ISSN ONLINE 1808-8546/ISSN CD 1808-3765

ECONOMIC DEPTH OF DRIP IRRIGATION ON SUGARCANE

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1 ABSTRACT

To optimize the use of irrigation along of the ratoons, was conducted a study was in Center of Agricultural Sciences of Federal University of Alagoas with seven irrigation depths (0, 25, 50, 75, 100, 125 and 150% of reference evapotranspiration-ET_0), in three cycles of production between January 2009 and February 2012. The adjustment of curve responses of the agricultural and agro-industrial yield of crop to irrigation depths has been performed. The irrigated sugarcane with 150% of ET_0 in the first, second and third production cycles has produced an average of 48.0 Mg ha^{-1} more than the sugarcane cultivated without irrigation. For an average value of 0.55 R$ kg^{-1} of commercially recoverable sucrose content (CRS), the depth of maximum economic efficiency was 666 (85% of ET_0), 290 (65% of ET_0) and 397 mm (70% of ET_0) with net revenue of US$ 3,272.07, US$ 2,456.90 and US$ 1,474.51 ha^{-1} in plant cane, 1st and 2nd ratoon, respectively. The final agro-industrial yield per acreage unit is more dependent of the stems yield and not of the amount of CRS per ton of cane. However, the economic irrigation depth in the range 0 to 150% of ET_0 is directly proportional to the increase in the price of CRS.

Keywords: stems yield, CRS, cost of water for irrigation

SILVA, S.; DANTAS NETO, J.; TEODORO, I.; SILVA, S. S.; NASCIMENTO, R.; BARBOSA, G. V. S.
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2 RESUMO

Para otimizar o uso da irrigação ao longo das socarias de cana-de-açúcar, foi conduzido um experimento no Centro de Ciências Agrárias da Universidade Federal de Alagoas com sete lâminas de irrigação por gotejamento (0, 25, 50, 75, 100, 125 e 150% da evapotranspiração de referência-ET_0), em três ciclos de produção durante janeiro de 2009 a fevereiro de 2012. As curvas de respostas da produtividade agrícola e industrial da cultura foram ajustadas às lâminas de irrigação. A cana-de-açúcar irrigada com 150% da ET_0 no 1º, 2º e 3º ciclos de cultivo,

Recebido em 11/06/2015 e aprovado para publicação em 25/06/2015

produziu em média 48,0 t ha^{-1} a mais do que a cana cultivada sem irrigação. Para o valor médio de R$ 0,55 kg^{-1} de açúcares totais recuperáveis (ATR), a lâmina de máxima eficiência econômica foi 666 (85% da ET_0), 290 (65% da ET_0) e 397 mm (70% da ET_0), com receita líquida de US$ 3.272,07, US$ 2.456,90 e US$ 1.474,51 ha^{-1} em cana-planta, 1ª e 2ª soca, respectivamente. O rendimento agroindustrial final por unidade de área cultivada é mais dependente da produtividade de colmos e não da quantidade de ATR por tonelada de cana. No entanto, a lâmina econômica de irrigação no intervalo de 0 a 150% da ET_0 é diretamente proporcional ao aumento do preço do ATR.

Palavras-chave: produtividade de colmos, ATR, custo da água para irrigação.

3 INTRODUCTION

The sugarcane crop is produced in different climatic regions of the world and its global agricultural production is around 1.5 billion tons of stems per year. According to the National Supply Company - CONAB (2014), Brazil is the world's largest producer and in the 2013/14 harvest produced 658.8 million tons, with an average yield of 74.7 Mg ha^{-1}. Among the Brazilian regions, the Northeast is the third largest producer of sugarcane, with a production of 53 million tons in the 2013/14 harvest. However, this region has the lowest yield (51.5 Mg ha^{-1}) to be disadvantaged by the irregular distribution of rainfall throughout the year (SOUZA et al., 2004; CARVALHO et al., 2013a; b).

The agro-industrial productivity of sugarcane is extremely dependent of the rainfall distribution over the production cycles. This effect was observed by Teodoro et al. (2015) and Abreu et al. (2013), who found that, in the cycle in which there was a higher water deficit, agricultural and agro-industrial productivity were affected significantly. This, for that the yields from the sugarcane industry are not impaired, depending on the amount and uniformity of rainfall distribution, the use of irrigation is required (TEODORO et al., 2009). However, in view of the great water need during the production cycle, more efficient irrigation systems in water use are required, such as drip, for example (PARKES et al., 2010; BOAS et al., 2011; MARTINS et al., 2011).

Recent studies in Brazil (FARIAS et al., 2008; OLIVEIRA et al., 2009; SILVA et al., 2014) show that the response of sugarcane to irrigation is significant and can be used as a decisive factor in the implementation of technologies in sugarcane fields. However, as irrigation is one of the most influential factors in productivity and cost of production of sugarcane (TEODORO et al., 2013), the use of this agricultural technique in the sugarcane fields requires close attention, since the farmer must use the amount of water to provide the maximum economic return (FERNANDES, 2003). Thus, to optimize the use of water in irrigation of sugarcane, this study aimed to analyze the levels of this resource that would provide economically viable yields along the ratoons.

4 MATERIAL AND METHODS

The experiment was conducted at the Center of Agricultural Sciences at the Federal University of Alagoas in Rio Largo-AL (09° 28' 02" S; 35° 49'43"W; 127 m), from January 2009 to February 2012, in an 0.5 ha area in three production cycles of sugarcane. The soil of the area was classified by Carvalho (2003) as cohesive argisolic yellow oxisol of silt mediumtextured with water storage capacity in the soil of approximately 1.0 mm at each 1.0 cm of depth. The climate is characterized, by Thornthwaite and Mather rating, as hot and humid (B_1), megathermic (A'), with moderate water stress in summer (s) and large excess of water in winter (w_2). The average rainfall in the region is 1,800 mm per year (SOUZA et al., 2004).

The statistical design used was randomized blocks with seven treatments and four replications. The plots consisted of 10 lines with 12 meters long and the treatments were seven irrigation depths at levels of 0 (L0), 25 (L1), 50 (L2), 75 (L3), 100 (L4), 125 (L5) and 150% (L6) of the reference evapotranspiration (ET_0).

The irrigation system used was drip superficial with drip tapes 22 mm of diameter, drippers at each 0.5 m and 2.0 m between lines, operating pressure of 14 mca and nominal flow rate of 1.0 l h^{-1}. The variety RB92579 was used and planted in double rows spaced 1.4 x 0.6 m, putting up 18 gems per linear meter. Planting was done from 12 to 21 January 2009. The sugarcane plant fertilizing with NPK and liming were made based on the chemical analysis of the soil. The foundation fertilization was performed by placing the fertilizer in the bottom of the furrow with 180 kg ha^{-1} of P_2O_5 and 200 kg ha^{-1} of K_2O. 100 kg ha^{-1} of N was placed in coverage at 66 days after planting. The fertilization of the ratoons was held with 120 kg ha^{-1} of P_2O_5, 160 kg ha^{-1} of K_2O and 100 kg ha^{-1} of N, 30 days after cutting. The nitrogen source used in the three production cycles was urea, which was incorporated into the soil to prevent volatilization. The first harvest took place in February 22nd, 2010, the second in February 28th, 2011 and the third on February 20th, 2012.

Agricultural productivity was estimated by weighing the production of ten central rows of each plot (100 linear meters), making use of a dynamometer with capacity to weigh up to 100 kg, in which the stems sheaves were raised manually by two people. Chemical analysis of the sugarcane to determine the commercially recoverable sucrose content (CRS) was made at the laboratory of Usina Santa Clotilde sugar mill, located in Rio Largo - AL with 25 stems of each plot. Agricultural and agro-industrial productivity of crop as a function of gross irrigation depth was submitted to analysis of variance by F test and later regression analysis was made when significant.

The response function of crop to irrigation levels was obtained by quadratic polynomial regression models and the equation used to estimate the irrigation depth which provides maximum productivity was deduced by equating to zero the first derivative of the production function (VIEIRA et al., 2012). According to the authors, the production costs and the selling price of the product were used for the economic analysis of production. Costs were divided into fixed costs (operating cost of sugarcane production) and variable costs (gross irrigation depth of each treatment), whose values were used to calculate the agricultural contribution margin (MCA, net revenue), which was converted into US\$ ha^{-1}, with equivalent trade dollar at R\$ 2.20, according to the BOVESPA, on July 1st, 2014.

Prices of CRS, used for remuneration calculation, were three standardized values due to variation in harvests. The cost values of water millimeter, of the sugarcane annual cost production and cost of cutting, loading and transportation (CCT), used in the calculations, were obtained from sugar mills, which use drip irrigation systems and have the costs of production monitored by computer programs (Table 1). The operating cost of sugarcane production was considered as the sum of planting cost, cultural practices and the CCT cost of each production cycle. The planting cost was diluted in the annual cost of crop production considering 10 years of useful life or 10 harvests without renewal of plantation. The total cost of CCT in each cycle varied according to the estimated average yield. In calculating the water millimeter cost were considered 10 years of the amortization period for the capital employed in the irrigation system, which theoretically corresponds to its useful life in the field. Price of the sugarcane delivered at industry was calculated according to Fernandes (2003), wherein the value of CRS amount (kg Mg^{-1}) used was the estimated average among the treatments for each production cycle, since there was no change with irrigation depths due to water stress caused by the ripening of sugarcane. The water depth of maximum economic efficiency was estimated according to Vieira et al. (2012).

Table 1. Cost of the water millimeter for drip irrigation, costs of planting and cultural practices, cost with cutting, loading and transportation (CCT) and price of commercially recoverable sucrose content (CRS).

Description	R\$ mm^{-1}	%	R\$ ha^{-1}
Hydraulic Infrastructure / Buildings (amortized in 20 years)	0,25	6,4	
Irrigation system (amortized in 10 years)	1,16	29,7	
Annual operating cost of irrigation	2,50	63,9	
Total annual cost of irrigation	3,91	100,0	
Planting (amortized in 10 years)			500,00
Annual cost with cultural practices			1.300,00
Cost with cutting, loading and transportation - CCT (R\$ Mg^{-1}): 17,00			
Annual cost of production (Planting + cultural practices + CCT):			
Plant-sugarcane with average TCH of 160,3 t ha^{-1}			4.525,10
1ª ratoon with average TCH of 130,4 t ha^{-1}			4.016,80
2ª ratoon with average TCH of 101,1 t ha^{-1}			3.018,70
Price of CRS (R\$ kg^{-1}): 0,30; 0,55 e 0,80			
Average CRS between treatments: 145,7 kg Mg^{-1} (plant-sugarcane) 147,7 kg Mg^{-1} (1ª ratoon) 144,2 kg Mg^{-1} (2ª ratoon)			

5 RESULTS AND DISCUSSION

The 1st, 2nd and 3rd cycles of cultivation, lasting 406, 371 and 357 days, had 2,208, 1,952 and 1,915 mm of total rainfall, respectively. However, in the 1st, 2nd and 3rd cycles, the effective rain ranged 705-834 mm, 611-841 mm and 609-762 mm in L6 and rainfed treatment, respectively (Table 2). The irrigation depths ranged 157-873 mm, 127-734 mm and 117-707 mm between L1 and L6, in the 1st, 2nd and 3rd cycles, respectively, during which the total effective depth applied in the irrigated treatments remained in the interval 981-1,578, 906-1,345 and 837-1,316 mm, respectively.

Table 2. Total values of effective rain, irrigation, effective rain more irrigation, stems yield (TCH) and commercially recoverable sucrose content (CRS) for treatments in the harvests of 2009/10, 2010/11 and 2011/12 in the region of Rio Largo-AL.

Treat.	Effective rain (mm)			Irrigation (mm)			Effective rain + Irrigation (mm)			TCH (Mg ha^{-1})			CRS (kg Mg^{-1})		
	1º *	2º	3º	1º	2º	3º	1º	2º	3º	1º	2º	3º	1º	2º	3º
L0	834	841	762	0	0	0	834	841	762	118	112	79	147	147	143
L1	824	779	720	157	127	117	981	906	837	141	120	93	147	148	145
L2	805	761	698	312	240	234	1.117	1.001	932	160	126	96	149	151	146
L3	777	751	677	447	346	347	1.224	1.097	1.024	161	136	104	145	149	147
L4	727	715	630	585	473	467	1.312	1.188	1.097	173	139	108	147	149	143
L5	707	663	610	741	587	572	1.448	1.250	1.182	181	136	108	144	145	141
L6	705	611	609	873	734	707	1.578	1.345	1.316	188	144	121	142	146	144

*Number corresponding to the production cycle of the culture, wherein 1º: plant-sugarcane (2009-2010, 406 days with total rain of 2.208 mm); 2º: first ratoon (2010-2011, 371 days with total rain of 1.952 mm); 3º: second ratoon (2011-2012, 357 days with total rain of 1.915 mm); Treat.: treatment.

The productivity values depending on irrigation depths submitted to F test were significant at the 1% level of error probability. The mathematical equations used as production functions presented significant adjusting of the coefficients only for TCH, wherein the determination coefficient of equation (R^2) were 98, 95 and 95% on the 1st, 2nd and 3rd production cycles (Table 3). Since there was no maximum point followed by decrease in TCH range studied in this work, the quadratic coefficients of the regression equation were not significant, but the study of second degree equation became reliable due to the behavior of smaller additions (smaller marginal physical product) of TCH near the point with the maximum irrigation depth.

Table 3. Mathematical equations to estimate the stems yield (TCH) and of commercially recoverable sucrose content (CRS) of sugarcane, as a function of drip irrigation depths (L) in the plant-sugarcane (harvest of 2009/10), 1ª ratoon (harvest of 2010/11) e 2ª ratoon (harvest of 2011/12) in the region of Rio Largo-AL.

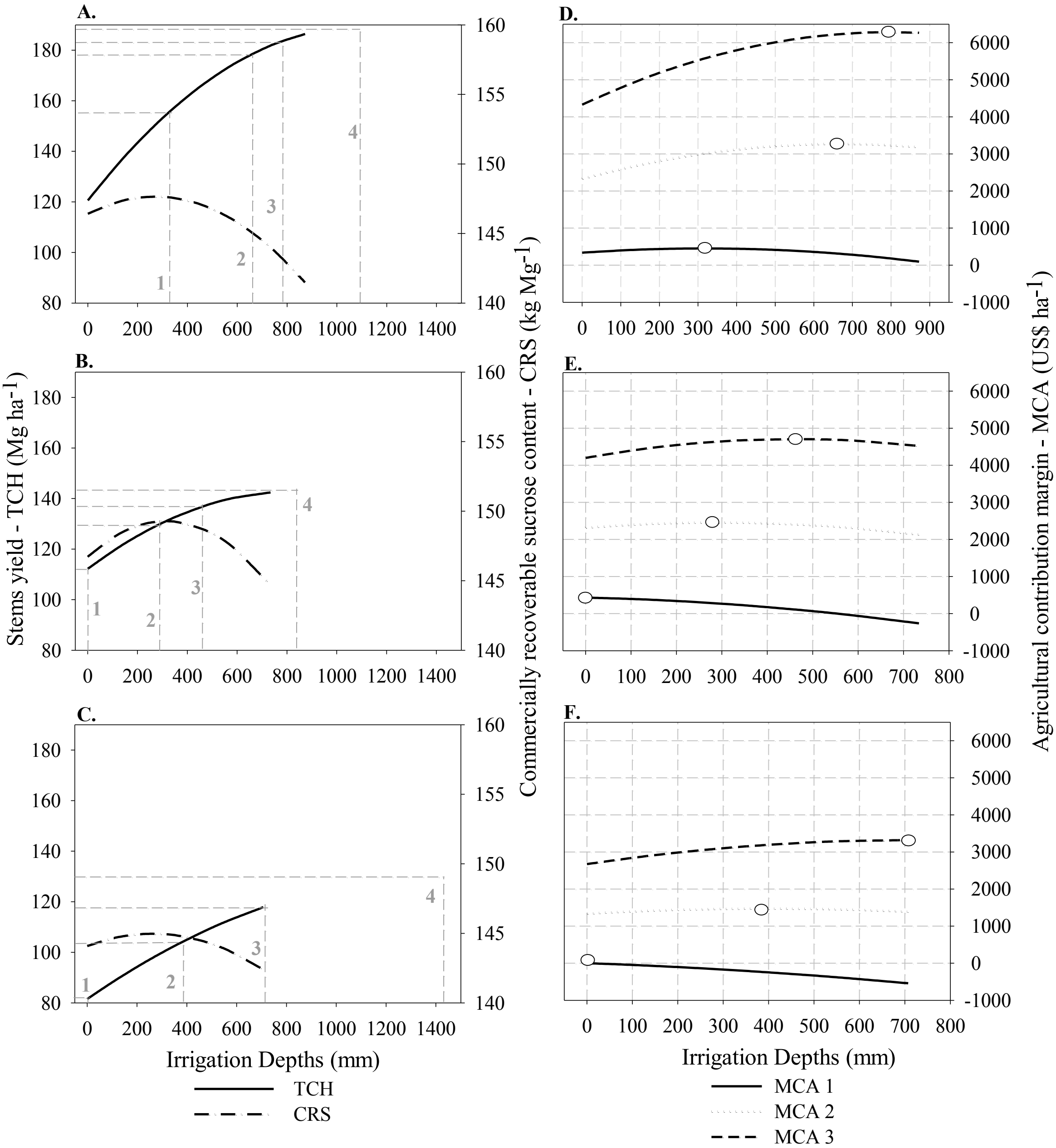
	Stems yield (TCH) in Mg ha^{-1}	
Plant-sugarcane	$TCH = 120{,}5559^{**} + 0{,}1261^{**} L - 0{,}000058097^{ns} L^2$	$R^2 = 0{,}98$
1ª ratoon	$TCH = 112{,}1860^{**} + 0{,}0737^{*} L - 0{,}000043826^{ns} L^2$	$R^2 = 0{,}95$
2ª ratoon	$TCH = 81{,}5167^{**} + 0{,}0683^{*} L - 0{,}000023709^{ns} L^2$	$R^2 = 0{,}95$
	Commercially recoverable sucrose content (CRS) in kg Mg^{-1}	
Plant-sugarcane	$CRS = 146{,}4196^{**} + 0{,}0091^{ns} L - 0{,}000016779^{ns} L^2$	$R^2 = 0{,}75$
1ª ratoon	$CRS = 147{,}1734^{**} + 0{,}0139^{ns} L - 0{,}000023209^{ns} L^2$	$R^2 = 0{,}63$
2ª ratoon	$CRS = 144{,}0858^{**} + 0{,}0068^{ns} L - 0{,}00001273^{ns} L^2$	$R^2 = 0{,}18$

ns, * and **: not significant and significant at 5 and 1%, respectively, by t test.

The choice of fitting equation must be made by the mathematical properties of the function to represent the usual behavior of culture and not only by the greater coefficient of determination. According to some authors (LIMA JÚNIOR et al., 2010; OLIVEIRA et al., 2011), the second degree equation is one of the mathematical equations more used as a production function. However, the production functions should, generally, be used at convenient intervals, that is, without exceeding reasonable input levels. During the economic analysis, attention should be paid to the fact that the economic depth depends of the prices ratio of the water millimeter (P_x) and Mg of cane (Py) and not of its price itself, that is, when the mm becomes more expensive relative to Mg of sugarcane, the economic depth decreases.

The quadratic equation curves for agricultural yield and commercially recoverable sucrose content (CRS) per ton of cane as a function of gross irrigation depth and in the three production cycles are shown in Figures 1A, 1B and 1C. Agricultural productivity between L0 and L6 ranged 120-186 Mg ha^{-1}, 112-142 Mg ha^{-1} and 81-117 Mg ha^{-1}, in the 1st, 2nd and 3rd production cycles, respectively. The productivity gap between the rainfed treatment and irrigated with the greater depth was 65, 30 and 36 Mg ha^{-1}, corresponding to 55, 27 and 45% of the agricultural productivity of sugarcane without irrigation (rainfed) in the 1st, 2nd and 3rd cycles of cultivation, respectively.

Figure 1. Stems yield (TCH) and agro-industrial yield (CRS) in the harvest 2009/10 (A), 2010/11 (B) and 2011/12 (C), as also the agricultural contribution margin (MCA) as a function of drip irrigation depths in sugarcane in 2009/10 (D), 2010/11 (E) and 2011/12 (F), in the region of Rio Largo-AL.



Points on the curve of TCH marked with 1, 2 and 3 and also MCA 1, MCA 2 and MCA 3 are the maximum economic depths for the CRS prices equal to R$ 0.30, R$ 0.55 and R$ 0.80 kg^{-1}, respectively; 4 is the point of maximum TCH estimated by the production function.

The response of sugarcane to irrigation was greater in smaller treatments. For example, in the 1st, 2nd and 3rd production cycles, between L0 and L1 the crop produced an average of 117, 69 and 66 kg of stems per mm of irrigation water, while between L5 and L6 the response was 32, 15 and 38 kg stems mm^{-1}, respectively. This is due to the law of diminishing returns "law of the minimum" formulated by von Liebig (1840). This law applies to all living beings. Thus, in this case, as the soil moisture in the treatments with higher depths was no longer the limiting factor for plant growth, crop yield only increase under optimal conditions of nutrients, air temperature, light, CO_2 and other factors of vegetable production. The maximum physical yield of crop, estimated by the production function, it would be 189.1, 142.8 and 130.2 Mg ha^{-1}, obtained with gross irrigation depth of 1,087, 825 and 1,424 mm in the 1st, 2nd and 3rd cycles, respectively. For yields above those values, that is, with the crop in optimal moisture conditions in the soil, is necessary to resort to other agricultural practices such as fertilization, pests and diseases control, and others.

Agricultural productivity of maximum economic efficiency was calculated according to the cost of the water millimeter applied and the price of sugarcane megagram (Mg), which depends on the price of CRS. Although the CRS (kg Mg^{-1}) have presented graphically degree of variation depending on water depths, this variation was not significant and can be disregarded once that, due to water stress caused for the ripening of sugarcane, treatments remained practically in the same condition. Thus, in the 1st year the productivity of maximum economic efficiency, with the CRS price of R$ 0.30 kg^{-1}, was 154.6 Mg ha^{-1} obtained with 316 mm gross irrigation. For the average price of CRS of R$ 0.55 kg^{-1}, the productivity of maximum economic efficiency was 178.8 Mg ha^{-1} obtained with 666 mm. With the CRS R$ 0.80 kg^{-1}, the maximum economic depth was 798 mm and generated TCH equal to 184.2 Mg ha^{-1}.

In the second production cycle, with the CRS equal to R$ 0.30 kg^{-1}, irrigation would not be viable and so the maximum economic TCH was 112.2 Mg ha^{-1} obtained with 0 mm of irrigation. With CRS remuneration equal to R$ 0.55 kg^{-1}, the maximum economic depth was 290 mm, resulting in TCH of 129.9 Mg ha^{-1}. With the CRS price of R$ 0.80 kg^{-1}, the maximum economic TCH was 136.7 Mg ha^{-1} obtained with 457 mm.

In the third year, for the CRS prices of R$ 0,30, R$ 0,55 and R$ 0,80 kg^{-1}, the economic TCH was equal to 81,5, 104,8 e 118,2 Mg ha^{-1}, obtained with 0, 397 and 718 mm, respectively.

The maximum agricultural contribution margin (MCA) of 1st cycle generated with CRS prices equal to R$ 0.30, R$ 0.55 and R$ 0.80 kg^{-1} was US$ 453.20, US$ 3,272.07 and US$ 6,285.62 ha^{-1}, respectively (Figures 1D, 1E and 1F). In the 2nd year the maximum values of MCA were US$ 433.87, US$ 2,456.90 and US$ 4,705.50 ha^{-1} for the CRS of R$ 0.30, R$ 0.55 and R$ 0.80 kg^{-1}, respectively. In the 3rd year of cultivation the MCA had maximum value of US$ 3.05, US$ 1,474.51 and 3,321.83 ha^{-1} for respective CRS values equal to R$ 0.30, R$ 0.55 and R$ 0.80 kg^{-1}.

The MCA of plant-sugarcane with CRS of R$ 0.55 kg^{-1} was 33 and 122% greater than the 1st and 2nd cycle, respectively. For the CRS of R$ 0.80 kg^{-1} the MCA of 1st cycle was 34 and 89% greater than the production of the 2nd and 3rd cycle, respectively. As the plant-cane usually has greater vegetative vigor, it can produce biomass and generate enough revenue to pay off the deployment cost of sugarcane field if the CRS has a minimum price of R$ 0.45 kg^{-1}. However, if the CRS price is too low or if the planting-cane has low quality, the farmer can extend the payback period for a determined number of harvests due to factors such as the useful life of sugarcane field (plantation renewal time) and the expectation of yield in each cycle. Furthermore, the farmer must be aware of the fact that, as the MCA depends on the operating cost of sugarcane production and in this is diluted the costs with cutting, loading and transportation (CCT), and greater is the stems biomass produced, the greater will be the cost of the CCT. However, in this study we used the average cost of CCT among the treatments, because the objective was to analyze only the change of the cost with irrigation water. Thus, the analysis of the interaction between the two costs can be performed in other studies to be developed.

Vieira et al. (2012) found, by working with the variety RB867515, irrigated by center pivot and total depths between 1,242 and 2,086 mm, a maximum crop yield of 125.9 Mg ha^{-1}

with total depth (rain + irrigation) of 1,854.4 mm. The depth of greater economic efficiency was 1,726.2 mm for an agricultural yield of 123.9 Mg ha^{-1}. The greater amount of sugar by megagram of stems (CRS) was 141.3 kg^{-1} Mg to the total depth of 1,617.7 mm. From this value the CRS has been reduced due to the greater amount of available water for the crop in the ripening stage, wherein the compensation of high TCH and low CRS resulted in maximum sugar yield of 17.25 Mg ha^{-1} with total depth of 1,740.5 mm.

Farias et al. (2009), studying the water use efficiency of sugarcane in the region of Capim-PB, has observed that the maximization of the efficient water usage for variety SP 79-1011 has been obtained with total depth of 1,276.29 mm.

The calculation of input costs in agriculture to have the maximum return on capital involves several factors that cannot always be controlled, especially when it comes to environmental factors. Thus, works like this serve to be taken as the basis of administrative decisions, provided that the conditions are similar to the place where this research was conducted. In addition, economic issues, as input prices and agricultural commodities are subject to change daily, getting to the administrator criterion to seek the best solution and choose the most compensatory alternative to the use of an input.

6 CONCLUSIONS

For regions with edaphoclimatic characteristics similar to the region of this research, it is concluded that:

The response of sugarcane to irrigation levels is statistically significant in the first, second and third years of cultivation;

The maximum physical yield in plant sugarcane, first and second ratoons, is obtained with irrigation depth equal to 138, 184 and 252% of ET_0, respectively;

The sugarcane irrigated with maximum Kc of 1.5 (150% of ET_0), in the first, second and third production cycles, produces an average of 48.0 Mg ha^{-1} more than the sugarcane cultivated without irrigation;

The amount of CRS per ton of cane as a function of irrigation depths follows a quadratic equation, but almost no effect on the final agro-industrial yield by unit of acreage, being this solely dependent of stems yield;

The economic irrigation depth in the range of 0 to 150% of the ET_0 of the rainless period is directly proportional to the increase in the price of CRS; and for the average value of R$ 0.55 kg^{-1} of CRS, the depth of maximum economic efficiency is 666 (85% of ET_0), 290 (65% of ET_0) and 397 mm (70% of ET_0), generating agricultural contribution margin of US$ 3,272.07, US$ 2,456.90 and US$ 1,474.51 ha^{-1} in plant sugarcane, 1st and 2nd ratoons, respectively. The average economic depth is 451 mm (73% of ET_0) and generates net revenue of US$ 2,401.16.

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