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Economic indicators for ethanol production from starch crops under different irrigation managements[1]

Indicadores econômicos para produção de etanol proveniente de culturas amiláceas sob diferentes manejos de irrigação

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HIGHLIGHTS:

The market value of ethanol influences its production viability.
Full irrigation (100% of ETo) reduces the unit cost of ethanol production.
The scenarios are favorable for maize and grain sorghum in ethanol production, with selling prices above R$ 2.50 L^{-1}.

ABSTRACT: The study aims to quantify the production costs of maize and sorghum crops under rainfed and irrigated conditions for the generation of ethanol and to evaluate the economic feasibility in different scenarios of marketing price. Two experiments were carried out in the years 2019/2020 and 2020/2021, in an experimental area at the Federal University of Santa Maria, Santa Maria, RS, Brazil. The experiment was in strip plots, in a randomized block design and four replicates. Three irrigation depths, 0, 50 and 100% of the reference evapotranspiration (ETo), as first factor, and two maize cultivars and one grain sorghum cultivar as second factor, using 45 scenarios. The use of full irrigation (100% of ETo) reduces the production costs of the liter of ethanol by 15 and 17.89% and increases ethanol production by 44.18 and 48.25% for maize and grain sorghum crops, respectively. For the market price of R$ 2.00 L^{-1}, the grain sorghum does not show good performance, with negative net present value (NPV) and internal rate of return (IRR). The sale price of R$ 4.00 L^{-1} and full irrigation is the best economic scenario, with values of NPV of R$ 90,356.93, IRR of 33.83%, benefit/cost ratio (B/C) of 2.28, profitability index (PI) of 3.99 and payback of three years. Maize is economically viable for ethanol production in all scenarios. Full irrigation and market price of R$ 4.00 L^{-1} represent the best economic scenario, with mean values for NPV of R$ 204,381.68, IRR of 63.35%, B/C of 2.96, PI of 8.67 and payback of 1.58 years, among the cultivars.

Key words: grain sorghum, maize, economic viability, water management, biofuel

RESUMO: O estudo visa quantificar os custos de produção das culturas de milho e sorgo em condições de sequeiro e irrigado para a geração de etanol, e avaliar a viabilidade econômica em diferentes cenários de preço de comercialização. Foram realizados dois experimentos nos anos de 2019/2020 e 2020/2021, em área experimental da Universidade Federal de Santa Maria, Santa Maria, RS. O delineamento experimental foi em faixas, com blocos ao acaso e quatro repetições. Foram avaliadas três lâminas de irrigação: 0, 50 e 100% da evapotranspiração de referência (ETo) como o primeiro fator, e duas cultivares de milho e uma de sorgo granífero como o segundo fator, sendo utilizados 45 cenários. O uso da irrigação plena (100% de ETo) reduz os custos de produção do litro de etanol em 15 e 17,89% e aumenta a produção de etanol em 44,18 e 48,25% para as culturas de milho e sorgo, respectivamente. Para o preço de mercado de R$ 2,00 L^{-1}, o sorgo granífero não apresenta bom desempenho, com valor presente líquido (NPV) e taxa interna de retorno (IRR) negativos. O preço de venda de R$ 4,00 L^{-1} e irrigação plena é o melhor cenário econômico, com valores de NPV de R$ 90.356,93, IRR de 33,83%, relação benefício/custo (B/C) de 2,28, índice de rentabilidade (PI) de 3,99 e payback de três anos. O milho é economicamente viável para a produção de etanol em todos os cenários, sendo a irrigação plena e preço de comercialização de R$ 4,00 L^{-1}, o que apresentou o melhor cenário econômico, com valores médios para o NPV de R$ 204.381,68, IRR de 63,35%, B/C de 2,96, IR 8,67 e payback de 1,58 anos, entre as cultivares.

Palavras-chave: sorgo granífero, milho, viabilidade econômica, manejo de água, biocombustível

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Introduction

Currently, ethanol is the main alternative to replace fossil fuels (Persson et al., 2020), and in Brazil sugarcane is the main raw material used. However, alternative crops have been gaining space, especially maize (Szambelan et al., 2018). The use of grain sorghum for ethanol production in Brazil is still limited, but the production process is similar to that of maize (Menezes et al., 2021). And due to its performance under water restrictions, sorghum is on the rise in other regions (Kothari et al., 2019).

Irrigated agriculture is the main consumer of water in the world. However, without the use of this technology, the demands for food and biofuels would hardly be achieved due to the impact of climate change on production (Asseng et al., 2018; Davarpanah & Ahmadi, 2021; Ding et al., 2021). Water requirement for maize and sorghum crops is 660 mm (Zhang et al., 2019) and 460 mm (Araya et al., 2018), respectively. In localities where effective rainfall is lower, the use of irrigation is important to meet crop water demand (Comas et al., 2019).

Furlaneto & Esperancini (2010) highlight that to estimate the production costs of an agricultural activity, it is necessary to use some economic indicators, the main ones being net revenue, profitability index, net operating revenue and rate of return. For Sesmero et al. (2012), the economic viability of maize ethanol production involves the technical and financial efficiency of industries, prices of raw material, ethanol and public policies. Stamenković et al. (2020) highlight the various possibilities of obtaining sorghum ethanol and emphasize the importance of further research to improve processes.

The study aims to quantify the production costs of maize and sorghum crops under rainfed and irrigated conditions for the generation of ethanol and to evaluate the economic feasibility in different scenarios of product marketing price.

Material and Methods

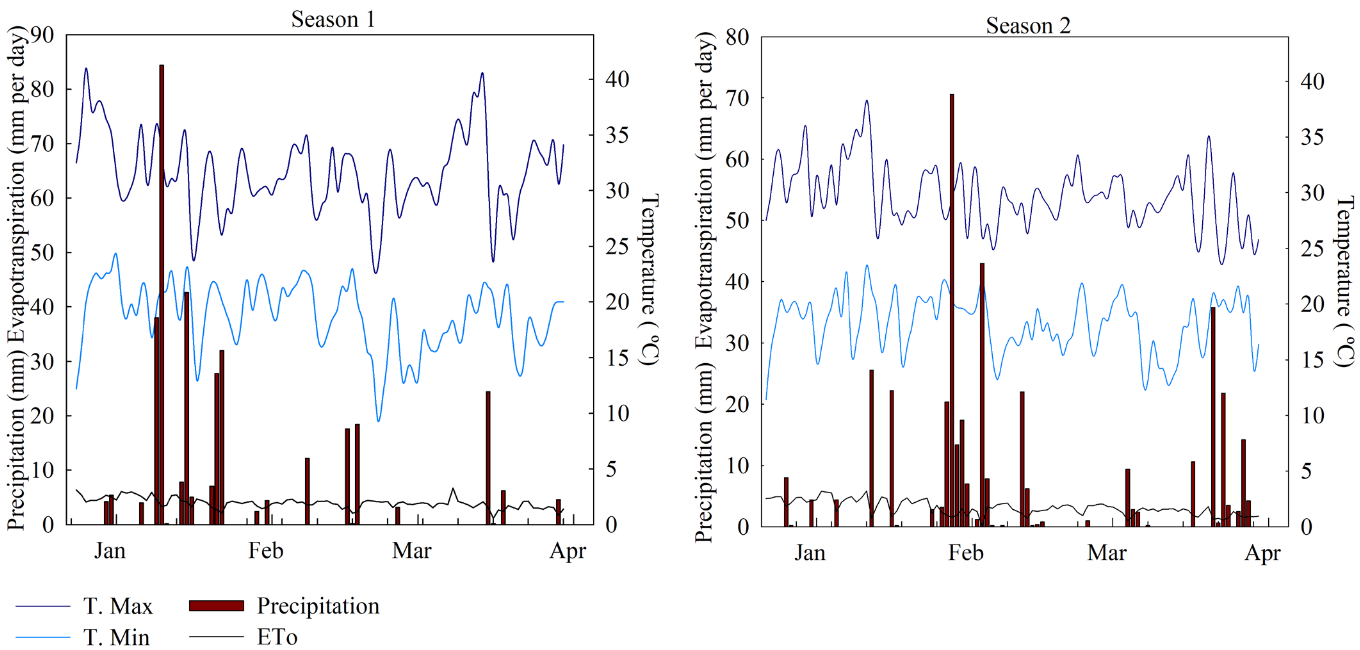
The present study was conducted in 2019/2020 (crop season 1) and 2020/2021 (crop season 2), with sowing carried out on December 15, 2019, and on December 17, 2020, respectively. The maize cultivars DKB345 IPRO3 RR and DKB230 IPRO3, and the sorghum cultivar biomatrix BM 737 were cultivated with sowing densities of 90,000 and 180,000 plants ha^{-1}, respectively.

The experimental area, with 3000 m^2, is located in the Polytechnic School of UFSM, in the physiographic region of the Central Depression of Rio Grande do Sul state, RS, Brazil, at 29° 42' 55.20" S latitude, 53° 44' 22.60" W longitude and altitude of 120 m. The soil is classified as Ultisol.

The climate of the region, according to the classification of Köppen (Moreno, 1961) is Cfa – humid subtropical, without dry season and with average temperatures of 16.1 °C in the winter and 22.5 °C in the summer, with average annual rainfall of 1,688 mm distributed throughout the year. Figure 1 shows the average maximum and minimum temperatures, effective precipitation, and daily evapotranspiration for crop seasons 1 and 2.

The experiment was arranged in strip plots, in a randomized block design and four replicates. The influence of two irrigation depths (50 and 100% of the reference evapotranspiration - ETo) and the control without irrigation were evaluated as first factor and the responses of maize and grain sorghum cultivars were evaluated as second factor. The experimental plots were 4 m wide and 4 m long, totaling an area of 16 m^2 and were irrigated by four sprinklers with 100% overlap within the plot for better uniformity of water application. Each experimental plot was spaced 4 m apart to avoid interference between treatments.

Soil water infiltration rate was determined by the double-ring infiltrometer method and was equal to 15 mm h^{-1}. The limits of field capacity and permanent wilting point of the soil were 0.30 and 0.16 m^3 m^{-3}, respectively. Soil chemical analysis



Season 1 - 2019/2020; Season 2 - 2020/2021

Figure 1. Maximum (T.Max) and minimum (T.Min) temperature, precipitation, and evapotranspiration (ETo) data for both analyzed crop seasons

showed the following results: pH of 5.6, 8.1 $cmol_c\ dm^{-3}$ of Ca, 3.3 $cmol_c\ dm^{-3}$ of Mg, 0.0 $cmol_c\ dm^{-3}$ of Al, effective CEC of 11.7 $cmol_c\ dm^{-3}$, CEC at pH 7 of 15.2 $cmol_c\ dm^{-3}$, base saturation of 77%, SMP index of 6.2, 2.3% organic matter, 28% clay, 9.7 mg dm^{-3} of P (Mehlich) and 96 mg dm^{-3} of K (Mehlich).

Fertilization for the crops was carried out in the recommended amount after chemical analysis, according to the Fertilization and Liming Manual for RS and SC (CQFS, 2016). Basal fertilization was 380 kg ha^{-1} with a formulation of 5-20-20 NPK with two applications of 200 kg ha^{-1} of urea. During the development of the crops, three applications of insecticide and two applications of herbicide were carried out to control weeds.

Irrigation management was carried out based on the water balance, through the monitoring of meteorological variables. The data were obtained through the National Institute of Meteorology's automatic meteorological station, located at UFSM, situated approximately 2 km from the area. The data collected daily were maximum and minimum temperatures (°C), relative air humidity (%), wind speed (m s^{-1}), solar radiation (kJ m^{-2}), and precipitation (mm). The reference evapotranspiration (ETo) was calculated using the Penman-Monteith method (Allen et al., 1998). In the occurrence of rainfall during this interval, the methodology proposed by Millar (1978) was used to obtain the effective rainfall. The irrigation interval adopted was fixed to seven days, and when there was no effective rainfall to meet the water demand, irrigation was performed with the sum of the ETo of the period.

By performing a sprinkle irrigation test, an application rate of 13 mm h^{-1} and a Christiansen uniformity coefficient (CUC) of 93.50% were determined. The different irrigation depths were obtained by varying the time of water application in order to obtain the 50 and 100% ETo treatments, and the irrigation time was determined by Eq. 1:

$$\mathrm{Ti} = \frac{\mathrm{Drq}}{\mathrm{Drf} \cdot \mathrm{CUC}} 100 \quad (1)$$

where:

Ti - irrigation time (h);
Drq - required depth (mm);
Drf - reference depth (mm h^{-1}); and,
CUC - Christiansen uniformity coefficient (%).

Ethanol production was obtained by the product between grain yield and average ethanol yield for each crop in the different irrigation treatments, according to Eq. 2. The average ethanol yield adopted was 390 L t^{-1} (Kumar et al., 2020).

$$P_{ethanol} = P_{grain} \cdot Y_{ethanol} \quad (2)$$

where:

$P_{ethanol}$ - ethanol production (L);
P_{grain} - grain yield (ton); and,
$Y_{ethanol}$ - ethanol yield (L t^{-1}).

The study of production costs was carried out based on the methodology proposed by CONAB (2010). Installation and maintenance costs were elaborated according to a standard irrigation system adapted from Torres et al. (2019). Figure 2 shows the sketch of the experimental area, with the arrangement of crops and sprinklers.

The costs of inputs not related to irrigation were quantified and adjusted to R$ ha^{-1}. The fixed costs of irrigation were related to the acquisition and installation of the sprinkle irrigation system, with the initial value diluted throughout its useful life, and this value was fixed regardless of the system being triggered or not. Fixed costs related to irrigation were calculated using Eq. 3, according to CONAB (2010).

$$\mathrm{FCRI} = \mathrm{DC} + \mathrm{JC} + \mathrm{IN} \quad (3)$$

where:

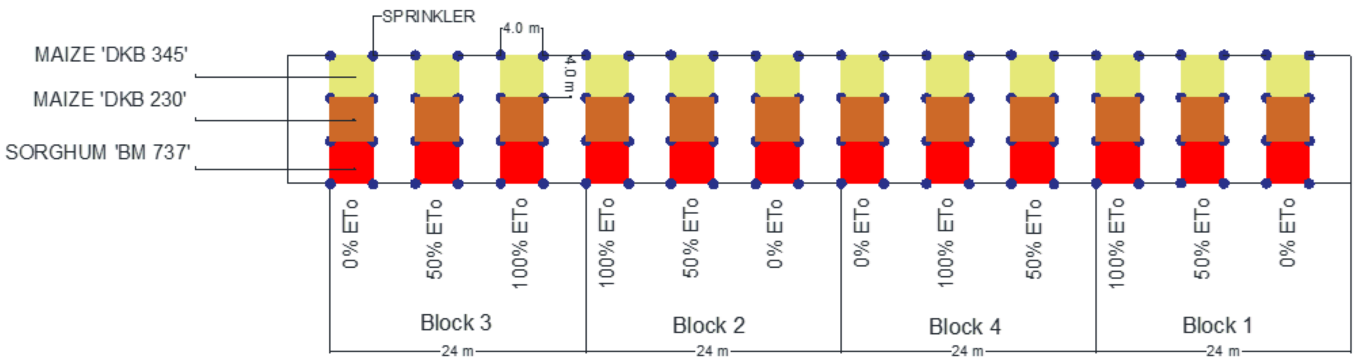
FCRI - fixed cost related to irrigation (R$ ha^{-1});
DC - cost with depreciation of irrigation system components (R$ ha^{-1});
JC - cost with interest on invested capital (R$ ha^{-1}); and,
IN - cost with insurance of irrigation system components (R$ ha^{-1}).

For the calculation of irrigation system depreciation (Eq. 4), the residual value of the asset was considered to be 20% of that of the new equipment (CONAB, 2010).

$$\mathrm{DC} = \left(\frac{\mathrm{VN} - \mathrm{VR}}{\mathrm{ULh}} \right) \mathrm{HsWr} \quad (4)$$

where:

DC - depreciation of the irrigation system component (R$);



ETo – Reference evapotranspiration

Figure 2. Sketch of the experimental area

VN - acquisition value of the new irrigation system component (R$);
VR - residual value of the irrigation system component (R$);
ULh - useful life of the irrigation system component (h); and,
HsWr - total hours worked per hectare.

Opportunity cost was calculated according to the interest rate on the invested capital, adopting an annual rate of 2.8% (based on the 2020 Selic rate) according to Eq. 5.

$$JC = AIR \cdot VN \tag{5}$$

where:
JC - interest rate on invested capital (R$);
AIR - annual interest rate (%); and,
VN - acquisition value of the irrigation system new component (R$).

Investment insurance was determined by CONAB (2010) (Eq. 6) as 0.35% of the average value of the investment.

$$IN = \frac{VN}{2} 0.0035 \tag{6}$$

where:
IN - cost of insurance (R$); and,
VN - acquisition value of the new irrigation system component (R$).

Eq. 7 was used to determine the variable costs related to irrigation:

$$VCRI = VCE + VCL + VCM \tag{7}$$

where:
VCRI - variable cost related to irrigation (R$);
VCE - variable cost with electricity (R$);
VCL - cost of labor used in irrigation (R$); and,
VCM - cost with equipment maintenance (R$).

The variable cost of electricity was determined according to the power of the motor-pump set and the time for application of the irrigation depth (Eq. 8). The cost of electricity was obtained according to the price of electricity practiced by the concessionaire of the region, considering the green tariff, which allows the use for 21 hours a day.

$$VCE = Pw \cdot E \cdot T \cdot D \tag{8}$$

where:
VCE - variable cost with electricity (R$);
Pw - power of the motor-pump set (kW);
E - price of electricity (R$ kWh^{-1});
T - time for applying one millimeter of water (h mm^{-1}); and,
D - irrigation depth (mm).

The value of the hour worked was determined based on the methodology of CONAB (2010), with the hourly value equivalent to the rural minimum wage (Eq. 9).

$$VCL = Ni \cdot Ns \cdot 0.5 \cdot \frac{VMinW}{220} \tag{9}$$

where:
VCL - cost of labor used in irrigation (R$);
Ni - number of irrigation events;
Ns - number of sectors of the irrigation system; and,
VMinW - value of rural minimum wage (R$).

Maintenance costs were calculated considering the values relative to 1% of the value of the irrigation system and 10% of the value spent on electricity (Eq. 10).

$$VCM = VN \cdot 0.01 \cdot \frac{VCE}{10} \tag{10}$$

where:
VCM - cost with equipment maintenance (R$);
VN - acquisition value of the new irrigation system component (R$ ha^{-1}); and,
VCE - variable cost of electricity.

After surveying all costs present in the production system and obtaining ethanol productivity data, the economic analysis was performed with the following investment indicators: net present value (NPV), internal rate of return (IRR), benefit/cost ratio (B/C), profitability index (PI) and payback (PB).

NPV was calculated using Eq. 11:

$$NPV = \sum_{t=0}^{N} \frac{Ft}{(1+j)^t} \tag{11}$$

where:
NPV - net present value (R$ ha^{-1});
j - discount rate or minimum attractiveness rate (MAR);
N - project horizon (years);
t - project time (period) (years); and,
Ft - net cash flow each year (R$ ha^{-1}).

The IRR of a project consists in determining the interest rate at which the NPV is null. It is at this rate that the sum of benefits becomes equal to the sum of costs, because the net present value is the algebraic sum, at instant zero, of the benefits and costs (Eq. 12).

$$\sum_{j=0}^{N} \frac{Ft}{(1+IRR)^t} = 0 \tag{12}$$

where:
IRR - internal rate of return, decimal; and,
j - discount rate or minimum attractiveness rate (MAR), decimal.

With B/C, it was verified under which condition of the project the benefits were greater than the updated expenses. This ratio was calculated using Eq. 13:

$$B/C = \frac{\sum_{t=0}^{N} \frac{B}{(1+j)^t}}{\sum_{t=0}^{N} \frac{C}{(1+j)^t}} \quad (13)$$

where:

B/C - benefit/cost ratio;
B - revenues (R$ ha^{-1}); and,
C - expenses (R$ ha^{-1}).

The payback (PB) was calculated with the quotient of the initial investment by the average cash flow of the period (20 years). The profitability index (PI) was calculated considering the NPV divided by the initial cost of the project.

For the economic viability analysis, scenarios were elaborated with the two conditions of raw material. Five ethanol market values (R$ 2.00; R$ 2.50; R$ 3.00; R$ 3.50; and R$ 4.00 L^{-1}) were evaluated and, according to Center for Advanced Studies in Applied Economics (CEPEA), the average price for the period under study was R$ 3.00 L^{-1}. The fixed cost of production for one liter of ethanol (both crops) was R$ 0.40 L^{-1}, according to Silva et al. (2020). As a way of comparing the results obtained with the international literature, the dollar price of R$ 5.60 was adopted. Forty five scenarios were created, as described below:

For the scenarios 1 to 30, maize was used as a source of raw material for ethanol production. The costs and yields were obtained from the two crop seasons for irrigated and rainfed conditions. The difference between the scenarios was the market value of ethanol. For the scenarios 31 to 45, grain sorghum was used as a source of raw material, with the same procedures as the previous scenarios.

Results and Discussion

The fixed cost not related to irrigation (FCNRI) values found were R$ 3,807.60 ha^{-1} for maize crop and R$ 2,862.30 ha^{-1} for sorghum crop. The fixed cost related to irrigation (FCRI) values were R$ 1,378.70 ha^{-1}, while the variable cost related to irrigation (VCRI) values were R$ 294.80 and R$ 179.95 ha^{-1} for the 2019/2020 and 2020/2021 seasons, respectively.

The costs for ethanol production in the grain sorghum crop in the 2019/2020 and 2020/2021 seasons ranged from R$ 512.00 to R$ 860.15, R$ 933.90 to R$ 1,294.80 and R$ 1,121.10 to R$ 1,530.68 ha^{-1} in treatments without the use of irrigation, with 50% of the ETo and 100% of the ETo, respectively, representing an increase of 48.25% in costs, when comparing treatments with full irrigation and without irrigation.

In maize crop, the variation of costs in the two years was from R$ 1,320.31 to R$ 1,236.17 ha^{-1}, R$ 2,181.36 to R$ 1,811.56 ha^{-1} and R$ 2,425.90 to 2,302.30 ha^{-1} in treatments without irrigation, with 50% of the ETo and with 100% of the ETo, respectively. The treatment with full irrigation increased the cost of ethanol production by 45.93% when compared to the non-irrigated treatment.

The use of irrigation increased grain production per hectare and, consequently, reduced the cost of production of the liter of ethanol. In maize crop, the calculated cost of ethanol was R$ 1.60, R$ 1.47 and R$ 1.36 L^{-1}, for treatments without irrigation, with 50% of the ETo and 100% of the ETo, respectively, which imply a range of 15% this percentage represents the difference between treatments without irrigation and 100% of the ETo. This cost for the grain sorghum crop was slightly higher, with values of R$ 2.18, R$ 2.01 and R$ 1.79 L^{-1} for the same treatments, which represents a variation of 17.89%.

Somavat et al. (2018) worked with three varieties of maize for ethanol production and obtained a production cost of approximately R$ 1.48 L^{-1}, which is consistent with the results obtained in the present study for maize crop and lower than that for grain sorghum.

Li et al. (2020) observed that the cost of ethanol production with maize grains was R$ 2.98 L^{-1}. This value is 86.25% (without irrigation), 102.72% (50% of the ETo) and 119.11% (100% of the ETo) higher than those found for maize and 36.69% (without irrigation), 48.25% (50% of the ETo) and 66.48% (100% of the ETo) higher than those found for grain sorghum.

An ethanol productivity of 6,698 L ha^{-1} per year with yield of 446 L t^{-1} and production cost of R$ 1.30 L^{-1} were reported by Quintero et al. (2008). These values corroborate those obtained for maize in the present study, where the cost of production was R$ 1.36 L^{-1} with an average productivity of 5,685.00 L ha^{-1} and ethanol yield of 390 L t^{-1}.

Figure 3 presents the results of the analysis of the economic indicators NPV and IRR in the different scenarios.

The NPV showed a negative value only for the grain sorghum crop when the remuneration for the liter of ethanol sold was R$ 2.00 L^{-1} for the three ETo conditions. From the value of R$ 2.50 L^{-1}, the NPV was positive and increasing with the increment in the remuneration paid for the liter. For the two maize cultivars, the returns were positive and increasing in all evaluated scenarios.

The IRR showed a behavior similar to that of NPV, being lower than the minimum attractiveness rate (MAR) only for the scenario with a selling price of R$ 2.00 L^{-1} for the irrigation conditions tested. The IRR showed higher rates of return for treatments without the use of irrigation, which is due to its lower initial investment. However, NPV increased with the use of irrigation.

Evaluating ethanol productivity and profitability, Quintero et al. (2008) obtained IRR of 66.75% and NPV of R$ 3,650.00 ha^{-1} for the maize crop. The IRR value found by the authors is consistent with those found with the scenario of full irrigation and ethanol market value of R$ 4.00 L^{-1}, and for the scenarios from R$ 2.50 to R$ 3.00 L^{-1} when irrigation was not used for both crops.

For ethanol production using sweet potato crop, Bernardi et al. (2021) found IRR values of 11.47%, similar to those observed for irrigated grain sorghum and lower than those found for maize, at a selling price of R$ 3.00 L^{-1}.

A study with sweet sorghum in different conversion rate scenarios showed that, despite the increased prices of both

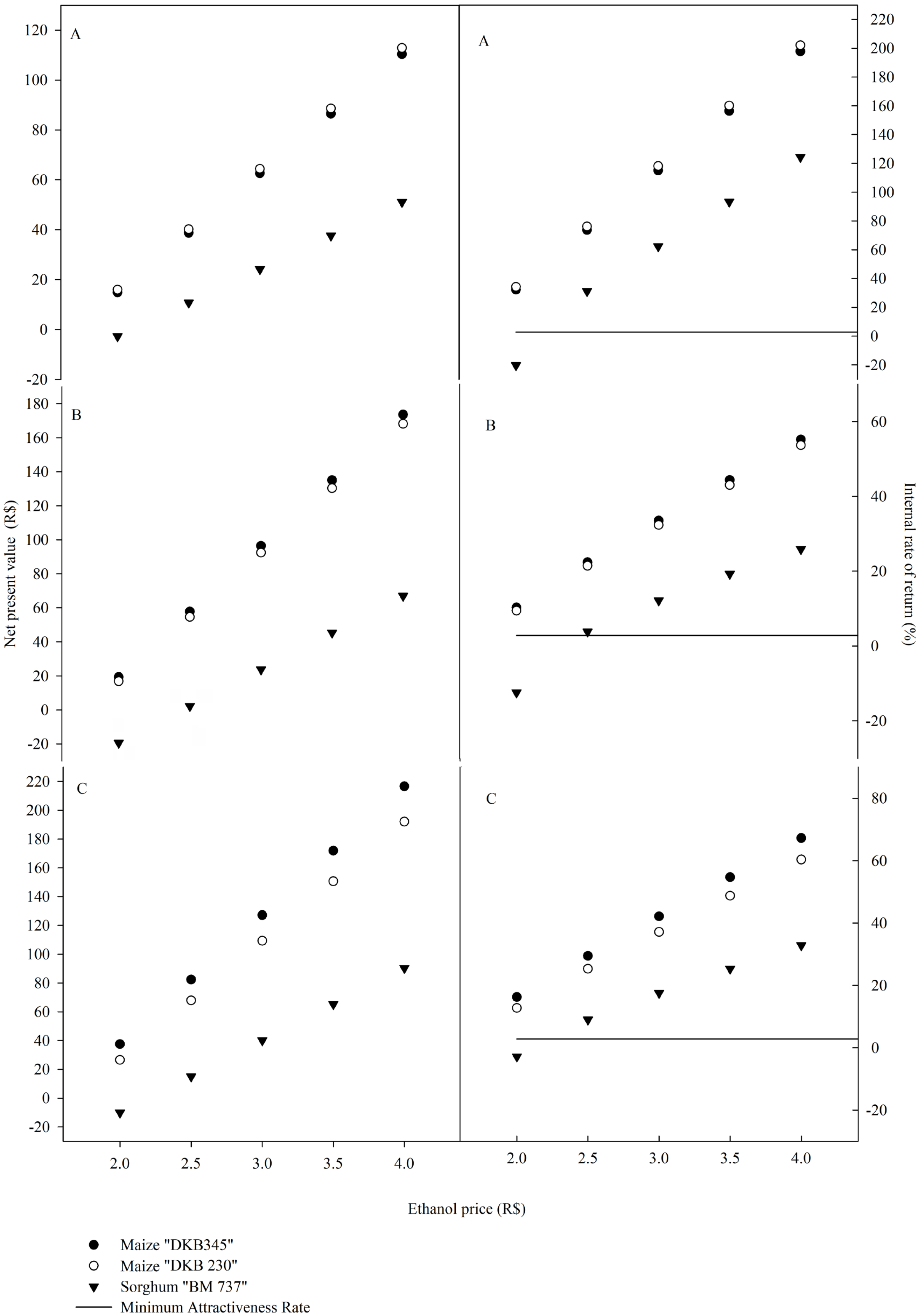


Figure 3. Net present value (NPV) and internal rate of return (IRR) values for the 45 scenarios analyzed, for treatments without irrigation - 0% of the ETo (A), with 50% of the ETo (B) and 100% of the ETo (C)

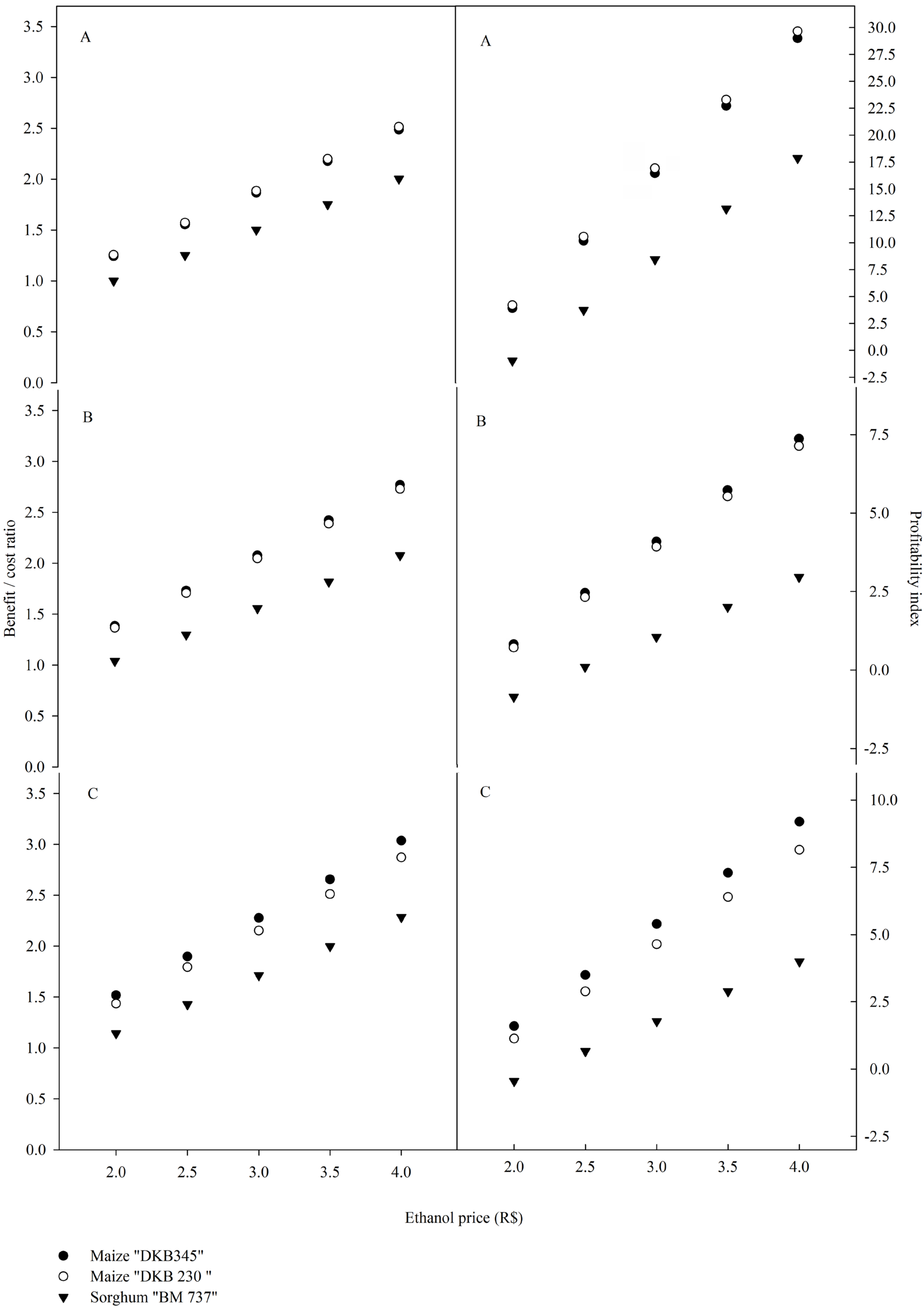


Figure 4. Benefit/cost ratio (B/C) and profitability index (PI) values for the 45 scenarios analyzed, for treatments without irrigation - 0% of the ETo (A), with 50% of the ETo (B) and 100% of the ETo (C)

raw material and liter of ethanol (R$ 2.03 and R$ 2.70 L^{-1}), the NPV remained negative (Basavaraj et al., 2013). In the case of grain sorghum, at a price of R$ 2.00 L^{-1}, the NPV also remained negative for both irrigated and non-irrigated treatments, but becoming positive after the increase in remuneration to R$ 2.50 L^{-1}.

According to Bernardi et al. (2021), in the ethanol production system the selling price is extremely important because the changes in this scenario will directly influence the economic viability of the enterprises. The authors also point out that the equilibrium price for a positive NPV is R$ 3.00 L^{-1}. This is the value adopted as the average selling price in the present study.

Figure 4 shows the results obtained for the benefit/cost ratio (B/C) and profitability index (PI).

The benefit/cost ratio (B/C) did not show an attractive result only for the condition without irrigation, with a market value of R$ 2.00 L^{-1}. A B/C of 2.00 was reached in the remuneration of R$ 4.00 L^{-1} for the grain sorghum crop. For maize, the B/C ranged from 1.24 to 2.51 at the selling prices of R$ 2.00 and R$ 4.00 L^{-1}, respectively, showing a small variation between the cultivars evaluated.

With the use of irrigation with 50% of the ETo, B/C values ranged from 1.04 to 2.08 for grain sorghum and from 1.36 to 2.77 for maize in the two cultivars tested for the selling prices of R$ 2.00 and R$ 4.00 L^{-1}. For the use of 100% of the ETo, the variation was from 1.14 to 2.28 and from 1.44 to 3.04 for the lowest and highest selling price with grain sorghum and maize crops, respectively.

Basavaraj et al. (2013) found a B/C of 0.89 for ethanol production with sweet sorghum. These values are lower than those observed for grain sorghum and maize, which were above 1.00 in all studied scenarios.

The PI in the remuneration of R$ 2.00 L^{-1} for grain sorghum did not obtain a positive return in the three irrigation managements. Although some values for the maize crop were low, as in the case of 50% of the ETo with a selling price of R$ 2.00 L^{-1}, all were viable, showing a positive relationship according to the remuneration.

Table 1 presents the payback over time in years for the investment to generate economic return.

It is possible to verify that only three scenarios did not have economic return within the useful life of the production system. These scenarios combine the grain sorghum crop with the low remuneration of ethanol sales, thus showing a PB that ranged from 27.4 to 451.8 years, not being profitable for the project period. In the other scenarios evaluated, the economic return occurred within the expected period, and in some cases the investment was returned already in the first year.

The production of ethanol from maize and sugarcane in Colombia showed PB of 3.85 and 4.13 years for the two crops, respectively (Quintero et al., 2008). These results are in accordance with some scenarios analyzed in the present study, varying for maize and grain sorghum, with and without irrigation.

Bernardi et al. (2021), in a scenario of the sweet potato ethanol selling price of R$ 3.00 L^{-1}, obtained a PB value of 9.85 years. This value is close to the results found in the present study in the scenarios with the use of irrigation and low remuneration for maize and grain sorghum.

Table 1. Payback values for the 45 scenarios analyzed

Raw material	Payback (years)				
	Variation of selling price (R$)				
	2.00	2.50	3.00	3.50	4.00
	Without irrigation – 0% of the ETo				
Maize 'DKB 345'	3.1	1.4	0.9	0.6	0.5
Maize 'DKB 230'	2.9	1.3	0.8	0.6	0.5
Sorghum 'BM 737'	451.8	3.2	1.6	1.1	0.8
	50% of the ETo				
Maize 'DKB 345'	8.3	4.4	3.0	2.3	1.8
Maize 'DKB 230'	8.8	4.6	3.1	2.3	1.9
Sorghum 'BM 737'	106.7	14.2	7.4	5.0	3.8
	100% of the ETo				
Maize 'DKB 345'	5.8	3.4	2.4	1.8	1.5
Maize 'DKB 230'	7.1	3.9	2.7	2.1	1.7
Sorghum 'BM 737'	27.4	9.1	5.5	3.9	3.0

ETo - Reference evapotranspiration

Conclusions

1. The use of full irrigation (100% of ETo) reduces the production costs of the liter of ethanol by 15 and 17.89% and increases ethanol production by 44.18 and 48.25% for maize and grain sorghum crops, respectively.

2. For the market price of R$ 2.00 L^{-1}, the grain sorghum crop does not show good performance, with negative net present value (NPV) and internal rate of return (IRR); in the other scenarios, the crop showed positive results for all indicators. The sale price of R$ 4.00 L^{-1} and full irrigation is the best economic scenario, with values of NPV of R$ 90,356.93, IRR of 33.83%, benefit/cost ratio (B/C) of 2.28, profitability index (PI) of 3.99 and payback of three years.

3. Maize crop is economically viable for ethanol production in all scenarios, with positive results for all indicators. The full irrigation and market price of R$ 4.00 L^{-1} represent the best economic scenario, with mean values for NPV of R$ 204,381.68, IRR of 63.35%, B/C of 2.96, PI of 8.67 and payback of 1.58 years, among the cultivars.

4. With the economic evaluations carried out, maize and grain sorghum crops are viable alternatives for the production of ethanol due to their adaptability to the climatic conditions of the study region, and the final product's sale price is an important factor in the economic viability of the activity.

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