

Full Length Research Paper

## Technological parameters and economic analysis of sugarcane cultivated under irrigation depths for ethanol production in Santa Maria-RS, Brazil

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This study aimed to perform economic analysis and evaluate the effect of technological parameters on plant and ratoon sugarcane under irrigation depths for ethanol production. Treatments were irrigation of 30, 60, 90, and 120% of  $ET_c$  and a control treatment (no irrigation). The experimental design was a randomized block with six repetitions. We used a drip irrigation system with management based on crop evapotranspiration, according to the methodology proposed by FAO. In rainfed and under irrigation plant cane, the variable cost represented 54.40 and 66.81% and the fixed cost represented 45.60 and 33.19%, respectively. The difference in the cost of production in rainfed and irrigated was 27.23 and 57.20%, for the plant cane and ratoon, respectively. Moreover, we presented the economic viability, which for sugarcane grown in rainfed is 60% of  $ET_c$ , with differences in the cost of production and net profit of 53.94 and 52.20%, and financial return in the year of implementation and 4 years and 4 months, respectively. The irrigation increased technological parameters for ethanol production. For plant cane, the only variable that showed no statistically significant difference was the fiber, and for ratoon cane the technological parameters did not have statistically significant difference.

**Key words:** *Saccharum*, drip irrigation, financial indicators, ratoon cane, plant cane, dryland.

### INTRODUCTION

In Brazil, sugarcane has played an important role in the formation of economic, political, and social bases since its introduction on 22 January, 1532 (Miranda, 2008), and

as a defining agent of production factors, especially in the use of agricultural areas (Castilho, 2000).

In addition to the importance of Brazil in the sugar

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processing, after the decade of 1970, sugarcane gained importance as a source of energy due to an increase in oil prices (1973 to 1979), and for offering a product able to generate clean energy. In this period, the ethanol production triggered relevant socioeconomic impacts such as increasing rural income, employment generation, reducing dependence on foreign oil, and the increase of Brazilian balance of trade (Negrão and Urban, 2005).

After the decade of 1990, with the opening of the Brazilian economy, the sugarcane sector faced important changes, passing to act in a free market environment that required greater competitiveness and effectiveness of all involved agents in order to remain in the activity (Melo and Esperancini, 2012).

In 2013, the Brazilian state of Rio Grande do Sul used one billion liters of ethanol and its production (six to eight million liters per year) is only 2% of the ethanol used, being produced in the main ethanol plant, the Cooperative of Sugarcane Growers Porto Xavier Ltda (COOPERCANA), in Porto Xavier (Prestes, 2013). The ethanol prices have never been so high, even equal or higher than gasoline because of transportation costs (away from ethanol plants located in São Paulo), where 70% of Brazilian ethanol is produced (Colussi, 2011).

Currently, Brazil is the greatest worldwide sugarcane producer, with 9,004.50 thousand hectares of area and production of 642.10 million tons of stalk (average yield of 71.31 t ha<sup>-1</sup>) (CONAB, 2014). Over 56% of production was used to produce ethanol (28.66 billion liters) and 47.72% for sugar (36.36 million tons). Furthermore, sugarcane production has been increasing annually due to the construction of new ethanol plants and selection of more productive varieties. Thereby, the commercialization of sugar and ethanol has represented an important part of the Gross Domestic Product (GDP) of the national agribusiness (Silva et al., 2012).

Despite the great expansion of sugarcane fields, environmental problems such as water deficit due to irregular rainfall and an increase of below-normal rainfall in the months where it is more required, causing more damage when occurring during vegetative stages have been observed (Dias, 1999; Rolim et al., 2007).

The soil and climate conditions in the new sugarcane fields require the use of irrigation. Abreu et al. (2013) and Teodoro et al. (2009, 2015) found that in the cycle where occurred greater water deficit, the agricultural and agro-industrial production were significantly affected. Sugarcane responds positively to irrigation and it may be used as a key factor for implementing irrigation systems in sugarcane fields. Moreover, it increases yield and lifetime of sugarcane fields (Demétrio, 1978; Matioli, 1998; Neto et al., 2006; Dalri and Cruz, 2008; Farias et al., 2008a; Farias et al., 2008b; Oliveira et al., 2009; Silva et al., 2011; Silva et al., 2014).

However, in view of the great need of water during the production cycle and the lack of water resources, proper irrigation water management has fundamental importance

for achieving greater yield, quality, cost reduction, and rational water use (Padrón et al., 2015a), such as drip irrigation system (Parkes et al., 2010; Boas et al., 2011; Martins et al., 2011). Moreover, Gava et al. (2011) investigating drip irrigation system in three sugarcane varieties obtained, on average, 20% increase in plant cane and 28% in ratoon cane.

Irrigation is one of the most influential factors in yield and production cost of sugarcane (Teodoro et al., 2013). Thus, the management of this agricultural technique requires special attention, since the farmer must use the amount of water that provides a maximum economic return (Fernandes, 2003). Thereby, the localized irrigation arises as a path of linking irrigation productivity gains with higher savings of water and electricity, becoming a technique with increasing use in Brazil and worldwide.

Analyzing the economic feasibility of the implementation of this specific method of irrigation on the current Brazilian agricultural and economic situation becomes increasingly important. The crop yield response regarding different irrigation depths is essential to enable and disseminate the exploitation of irrigated crop in a given region (Frizzzone, 1993).

Assessing technological quality of sugarcane has fundamental importance. It will define sugarcane potential as a feedstock for the production of sugar and ethanol in the various stages of industrialization (Stupiello and Fernandes, 1984). The production of sugar and ethanol from irrigated sugarcane depends on several factors, such as the amount of water applied by irrigation, variety, soil type, and the climate of the region (Neto et al., 2006). Therefore, this study aimed to perform the economic analysis and evaluate the effect of technological parameters of sugarcane cultivated for ethanol production under different irrigation depths, using a drip irrigation system.

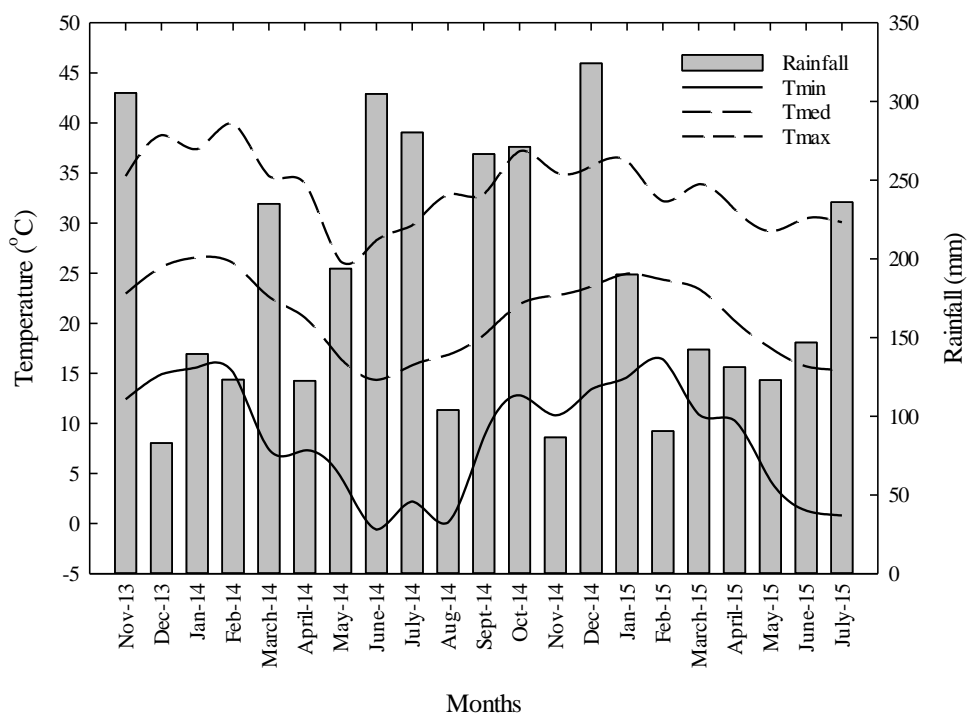
## MATERIALS AND METHODS

This experiment was carried out at the experimental area of the Polytechnic School of the Federal University of Santa Maria located at 29°41'25"S, 53°48'42"W, and altitude of 110 m, during the growing seasons of 2013-2014 and 2014-2015. The predominant soil in the region is Paleudalf, frank texture, according to Soil Taxonomy (USDA, 1999). According to the Köppen-Geiger climate classification, the climate of the region is humid subtropical (Cfa). During both growing seasons, relative air humidity (ranged from 69.50 to 86.80%), insolation (ranged from 134 to 286.20 h), and evapotranspiration (ranged from 41.50 to 175.20 mm; Table 1) were greater in the first growing season. The rainfall, maximum, average, and minimum temperatures are presented in Figure 1. In the 2013-2014 and 2014-2015 growing seasons, minimum, average, and maximum temperatures were -0.6; 21.20; 40°C and 0.1; 20.50; 37.20°C, respectively, showing greater variation in the first growing season. In the 2013-2014 growing season, maximum rainfall occurred in November and June, and the minimum rainfall in December. In the second growing season, maximum and minimum rainfall occurred in December and November, respectively.

Treatments (30, 60, 90 and 120% of crop evapotranspiration)

**Table 1.** Monthly climatic data of the experimental area with relative air humidity, insolation, and evaporation cumulative during the 2013-2014 and 2014-2015 growing seasons.

Months	Relative humidity mean (%)			Insolation (hour)			Evaporation (mm)		
	2013	2014	2015	2013	2014	2015	2013	2014	2015
Jan.		73.10	78.30		219.20	235.80		158.50	148.70
Feb.		73.80	79.70		211.20	207.20		138.20	122.10
March		76.80	77.60		212.60	229.40		113.70	118.60
April		78.20	77.00		219.80	207.20		86.50	81.90
May		83.40	82.50		142.80	146.90		49.10	52.50
June		86.80	80.90		199.80	145.80		41.50	34.80
July		80.60	86.20		176.40	89.60		53.20	41.70
Aug.		75.80			188.50			76.50	
Sept.		76.40			134.00			101.20	
Oct.		73.40			161.00			146.80	
Nov.	71.60	71.00		229.20	173.10		144.30	131.60	
Dec.	69.50	76.10		286.20	211.00		175.20	142.10	

**Figure 1.** Climograph of the experimental area, during the 2013-2014 and 2014-2015 growing seasons.

and a control treatment (rainfed) were arranged in a randomized block design with six repetitions. Each experimental unit was formed by 20 m<sup>2</sup> (4x5 m), and 600 m<sup>2</sup> of total experimental area, without plants on the border. The sugarcane (RB93-5581 variety) was planted on 14 November 2015, with a spacing of 1 m between rows, and continuous distribution of stalks (3-4 buds per stalk, and 18 buds per meter) into the furrow. The harvest occurred on 20 July 2014 (first growing season) and 8 June 2015 (second growing season). In order to reduce experimental errors and maintain

homogeneity, sugarcane stalks were divided into the top, middle, and bottom parts, and each part was planted in two blocks. A drip irrigation system, with drippers spaced 0.2 m and a flow rate of 0.8 L h<sup>-1</sup> was used. One spherical gate and one pressure control valve were installed in each experimental unit in order to control irrigation time and obtain regular pressure, respectively. Moreover, the uniformity distribution of the irrigation system was assessed and wetted soil volume tests were performed following the results reported by Padrón et al. (2015b). From day one up to 29 days after

**Table 2.** Average soil attributes of the experimental area.

Soil layers (m)	Bulk density (g cm <sup>-3</sup> )	Field capacity (m <sup>3</sup> m <sup>-3</sup> )	Wilting point (m <sup>3</sup> m <sup>-3</sup> )	Water content (m <sup>3</sup> m <sup>-3</sup> )	Infiltration (mm h <sup>-1</sup> )	Texture
0-0.2	1.42	0.31	0.14	0.18		Loam
0.2-0.4	1.38	0.34	0.17	0.17	15	Clay-loam
0.4-0.6	1.36	0.37	0.23	0.13		Clay

Source: Pádrón et al. (2015b).

planting, water management was performed based on 100% of evapotranspiration for all treatments to ensure sprouting and planting uniformity. Afterwards, the irrigation treatments were started and performed every seven days up to one month before each harvest.

The reference evapotranspiration was based on the methodology of Penman-Monteith/FAO (Equation 1), and the crop evapotranspiration at a standard condition was based on Equation 2 (Allen et al., 1998). Climate data were obtained from the weather station of the Federal University of Santa Maria, linked to the National Institute of Meteorology, localized approximately 2000 m from the experimental area. Rainfall (mm), maximum and minimum temperature (°C), maximum and minimum relative air humidity (%), insolation (hours), and wind speed (m s<sup>-1</sup>) were collected daily.

$$ET_o = \frac{0.408 \Delta \times (Rn - G) + \gamma \times \left( \frac{900}{T + 273} \right) \times U_2 \times (e_s - e_a)}{\Delta + \gamma \times (1 + 0.34 \times U_2)} \quad (1)$$

Where ET<sub>o</sub> is the reference evapotranspiration (mm day<sup>-1</sup>), R<sub>n</sub>, G, and T are net radiation value at crop surface (MJ m<sup>-2</sup> day<sup>-1</sup>), soil heat flux density (MJ m<sup>-2</sup> day<sup>-1</sup>), and daily mean air temperature at 2 m height (°C), respectively. Also, U<sub>2</sub>, e<sub>s</sub>, e<sub>a</sub>, (e<sub>s</sub> - e<sub>a</sub>), Δ, and γ represent wind speed at 2 m height (m s<sup>-1</sup>), saturation vapor pressure (kPa), actual vapor pressure (kPa), saturation vapor pressure deficit (kPa), slope of the saturation vapor pressure curve (kPa°C<sup>-1</sup>), and psychrometric constant (kPa°C<sup>-1</sup>), respectively.

$$ET_c = k_c \times ET_o \quad (2)$$

Where ET<sub>c</sub> stands for crop evapotranspiration (mm), ET<sub>o</sub> is the reference crop evapotranspiration (mm), and k<sub>c</sub> is the single crop coefficient. The following single crop coefficient values were used:

$$K_{cini}=0.40; K_{cmed}=1.25 \text{ and } K_{cfin}=0.75 \quad (\text{Allen et al., 1998}).$$

The soil texture, apparent density, field capacity, infiltration test, and chemical analysis were performed according to Pádrón et al. (2015b) (Table 2). Furthermore, fertilizers were applied according to the soil chemical analysis and crop requirements (expected yield of 80 to 100 t ha<sup>-1</sup>). In order to correct soil pH, 3.5 t ha<sup>-1</sup> of lime was broadcasted on the soil surface and incorporated with a disk harrow.

The economic analysis was carried out for each study period (plant cane and ratoon cane). The value of sugarcane commercial production in each period was calculated based on the average value of the study locality and from the Cooperative of Sugarcane Growers Porto Xavier Ltda (COOPERCANA) (the main sugarcane processing cooperative of Rio Grande do Sul), establishing R\$ 55,00 for each t ha<sup>-1</sup> for the five years of analysis. The production system cost (fixed and variable costs) for each period of upland sugarcane (including all operations involved and the necessary inputs for the production: number of machine hours, tractor daily

rate, number of men day<sup>-1</sup>, soil preparation, seedlings, planting, herbicides, insecticides, cutting, loading, transport, and manual harvesting) were also calculated by the average value of the study locality and with the average value of COOPERCANA. For irrigated sugarcane the costs are from the drip irrigation system. Considering an initial investment of R\$ 10,000.00 and without including land and water value for irrigation, but adding labor and electricity costs, we estimated the unit cost of water depth (R\$ 1.56 mm<sup>-1</sup> ha<sup>-1</sup>). It should be noted that the average values of the expenditure were determined for the first two years. In the subsequent periods, the values were calculated from a forecasted value of the services plus a cumulative adjustment of the second year, considering a rate of 7.2% per year according to (Vieira et al., 2014). Likewise, the yield was determined for the first two years, being the coming years estimated from the second year. There is a tendency in reducing yield after a time, ranging from 12 to 15% per year (Pereira et al., 2015). However, the price per ton also presents annual increments, which can be equivalent to productivity losses. Thereby, both were considered constant after the third year. The net profit of the production system was determined by Equation 3.

$$L(x) = P_y y - P_x x - c \quad (3)$$

Where: onde: L<sub>(x)</sub> = net profit (R\$ ha<sup>-1</sup>); P<sub>y</sub> = production value (R\$ t<sup>-1</sup>); Y = yield (t ha<sup>-1</sup>); P<sub>x</sub> = irrigation water price (R\$ mm<sup>-1</sup>); x = irrigation depth (mm); c = production system costs (R\$ ha<sup>-1</sup>).

A second order polynomial regression analysis between the dependent variable (net profit) and the independent variable (irrigation depth) was used to obtain the net income function (Equation 4). In addition, the point of maximum technical efficiency was determined, where the irrigation depth maximized net profit (Equation 5).

$$y = a + bx + cx^2 \quad (4)$$

Where: y = net profit (R\$); x = applied irrigation depth (mm); a, b, c = equation parameters.

$$X_{max} = -b/2c \quad (5)$$

From the projection of cash flows associated with each studied production systems, we carried out economic analysis using the following criteria: net present value (NPV), internal rate of return (IRR), relative benefit cost (B/C), equilibrium point (EP), *payback* (PB), and discounted *payback* (PBD). It is important to highlight a peculiar feature of rainfed treatment compared to the others, which there was no need for initial investment in irrigation equipments. This fact directly affected the determination of the IRR, which presupposes a relationship between the investment value (cash outflow) and the value resulting from the cash flows. Thereby, it was not possible to determine IRR because all flows over the five years of analysis were positive. Moreover, to establish a comparative basis in relation to other treatments, we calculated the rate of return

**Table 3.** Production costs of plant and ratoon cane under irrigation and rainfed.

Variable	Plant cane				Ratoon cane			
	Rainfed		Under irrigation		Rainfed		Under irrigation	
	(R\$ ha <sup>-1</sup> )	(US\$ ha <sup>-1</sup> )	(R\$ ha <sup>-1</sup> )	(US\$ ha <sup>-1</sup> )	(R\$ ha <sup>-1</sup> )	(US\$ ha <sup>-1</sup> )	(R\$ ha <sup>-1</sup> )	(US\$ ha <sup>-1</sup> )
Soil preparation	504.00	144.00	504.00	144.00	-	-	-	-
Plantation	2,030.00	580.00	2,030.00	580.00	-	-	-	-
Cultural tract	820.00	234.30	820.00	234.30	638.00	182.30	638.00	182.30
Supplies	927.00	264.90	927.00	3,122.00	927.00	264.90	1,927.00	550.60
Harvest	350.00	100.00	350.00	100.00	350.00	100.00	350.00	100.00
Services	180.00	51.40	1,980.00	565.70	180.00	51.40	1,980.00	565.70
Cost total	4,811.00	1,374.60	6,611.00	1,888.90	2,095.00	598.60	4,895.00	1,398.60
Fixed costs	2,194.00	626.90	2,194.00	626.90	150.00	42.90	1,200.00	342.90
Variable costs	2,617.00	747.70	4,417.00	1262.00	1,945.00	555.70	3,695.00	1,055.70

in each year (comparing the net result with the expenses). Then, the cumulative rate of the analyzed period (five years) and its annual equivalent were determined. The analysis considered a minimum rate of attractiveness (14.25%) based on Brazil interest rate.

Samples of technological parameters evaluated in this study were obtained from the central rows by collecting six industrial stalks per plot at the end of the growing cycle. The total soluble solids (°Brix), the sugarcane fiber (Fiber =  $0.08 \times \text{WBM} + 0.876$ ; where WBM = wet bagasse mass), the apparent sucrose of the sugarcane juice ( $\text{Pol}_{\text{sugarcane juice}} = (1.0078 \times \text{Sacch.reading} + 0.0444) \times (0.2607 - 0.009882 \times \text{Brix})$ ; where Sacch.reading = reading of the saccharimeter), the apparent sucrose of the sugarcane ( $\text{Pol}_{\text{sugarcane}} = \text{Pol}_{\text{sugarcane juice}} \times (1 - 0.01 \times \text{fiber}) \times C$ ) and ( $C = 1.0313 - 0.00575 \times \text{Fiber}$ ; where C is the sugarcane juice transformation coefficient), the purity of sugarcane (Purity =  $\text{Pol}_{\text{sugarcane}} \div \text{Brix}_{\text{sugarcane}} \times 100$ ) and ( $\text{Brix}_{\text{sugarcane}} = \text{Brix}_{\text{sugarcane}} \times (1 - 0.01) \times C$ ), the sugarcane total reducing sugars ( $\text{TRS}_{\text{sugarcane}} = \text{TRS}_{\text{sugarcane juice}} \times (1 - 0.01 \times \text{fiber}) \times C$ ), ( $\text{TRS}_{\text{sugarcane juice}} = (\text{Pol}_{\text{sugarcane juice}} / 0.95) + \text{RS}_{\text{sugarcane juice}}$ ), and ( $\text{RS}_{\text{sugarcane juice}} = 3.641 - 0.0343 \times \text{Purity}$ ;  $\text{TRS}_{\text{sugarcane juice}}$  = the total reducing sugars in the juice;  $\text{RS}_{\text{sugarcane juice}}$  = the reducing sugars of the sugarcane juice, the recoverable total sugar ( $\text{RTS} = 10 \times \text{IC} \times 1.0526 \times 0.905 + 10 \times \text{RSS} \times 0.905$ ) and ( $10 \times \text{IC}$  = inches per ton of sugarcane; 1.05263 = stoichiometric coefficient for the conversion of sucrose into reducing sugars; 0.905 = recovery coefficient for an industrial loss of 9.5%;  $10 \times \text{RSS}$  = reducing sugar per ton of sugarcane), and the estimation of ethanol production (Ethanol =  $\text{TRS}_{\text{sugarcane juice}} \times 10 \times 0.6475$ ) were calculated. The value of 100% ethanol was later transformed to 85% ethanol, considering the efficiency of the fermentation process. The determination of the parameters evaluated followed the methodology of the Instruction Manual provided by the Council of Sugarcane, Sugar, and Alcohol Producers of São Paulo State (CONSECANA, 2006). Statistical analysis was performed using the SPSS software package (SPSS V17.0).

## RESULTS AND DISCUSSION

The crop cycles during the growing seasons of 2013-2014 and 2014-2015 were 237 days and 323 days, respectively, with a difference of 86 days. Evapotranspiration, rainfall, and irrigation days were greater in the 2014-2015 growing season, with a

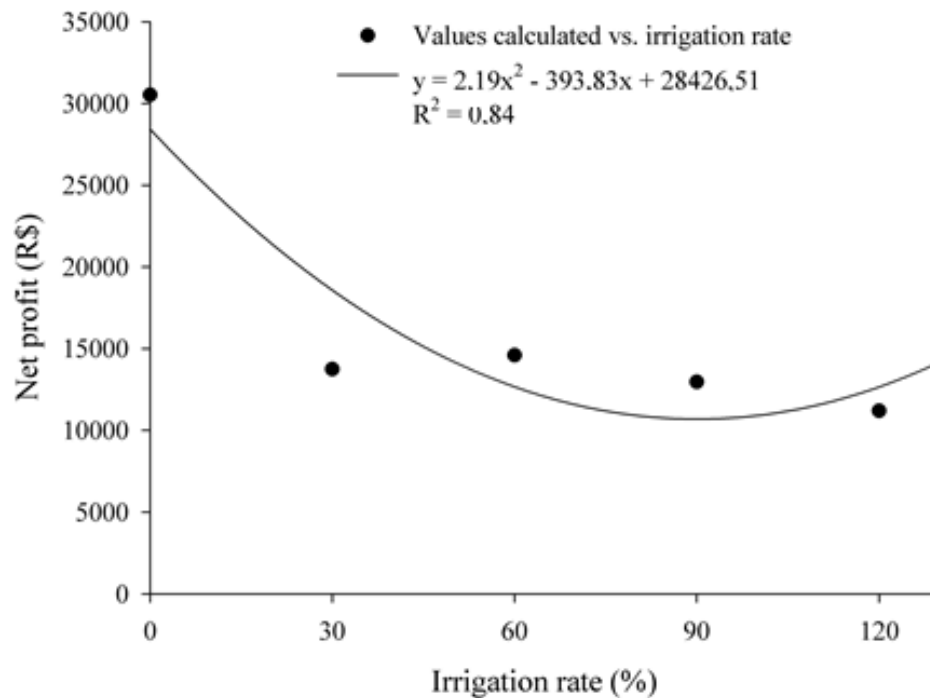
difference of 312 and 147 mm, and 7 days, respectively. These differences were possibly influenced by the period of the crop cycle and climatic conditions of the region, but the irrigation depths applied were similar in both growing seasons.

The production cost for plant and ratoon cane under irrigation and rainfed are shown in Table 3. In plant cane (rainfed condition), planting was the variable that had the highest cost, with 42.19% of the total cost, followed by supplies with 19.27%. Moreover, in plant cane under irrigation, input planting for 30.71%, followed by services (29.95%). For rainfed ratoon cane, input was the variable that had the supplies cost (44.24%), followed by cultural practices (30.45%). In ratoon cane under irrigation, service and supplies costs were those with the highest cost (40.45 and 39.37%, respectively). For plant cane, in rainfed and under irrigation, the variable cost (54.40 and 66.81%, respectively) and the fixed cost represented 45.60 and 33.19%, respectively. For rainfed ratoon cane, the variables cost and fixed cost accounted for 92.84 and 7.16%, and under irrigation, 75.49 and 24.51%, respectively. The difference in production cost for plant cane in rainfed and under irrigation was 27.23%, and for ratoon cane was 57.20%.

Irrigation depth, yield, the gross profit and the total cost are shown in Table 4. There was no significant difference between yield and treatments in both growing seasons. The 60% ET<sub>c</sub> treatment had the best yield in plant and ratoon cane, differing from rainfed with an increase of 10.73 and 7.11%, respectively. The largest gross profit occurred in treatments under irrigation, being 60% ET<sub>c</sub> the greatest, with an increase of 7.79%, compared to rainfed. In addition, the higher total cost was in the irrigated treatment (120% of ET<sub>c</sub>), with a difference (56.46%) compared to rainfed. The net profit in terms of irrigation rate five-year analysis is shown in Figure 2. The rainfed treatments had the greatest net profit and the treatments under irrigation presented a decreased net profit. In relation to rainfed, the lower net profit occurred

**Table 4.** Treatments, irrigation depths (ID), yield, gross profit and the total cost in the cultivation of sugarcane for five years of study.

Treatment (% ET <sub>c</sub> )	Plant cane		Ratoon cane		Gross profit		Total cost	
	ID (mm)	Yield (t ha <sup>-1</sup> )	ID (mm)	Yield (t ha <sup>-1</sup> )	(R\$ ha <sup>-1</sup> )	(US\$ ha <sup>-1</sup> )	(R\$ ha <sup>-1</sup> )	(US\$ ha <sup>-1</sup> )
0	-	158.80	-	176.50	47,564.00	13,589.71	17,039.33	4,868.38
30	126.60	168.60	125.70	183.60	49,665.00	14,190.00	35,922.05	10,263.44
60	253.20	177.90	251.50	190.00	51,584.50	14,738.43	36,993.46	10,569.56
90	379.80	176.30	377.20	187.90	51,034.50	14,581.29	38,064.18	10,875.48
120	506.40	171.60	503.00	185.90	50,336.00	14,381.71	39,135.59	11,181.60

**Figure 2.** Net profit in terms of irrigation for sugarcane crop for five years of analysis.

with 120% da ET<sub>c</sub>, with decrease of 63.30%, the lowest decrease was in 60% da ET<sub>c</sub>, with 52.20%, and the minimum technical efficiency was in 90.04% da ET<sub>c</sub>.

The financial indicators are shown in (Table 5). In rainfed condition, because no there was a need for initial investment it was not possible to determine the IRR. The all flows over the five years of analysis were positive, being possible to calculate the rate of return within each year through the determination of the cumulative rate for the period of five years and their annual equivalent (288.73%). In the treatments under irrigation, the only treatment that presented favorable financial indicators was 60% ET<sub>c</sub>, with *paybacks* giving a financial return before the end of the reported period, without covering initial investment of R\$ 10,000.00. However, further studies with greater amount of planted land, more

production cycles, different genotypes, and irrigation systems are necessary.

The results showed financial viability in rainfed treatments. The only irrigated treatment that showed viability was 60% ET<sub>c</sub>. In the first year of cultivation, the balance of rainfed treatment matched with the average state productivity, which is approximately 55 t ha<sup>-1</sup> (CONAB, 2014). Similarly, Pereira et al. (2015) studied the production cost of sugarcane in the state of Mato Grosso do Sul and found that the sugarcane industry demands high initial investment and farmer's decision making is linked to the collection of real information about profitability. Moreover, the authors concluded that the economic viability of implementation of a sugarcane field is not feasible when the area is smaller than 1,700 hectares and the maximum value for implementation and

**Table 5.** Treatments, the net present value (NPV), internal rate of return (IRR), the equilibrium point (EP), benefit cost (B/C), payback (PB), and discounted *payback* (PBD) for sugarcane crop for five years of study.

Treatment (% ET <sub>c</sub> )	VPL	TIR	(B/C)	EP	EP	EP	EP	EP	Payback	PayBack discounted
	NPV R\$	IRR (%)	(B/C)	1 <sup>o</sup> year (t ha <sup>-1</sup> )	2 <sup>o</sup> year (t ha <sup>-1</sup> )	3 <sup>o</sup> year (t ha <sup>-1</sup> )	4 <sup>o</sup> year (t ha <sup>-1</sup> )	5 <sup>o</sup> year (t ha <sup>-1</sup> )		
0	20,513.64	-	-	56.96	3.41	4.22	4.68	5.20	-	-
30	-217.23	13.23	0.98	76.18	34.41	57.09	68.29	83.57	2.96	4.81
60	402.76	16.12	1.04	73.72	33.75	54.45	64.54	78.03	2.74	4.34
90	-687.73	10.93	0.93	73.26	33.96	55.27	65.69	79.72	3.08	5.21
120	-1,913.92	4.63	0.81	74.98	34.16	56.09	66.86	81.45	3.60	6.62

maintenance of ratoon cane is of R\$ 5,500 ha<sup>-1</sup> and R\$ 900 ha<sup>-1</sup>, respectively. Costa (2012) studied growth, yield, and economic viability of sugarcane under different irrigation levels in the region of Penápolis-SP, using RB855453 and RB965902 varieties. The author concluded that the unique situation that presented positive result of R\$ 210.23 ha<sup>-1</sup>, with an increase of 24.45 t ha<sup>-1</sup> (RB85545 variety), with a maximum economic efficiency irrigation depth of 1,024.53 mm (75% ET<sub>c</sub>) and generated a yield of 182.15 t ha<sup>-1</sup>. Farias (2006), in the study on optimizing the water and zinc use in sugarcane in Paraíba coastal board, stated that the application of 25% ET<sub>c</sub> results in a negative gross profit (loss) of R\$ 9.64 t<sup>-1</sup>. Yet, with 50 and 75% ET<sub>c</sub> generated an average gross profit of R\$ 4.92 t<sup>-1</sup>, and with 100% ET<sub>c</sub>, combined with the application of 2.39 kg ha<sup>-1</sup> of zinc had a gross profit of R\$ 19.60 t<sup>-1</sup>. Furthermore, Cintra et al. (2008) claimed from several authors' conclusions that a supplementary irrigation in the initial stages of development of sugarcane is crucial for increasing yield, especially in ratoon cane. Furthermore, the importance of further research on the responsiveness and production function of sugarcane varieties to irrigation in several production locations was emphasized. Amorim et al. (2007) investigated irrigation costs in sugarcane, carrying out a study with several irrigation systems in Juazeiro-BA, demonstrated that the best irrigation system evaluated by the variables yield per hectare and cost per hectare is dripping irrigation. It is the most viable system, besides its high efficiency in water application by crop utilization, being around 90 to 95%. However, it requires a high initial investment, yet the authors asserted that the expansion of agribusiness depends on the favorable evolution of the Brazilian and world scenario and in particular of macroeconomic and trade policies. The reform of public policy presupposes the provision of equal opportunities for Brazilian producers in relation to their competitors in developed countries, in isonomic conditions of competition.

The technological parameters of plant and ratoon cane under different irrigation management levels are shown in Table 6. In plant cane, irrigation had significant effect on

all parameters (°brix, Pol<sub>sugarcane juice</sub>, Pol<sub>sugarcane</sub>, Purity, TRS<sub>sugarcane</sub>, RTS, and Ethanol), except fiber. In ratoon cane, parameters did not have significant statistical difference, demonstrating different behavior regarding to plant cane, and fiber had the same behavior in both growing seasons. Irrigation influenced on the parameters evaluated in plant cane, agreeing to Silva et al. (2014), who also found differences in performance among the parameters evaluated only in plant cane. Regarding the treatments applied in both seasons, the variables had showed the highest values in the treatments under irrigation.

Moreover, as Assis et al. (2004) studied the response of technological parameters of sugarcane under different irrigation depths and fertilization. They found significant effect (°Brix, fiber, Pol<sub>sugarcane juice</sub>, and TRS<sub>sugarcane</sub>) in plant cane and for ratoon cane, and irrigation had no significant effect on all traits, which agrees with the results of this study. Dalri and Cruz (2008) investigated subsurface drip irrigation on sugarcane yield and quality, demonstrating that irrigation did not affect the technological traits in plant cane, disagreeing with the results obtained in this work. Simões et al. (2015) evaluated different irrigation systems and reported that there was no influence on the technological quality of sugarcane. Neto et al. (2006) studied the response of first ratoon sugarcane to irrigation levels and topdressing. They affirmed that only the variable Pol<sub>sugarcane juice</sub> responded significantly to the irrigation system. Conversely, Simões et al. (2015) and Neto et al. (2006) found different results.

Fibers in the plant cane cycle were lower (10%) and for ratoon cane they were within recommended. Fernandes (2003) and Oliveira et al. (2009) reported mean values among 10.5 and 12.5%, which are recommended for energetic maintenance of sugarcane processing industries. In addition, Barbosa et al. (2007), regarding the ideal amount of fiber, asserted that it has to be between 12 and 13%. For ethanol production, the lower fiber content benefits the process of sugarcane juice extraction and the increase in fiber content hinders the extraction process. Moreover, greater fiber content can

**Table 6.** Treatments, °brix, fiber, Pol%<sub>sugarcane juice</sub>, Pol%<sub>sugarcane</sub>, Purity, TRS%<sub>sugarcane</sub>, RTS and Ethanol for plant and ratoon sugarcane subjected to different levels of irrigation management.

Treatment (% ET <sub>c</sub> )	Plant cane							
	°Brix	Fiber	Pol% <sub>sugarcane juice</sub>	Pol% <sub>sugarcane</sub>	Purity	TRS% <sub>sugarcane</sub>	RTS (kg t <sup>-1</sup> )	Ethanol (L t <sup>-1</sup> )
0	17.20 <sup>b</sup>	10.00	14.60 <sup>b</sup>	12.80 <sup>b</sup>	77.00 <sup>b</sup>	14.30 <sup>b</sup>	130.80 <sup>b</sup>	89.90 <sup>b</sup>
30	17.20 <sup>b</sup>	9.90	14.60 <sup>b</sup>	12.80 <sup>b</sup>	77.30 <sup>a</sup>	14.30 <sup>b</sup>	131.00 <sup>b</sup>	89.90 <sup>b</sup>
60	17.80 <sup>a</sup>	10.00	15.10 <sup>a</sup>	13.30 <sup>a</sup>	77.40 <sup>a</sup>	14.80 <sup>a</sup>	135.20 <sup>a</sup>	92.90 <sup>a</sup>
90	18.00 <sup>a</sup>	10.00	15.30 <sup>a</sup>	13.40 <sup>a</sup>	77.00 <sup>b</sup>	15.00 <sup>a</sup>	136.60 <sup>a</sup>	93.80 <sup>a</sup>
120	17.20 <sup>b</sup>	10.00	14.60 <sup>b</sup>	12.80 <sup>b</sup>	77.30 <sup>a</sup>	14.30 <sup>b</sup>	130.90 <sup>b</sup>	89.90 <sup>b</sup>
CV%	2.09	1.37	2.03	2.15	4.17	1.37	1.38	1.25
Sig	P<1%	P>5%	P<1%	P<1%	P<1%	P<1%	P<1%	P<1%
	Ratoon cane							
0	17.20	10.60	15.50	12.70	81.60	14.90	135.70	94.40
30	17.30	10.80	15.50	12.70	80.60	14.90	135.90	94.60
60	17.50	11.00	15.60	12.80	80.20	15.00	136.20	95.20
90	17.50	10.90	15.80	12.80	81.30	15.10	137.80	96.10
120	17.20	10.80	15.80	12.70	82.90	15.10	137.50	95.80
CV%	2.49	2.50	2.380	2.45	4.79	1.57	1.58	1.50

assist sugarcane lodging resistance.

Apparent sucrose (Pol%<sub>sugarcane juice</sub> and Pol%<sub>sugarcane</sub>) had the same °brix behavior, which are correlated. Under irrigated condition, Pol%<sub>sugarcane juice</sub> and Pol%<sub>sugarcane</sub> had the greatest values compared to rainfed condition and probably irrigation contributed increasing these parameters. According to CONSECANA (1998), the sucrose content values above 12.26% correspond to a sugarcane-standard. In terms of quality, Ripoli and Ripoli (2004) found that sugarcane with values greater than 14% would be able to be industrialized. Moreover, sugarcane will be considered mature when presenting Pol%<sub>sugarcane</sub> ranging from 14.4 to 15.3% (Fernandes 2000).

Treatments under irrigation demonstrated the highest purity values. The raw materials quality standards designed by CONSECANA (2006) establish that the industrial plants could only refuse shipments with purity below 75%. Franco (2003) and Fernandes (2003) reported that the state of São Paulo has a minimum purity reference of 80% at the beginning and 85% in the course of the harvest season in order to recommend sugarcane industrialization.

The study of sugar contents in sugarcane is important because lower values of total reducing sugars (TRS%<sub>sugarcane</sub>) indicate lower industrial yield in production of sugar or alcohol. Moreover, recoverable total sugar (RTS) is the most important variable for both industry and producers, as industrial units determine the price to be paid to the producers based on RTS, following a methodology described by CONSECANA (2006). Thus, the results of larger RTS values imply in greater crop

economic profitability.

The ethanol amounts found in this study were similar to those reported by Oliveira et al. (2012), with values of 90.2 and 115.09 l (maximum and minimum). Neto et al. (2006), studying different irrigation depths and fertilizer levels, had gross yield of alcohol with an average of 6.25 m<sup>3</sup> ha<sup>-1</sup> at the minimum fertilization of 86 kg ha<sup>-1</sup> of N, and 8.91 m<sup>3</sup> ha<sup>-1</sup> at maximum N fertilization of 305 kg ha<sup>-1</sup>. Increasing alcohol productivity due to nitrogen application was also observed by Carvalho et al. (2009), who found that the application of 112 kg ha<sup>-1</sup> of nitrogen provided the greatest yield (9.8 m<sup>3</sup> ha<sup>-1</sup> of alcohol).

Results found in this research, regarding irrigated and rainfed sugarcane, are similar to those reported by Moura et al. (2005), Farias et al. (2009), Deon et al. (2010), Oliveira et al. (2012), Oliveira et al. (2014a, 2014b), Silva et al. (2014), and Simões et al. (2015), observing significant positive correlation among irrigation depth and the variables that define the quality of the sugarcane raw material. Dalri et al. (2008) reported that the irrigation factor did not presented significant effect for all traits studied in plant cane. Dalri and Cruz (2008) researched ratoon cane and second ratoon cane and they found that there were no statistical differences between the irrigated treatment and the control treatment. In fact, these authors observed that there were no treatment effects on the sugarcane technological quality in both cycles. Farias et al. (2009) found that only the fiber was negative. Deon et al. (2010) investigated the second ratoon cane and observed that technological variables were not altered by irrigation. According to Oliveira et al. (2011a, b), there was difference only for °Brix, Pol%<sub>sugarcane juice</sub>, and fiber,



with reduction only in the fiber content among the hydric regimes. Correia et al. (2014) observed that for the irrigation factor, there was significant difference in  $Pol\%_{\text{sugarcane juice}}$  and purity.

## Conclusion

The sugarcane grown in rainfed and irrigated with 60%  $ET_c$  had economic viability with financial return in the year of implementation and 4 years and 4 months, respectively. The difference in the cost of production and the net profit of sugarcane grown in rainfed and 60%  $ET_c$ , was 53.94 and 52.20%, respectively.

In the crop cycles, the irrigation promoted an increase in technological parameters for the production of ethanol compared to rainfed sugarcane. RTS received the largest increase in treatment 90% of  $ET_c$  with a difference of 4.25 and 1.52% for the plant and ratoon cane, respectively. The smallest increases were observed for purity and  $Pol\%_{\text{sugarcane}}$ , in treatment 60% of  $ET_c$ , with 0.52 and 0.78% in the plant and ratoon sugarcane, respectively.

Regarding irrigation, in plant cane, the only variable that showed no statistically significant difference was the fiber and, in ratoon cane, the technological parameters showed no statistically significant difference.

## Conflict of Interests

The authors have not declared any conflict of interests.

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