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ECONOMIC INDEXES OF MAIZE UNDER LEVELS OF WATER, NITROGEN AND PLANTING SEASONS

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ABSTRACT

The objective of this work was to evaluate economic indexes of maize under water and nitrogen (N) levels. The experiment was conducted in two seeding seasons (spring/summer and autumn/winter) in Rio Largo, Alagoas, Brazil, with 20 treatments and four repetitions. Maize was submitted to five irrigation levels (40, 80, 120, 160 and 200% of crop evapotranspiration - ET_c) and four nitrogen fertilization rates (0, 75, 150, 225 kg ha^{-1} of N). The crop was drip irrigated, where the costs of irrigation and nitrogen fertilizer more the sale price of the corn sack were used to determine the economic level of water and N. The maximum yield of maize grains grown in the rainy and dry seasons can be obtained with nitrogen rates equal to 156 kg ha^{-1} and above 225 kg ha^{-1}, respectively. In the dry season, maximum yield can be obtained with irrigation level equivalent to 164% of ET_c. Depending on input prices and grain sales, the most economically efficient nitrogen dose for the rainy season is around 93 kg ha^{-1}, while for the dry season it averages 200 kg ha^{-1}; for spring-summer cultivation, the maximum economical irrigation depth corresponds to 96% of ET_c.

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INTRODUCTION

The agricultural productivity of maize in the State of Alagoas, Brazil, is very low (1.0 Mg ha^{-1}) in relation to the potential of cultivars currently used in commercial crops (CONAB, 2018). The main reasons for this low agricultural productivity are: the technological level used by farmers, without fertilization, control of inadequate native plants and the irregular distribution of rainfall in the region, which even during the rainy season, small summers that cause water deficiency in the soil occur (Carvalho *et al*., 2013). The low technological level and the summer influence the ecophysiological variables such as photosynthesis, transpiration, growth, development and agricultural productivity of the crop. According to Brito *et al.* (2013), the occurrence of water deficit during tilling and grain filling causes losses in agricultural productivity because in this phase occurs the synthesis of yield components. The agronomic technique to mitigate the effects of deficit of water on the soil is irrigation. This technology considerably increases the agricultural productivity of agricultural enterprises, but is very costly. Therefore, the definition of the adequate amount of water, without deficit and excess water, is essential to optimize the economic yields of agriculture. The choice of the planting season is also fundamental to have better weather conditions and sufficient rainfall to meet the water demands of the crops. Similarly, fertilizer planning is necessary to ensure an increase in corn agricultural productivity, because this factor is determinant of the economic results of the harvest, especially the use of nitrogen (N). Several researchers studied nitrogen fertilization in maize and observed significant responses by culture in several variables analyzed (Godoy *et al*., 2013; Silva *et al*., 2013; Dantas *et al*., 2014). For Veloso *et*

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al. (2009) N is the most absorbed and exported nutrient, as well as the one with the highest cost and the one that most influences corn productivity. For, the growth and accumulation of dry matter of the plant depend on this element to constitute the proteins and enzymes, especially those that act on photosynthesis, besides the chlorophyll and nucleic acid molecules (Fornasieri Filho, 2007). The nutritional requirement of this crop in relation to nitrogen (N) grows linearly to some extent, where there is an increase in productivity and from the maximum point the productivity decreases. The use of technologies that make it possible to improve soil water and nutritional conditions is of great importance for increasing productivity (Arf *et al.*, 2007). However, besides the choice of the growing season, it is necessary to quantify the irrigation depth and the amount of fertilizers with higher economic efficiency. Therefore, the objective of this work was to evaluate economic indices of corn under water and nitrogen levels in two growing seasons in the region of Rio Largo, AL.

MATERIAL AND METHODS

The experiment was carried out at the Center for Agricultural Sciences of the Federal University of Alagoas, Rio Largo, Brazil (09 ° 28'02”S and 35 ° 49'43” W, 127 m altitude), in an area of 3,040.0 m^2, in an argisolic cohesive Yellow Latosol with a medium/clayey texture and a slope less than 2%. Experimental trials were carried out in two seasons, the first being an autumn-winter cultivation from February 29 to June 20, 2016, and the second a spring-summer cultivation from 19 November 2017 to 19 March 2018. The statistical design used was randomized blocks in the split plot with four replications. The treatments were five irrigation depths (L1-40, L2-80, L3-120, L4-160 and L5-200% of ET_c) in the plots and four doses of N (0, 75, 150, 225 kg ha^{-1}) in the subplots. The tillage was done with two harrows (plowing and grading) and furrowing was performed manually with 8.0 m long ridges spaced 0.8 m, resulting in five plant rows per subplot (32 m^2) and 20 rows per plot (128 m^2). Liming was performed according to soil analysis to raise base saturation to 60%.

Foundation fertilization was based on the expected yield of 10 t ha^{-1}, according to Coelho (2007). For this, the source of phosphorus plus half of the potassium was applied. The second half of potassium plus nitrogen were applied as cover at 15 days after planting (DAP), where nitrogen fertilization occurred according to the treatments of each subplot. Before planting the irrigation system was assembled and tested to ensure uniformity of germination and emergence. The AG7088 corn hybrid was sown by placing two seeds every 0.25 m, and when the plants reached 4 fully expanded leaves, thinning was done to remove the less vigorous plant, leaving 50,000 plants per hectare. Spontaneous herbs were controlled by hand weeding and herbicides, with atrazine at 2.6 L ha^{-1} and glyphosate at 6.5 L ha^{-1}. Insecticide was also applied due to the attack of the 0.6 L ha^{-1}metomil caterpillar. The irrigation system used was surface drip with 16 mm diameter drip tapes, drippers every 0.2 m and 0.8 m between lines, being one irrigation line per row of plants, measured service pressure of 5 mca and flow rate 1.1 L h^{-1}. Irrigation during the initial phase was carried out so as not to cause water deficit to the plants, where depths between 3 and 6 mm were applied in season 1 and from 4 to 14 mm in season 2. From the beginning of the growth phase, the depths irrigation were differentiated according to the treatments, in which the control of the depths and the irrigation frequency was performed using electronic spreadsheets containing rainfall, evapotranspiration and other necessary data. Agrometeorological data on rainfall, temperature and relative humidity of air, solar radiation and reference evapotranspiration (ET_o) were obtained from the CECA/UFAL Irrigation and Agrometeorology Laboratory (LIA), which maintains an automatic data acquisition station (Model Micrologger CR10X, Campbell Scientific) next to the experiment. The actual crop evapotranspiration (ET_r) calculation procedures were based on the methodology described and adapted for dripping by Allen *et al.* (1998), Allen *et al.* (2005) and Silva *et al.* (2012). The ET_0 was calculated by the Penman-Monteith method (Equation 1):

$$ETo = \frac{0{,}408\,\Delta(R_n - G) + \left(\gamma \frac{900}{T+273}\right) u_2 (e_s - e)}{\Delta + \left[\gamma(1 + 0{,}34\, u_2)\right]} \qquad \ldots\ldots(1)$$

Where: Δ is the slope of the saturated water vapor pressure versus air temperature curve (kPa $^{\circ}C^{-1}$); Rn is the measured net radiation (MJ m^{-2} day^{-1}); G is the heat flux in the soil (MJ m^{-2} day^{-1}); γ is the psychometric coefficient; T is the average air temperature; u_2 is the average wind speed at 2 m height (m s^{-1}); *es* is the air vapor saturation pressure (kPa) and *e* is the air vapor vapor pressure (kPa).

The ET_r was calculated by the “single” Kc method, as presented in Equation 2. The K_s coefficient represents the effects of soil water deficit in the root zone on crop evapotranspiration (ET_c). The ET_c was calculated by multiplying the ET_o by the crop coefficient (K_c). The K_c used was the Food Agriculture Organization-FAO 56 (Allen et al., 1998), whose initial, intermediate and final phase values were 0.40, 1.2 and 0.6, respectively. The initial K_c was adjusted by the graph method, considering drip irrigation, while the growth phase K_c and the final K_c were estimated by the equation method, both methodologies described in FAO-56. The growth phase K_c was interpolated between the initial and the intermediate.

$$ET_r = K_s \times ET_c = K_s \times K_c \times ET_o \qquad \ldots\ldots\ldots\ldots.(2)$$

Grain harvesting in the useful area of the subplot was carried out during the physiological maturation phase, where the grain yield (kg ha^{-1}) was estimated by weighing the grains of the plants located at 3 m linear from the three subplot centerlines, using a digital scale capable of weighing up to 30 kg. Agricultural yield of the crop was evaluated as a function of irrigation levels and N rates, and the function of crop response to treatments was obtained by regression equations.

The response function of the crop to irrigation levels and N rates was obtained by second degree polynomial regression curves (Frizzone, 1998) with the independent variable according to Equation 3:

$$Y = b_0 + b_1 x + b_2 x^2 \qquad \ldots\ldots\ldots\ldots\ldots..(3)$$

on what:

Y - is agricultural productivity (kg ha^{-1})

x - is the total irrigation depth or applied nitrogen dose
b_0, b_1 and b_2 - are the coefficients of the equation.

The equation used to estimate the irrigation depth and nitrogen dose that provides the maximum physical productivity was deduced by equating to zero the first derivative of the production function, according to Equations 4 and 5:

$$Y' = b_1 + 2b_2x \therefore b_1 + 2b_2x = 0 \therefore 2b_2x = -b_1 \quad \text{……..(4)}$$

$$X_{\max} = -\frac{b_1}{2b_2}$$

where: X_{max}. - It is the irrigation depth and N dose that provides the maximum agricultural productivity (kg ha^{-1}). Subsequently, the maximum yield (Y_{max} in kg ha^{-1}) was estimated by substituting x for X_{max} in Equation 3. For the economic analysis of production, the price per millimeter of water applied was calculated based on the costs of farms that use drip irrigation systems and have control of these costs, where 20 years of useful life of the hydraulic infrastructure (water mains, pump room, etc.) and 3 years for the surface irrigation system were considered, this being the amortization period for the employed capital, considering three irrigated cultivation cycles per year (Table 1).

Table 1. Cost of millimeter of water for drip irrigation in corn crop

Description	Total ha^{-1}	R\$ ha^{-1} $cycle^{-1}$	R\$ mm^{-1}	%
Hydraulic Infrastructure / Buildings (20 year amortization - 60 cycles)	2,500.00	41.67	0.14	3.6
Irrigation system (3 year amortization - 9 cycles)	6,000.00	666.67	2.22	57.1
Monthly operating cost + system maintenance (5%)	153.00	459.00	1.53	39.3
Total cost	8,653.00	1,167.33	3.89	100.0
Irrigation system operation during 3 production cycles per year				
Average irrigation depth per cycle: 300 mm				

Table 2. Prices of fertilizers used in corn nitrogen fertilization

Fertilizer	R\$ Mg^{-1} of fertilizer	R\$ kg^{-1} of Nitrogen
Ammonium Sulphate (20% N)	1,030.00	5.15
Urea (45% N)	1,720.00	3.82
Average	1,375.00	4.49

Source: Usifértil, Alagoas, Brazil (Consulted on 01/08/2019)

Table 3. Total values of crop evapotranspiration (ET_c), rainfall (P), total effective rainfall (P effective), irrigation (I), irrigation more effective rainfall (mm) and percentage of crop evapotranspiration (% of ET_c), during corn cultivation from February to June 2016 (season 1) and from November 2017 to March 2018 (season 2), in the region of Rio Largo, Alagoas, Brazil

Season	Treatment (% of ET_c)	Total values from 1 DAP to R4			Totals during period of differentiated depths (21 to 86 DAP in season 1 and 21 to 88 DAP in season 2)					
		Duration (days)	P (mm)	ET_c (mm)	P	ET_c	P effective (mm)	I (mm)	P effective + I	% of ET_c performed
1	L1 (40%)	86	599	278	349	238	229	4	233	98%
	L2 (80%)						209	43	252	106%
	L3 (120%)						202	57	259	109%
	L4 (160%)						167	123	290	122%
	L5 (200%)						172	160	332	139%
2	L1 (40%)	88	369	350	219	308	149	39	188	61%
	L2 (80%)						138	138	276	89%
	L3 (120%)						65	316	381	124%
	L4 (160%)						50	454	504	164%
	L5 (200%)						46	585	631	205%

The price of kg of N was derived from the average of the two most used sources of fertilizer in the region and obtained from a commercial company located near Rio Largo, Alagoas, Brazil (Table 2). The sale price of maize used for the calculation of compensation was obtained from the quotation of January 8, 2019 by the Bahia Farmers and Irrigants Association (AIBA), in which the sack was quoted at R\$ 32.00 and, consequently, the kg of corn at R\$ 0.53.

An irrigation level and a maximum economic economy N dose were estimated by Equation 6:

$$X_{ec} = \frac{P_x - P_y b_1}{2P_y b_2} \quad \text{……………….(6)}$$

on what:

Xec - is the N dose and irrigation depth that provides the optimal economic productivity (kg ha^{-1})
Px - is the average cost of mm of water (R\$ mm^{-1}) and kg of N (R\$ kg^{-1})
Py - is the selling price of kg of corn (R\$ kg^{-1});
b_1 and b_2 - are the coefficients of the production function (equation 3);
Subsequently, the maximum economic efficiency productivity was estimated by substituting x for X_{ec} in Equation 3.

RESULTS AND DISCUSSION

Total rainfall during the entire production cycle amounted to 599 and 369 mm in seasons 1 and 2, respectively, when season 1 coincided with the region's rainy season and as a result there were a large number of intense rainfall events, which were discounted within the control of the irrigation depths and thus only the actual rainfall was accounted for (Table 3). From the beginning of the growth phase, when the irrigation levels were

Table 4. Analysis of variance by the F test for grain yield in the physiological maturation phase (Mg ha^{-1}), as a function of irrigation levels and nitrogen rates applied in a two-season corn hybrid in the region of Rio Largo, Alagoas, Brazil

Source of Variation	Middle Squares of Season 1	Middle Squares of Season2
	Grain Productivity	Grain Productivity
Block	15.07*	2.42^{ns}
L	1.27^{ns}	7.97*
N	10.56**	36.00**
L x N	2.22^{ns}	1.61^{ns}
CV 1 (%)	27.25%	18.76%
CV 2 (%)	17.57%	14.26%
Overall Average	6.52	7.78

** significant ($p \leq 0.01$), * significant ($p \leq 0.05$) and ns not significant by the F test

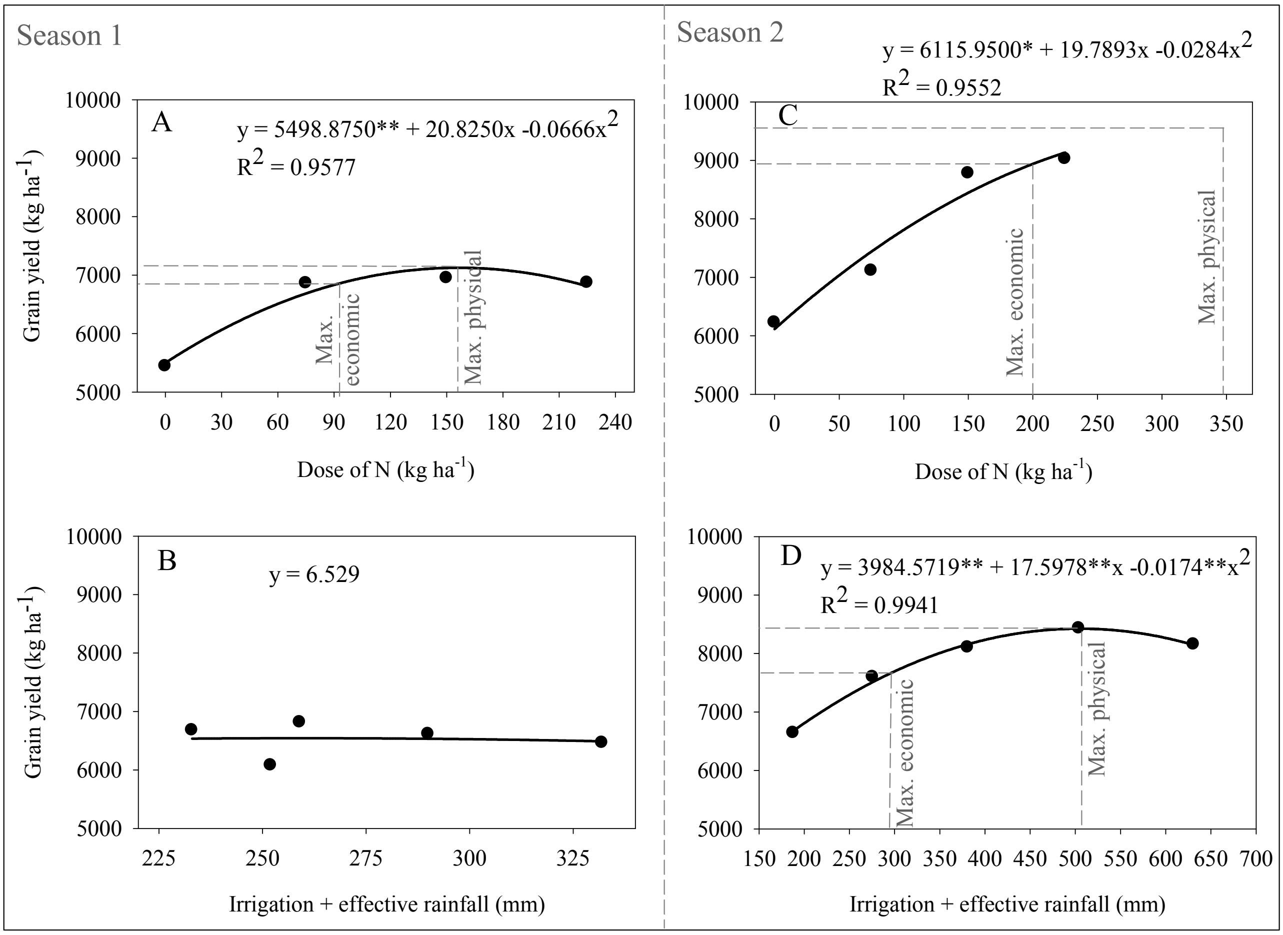

Figure 1. Grain yield in the physiological maturity phase of maize as a function of nitrogen rates (A and C) and irrigation levels (B and D) in crops from February to June 2016 (A and B) and from November 2017 to March 2018 (C and D), in the region of Rio Largo, Alagoas, Brazil

differentiated according to the treatments, in season 1 the occurrence of heavy rains reduced the need for irrigation and it was not possible to have control of the treatments, L1, L2, L3, L4 and L5 treatments were irrigated with totals of4, 43, 57, 123 and 160 mm, respectively, the sum of the irrigation depths with the effective precipitation was 233, 252, 259, 290 and 332 mm. At season 2 it was possible to have control of the treatments and the irrigation event depths averaged 3, 7, 11, 16 and 20 mm day^{-1} for L1, L2, L3, L4 and L5, respectively, the sum of the irrigation depths with the effective precipitation were, respectively, 188, 276, 381, 504 and 631 mm. Thus, the percentages of treatments were attended only in season 2, however, it is observed that in season 1 only the rain is sufficient to ensure the production, and the use of irrigation is unnecessary, since the effective rainfall corresponded to 96% of ET$_c$.

At season 2, irrigation needs to be used to complement effective rainfall and to ensure a good water supply that results in satisfactory production. However, due to the annual weather fluctuations, it is impossible to predict a fixed slate to be applied and, in this case, a crop planning must be carried out in which the irrigation costs take into account all the water demand intended to work in the crop. Grain yield as a function of nitrogen rates differed statistically and presented quadratic adjustment in the two growing seasons, while for irrigation levels there was significant difference only in the second season (Table 4 and Figure 1). Among nitrogen rates, grain yield ranged from 5,441 (N0) to 6,950 kg ha^{-1} (N150) at season 1, with a 28% difference from N0, while at the second season grain yield was between 6,226 (N0) and 9,023 kg ha^{-1} (N225), the difference being 45% of N0. For season 2 irrigation levels, productivity ranged from 6,641 to 8,153 kg ha^{-1}, where the difference between them was 23% in relation to the lowest treatment. For season 1, the maximum physical yield of the crop estimated by the production function was 7,127 kg ha^{-1} obtained with a N dose of 156 kg ha^{-1} and in season 2, the maximum physical yield would be 9,563 kg ha^{-1} (with N dose of 348 kg ha^{-1}). The adjustment of the production function for N doses at season 2 did not present a maximum point followed by a decrease in the interval studied in this study, but the study of the second degree function became reliable due to the behavior of smaller increases (decreasing tendency) of productivity close to the value obtained with the maximum applied dose. According to Silva et al. (2018), the second degree function represents well the response of an agricultural crop to inputs on the upward curve, but in the stationary or decreasing region it is bad because, normally, the increases in crop productivity are large near the level 0 (zero) of the input, but as it goes through the maximum return, productivity decreases slowly, which is not the case with the second degree function. In addition, it may happen that the maximum physical return point estimated by the equation is beyond the maximum input level used in the experiment, featuring extrapolation, which is not recommended to use; in this case, the production function must be studied within the test ranges, since the maximum productivity is generally poorly determined and not always possible to obtain, it is more important to obtain the maximum net revenue for the input under study.

Pizolato Neto et al. (2016) observed that the 140 kg ha^{-1} N rate provided a productivity of 6,065 kg ha^{-1}, which corresponds to an increase of 32% compared to the treatment with 35 kg ha^{-1} of N. For Fernandes et al. (2017) the maximum yield of maize was 4,438 kg ha^{-1}, obtained based on a nitrogen dose of 187 kg ha^{-1} split in three times. Ashraf et al. (2016) observed an increase in grain yield from 4.2 to 10.1 Mg ha^{-1} by increasing the N dose from 0 to 250 kg ha^{-1} and improving irrigation management. Silva et al. (2016) measured corn yield in four growing seasons in the Rio Largo, Alagoas, and after finding response with significant adjustment to N doses, found maximum grain yield values estimated at 9,543, 9,494, 8,107 and 7,111 kg ha^{-1}, obtained with N rates of 209, 187, 275 and 86 kg ha^{-1}, respectively. Regarding irrigation, at season 1 there was no difference between levels, but at season 2 the maximum physical yield was 8,434 kg ha^{-1} of grain for a 506 mm depth (164% of ET_c). For yields above these values, that is, with the crop in optimal conditions of nitrogen availability and soil moisture, it is necessary to resort to other agricultural practices such as fertilization with other nutrients, pest and disease control, among others. It was observed that the maximum productivity was reached with a depth superior to ET_c, which doesn't make sense at first, since it represents the maximum water demand of the crop. However, water uptake by the plant is regulated by its transpiration mechanism, which has a higher velocity than the rate of root absorption and conduction in the xylem (Taiz & Zeiger, 2013). Thus, the fact that the application of an irrigation depth greater than the transpirometric demand promotes a higher response in productivity. This is because the rate of perspiration is limited by atmospheric water potential or relative humidity and reaches higher values when there is maximum stomatal opening, which also favors greater CO_2 input and, consequently, increased production of photoassimilates for grain formation and filling, as long as soil water is more available to maintain stomatal conductance at all times. Souza et al. (2016) observed that for winter-spring cultivation, the irrigation depth that maximized ear weight was 87.8% of ET_c, while for summer-autumn the irrigation depth that maximized ear weight was 80.5% of ET_c. Silva et al. (2018) cultivated maize in Piranhas, Alagoas (semi-arid region), and obtained a maximum irrigation depth of 919 mm (175% of ET_c) for a yield of 11.3 t ha^{-1}. Souza et al. (2011) cultivated maize in the Petrolina, Pernambuco, Brazil, and verified linear response in the range of tested depths, where the maximum yield (3,860 kg ha^{-1}) was reached with 499 mm depth (125% of ET_o). The agricultural productivity of maximum economic efficiency with the price of sack of corn equal to R$ 32.00 and the cost of N equal to 4.49 R$ kg^{-1}, was 6,861 kg ha^{-1} at season 1, obtained with N dose of 93 kg ha^{-1} and in relation to irrigation, there was no difference between levels. In season 2, for the same price of corn and nitrogen, the maximum economic yield was 8,940 kg ha^{-1} (with N dose of 200 kg ha^{-1}), while for the irrigation cost equal to 3.89 R$ mm^{-1}, the maximum economic productivity was 7,669 kg ha^{-1} for an irrigation level of 296 mm (96% of ET_c).

Silva et al. (2016), for four growing seasons in the region of Rio Largo, Alagoas, yields of maximum economic efficiency equal to 9,149, 9,026, 7,269 and 6,605 kg ha^{-1}, obtained with 138, 139, 158 and 17 kg ha^{-1} of N, respectively, with the price of corn bag of R$ 15.00. For the average sack price of R$ 30.00, the highest economic efficiency yield was 9,413, 9,408, 7,897 and 6,885 kg ha^{-1}, obtained with 174, 163, 215 and 52 kg ha^{-1} of N, respectively. With the price of the bag of corn equal to R$ 45.00, the maximum economic dose was 186, 171, 234 and 63 kg ha^{-1} of N, yielding grain yield of 9,485, 9,456, 8,014 and 7,055 kg ha^{-1}, respectively. Silva et al. (2018) performed economic analysis of irrigated maize in Piranhas, Alagoas, Brazil, and found maximum economic irrigation depth equal to 841 mm (160% of ET_c) for a yield of 11.21 Mg ha^{-1}. In general, the economical maximum irrigation depth is slightly smaller than the maximum physical productivity irrigation depth, varying according to the price of the product and the input cost. According to Martins et al. (2016), the economic viability of deficient drip irrigation is dependent on the fixed cost of lateral line acquisition, the spacing between the drip lines and the marketing price of maize, where lateral piping costs represent approximately 45% of the total cost of a irrigation system for corn crop. Thus, increased lateral line spacing of drip lines is the most important factor in reducing the high costs of drip irrigation. Couto et al. (2013), testing irrigation row spacing of 1.10 m and 1.65 m for cultivated maize with 0.55 m line spacing, found no significant differences in yield and recommend the use of row spacing. 1.65 m between irrigation lines because it is more economical. Another option is to use a side drip line for two crop lines. Henggeler (1995) reports that drip lines with a spacing of 1 m increase the system cost by approximately 40% compared to the 2 m spacing. In addition, the larger the acreage used in drip irrigation projects, the lower the costs per hectare. Calculating input costs in agriculture for maximum capital return involves several factors that cannot always be controlled, especially when it comes to environmental factors. Therefore, works like this serve as a reference base for administrative decisions, provided that the conditions are similar to those of the place where the research was conducted.In addition, economic issues, such as input prices and agricultural commodities, are subject to daily change, and it is up to the administrator to find the best solution and choose the most viable alternative for using a given input.

Conclusions

Corn cultivation in the autumn-winter period has a lower water requirement and promotes lower grain yield than in the spring-summer period. The maximum yield of maize grains grown in the rainy and dry seasons can be obtained with nitrogen rates equal to 156 kg ha^{-1} and above 225 kg ha^{-1}, respectively. In the dry season, maximum yield can be obtained with the irrigation depth equivalent to 164% of ET_c. Depending on input prices and grain sales, the most economically efficient nitrogen dose for the rainy season is around 93 kg ha^{-1}, while for the dry season it is 200 kg ha^{-1}; for dry season cultivation, the maximum economical irrigation depth corresponds to 96% of ET_c.

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