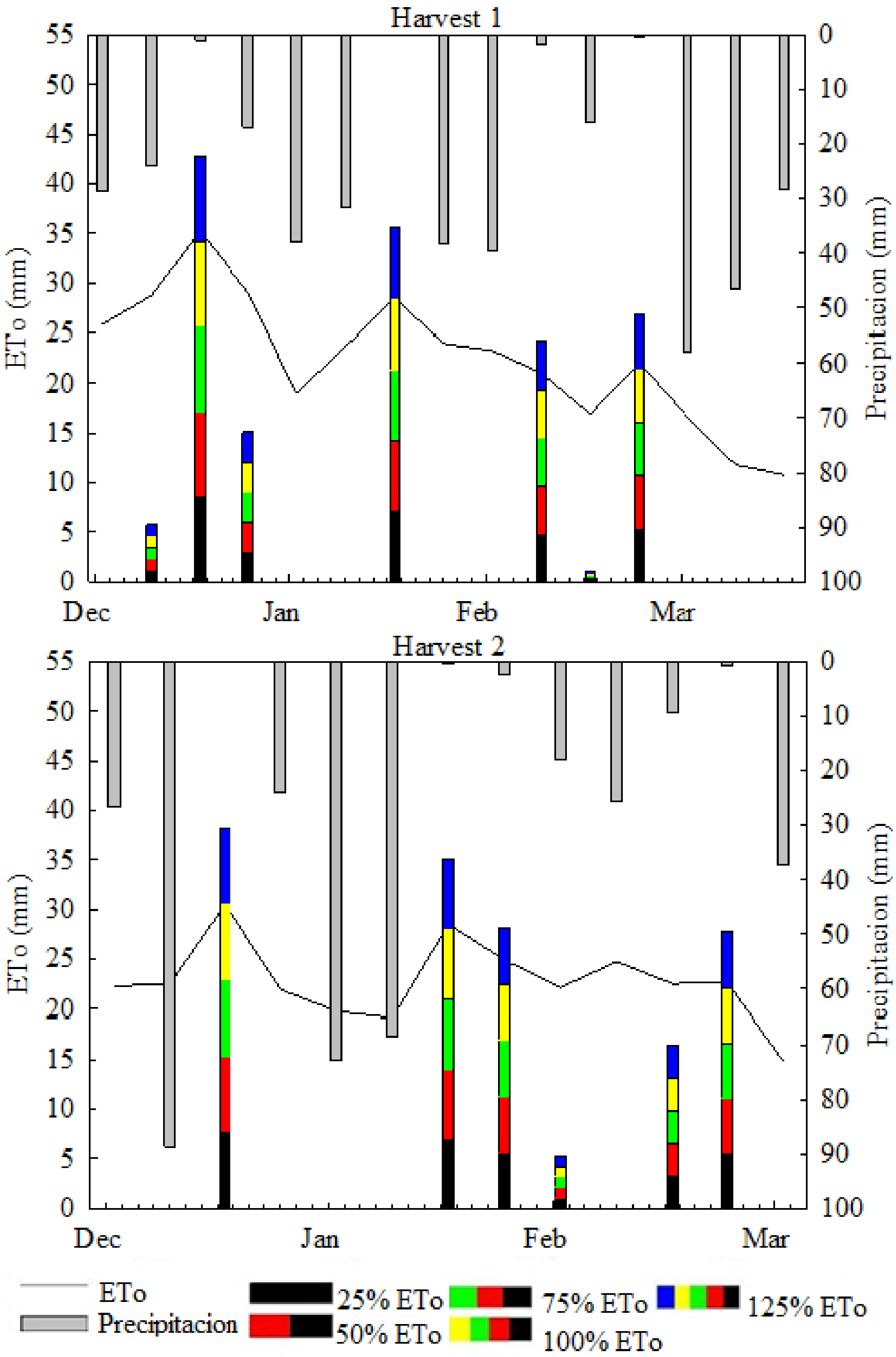


Figure 3: Precipitation (mm), evapotranspiration (mm), and irrigation depth (mm) accumulated for both crop cycles with an interval of seven days.

The analysis of variance showed no interaction between the depth and cultivar factors at the 5% level of significance for the soybean crop productivity. However, the cultivars showed a statistical difference for productivity, water productivity, and economic water productivity in both crops studied (Table 2).

Table 2: Crop productivity (kg ha^{-1}), water productivity (WP) (kg ha^{-1} mm^{-1}), and economic water productivity (EWP) (US$ ha^{-1} mm^{-1}) in the different soybean cultivars in Harvests 1 and 2

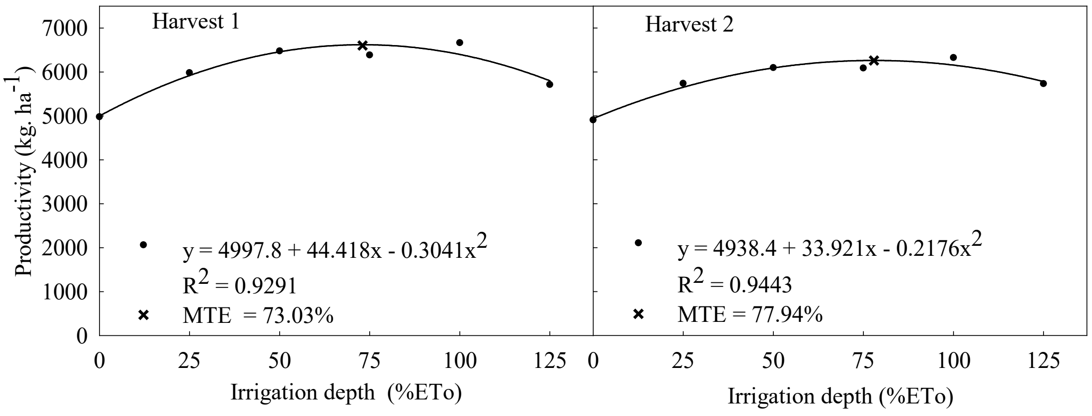
Cultivars	**Productivity**		**WP**		**EWP**	
	Harvest 1	**Harvest 2**	**Harvest 1**	**Harvest 2**	**Harvest 1**	**Harvest 2**
NS 6909	5,715.41b*	5,395.36b	12.92b	12.08b	4.21b	3.77b
BMX Ponta	5,990.72ab	5,916.43a	13.59ab	13.24a	4.43ab	4.13a
BMX Valente	6,389.23a	6,123.94a	14.47a	13.70a	4.72a	4.28a
**CV (%)	12.27	10.27	12.71	11.25	12.71	11.25

*Mean followed by lowercase letters different in the vertical significantly differ at a 5% level of error of probability. **CV = coefficient of variation.

Cultivar BMX Valente presented the highest productivity, water productivity, and economic water productivity values in both harvest years, with no significant difference cultivar BMX Ponta, while cultivar NS 6909 showed the lowest results. Santos *et al.* (2019) found that the cultivars showed a significant difference at the level of 1% error probability for grain production when evaluating the productivity and water productivity of different soybean cultivars, corroborating the results of the present study.

The three cultivars studied responded equally to irrigation, unlike in the study conducted by Gava *et al.* (2017), who found that some genotypes do not respond to irrigation depending on each cultivar's genetic characteristics when evaluating irrigated and non-irrigated soybean cultivars.

According to Kukal & Irmak (2020), irrigation has become a fundamental agricultural production tool, reducing crops' annual variability due to climatic variations and efficient water resource use. Soybean productivity in both harvests responded positively to the amount of water supplied, showing a very similar behavior in both situations studied (Figure 4). This is in agreement with a study conducted by Montoya *et al.* (2017) in Salto, Uruguay, where the authors found that the soybean crop development was similar in both years regarding the total crop cycle and accumulated thermal time.



MTE = maximum technical efficiency

Figure 4: Average productivity of the soybean crop in function of the irrigation depths of Harvests 1 and 2.

The maximum technical efficiency for the irrigation depths in Harvest 1 was reached at 73.03% of ETo, providing a productivity of 6,602.92 kg ha^{-1}. In Harvest 2, the maximum technical efficiency was achieved with 77.94% of ETo, which produced 6,260.36 kg ha^{-1}. The productivity of irrigated soybeans ranged from 4,978.45 kg ha^{-1} to 6,661.96 kg ha^{-1} in Harvest 1, and 4,903.75 kg ha^{-1} to 6,324.44 kg ha^{-1} in Harvest 2, with little difference between harvests.

The increase in soybean crop productivity with irrigation depths of 25%, 50%, 75%, 100%, and 125% of ETo compared to productivity without irrigation, presenting values of 20.13%, 30.09%, 28.22%, 33.82%, and 14.69% for Harvest 1 and 16.95%, 24.29%, 24.08%, 28.97%, and 16.82% for Harvest 2. Montoya *et al.* (2017) reported that supplementary irrigation in the soybean crop provided an increase in grain productivity, after two experimental harvests, with grain yield values up to 35% higher than the non-irrigated experiment. The author also reports that, during both seasons studied, the maximum grain yield values were reached at 75% of crop evapotranspiration (ETc), which is similar to the maximum technical efficiency found in the present study.

The production functions were adjusted to a second-degree polynomial model, with a coefficient of determination inferior to 0.91. The productivity averages with the lowest values were obtained in the control, with 4,978.45 kg ha^{-1} (Harvest 1) and 4,903.75 kg ha^{-1} (Harvest 2). The highest values of 6,661.96 kg ha^{-1} and 6,324.44 kg ha^{-1} of productivity were found with the depth of 100% ETo for Harvests 1 and 2, respectively. There was an increase of 33.82% and 28.97% between the control and the depth of 100% of ETo.

Gajić *et al.* (2018) observed an increase of 42% in the treatment that obtained the highest productivity than the non-irrigated treatment. Panday *et al.* (2018) observed an increase in productivity of 27% when comparing irrigated and non-irrigated treatments. Candoğan & Yazgan (2016) report that the highest grain yield was obtained in treatments with total irrigation, presenting an average gain of 50.6% compared to the precipitation treatment.

Gava *et al.* (2018) observed that supplementary irrigation contributes to higher productivity in intermediate cycle cultivars than in super early cycle cultivars. The three cultivars evaluated in this study are of the intermediate cycle and corroborate that irrigation contributed to the increase in productivity since crop yield increased from the 25% ETo depth.

Despite the increase in productivity with the depth of 100% in both harvests, water productivity showed the best values at depths of 50% and 25% with productivity of 15.07 and 14.17 kg ha^{-1} mm^{-1} for Harvest 1 and 2, respectively. Consequently, the highest economic water productivity was obtained on the same irrigation depths (Table 3).

These results are similar with those found by Candogan *et al.* (2013), who observed the highest water productivity values for 25% of ETc. However, the authors report that this irrigation strategy can cause a 27.5% reduction in grain yield, differing from this study where reduction in the productivity of was 2.78% (Harvest 1) and 9.32% (Harvest 2). This information can facilitate decision-making when choosing the type of irrigation to provide greater water availability for an increase in productivity or smaller depths when there is water scarcity in a reservoir or for water cost savings (Candogan *et al.*, 2013; Çetin & Kara, 2019).

Table 3: Crop productivity (kg ha^{-1}), water productivity (WP) (kg ha^{-1} mm^{-1}), and economic water productivity (EWP) (US$ ha^{-1} mm^{-1}) in the different irrigation depths (%ETo)

Irrigation Depths	Harvest 1			Harvest 2		
	Productivity	**WP**	**EWP**	**Productivity**	**WP**	**EWP**
0	4,978.45	13.49	4.58	4,737.08	12.65	4.09
25	5,980.44	14.97	5.08	5,734.93	14.17	4.42
50	6,476.67	15.07	5.12	6,094.98	14.02	4.38
75	6,383.53	13.88	4.71	5,984.61	12.87	4.08
100	6,661.96	13.59	4.61	6,074.44	12.27	3.99
125	5,709.65	10.97	3.72	5,745.42	10.94	3.40

Different results were found by Panday *et al.* (2018) when comparing soybean productivity in dryland (600 mm precipitation) and irrigated, finding higher average water productivity values for the treatment that received supplementary irrigation. Adeboye *et al.* (2015) also found a increase in water productivity in full irrigation treatment. In contrast, Gajić *et al.* (2018) obtained a water productivity value in the non-irrigated treatment 10% higher than in the treatment of 100% water replacement.

Montoya *et al.* (2017) found higher water productivity in treatments with less water availability and the lowest result for full water replacement based on the culture's evapotranspiration, which corroborated the findings of this study. The irrigation depth of 125% of ETo presented the lowest average value of water productivity, reaffirming that water availability above the crop's evapotranspiration demand reduces the system's productive efficiency.

The economic water productivity values ranged between 3.72 and 5.12 US\$ ha^{-1} mm^{-1} for Harvest 1 and 3.40 and 4.42 US\$ ha^{-1} mm^{-1} for the Harvest 2. The lowest values were obtained for the depth of 125% of ETo and the highest values for the depth of 50% (Harvest 1) and 25% (Harvest 2) of ETo, corresponding to an increase of 27.34% and 23.08% in relation to the lowest values of economic water productivity.

A similar behavior was obtained by Uygan *et al.* (2021) reporting values higher than those found in this study, reaching an increase of up to 70% at the lowest irrigation depth. Sahoo *et al.* (2018), working with different irrigation methods obtained an economic water productivity was 20.9% higher in drip than furrow irrigation.

The average price of soybeans in Rio Grande do Sul for April 2018 (Harvest 1) was US\$ 20.38 per bag and US\$ 18.73 for Harvest 2 in April 2019. This economic gain increases proportionally to the price of soybean. Noellemeyer *et al.* (2013) found low economic water productivity values for soybean, which reflected a low grain yield that does not counterbalance a high market cost.

Unlike what was found in this study, Adeboye *et al.* (2015) observed higher economic water productivity in the treatment with full irrigation than treatments that underwent water deficit in different phenological stages. Ben *et al.* (2017) report that the use of the lowest amount of irrigation provided the highest economic water productivity for rice crops and that this calculation shows the irrigation condition that makes production economically more efficient, as the volume of water is low enough to allow economic production, corroborating the results found in this study.

Although the 100% ETo irrigation depth provides a higher increase in soybean productivity for both studied harvests, in similar years when the rainfall regime is not scarce, one can opt for a lower water supplementation to obtain greater irrigation water productivity cost.

CONCLUSION

Supplementary irrigation provided an increase in grain yield for both crops, presenting a maximum technical efficiency of 73.03% and 77.94% of ETo for the irrigation depths. Water productivity demonstrated that better efficiency in water resources could be obtained for lower values of irrigation, minimizing the amount of water used in this process. Economic water productivity could assist in the decision-making of how much to irrigate to reduce production costs and ensure an economic return, even when higher soybean productivity is not achieved.

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