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ORIGINAL ARTICLE

Hydrogel polymer in yellow melon plants cultivated under different irrigation depths[1]

Polímero de hidrogel em plantas de melão amarelo cultivadas sob diferentes lâminas de irrigação

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HIGHLIGHTS:
High irrigation depths promoted an increase in melon yield.
Hydrogel did not improve melon performance under deficit irrigation.
High irrigation depths increased the pulp thickness of melon fruits.

ABSTRACT: Water is an essential resource in agriculture, and its efficient use is fundamental to ensuring the sustainability of the sector. The use of more rational and sustainable technologies is an important strategy for optimizing the use of water in agriculture. In view of the above, the aim of this study was to evaluate the effect of different irrigation depths on both chemical and physical variables of melon fruits, and yield, in plants grown with or without hydrogel application. The experiment was conducted in a randomized block design with ten treatments and four blocks. The treatments were arranged in a 5 × 2 factorial scheme, referring to five irrigation depths (50, 75, 100, 125, and 150% of crop evapotranspiration - ETc), and with or without hydrogel application (4 g L^{-1}). The irrigation system used was drip irrigation. Irrigation depths positively influenced the variables evaluated, with the highest yield (39,075.69 kg ha^{-1}) obtained with the highest water depth of 394 mm (150% ETc), while the use of hydrogel reduced the internal cavity of the fruit. The fruit physical characteristics (pulp thickness and internal cavity) showed positive linear increments within the interval of irrigation depth evaluated. Fruit electrical conductivity showed a linear decrease as the irrigation depths increased, while the pH was described by a quadratic polynomial equation. The use of hydrogel was not enough to mitigate the negative effects of deficit irrigation. However, the increase in irrigation depths improved the quality and yield of melon fruit.

Key words: *Cucumis melo* L., soil conditioner, water use efficiency

RESUMO: A água é um recurso essencial na agricultura e a sua utilização eficiente é fundamental para garantir a sustentabilidade do sector. A utilização de tecnologias mais racionais e sustentáveis é uma estratégia importante para otimizar o uso da água na agricultura. Diante do exposto, o objetivo deste estudo foi avaliar o efeito de diferentes lâminas de irrigação nas variáveis químicas e físicas de melão, e produtividade, em plantas cultivadas com ou sem aplicação de hidrogel. O experimento foi conduzido em delineamento de blocos casualizados com dez tratamentos e quatro blocos. Os tratamentos foram dispostos em esquema fatorial 5 × 2, referente a cinco lâminas de irrigação (50, 75, 100, 125 e 150% da evapotranspiração da cultura - ETc), e com ou sem aplicação de hidrogel (4 g L^{-1}). O sistema de irrigação utilizado foi o gotejamento. As lâminas de irrigação influenciaram positivamente as variáveis avaliadas, sendo a maior produtividade (39.075,69 kg ha^{-1}) obtida com a maior lâmina de água de 394 mm (150% ETc), enquanto o uso de hidrogel reduziu a cavidade interna do fruto. As características físicas dos frutos (espessura da polpa e cavidade interna) apresentaram incrementos lineares positivos dentro do intervalo de lâminas de irrigação avaliadas. A condutividade elétrica dos frutos apresentou diminuição linear com o aumento das lâminas de irrigação, enquanto o pH se comportou como equação polinomial quadrática. O uso de hidrogel não foi suficiente para mitigar os efeitos negativos das lâminas deficitárias. Porém, o aumento das lâminas de água melhorou a qualidade e a produtividade de melão.

Palavras-chave: *Cucumis melo* L., condicionador de solo, uso eficiente da água

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Introduction

Melon (*Cucumis melo* L. - Cucurbitaceae) is widely cultivated throughout the world due to its high yield and nutritional value. However, low water availability can negatively affect both yield and fruit quality (Taiz et al., 2017). Brazil is the largest melon producer in South America, with production of 877,243 tons in 2022, concentrating 77% of national production in the Northeast region, especially in the Rio Grande do Norte, Ceará and Bahia states, while China is the largest producer in the world (FAO, 2021; IBGE, 2022).

According to Bernardo et al. (2019), the irrigation depth can be defined as the amount of water to be supplied by irrigation, in order to complement the actual rainfall, with the aim of supplying crop water needs. Determining the correct water level is one of the main parameters for the correct planning and management of any irrigation system, as well as for assessing water resources (Ewaid, 2019).

A class of hydrophilic polymers known as "hydrogels" have extensive water content and three-dimensional crosslinked networks. Since the old period, they have been utilized as plant culture substrates to get around the drawbacks of soil (Ma et al., 2023). This polymer is highly effective at retaining water, keeping plant root zone moist, and can optimize the use of fertilizers by retaining and making available a high concentration of macronutrients in the substrate, promoting greater plant development (Navroski et al., 2015; Neves et al., 2021).

The use of irrigation depths and hydrogels has been studied in order to improve the water efficiency and nutrient use in the melon crop (Pereira, 2019; Melo, 2021). Irrigation depths are tools for determining the appropriate amount of water needed for the crop in each region, while hydrogel is a polymer capable of absorbing and retaining large amounts of water, gradually releasing it to the plants (Cavalcante et al., 2018). The application of hydrogel influences root development, plant growth and development, maximizes the use of water (irrigation or precipitation), reduces the water deficit in periods of drought, as well as reducing nutrient losses through leaching, reducing production costs and allowing greater flexibility between irrigation operations (Benett et al., 2015; Felippe et al., 2021).

Therefore, the use of irrigation depths and hydrogel could be a promising solution to the problem of low water availability in melon production, contributing to increased yield. In view of the above, the aim of this study was to evaluate the effect of different irrigation depths on both chemical and physical variables of melon fruits, and yield, in plants grown with or without hydrogel application.

Material and Methods

The experiment was carried out in the experimental area of Instituto Federal de Educação, Ciência e Tecnologia do Ceará, Campus Iguatu, Ceará state, Brazil (6° 21' 34" S; 39° 17' 55" W, with altitude of 217.5 m). According to Köppen's classification, the climate of the region is BSw'h', characterized as hot semi-arid, with an average annual rainfall of 867 mm and with an average annual temperature of 27.5 °C (INMET, 2023). Soil physicochemical characteristics of the area were obtained from soil samples collected at a depth of 0 to 20 cm and analyzed in laboratory (Table 1).

For the experiment, a randomized block design was used in a 5 × 2 factorial scheme, with four replicates, corresponding to five irrigation depths (50, 75, 100, 125, and 150% of the crop evapotranspiration - ETc), and with or without hydrogel application, according to the manufacturer's recommendation (4 g L^{-1}), applied in the furrows and mixed evenly, 8 L of the hydrated product per row of the units that received this treatment. The total experimental area was divided into four blocks. Each block had 10 treatments (5 × 2 factorial) in 5 m^2 of area. Each treatment within the block had ten plants and the six central plants were used to analyze the variables.

The research was carried out with the yellow melon crop (*Cucumis melo* L.), hybrid Tropical F1 (TopSeed), grown with a spacing of 0.5 m between plants and 1.0 m between rows. The melon seedlings were grown in expanded plastic trays with 128 cells filled with coconut fiber substrate. One seed was distributed per cell and the trays were kept in a protected environment with 50% shading. When they had two true leaves, they were transplanted to the area, fourteen days after sowing (DAS).

The area was prepared for the experiment by cross harrowing. Subsequently, the land was manually prepared using a hoe with the aim of removing cultural remains from the soil, eliminating the possibility of interference in the application of the treatments.

The quantification of the nutrients to be applied was carried out according to the soil analysis of the experimental area, and the fertilizers were applied by fertigation according to Sousa et al. (2011) (Table 2). The nutrient sources were urea (45% N), MAP (61% P_2O_5 and 12% N) and white potassium chloride (60% K_2O).

The irrigation method used in the experiment was surface drip irrigation with integrated pressure-compensating drippers spaced 0.2 m apart and with flow rate of 1.6 L h^{-1} at a working pressure of 100 kPa. A mini fluted valve was installed at the beginning of each lateral line to control the irrigation depths for each treatment.

Table 1. Soil physicochemical characteristics of the experimental area

Physicochemical characteristics													
Layer	N	C	OM	EC	pH	K^+	Ca^{2+}	Mg^{2+}	Na^+	$H^+ Al^{3+}$	SB	V	ESP
(cm)	(g kg^{-1})			(dS m^{-1})	H_2O	(mmol$_c$ dm^{-3})						(%)	
0-20	1.53	12.83	22.11	0.4	7.1	8.44	51.3	13.2	1.86	N. D.	74.8	100	2

Particle-size fraction (g kg^{-1})			Textural class	BD	PD
Sand	Silt	Clay		(kg dm^{-3})	
742	204	54	SL	1.5	2.57

O.M - Organic matter; H+Al - Potential acidity; SB - Sum of bases; V - Base saturation; ESP - Exchangeable sodium percentage; SL - Sandy loam; BD - Bulk density; PD - Particle density

Table 2. Percentage distribution of nutrients throughout the melon crop cycle

Nutrients	Crop cycle (days)							
	1 - 6	7 - 13	14 - 20	21 - 27	28 - 34	35 - 41	42 - 48	49 - 55
	Relative quantity of nutrients (%)							
N	3	4	6	15	27	30	10	5
P_2O_5	10	10	10	10	20	20	10	10
K_2O	2	3	5	10	17	20	28	15

Source: Sousa et al. (2011)

Irrigation was carried out daily in the morning by estimating the crop evapotranspiration (ETc) (Eq.1), calculated from the reference evapotranspiration (ETo) obtained by the Penman-Monteith - FAO equation (Allen et al., 1998), using climate data obtained from an automatic station belonging to the Instituto Nacional de Meteorologia (INMET). The crop coefficient (Kc) used was determined according to development stage. The Kc values were 0.52, 0.88, 1.13 and 0.91, for stages I, II, III and IV, respectively (Sousa et al., 1999).

$$ETc = ETo \cdot Kc \quad (1)$$

where:

ETc - crop evapotranspiration, mm

ETo - reference evapotranspiration, mm; and,

Kc - crop coefficient for each stage of development (dimensionless).

During the experiment, crop management consisted of manual weeding throughout the area to keep the crop free of spontaneous plants and the elimination of pests and diseases, according to the manifestation, being controlled through the application of chemical products, as necessary.

The fruits were harvested at 59 days after transplanting (DAT). Four fruits were taken from each replicate, and for fruit quality the variables analyzed were: pulp thickness (PT) and fruit internal cavity (IC), using a digital caliper; fruit electrical conductivity (EC) and hydrogen potential (pH); soluble solids (SS): determined using a digital refractometer (model Pocket Refractometer PAL-1). For fruit production parameters the variables analyzed were: number of fruits per plant (NFP), obtained by manual counting in the field; fruit mass per plant (FMP), obtained by the total sum of the masses of the fruits harvested in each replicate and divided by the number of plants; average fruit mass (AFM): obtained by the total sum of the masses of fruits harvested in each replicate divided by the number of fruits; and yield (YIELD).

The data were subjected to analysis of variance using the F test ($p \leq 0.05$). When the analysis of variance presented a significant effect for the quantitative treatment (irrigation depth), the data were subjected to regression analysis. When the effect was significant for the qualitative treatment (hydrogel application), means comparison by Tukey test was used. The analyses were carried out using Microsoft Excel®, version 2019 and ASSISTAT®, version 7.6 beta (Silva, 2015).

Results and Discussion

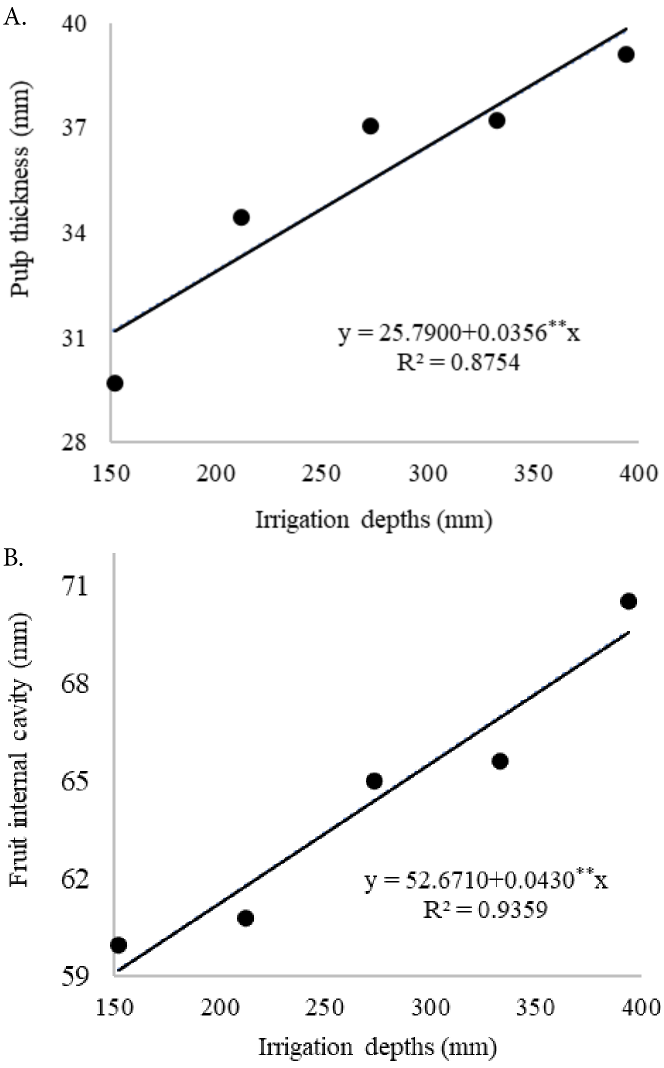
According to the analysis of variance for variables of melon fruits, there were significant effects of the irrigation depth for pulp thickness (PT) and fruit internal cavity (IC) ($p \leq 0.01$), as well as for fruit electrical conductivity (EC) and pH ($p \leq 0.05$). There was no significant effect ($p > 0.05$) of the irrigation depth on soluble solids (SS). The use of hydrogel was only significant for the fruit internal cavity (IC) and the interaction Depth × Hyd was not significant for any of the variables evaluated (Table 3).

The irrigation depths had a significant effect on both pulp thickness (Figure 1A) and fruit internal cavity (Figure 1B). Regression analysis showed that the model with the best fit was the increasing linear one (Figure 1A and B). When analyzing the pulp thickness, it was observed that, when increasing the irrigation depth from 152 to 394 mm, considered as minimum and maximum values to irrigation depth, respectively, the values were 29.70 and 39.08 mm for pulp thickness. Taking into account the 273 mm irrigation depth (100% ETc), there was a decrease of 19.85% when the irrigation depth was reduced to 50% ETc and an increase of 31.58% when the irrigation depth was increased to 150% ETc. For fruit internal cavity, the values found were 59.97 mm at the lowest irrigation depth used, 152 mm (50% ETc), and 70.54 mm for the highest irrigation depth used (150% ETc), generating an increase of 17.63%.

Table 3. Summary of the analysis of variance for pulp thickness (PT), fruit internal cavity (IC), fruit electrical conductivity (EC), pH, and soluble solids (SS) of melon fruits under different irrigation depths, and with or without hydrogel application

SV	DF	Mean square				
		PT	IC	EC	pH	SS
Depth	4	106.11**	144.47**	0.23*	0.0006*	0.0006ns
Linear	1	185.86**	221.01**	0.40**	0.00005ns	0.02316ns
Quadratic	1	19.35ns	2.72ns	0.02ns	0.00115ns	1.18248ns
Hydrogel - Hyd	1	9.33ns	181.22**	0.005ns	0.001ns	0.001ns
Depth × Hyd	4	1.46ns	9.09ns	0.04ns	0.006ns	0.006ns
Blocks	3	13.46ns	162.86*	0.40**	0.01ns	0.01ns
Residual	27	10.91	39.85	0.08	0.006	0.006
Total	39	-	-	-	-	-
CV (%)	-	9.30	9.80	5.59	1.55	1.55

SV - Source of variation; DF - Degrees of freedom; *, **, ns - Significant at $p \leq 0.05$ and $p \leq 0.01$ and not significant, respectively, by the F test



** - Significant at $p \leq 0.01$ by F test

Figure 1. Pulp thickness (A) and internal cavity (B) of melon fruit grown under different irrigation depths

Pulp thickness is related to the yield of the edible part for the consumer and market acceptance, are melons with greater thickness are preferred by consumers. Possibly the reduction in the irrigation depth generated plants with a lower leaf area, thus resulting in a smaller pulp thickness as the water deficit increased. The reduction in leaf area implies a reduction in the photosynthetic capacity of the plant and, consequently, a lower amount of carbohydrates for fruits (Taiz et al., 2017). Fruit internal cavity values were lower at low irrigation depths due to the smaller size of the fruits, which can be seen in Figure 4 through the fruit mass.

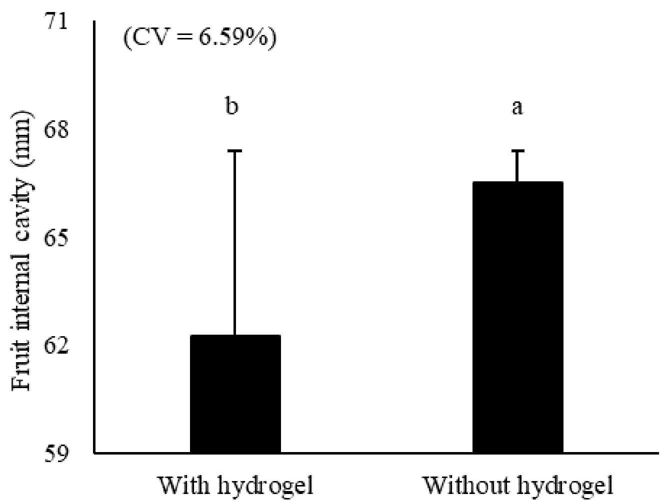
The response found in this study is different from that observed by Cavalcanti et al. (2015), when assessing the pulp thickness of the 'Mandacaru' melon cultivar, in the municipality of Catolé do Rocha, in the Paraíba state, Brazil, in a protected environment applying different irrigation depths. The authors obtained a quadratic polynomial equation, with a maximum pulp thickness of 18.3 mm for an estimated 116 mm of water. Lozano et al. (2018), when evaluating lacy melon fertigated with a drip system, obtained a pulp thickness of 30.4 mm. These values are lower than those mentioned in this study.

The results presented are different from those obtained by Sharma et al. (2014); however, it must be considered that these authors used surface furrow irrigation, which could have negatively affected the quality of the fruits, while in this study drip irrigation was used. This statement can also explain the fact that increasing linear models were the ones that best fitted to these variables, considering that the water levels applied in the present study were not capable of causing excess water to the point of reaching points of maximums in the expressions of the variables under study.

For post-harvest purposes, fruit with thicker pulp, resistance to handling, transportation and greater durability, and a small internal cavity is considered ideal (Medeiros et al., 2015). The responses observed in this study showed that increasing the irrigation depths promotes increases in pulp thickness and fruit internal cavity, with the former being beneficial and the latter being the contrary to what is desired. The increase in fruit internal cavity is not desirable, since the smaller internal cavity is one of the best melon fruit quality attributes. For Queiroga et al. (2008), the increase in fruit diameter commonly reflects a weak connection between the structure that contains the seeds and the pulp, which may result in seed detachment and fruit fermentation during post-harvest handling, which were not observed in this study. In each case the producer should opt for improving the variable that most appeals to the consumer market.

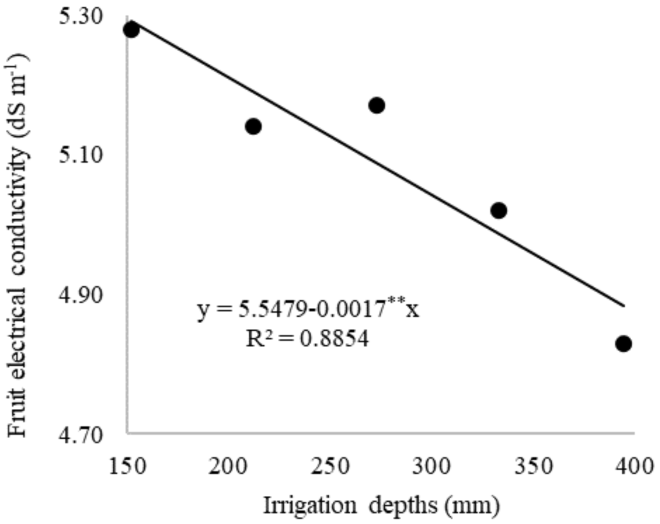
The highest absolute value of fruit internal cavity (66.52 mm) was observed without hydrogel application (Figure 2), differing statistically from that obtained with hydrogel application (62.26 mm), with a reduction of 6.40% in fruit internal cavity. According to Nunes et al. (2011), melon fruit is desired to have a smaller internal cavity and thicker pulp, as these characteristics reduce the displacement of the placenta, slowing down the deterioration of the fruit. On the other hand, when the fruit has a large internal cavity, it is susceptible to placental displacement, which can be a factor that accelerates early deterioration of the fruit, compromising post-harvest quality.

Figure 3 shows the fruit electrical conductivity of melon fruit under different irrigation depths. By estimating the maximum value for fruit electrical conductivity based on the model obtained, it was found 5.29 dS m^{-1} (Figure 3). Regarding the



Means with the same letters do not differ significantly by the Tukey test ($p \leq 0.05$)

Figure 2. Fruit internal cavity of melon fruit grown with or without hydrogel application



** - Significant at $p \leq 0.01$ by F test

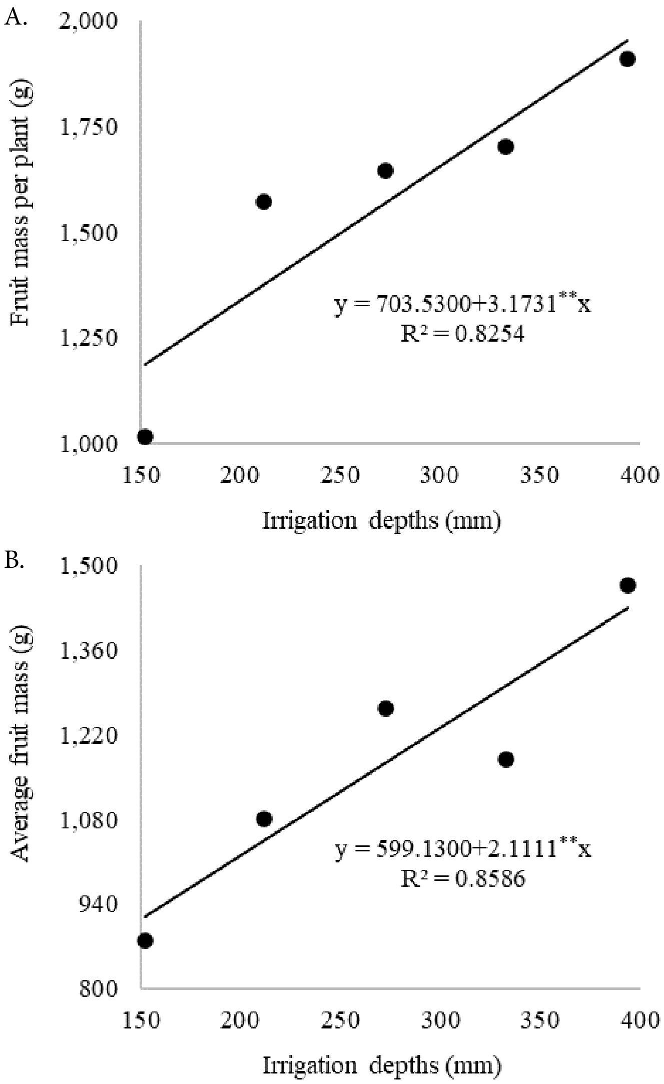
Figure 3. Electrical conductivity of melon fruit grown under different irrigation depths

pH of the melon fruit pulp juice, although the values measured were significantly influenced by the different irrigation depths, it was observed that the data obtained were not described by any mathematical model (linear or quadratic) as a function of the increases in availability of water in the soil (Table 3), with an overall mean of around 5.29 ± 0.01 for that variable.

The influence of the amount of water in the soil on the quality of melon fruits has been discussed by some authors. The response found in this study is different from that observed by Medeiros et al. (2012), who obtained a linear response for the pH of Piel de Sapo melon with increasing irrigation depths, obtaining the highest value of 6.92 for a depth of 423 mm.

With regard to the production variables evaluated, there was a significant difference ($p \leq 0.01$) for the treatment of irrigation depths for the variables fruit mass per plant (FMP), average fruit mass (AFM), and yield (YIELD), while the number of fruits per plant (NFP) was not statistically influenced ($p > 0.05$) by the treatments applied. The use of hydrogel and the interaction Depth x Hydrogel did not significantly influence any of the production variables evaluated (Table 4).

Figure 4 shows the fruit mass per plant and the average fruit mass of the melon plants under different irrigation depths. The lowest average fruit mass per plant (1,015.72 g) was obtained when the 154 mm irrigation depth (50% ETc) was applied. On the other hand, the highest irrigation depth, 394 mm (150% ETc), promoted the highest average fruit mass



** - Significant at $p \leq 0.01$ by F test

Figure 4. Fruit mass per plant (A) and average fruit mass (B) of melon fruit grown under different irrigation depths

(1,910.54 g), generating an increase of almost 50%. When analyzing the average fruit mass, it was observed that, when increasing the irrigation depth from 152 mm (50% ETc) to 394 mm (150% ETc), considered as minimum and maximum values for irrigation depth, respectively, the values were 880.31 and 1,468.46 g.

The average fruit mass (Figure 4) is in accordance with the requirements established by melon marketing standards. According to Medeiros et al. (2012), commercial fruits of melon

Table 4. Summary of the analysis of variance for number of fruits per plant (NFP), fruit mass per plant (FMP), average fruit mass (AFM), and yield (YIELD) of melon plants under different irrigation depths, and with or without hydrogel application

SV	DF	Mean squares			
		NFP	FMP	AFM	YIELD
Depth	4	0.23^{ns}	893032.02**	381086.91**	357212586.91**
Linear	1	0.039^{ns}	1475934.04**	651796.14**	590373170.97**
Quadratic	1	0.090^{ns}	145588.62^{ns}	2852.78^{ns}	58235454.71^{ns}
Hydrogel - Hyd	1	0.05^{ns}	22855.71^{ns}	99193.85^{ns}	9142314.27^{ns}
Depth x Hyd	4	0.02^{ns}	92833.39^{ns}	17145.30^{ns}	37133352.01^{ns}
Blocks	3	0.07^{ns}	225455.78^{ns}	63613.92^{ns}	90182366.06^{ns}
Residual	27	0.09	176867.41	58204.53	70746967.86
Total	39	-	-	-	-
CV (%)	-	22.55	26.80	20.52	26.80

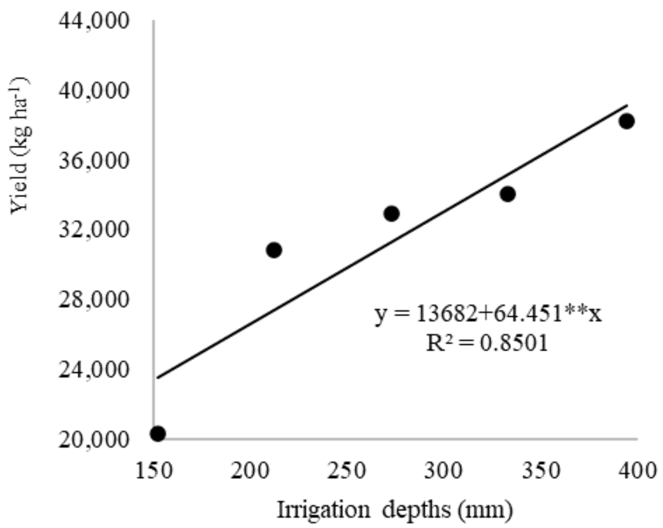
SV - Source of variation; DF - Degrees of freedom **, ^{ns} - Significant at $p \leq 0.01$ and not significant, respectively, by the F test generally have masses ranging from 1,000 to 1,500 g, with larger fruits tending to be less valued on the international market but appreciated on the domestic market. However, it is important to note that the average mass obtained in this study is higher than that reported by Dalastra et al. (2016), who identified an average fruit mass for yellow melons of 1,083.47 g, grown in a protected environment in the western region of Paraná state, Brazil. Increased water availability in the crop is related to fruit size, as the plant will produce more photoassimilates, which are used in fruit development, resulting in greater fruit mass per plant and greater average fruit mass (Duarte & Peil, 2010).

Yield was significantly influenced by the increase in the irrigation depth, but there was no significance for the hydrogel application. As the irrigation depths increased, there was a linear increase in yield (Figure 5), up to the highest estimated depth of 150% of crop evapotranspiration, corresponding to a yield of 39,075.69 kg ha^{-1}.

When evaluating the increase in irrigation depths and potassium fertilization, Sousa et al. (2010) obtained yields between 19.7 and 34.7 t ha^{-1}, with an estimated irrigation depth of 150% ETc, when cultivating Gold Mine AF 10.00 hybrid melon, and they concluded that the higher irrigation depths increased the yield, although the K doses did not modify the yield.

The linear performance obtained for all the production variables and for the fruit quality variables related to fruit size shows that, for the region under study, the irrigation depths applied were below those suitable for obtaining the best crop performance, even the highest irrigation depth of 394 mm, which corresponds to 150% ETc. It is therefore important to evaluate higher percentages of ETc for the crop, in order to reach the maximum performance for the variables, with a view to correcting the Kc values used, for subsequent dissemination and use in the region, thus contributing to an irrigation management recommendation that is more appropriate to local conditions.

It is important to highlight that, when applying the lowest level of irrigation depth studied (152 mm), melon yield was shown to be higher than the national average and the average



** - Significant at p ≤ 0.01 by F test

Figure 5. Yield of melon fruits grown under different irrigation depths

for the Ceará state (Brazil), on the order of 25,468 kg ha^{-1} and 29,636 kg ha^{-1}, respectively (IBGE, 2022).

Positive correlations between yield and the water volume applied in irrigation are commonly reported in the specialized literature, since as the volume of water applied increases, the yield is also increased. This positive correlation leads to the assumption that the crop coefficients established by Sousa et al. (1999) and employed in the present study proved to be incapable of optimizing the responses of the melon crop for the edaphoclimatic conditions under which the present study was conducted. It may be considered that the range of variation in soil water availability, caused by different levels of irrigation, did not allow reaching a maximum point. Thus, it raises the hypothesis that the climatic and soil conditions of the research site caused a large deviation between the melon crop coefficients applicable to this region and those recommended by the aforementioned authors, even under different amounts of irrigation.

From this perspective, it is important to highlight the importance of crop coefficients being optimized based on regional conditions, including climate, cultivated species and management practices due to regional characteristics in new research focused on this relevant topic, given that the determination of Kc considering the local conditions of the areas is the basis for establishing an adequate production system under irrigation (Hou et al., 2022).

It should be noted that such inferences are based on data obtained during a harvest season in a location. Furthermore, crop water needs vary across space and time, depending on climate and other dynamic conditions. Although the data is consistent with what has been previously reported, the effects of climate and soil will need to be taken into account to apply the conclusions to other locations.

Conclusion

The use of hydrogel at the analyzed concentration (4 g L^{-1}) was not enough to mitigate the negative effects of deficit irrigation depths or to intensify the positive effects of ideal irrigation depths on melon. However, individually, the increase in irrigation depths, from 50 to 150% ETc, improved the quality of the fruit with a greater quantity of pulp, higher mass and consequently promoting greater yield.

Contribution of authors: Gleyciane R. Lins: Conceptualization, Methodology, Data curation, Formal analysis, Writing - review & editing. Carla E. de Oliveira: Formal analysis, Methodology. Carlos N. V. Fernandes: Conceptualization, Methodology, Data curation, Formal analysis, Supervision, Writing - review & editing. Alexandre R. A. da Silva: Formal analysis, Data curation, Writing - review & editing. Lucio J. V. Silva: Formal analysis, Methodology. Francisco F. C. de Oliveira: Formal analysis, Methodology. Reivany E. M. Lima: Data curation, Writing – review & editing.

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