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DESEMPENHO AGRONÔMICO DO MILHO CULTIVADO NO LITORAL CEARENSE SOB LÂMINAS DE IRRIGAÇÃO[1]

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1 RESUMO

Na região Nordeste, particularmente no Ceará, a agricultura irrigada contribui significativamente com a produção agrícola, destacando-se a cultura do milho, que apresenta grande importância socioeconômica, contribuindo para a geração de emprego, renda e para fixação do homem no campo. Neste sentido, objetivou-se avaliar o efeito de diferentes lâminas de irrigação no desempenho agronômico do milho cultivado no litoral cearense em diferentes anos de cultivo. O experimento foi conduzido na área experimental da Estação Agrometeorológica da Universidade Federal do Ceará, no delineamento experimental em blocos ao acaso, composto de seis tratamentos e cinco repetições. O experimento consistiu na aplicação de lâminas de irrigação com base na evapotranspiração da cultura (ETc), correspondendo aos tratamentos: 30% da ETc, 60% da ETc, 90% da ETc, 120% da ETc, 150% da ETc e 180% da ETc. A utilização da irrigação no cultivo de milho proporcionou maior massa da espiga com e sem palha, maior massa de 1.000 grãos e maior produtividade. A aplicação da lâmina de irrigação corresponde a 120% da ETc promoveu resultados produtivos satisfatórios. Portanto, recomenda-se o uso dessa estratégia de irrigação para o incremento da produção de milho na região do litoral cearense.

Palavras-chave: *Zea mays* L, evapotranspiração, produção.

MESQUITA, JBR; AZEVEDO, BM; SOUSA, GG; VIANA, TVA; SALES, JRS; GOES, G.F.
AGRONOMIC PERFORMANCE OF CORN GROWN ON THE COAST OF CEARÁ UNDER IRRIGATION DEPTHS

2 ABSTRACT

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In the Northeast Region, particularly in Ceará, irrigated agriculture contributes significantly to agricultural production, with an emphasis on corn cultivation, which has great socioeconomic importance and contributes to the generation of employment, income, and retention of men in the countryside. In this sense, the objective was to evaluate the effects of different irrigation depths on the agronomic performance of corn grown on the coast of Ceará in different growing years. The experiment was conducted in the experimental area of the Agrometeorological Station of the Federal University of Ceará in a randomized block experimental design consisting of six treatments and five replications. The experiment consisted of applying irrigation depths based on ETc, corresponding to the following treatments: crop evapotranspiration (ETc), corresponding to the following treatments: 30% of the ETc, 60% of the ETc, 90% of the ETc, 120% of the ETc, 150% of the ETc, and 180% of the ETc. The use of irrigation in corn cultivation resulted in higher ear mass with and without straw, higher mass of 1,000 grains and higher productivity. The application of an irrigation rate corresponding to 120% of ETc promoted satisfactory production results. Therefore, the use of this irrigation strategy is recommended to increase corn production in the coastal region of Ceará.

Keywords: *Zea mays* L., evapotranspiration, production.

3 INTRODUCTION

One of the great challenges of contemporary irrigated agriculture is directly related to water issues. Owing to the effects of climate change and the lack of more effective water recycling policies, water tends to become increasingly limited, both qualitatively and quantitatively (BEZERRA *et al.*, 2020).

Among the Brazilian irrigated areas, the Northeast Region accounts for 14.4%, characterized by semiaridity with high spatial and temporal variability in rainfall, with water deficit occurring in plants because the potential evapotranspiration rate exceeds the precipitation rate during most of the year (ANDRADE *et al*., 2012; ANA, 2021). In this way, the use of irrigation becomes essential for the success of agricultural activities.

In Northeast China, especially in Ceará, irrigated agriculture has contributed to agricultural production in the areas of fruit growing, horticulture, horticulture and grain production. In the latter, corn cultivation, which is very traditional in the region, has relevant socioeconomic importance, being cultivated the most by small, medium and large farmers, contributing to the retention of men in the countryside and generating employment and income (LOPES, DANTAS; FERREIRA, 2019; CHAIBEN Neto *et al*., 2022).

Kukal and Irmak (2020) and Li *et al*. (2020) highlighted the importance of efficient management of agricultural irrigation water, especially for developing countries such as Brazil. However, Brazilian agricultural production, in many cases, is associated with inadequate management of irrigation and fertilization, which are factors that lead to reduced productivity.

The application of insufficient irrigation depths leads to greater risks of soil salinization, whereas the use of excessive depths can cause nutrient leaching. Ben *et al.* (2016) reported greater corn productivity when an irrigation depth equivalent to 100% of the crop's evapotranspiration (ETc) was used. On the other hand, Ferreira *et al.* (2021) reported that, for the same crop, water deficit, with sheet irrigation equivalent to 50% of ETc, negatively affects its productivity.

Given the above, the objective of this work was to evaluate the effects of different irrigation depths on the agronomic performance of corn grown on the coast of Ceará over different years of cultivation.

4 MATERIALS AND METHODS

The experiment was conducted in the experimental area of the Meteorological Station of the Department of Agricultural Engineering of the Federal University of Ceará (UFC), Fortaleza, Ceará, which has the following geographic coordinates: 3° 44'S and 38° 33'W and 19.5 m altitude.

According to Thornthwaite's climate classification (1948), the region's climate is type C_2 WA'a', characterized as humid to subhumid, with moderate water deficiency in winter and potential evapotranspiration well distributed throughout the year. The region is characterized by the following average annual conditions: a precipitation of 1,564 mm, an air temperature of 27°C and a relative air humidity of 80%, according to data provided by the UFC Agrometeorological Station, which is located in the experimental area.

The soil in the region is classified as Red–Yellow Argisol with a sandy texture (EMBRAPA, 2018). For the purpose of physical–chemical characterization of the soil, before the experiments were performed, soil samples were taken from a layer 0.0 to 0.2 m deep with the aid of an auger. The samples were subsequently homogenized and taken to the UFC Water and Soil Laboratory, where they were analyzed. Tables 1 and 2 show the results of the physical–chemical analysis of the soil in the experimental area in 2011 and 2012.

Table 1. Physical-water analysis of the soil in the experimental area

Physical-water characteristics	**Year 2011**	**Year 2012**
Soil specific mass (kg dm^{-3})	1.50	1.55
Specific mass of particles (kg dm^{-3})	2.62	2.59
Field capacity ($m^3 m^{-3}$)	0.187	0.192
Permanent wilting point ($m^3 m^{-3}$)	0.056	0.066
Saturation humidity ($m^3 m^{-3}$)	0.430	0.415
pH (water)	6.6	5.9

Source: Research data (2011, 2012).

Table 2. Chemical analysis of the soil in the experimental area

Prof. (m)	**Assortative complex ($cmol_c$ dm^{-3})**							**%**	**(mg dm^{-3})**	**(g kg^{-1})**
2011										
	Ca^{2+}	Mg^{2+}	Na^+	K^+	s	$H^+ + Al^{2+}$	Al^{3+}	V	P	MO
0.0-0.2	1.5	1.5	0.23	0.1	3.3	1.15	0.0	74	8.0	7.03
2012										
	Ca^{2+}	Mg^{2+}	Na^+	K^+	s	$H^+ + Al^{2+}$	Al^{3+}	V	P	MO
0.0-0.2	2.1	1.7	0.07	0.09	3.1	1.15	0.0	76	8.0	8.1

Prof. = depth; V = base saturation; MO = organic matter; P, K, Na: Melich 1 extractor; Al, Ca, Mg: KCl extractor; pH in water. Source: Research data (2011, 2012).

The crop used in the experiment was hybrid maize AG 1051, which is characterized by a semiearly cycle; the size and insertion of the cob are considered high; the grain is toothed and yellow; excellent stuffing; good quality of the stem and root system; and grain production is the main purpose of use. Despite these characteristics, the choice of this hybrid was because it is one of the most widely distributed hybrids to farmers in the region through Ceará Government Programs to support and encourage agriculture.

Sowing was carried out with the aid of a manual planting machine (ratchet) at a depth of 0.05 m, and the spacing between plants was 0.2 m along the entire length of the lateral irrigation lines. Fertilization was carried out following the recommendations of Fernandes *et al.* (1993), with 90 kg ha $^{-1}$ of N, 40 kg ha $^{-1}$ of P and 30 kg ha $^{-1}$ of K applied to the following sources: urea, simple superphosphate and potassium chloride, respectively. Half was applied to the foundation, and half was applied to the coverage area.

The experimental design used was a randomized block design consisting of six treatments (irrigation depths) and five replications. The treatments corresponded to irrigation levels corresponding to 30, 60, 90, 120, 150 and 180% of ETc (mm day $^{-1}$). Two consecutive years of cultivation were evaluated (2011 and 2012).

For driving and management purposes, a localized drip irrigation system was installed, with lines spaced 1 m apart and self-compensating drippers spaced 0.3 m apart, with a flow rate of 2 L h $^{-1}$ at a working pressure of 1. 0 kgf cm $^{-2}$. At the beginning of each lateral line, a 16 mm diameter drawer valve was installed to control the irrigation depth.

Irrigation management occurred according to the principle of accumulated depth; thus, the experiment's irrigation was carried out on the basis of the replacement of the evapotranspirated water depth over two consecutive days. Reference evapotranspiration was estimated via the Penman–Monteith method, which is considered a reference by the Food and Agriculture Organization (FAO) of the United Nations (ALLEN *et al.*, 1998). The climatic data used in the calculations were obtained from an automatic meteorological station located next to the experimental area.

The crop evapotranspiration, in mm day $^{-1}$, was calculated from the evaporation measured in the class A tank, according to Equation (1).

$$ETc = ACE \times Kp \times Kc \qquad (1)$$

On what:
ETc – Crop evapotranspiration, in mm day $^{-1}$;
ECA - Evaporation measured in class “A” tank, mm day $^{-1}$;
Kp - Class “A” tank coefficient, dimensionless;
Kc - Crop cultivation coefficient, dimensionless.

The following crop coefficients (Kc) were adopted: 0.86 to 40 days after sowing (DAS); 1.23 from 41 to 53 DAS; 0.97 from 54 to 73 DAS; and 0.52 from 74 DAS until the end of the cycle (SOUZA *et al*., 2015). A 15% leaching fraction was added to the applied slide (AYERS AND WESTCOT, 1999). The irrigation time was obtained via Equation 2:

$$Ti = (ETc \times Ep)/(Ea \times q) \times 60 \qquad \text{(two)}$$

On what:
Ti - Irrigation time (min);
ETc - Evapotranspiration of the crop in the period (mm);
Ep - Spacing between drippers;
Ea - Application efficiency (0.92);
q - flow rate (L h $^{-1}$).

Table 3 shows the total depth applied in the experiment during the crop cycle according to each treatment and year of evaluation.

Table 3. Percentages of evapotranspiration (ETc) and water depth applied in the experiment

Treatment	Etc (%)	Irrigation blade (mm)	
		2011	2012
Read $_{30}$	30	143.2	153.2
Read $_{60}$	60	286.4	306.4
Read $_{90}$	90	429.6	459.59
Read $_{120}$	120	572.7	612.69
Read $_{150}$	150	715.9	775.99
Read $_{180}$	180	859.1	919.19

Source: Research data (2011, 2012).

At 85 days after sowing, ears were manually harvested from the useful area of each experimental plot. After the grains were dried, the plants were analyzed for ear mass with straw (MECP) and without straw (MESP), mass of 1000 grains (M1000) and straw mass (MPE) with the aid of a digital scale with the ability to measure hundreds of grams. The grain productivity (PROD) was estimated in kg ha $^{-1}$.

The Shapiro–Wilk test revealed that the observed data followed a normal distribution. Thus, analysis of variance was carried out with the application of the F test via the ASSISTAT program, version 7.7 Beta (SILVA; AZEVEDO, 2016). The data were also subjected to quadratic polynomial linear regression models with the aid of Microsoft Office Excel.

5 RESULTS AND DISCUSSION

According to the summary of the analysis of variance (Table 4), irrigation depth had a significant effect on the variables MECP, MESP, M1000 and PROD in the years 2011 and 2012. In 2011, the F test verified that differences between treatments were statistically significant at a significance level of 0.01, whereas in 2012, these differences occurred at a significance level of 0.05. The MPE variable did not have a significant effect in any of the years evaluated.

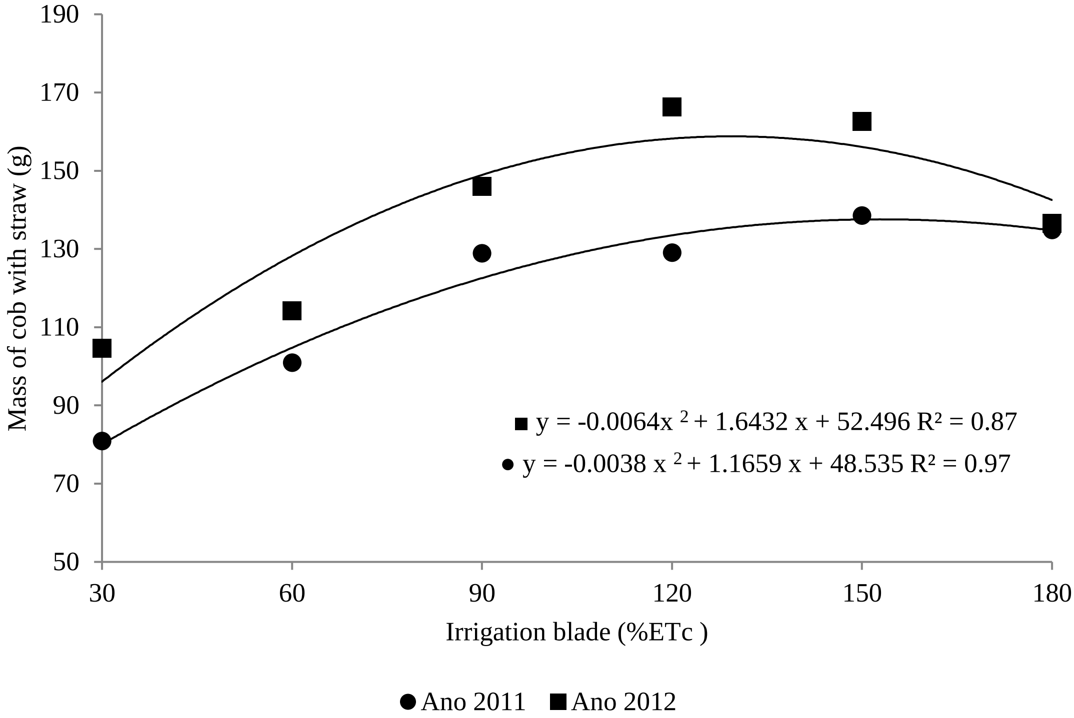
Table 4. Analysis of variance of data on ear mass with straw (MECP), without straw (MESP) and with ear straw (MPE), thousand-grain mass (M1000) and productivity (PROD.) of corn subjected to different irrigation blades

Year	Source of variation	Medium Square				
			Treatment	Block	Residue	CV (%)
2011		GL	5	4	20	
	MECP		2,608.32**	1,436.33**	264.46	13.68
	MESP		2,193.47**	963.45**	200.52	14.71
	MPE		75.15ns	40.14ns	34.94	26.16
	M1000		30.03**	14.25ns	6.93	8.13
	PROD		3,510,082**	1,480,365**	257752	13.11
2012	MECP		3,150.73*	6,225.50**	911.14	21.82
	MESP		2,929.39*	3,852.48**	953.04	27.53
	MPE		60.68ns	26.49 ns	27.2	18.18
	M1000		6.31*	441.34**	15.4	10.95
	PROD		901,783*	11,702,094**	2314.06	35.23

Source: Authors (2023).
GL - degree of freedom; CV - coefficient of variation; * significant at the 0.05 probability level according to the F test ($p < 0.05$); ** significant at the 0.01 probability level according to the F test ($p < 0.01$). ns - not significant according to the F test.

The behavior of the MECP variable in the two years of cultivation (2011 and 2012) can be observed in Figure 1. The results were similar in the two years evaluated, and a quadratic polynomial model was fit. Considering only the cultivation carried out in 2011, an optimal value for MECP was estimated at 138 g when a layer equivalent to 153.4% of ETc was applied. For the cultivation carried out in 2012, the maximum estimated value for this variable was 158 g when a layer equivalent to 128.4% of ETc was applied.

Figure 1. Ear mass with straw as a function of irrigation depth based on crop evapotranspiration (ETc)



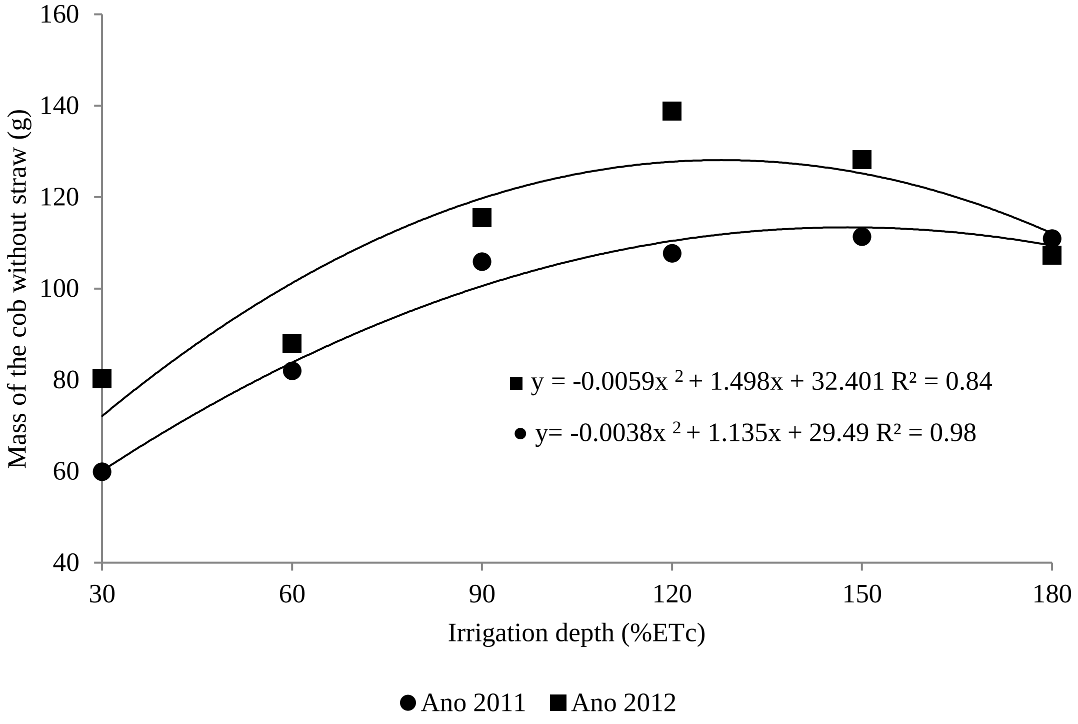
Source: Authors (2023).

When observing the two agricultural years, it is clear that the irrigation depth applied in 2011 was approximately 19.5% greater than that applied to cultivation in 2012 (Table 3), and this fact was reflected in the MECP, which was approximately 14% greater in 2012 than in 2011 (Figure 1).

Ferreira *et al* . (2021) reported that water stress due to excess moisture below the soil surface causes a reduction in a crop's productive potential. Taiz *et al*. (2017) reported that the closure of stomata and a decrease in photosynthesis are common responses to the restriction or lack of oxygen in the soil caused by waterlogging, which impacts productivity.

In Figure 2, the behavior of the MESP variable is shown as a function of the irrigation depth in the two years of cultivation (2011 and 2012). The model used suggests an increase in the average mass per ear due to the increasing supply of water in the crop to an optimum depth estimated at 149.3% of ETc, with an estimate of 114.2 g for the maximum MESP in 2011. In 2012, the estimated optimum blade was 126.9% of ETc for a maximum MESP estimated at 127.5 g.

Figure 2. Mass of corn cobs without straw as a function of irrigation depth on the basis of crop evapotranspiration (ETc)



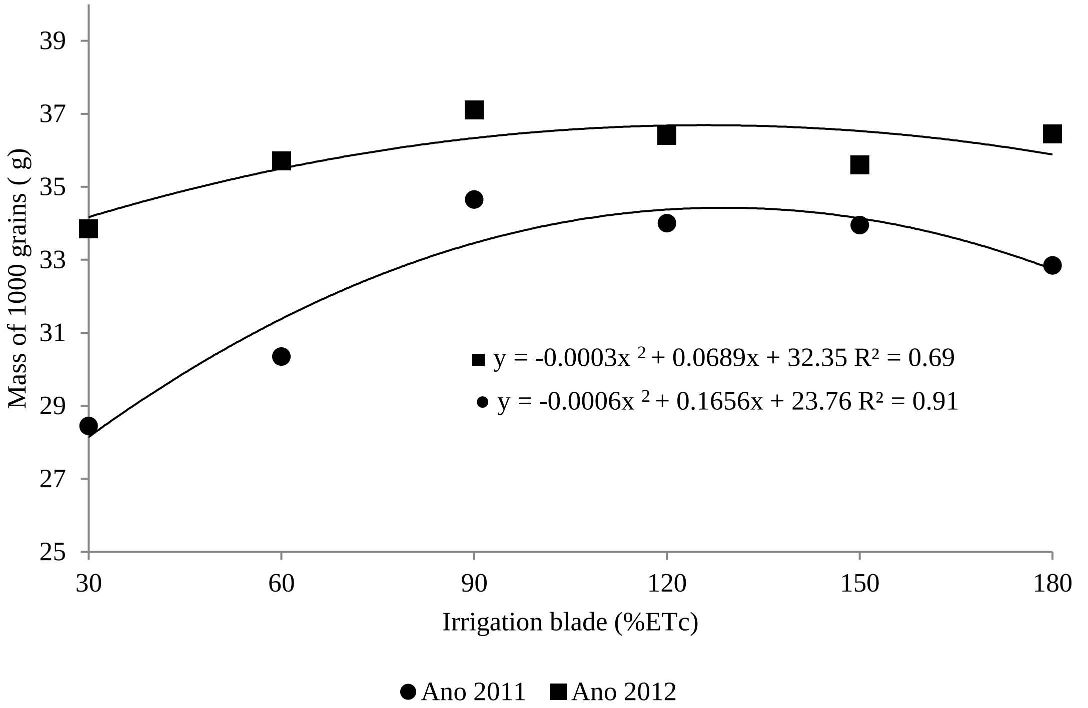
Source: Authors (2023).

The use of high irrigation depths did not translate into greater mass, as in 2012, the mass of ears increased by only 10%, even though the crop received greater volumes of water than in 2011 (Table 3). This finding indicates that the application of larger volumes of water did not necessarily result in productive gains, which may be related to the sandy texture of the soil (Table 1), which favors rapid infiltration of water into the profile (CENTENO *et al*., 2017).

The results for the MECP and MESP variables are within the range found in the research by Blanco, Veloso and Cardoso (2009) and are closer to the minimum values, which were 192 g for the MECP and 112 g for the MESP. Ferreira *et al* . (2021) reported that corn cultivation is strongly influenced by climatic factors, mainly rainfall.

According to the regression analysis, regardless of the year of cultivation, the quadratic model best explained the behavior of M1000. There are increases as the irrigation depth increases, reaching, in 2011, a maximum value of 35.2 g for an estimated depth equivalent to 138% of ETc and 36.3 g in 2012 for an estimated depth corresponding to 114% of ETc (Figure 3). This result presents a difference between the 1st and 2nd years of just 3%, whereas in 2012, grains of greater mass were obtained, but with a water savings of approximately 17.4%.

Figure 3. Mass of 1,000 corn grains as a function of irrigation depth based on crop evapotranspiration (ETc)



Source: Authors (2023).

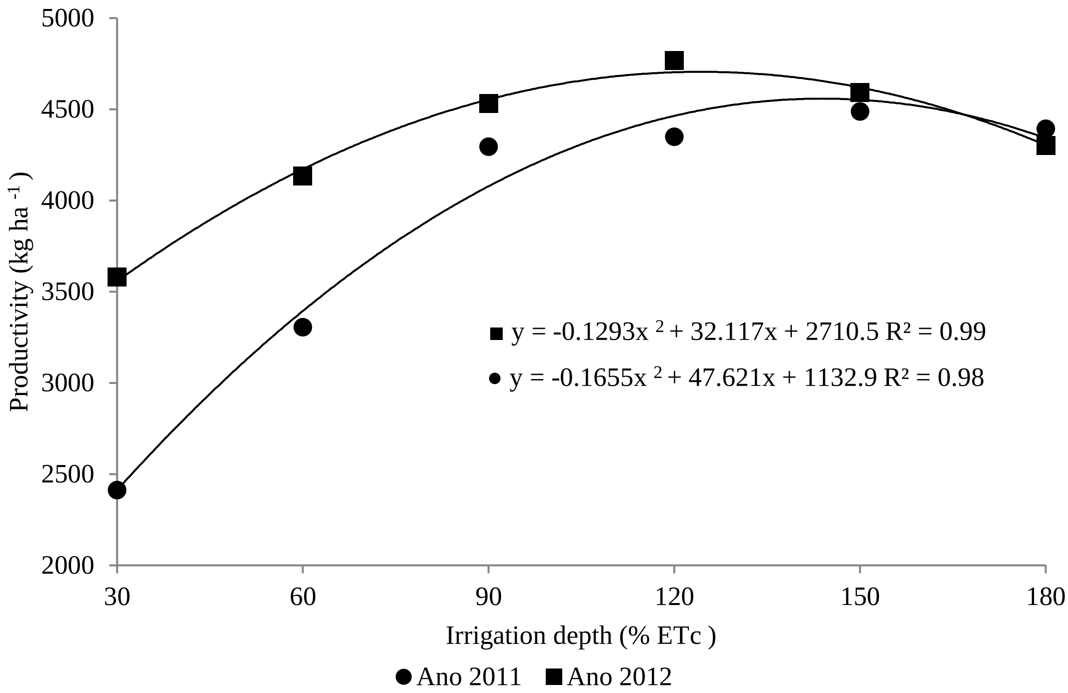
Taiz *et al.* (2017) reported that a lack or excess of water affects the synthesis, accumulation, partitioning and translocation of photoassimilated products and influences the production components of agricultural crops, such as corn, thus reducing their productive yield.

A similar response was expected in the crop, regardless of the production cycle, but this was not observed. In 2011, the results were lower than those in 2012. These results may be related not only to the volume and distribution of rainfall and the use of irrigation but also to the structural quality of the cultivated soil, which is capable of limiting the retention capacity of water (SAFADOUST *et al*., 2014).

Inadequate management practices can affect water infiltration and retention in the soil (BLANCO-CANQUI *et al*., 2017), directly influencing root growth, which in turn affects plant development and production.

Crop productivity (Figure 4) tends to increase as the irrigation depth increases. The statistical model used estimates a maximum productivity for corn of 4,558.5 kg ha $^{-1}$ when applying the optimal irrigation depth, estimated at 143.9% of ETc, in the cultivation carried out in 2011. For the cultivation carried out in 2012, a maximum productivity of 4,704.9 kg ha $^{-1}$ was achieved when the blade was estimated at 124.2% of ETc, which highlights the downward trend in productivity after the estimated optimum depth was used, regardless of the year of cultivation.

Figure 4. Corn crop productivity as a function of irrigation depth based on crop evapotranspiration (ETc)



Source: Authors (2023).

In the comparison between the two years of cultivation, the optimal depth applied in the cultivation in 2011 was approximately 13% greater than that applied in 2012; however, this greater depth did not translate into an increase in productivity, since in 2011, the productivity maximum was approximately 3.5% lower than that in 2012.

The irrigation depths maximized MECP, MESP and M1000, which followed the same pattern of proximity within each production cycle (Figures 1, 2 and 3). Thus, the behavior of all the variables analyzed was similar, clearly indicating that the increase in crop productivity (Figure 4) was directly related to irrigation depth.

In general, corn presented a lower production potential in the treatments with lower irrigation levels, which was correlated with the water deficit conditions, as the plants close their stomata to protect themselves from water loss through transpiration, leading to a reduced photosynthetic rate (TAIZ *et al*., 2017).

The results of the present study corroborate those reported by Martins *et al*. (2016), who reported that corn productivity increased with increasing water volume at each irrigation depth. Ben *et al*. (2016) also reported greater grain productivity (15,250 kg ha $^{-1}$) in the treatment with replacement blades, corresponding to 100% of ETc, with the lowest productivity (5170 kg ha $^{-1}$) found in rainfed cultivation (without irrigation).

Similar results were also obtained by Ferreira *et al*. (2021), who reported greater grain productivity for corn crops with the application of irrigation depths corresponding to 100% of the ETc, resulting in a productivity of 12,619.66 kg ha $^{-1}$, with a total amount of water applied (irrigation + precipitation) of 609 mm throughout the crop cycle.

6 CONCLUSION

The use of irrigation in corn cultivation provided greater ear mass with and without straw, a greater mass of 1,000 grains and greater productivity. The application of the irrigation depth corresponding to 120% of the ETc promoted satisfactory productive results. Therefore, the use of this irrigation strategy to increase corn production in the coastal region of Ceará is recommended.

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